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BIO-DIESEL AND THE PUBLIC TRANSPORTATION SYSTEM OF SAN JOSÉ

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This report in the product of an education program and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

This report, prepared for the National Cleaner Production Centers (CNP+L) of San José, Costa Rica assessed the feasibility of using bio-diesel or bio-diesel blends in public transportation buses. There were three primary questions this report addressed. First, what is the fuel efficiency of bio-diesel compared to diesel in public transit buses? Second, what is the cost difference for the use of bio-diesel versus diesel in the public transit sector of San José? Finally, what impact will bio-diesel have on the economy, environment, and society and how are these impacts interrelated? Our findings were used to assist CNP+L in making policy decisions regarding bio-diesel use in the public transportation system of San José.

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Executive Summary

Every day more and more fossil fuels are being consumed across the globe. Burning these carbon-rich energy sources releases many hazardous by-products into the air. These emissions include nitrogen oxides, volatile organic compounds (VOCs), particulate matter, and carbon monoxide.

In its most recent report to the United Nations Framework Convention on Climate Change, Costa Rica cited the transportation sector as its main energy consumption activity, and burning fossil fuels to support this sector is the largest contributor to greenhouse gas emissions in Costa Rica (S. Musmanni, personal communication, February 5 2007). The air pollution is particularly noticeable in San José where one can literally see, smell and taste the contamination. These high concentrations of contaminants produced by modern industry, including the automotive sector, can have severe adverse effects on public health. Estimates indicate that over half a million deaths worldwide each year are directly attributed to airborne pollution (Kemp, 2006).

The National Cleaner Production Centers is a global organization which seeks to find more environmentally friendly and financially sustainable industrial policies. The Costa Rican branch of The National Cleaner Production Centers (CNP+L) requested that this project team conduct a bio-diesel study in order to evaluate the fuel efficiency and social benefits of using bio-diesel versus diesel fuel in San José.

Diesel is a non-renewable fossil fuel resource derived from crude oil. It is used in some cars but mostly heavy hauling vehicles. Costa Rica imports 55% of its crude oil from Venezuela, and the rest is imported from the US, Brazil and Columbia (Oliveina and Silva, 2005). Many airborne pollutants have been linked to diesel exhaust including carbon monoxide, volatile organic compounds, carbon dioxide, nitrogen oxides, and sulfur dioxide. Bio-diesel is a renewable fuel made from the fatty acids of plants and animals. It has been used in pure form and blended with diesel. Only minor engine modification is necessary when using high concentrations of bio-diesel. Bio-diesel exhaust is lower in all the above mentioned emissions except for nitrogen oxides (Mittelbach, 2004).

The objective of this project was to research the feasibility of bio-diesel use within the context of San José, Costa Rica. In order to meet this objective the project team formulated three research questions:

- What is the fuel efficiency of bio-diesel compared to diesel in public transit buses for the San José area?
- What is the cost difference for the use of bio-diesel versus diesel in the public transit sector of San José?
- What impact will bio-diesel have on the economy, environment, and society and how are these impacts interrelated?

These three research questions were used to develop knowledge regarding bio-diesel use in San José. Then recommendations were formed regarding future use of bio-diesel fuel and final recommendations were presented to CNP+L.

Determining the fuel efficiency of buses operating on bio-diesel fuel in San José was the first task for the project team. The project team created and conducted an experiment with Consorcio Operativo, one of the public transportation companies servicing San José, to determine the fuel efficiencies of six buses.

The buses operated on diesel fuel, B15 blend, B30 blend, and B100. The B15 blend consisted of 15% bio-diesel fuel and 85% diesel fuel. B30 consisted of 30% bio-diesel, and B100 was 100% bio-diesel fuel. Our study determined the average fuel efficiency of each fuel type in kilometers per liter. The study showed that diesel fuel, B15, and B30 all had similar fuel efficiencies. The average fuel efficiencies were between 3.0 km/L and 2.75 km/L. The fuel efficiencies of B100 were slightly less, averaging about 2.5 km/L. The project team determined that fuel efficiency would not be a primary concern when determining the feasibility of bio-diesel fuel use.

The project team used the bus company, Consorcio Operativo, as a case study for evaluating the interrelationships between economic, environmental, and social impacts of using bio-diesel fuel. At the time of the study bio-diesel fuel cost Consorcio Operativo about ¢568 ($1.10) per liter. Diesel fuel was about ¢368 ($0.71) per liter. According to O. Ramirez, the diesel fuel prices have been increasing each year, closing the price gap (personal communication, May 24 2007). Energías Biodegradables, the bio-diesel production company supplying Consorcio Operativo, will begin growing and refining their own bio-diesel feedstock in about one year. Consorcio Operativo is the major consumer of bio-diesel produced by Energías Biodegradables which means that they receive priority for bio-diesel fuel.

The project team also researched aspects of domestic fuel production in order to determine the feasibility of Costa Rica producing bio-diesel fuel. The team found that it was important when choosing raw stocks for bio-fuel production to diversify raw stocks and ideally choose a non-food staple as the source. It is also important to protect the bio-fuel industry from fluctuating crude oil prices through bio-fuel subsidies, taxes on crude oil or measures such as mandatory bio-fuel blends. The project team concluded that internal fuel production would be economically viable, adding jobs and strengthening the economy while reducing foreign oil dependence.

The project team also investigated the environmental impact of combusting diesel fuel compared to bio-diesel fuel. Air pollution maps of San José depicted where the areas of high contamination were. The project team used the air pollution data and maps to project improved air quality due to bio-diesel use. The reduction in emissions has been studied by several different organizations. Hydrocarbons are reduced the most, demonstrating a 68% decrease when comparing diesel fuel to B100. Particulate matter and carbon monoxide are also reduced by 48% (McCormick *et al.,* 2005). Decreased emissions also reduce health risks to San José citizens (Burgoa, 2000) and assists bus companies in meeting national regulations for emissions.

The project team also investigated the impact of greenhouse gas emissions on San José which contribute to climate change, the altering of weather patterns due to various airborne particles like VOC's, NO_x, PM, and CO_2 (EPA, 2006). These particles are emitted when fuel is burned (Air Quality Expert Group, 2006). One of the side effects of climate change is increased air temperature. Should the temperature increase San José would experience more severe air pollution, water pollution, and greater numbers of infectious parasites (EPA, 2006). The project team calculated that 1,881,178,510 kilograms of the greenhouse gas, CO_2 would be produced in Costa Rica based on the 2007 diesel consumption projections by RECOPE, the national fuel provider. If only B100 were used, the number of kilograms of CO_2 produced in 2007 would be

470,294,628 kg. Use of B100 would result in a seventy-five percent decrease of carbon dioxide in the atmosphere. This calculation shows that San José could slow the progress of climate change by using B100 or bio-diesel blends.

The team also conducted a survey to determine public awareness regarding air quality in San José and public's familiarity with bio-diesel. The project team conducted a six question survey aimed at evaluating public awareness of both the air quality in San José and of bio-diesel fuel. One-hundred adults participated in the survey at various locations around San José. Eighty-six percent of the people surveyed said they believed that the air was not healthy in San José. Fifty-five percent of the participants responded that the air quality was either "bad" or "less than sufficient", and only five percent indicated that the air quality was more than "sufficient" or "excellent". In addition, ninety-three percent of the participants indicated that they believed that the public buses have a negative impact on air quality. Finally, ninety-four percent of the participants indicated that they would pay 5 Colones more if buses operated on bio-diesel fuel. The results from the public opinion survey allowed the team to conclude that the public would be receptive to bio-diesel programs.

During a five year study conducted between 1991 and 1996, Burgoa (2000) found that the occurrence of several illnesses caused by atmospheric pollution had increased as well as their respective mortality rates. In the general population of Costa Rica, leukemia and lymphoma increased 17% between 1996 and1997. These illnesses had a particularly strong showing in San José where the risk of developing leukemia and lymphoma was 78%, 13 times greater than in other dense population centers in Costa Rica. Death by acute respiratory illness was found to be three times greater in downtown San José. This research concluded that the adverse health effects and disease rates in downtown San José were the highest in Costa Rica, and that those rates fell the further one was from the city center.

The project team's findings determined that emissions from public transportation buses have an adverse affect on public health. In the study done by Carlos Burgoa, direct and indirect healthcare costs due to respiratory illnesses caused by airborne pollutants were estimated to average $27 million between the years 1991-1996. Cost Rica has universal health care which means that the government pays for the health care for the entire populace. Because emissions from diesel buses cause adverse health effects, they contribute to the financial burden on the nation due to these illnesses. This project team predicts that using bio-diesel will reduce harmful emissions in the area, thus reducing cases of respiratory illness and reduce health care costs.

In conclusion the project team presented these findings on the feasibility of bio-diesel in San José, Costa Rica:

- The decision to switch to using bio-diesel should not be based on efficiency.
- A switch to bio-diesel would strengthen the economy and reduce dependence on foreign oil.
- A switch to bio-diesel would better the environment as well as the health of the population.
- A switch to bio-diesel would be well received by the populace.

Based on these conclusions, the project team recommends the following:

- Support should be given to already existing bio-diesel initiatives.
  - Costa Rica should give route preference to bus companies which use bio-diesel.
  - Costa Rica should mandate a blend of bio-diesel, intending to increase the blend annually and with the goal of eventually reaching B100
- Further research should be done to:
  - Identify an appropriate raw stock for Costa Rica that produces a high energy yield.
  - Determine how to grow adequate bio-diesel raw stock without displacing major food staples or causing deforestation.
  - Determine the economic environment needed for a successful bio-diesel industry.

1.0 Introduction

The world's supply of fossil fuels is finite. There is a big appetite for them, causing the global supply to decrease and increasing the level of pollutant by-products due to the combustion of these fuels. Burning these carbon rich energy sources releases several hazardous by-products into the air. These emissions include nitrogen oxides, volatile organic compounds (VOCs), particulate matter, and carbon monoxide. Some of these pollutants already exist in the atmosphere naturally but the high concentrations produced by modern industry, including the automotive sector, can have severe adverse effects on public health. Estimates indicate that over half a million deaths worldwide each year are directly attributed to airborne pollution (Kemp, 2006).

In its most recent report to the United Nations Framework Convention on Climate Change, Costa Rica cited the transportation sector as its main energy consumption activity, and burning fossil fuels to support this sector is the largest contributor to green-house gas emissions in Costa Rica (Musmanni, 2007). The air pollution is particularly noticeable in San José where one can literally see, smell, and taste the contamination. Not only are the environmental effects of using fossil fuels detrimental to Costa Rica, but the economic impacts of Costa Rica's complete dependence on foreign oil are potentially devastating. According to an article in the *Caribbean & Central America Report*, as recently as April 2005, rising oil prices nearly prompted the Costa Rican government to declare a state of economic emergency. At the time, the environment and energy deputy minister Allan Flores said that if oil reached US$60 a barrel Costa Rica would be unable to pay its annual energy bill (2005).

This energy crisis in Costa Rica has stimulated interest in bio-diesel fuels as an alternative and renewable source of energy. Bio-diesel and bio-diesel blends have been proven to decrease emissions and decrease wear on engines. Several countries around the world have been using blends of diesel and bio-diesel to decrease costs of fuel, to increase fuel economy and help to decrease harmful emissions (Kemp, 2006). Costa Rica is an environmentally conscious nation because it has many green policies and practices including a program in which 99% of its household electricity generation is renewable (CNP+L, 2006). Many organizations in Costa Rica began considering the possibility of using bio-diesel fuel to decrease the emissions from the country's transportation sector as well as providing an alternative to fossil fuels. The issue became whether or not Costa Rica could benefit from the utilization of bio-diesel fuels. Factors such as cost, economic, health, and environmental impacts were balanced by the project team in order to evaluate this benefit.

There are organizations throughout the world that have taken an interest in the costs of production, fuel efficiency and other variables of using bio-diesel and bio-diesel blends in diesel engines. The National Cleaner Production Centers is a global organization which seeks to find more environmentally friendly and financially sustainable industrial policies in the developing world. The Costa Rican branch of The National Cleaner Production Centers (CNP+L) requested that this project team create a study to monitor the fuel efficiency of diesel vs. bio-diesel in buses and to evaluate economic, environmental, and social aspects of using bio-diesel in public buses of the city of San José. The project team identified key issues that policy makers would need to consider when determining if bio-diesel would be a good alternative:

- Fuel Efficiency of bio-diesel compared to diesel
- Comparative costs between the fuels
- Economic, environmental, and societal impacts associated with implementing bio-diesel fuel

By asking the WPI project team to carry out this research, CNP+L wished to obtain data and receive policy recommendations as to whether using bio-diesel (pure or in blends) would be feasible.

In order to provide the sponsor with relevant recommendations on the use of bio-diesel the project team conducted an experiment in which several buses were loaded with different types and blends of fuel. This experiment was done with Consorcio Operativo, a bus company in San José which had been using bio-diesel for about a year and a half. Energías Biodegradables was the company which supplied Consorcio Operativo with its bio-diesel. For the selected buses and drivers, mileage and fuel consumption during shifts was recorded. Then fuel efficiency was calculated by taking kilometers traveled and dividing by liters of fuel consumed (km/L). The project team also evaluated costs associated with bio-diesel vs. diesel as well as social, economic, and environmental implications of using bio-diesel. Based on this research, the project team provided recommendations as to the feasibility of using bio-diesel in San José buses.

2.0 Background

This Chapter establishes the context for the study by discussing the transportation sector of Costa Rica and its impact on the environment. Furthermore, the Chapter introduces studies that have previously been conducted on bio-diesel. This Chapter highlights potential advantages and disadvantages of using bio-diesel vs. diesel as well as sources, production methods, and engine effects of bio-diesel.

2.1 An Introduction to the Transportation Sector in Costa Rica

Costa Rica has an extensive transportation sector, both public and private. A vast majority of the local populace uses the public buses, but many people drive privately owned vehicles as well. The transportation sector is so large in Costa Rica that it accounts for over 50% of the country’s total energy consumption of fossil fuels (EarthTrends, 2007). This consumption comes at a cost. Carbon dioxide emissions from the transit sector account for over 50% of the total CO_2 emissions in the entire country. In 2002, Costa Rica’s carbon dioxide emissions from the burning of fossil fuels totaled 5.8 million metric tons (Herro, 2007) over half of which were generated by the transportation sector.

As in most Latin American cities, San José’s public transportation sector fulfills the majority of the population’s transit needs (Valverde, 2006). Public buses in San José are responsible for 65% to 85% of all vehicular transportation (Contreras-Montoya, Carlos, and Enilson; 2006). A reason for this percentage is that public transportation is more economical in Costa Rica. The average worker earns roughly a quarter of that of a worker in the US and personal cars in Costa Rica are 1.5 times more expensive than in the US (Valverde, 2006).

In 2001, a study was conducted by F. Alpizar and F. Carlson on ways to entice San José citizens to use public transportation instead of privately owned vehicles. Even though a vast number of citizens already use public transportation, the study addressed some reasons why public transportation was not utilized by more people in San José. They found that public transportation until recently had not been given the attention it needed by the government as it expanded. Alpizar and Carlson stated that the result was an inefficient system where San José became a congested hub of travel. The combination of a lack of urban planning and an inefficient public transportation system led to increased pollution because the massive traffic congestion caused a decrease in travel speed which subsequently increased emissions (2001).

High levels of pollutants that San José citizens are exposed to daily have had many inhabitants citing respiratory and pulmonary illnesses as the main reasons for their visiting the public health centers according to a survey taken by the Ministry of Health in Costa Rica (Alpizar and Carlson, 2001). Over the past few years the Costa Rican government has been trying to improve and restructure the public transportation sector in an attempt to reduce congestion and pollution caused by urban transportation. The Federal Department of Transportation grants routes to private companies (Valverde, 2006) for a fixed number of years. This regulates the number of buses operating on a certain route. These bus companies pay lower taxes if they use diesel instead of gasoline. Another way the government regulates the bus system is by performing random emissions testing on buses throughout San José. At certain check points government officials stop buses and check their emissions output. If the bus does not meet a certain standard the government confiscates the license plate of the bus until a fine is paid and the bus is recertified. This process results in the bus being out of circulation anywhere between one to two weeks. Because this results in a loss of revenue, bus companies make it a priority to keep buses in good repair. The government has also encouraged the use of hybrid vehicles, clean energy, and bio-fuels through incentives and laws (Herro, 2007).

Most public transportation vehicles in Costa Rica run on diesel. In the subsequent sections we will briefly evaluate the effects and properties of diesel as a fuel source. Costa Rica has been contemplating the use of bio-diesel fuel as a possible substitute or supplement for diesel fuel in public transportation buses in an attempt to decrease emissions. In the following sections diesel properties are compared to those of bio-diesel fuel.

2.2 Life Cycle Analysis of Bio-diesel Fuel

Life cycle analysis is a very helpful tool that allows individuals with a new product to grasp the full impact of the product in every stage of its creation and use. This includes evaluating raw materials used to create the product through the wastes produced in its use (Rubin, 2001). Conducting a life cycle assessment on bio-diesel allowed this project team to research production and use in terms of the impacts on human population, resource consumption and emissions, pollution, changes to the environment, technology development, and public safety measures. This preliminary research, added to the on-site data acquisition, ultimately allowed the project team to help the sponsor make decisions based on a holistic view of bio-diesel usage as the cycle depicts in Figure 1.

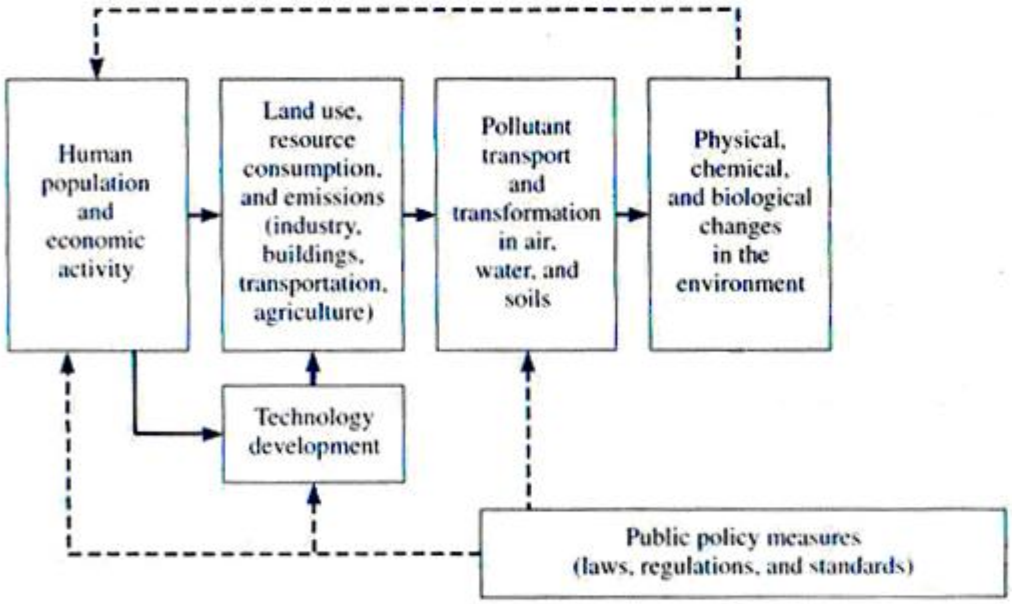


Figure 1: Sample Set Up for a Life Cycle Analysis
(Source: Rubin, 2001)

This life cycle analysis for bio-diesel fuel considers the following steps: growth or gathering of production materials, refinement, distribution, and the use of completed bio-diesel fuel. Within the chain of production and consumption, possible outside factors which may influence the success of bio-diesel over diesel fuel are considered.

Figure 2 depicts the primary elements in the bio-diesel fuel life cycle. The first step in a life cycle is determining the appropriate feedstock for the fuel. Based on the feedstock chosen a refinement process follows to convert the feedstock into a fuel source. The refined bio-diesel fuel is then distributed to appropriate users. After fuel consumption, the mechanical effects, emissions, and economic and social impacts are considered to complete the analysis of bio-diesel usage. Below, the project team addresses these factors in order with the exception of emissions. Due to the implications of emissions on public health, the project team addresses this effect of combustible fuel first in Section 2.3. San José has experienced public health problems related to combustion emission in the past; the city is also very interested in decreasing emissions in order to improve public health (Musmanni, 2007). After first considering public health effects, the project team's life cycle analysis investigates soy, palm, recycled fryer oils, and castor oil as viable options for bio-diesel fuel production in Costa Rica (see Section 2.5). Following fuel sources, refinement processes for each fuel source are evaluated. Evaluations consider cost, refinement methods, and production by-products. After refinement, issues concerning bio-diesel fuel distribution and storage are evaluated. Fuel quality issues may arise during storage if the fuel is exposed to external factors such as heat, air, light, and water (see Section 2.7). Finally in the last section of this Chapter the maintenance issues are discussed

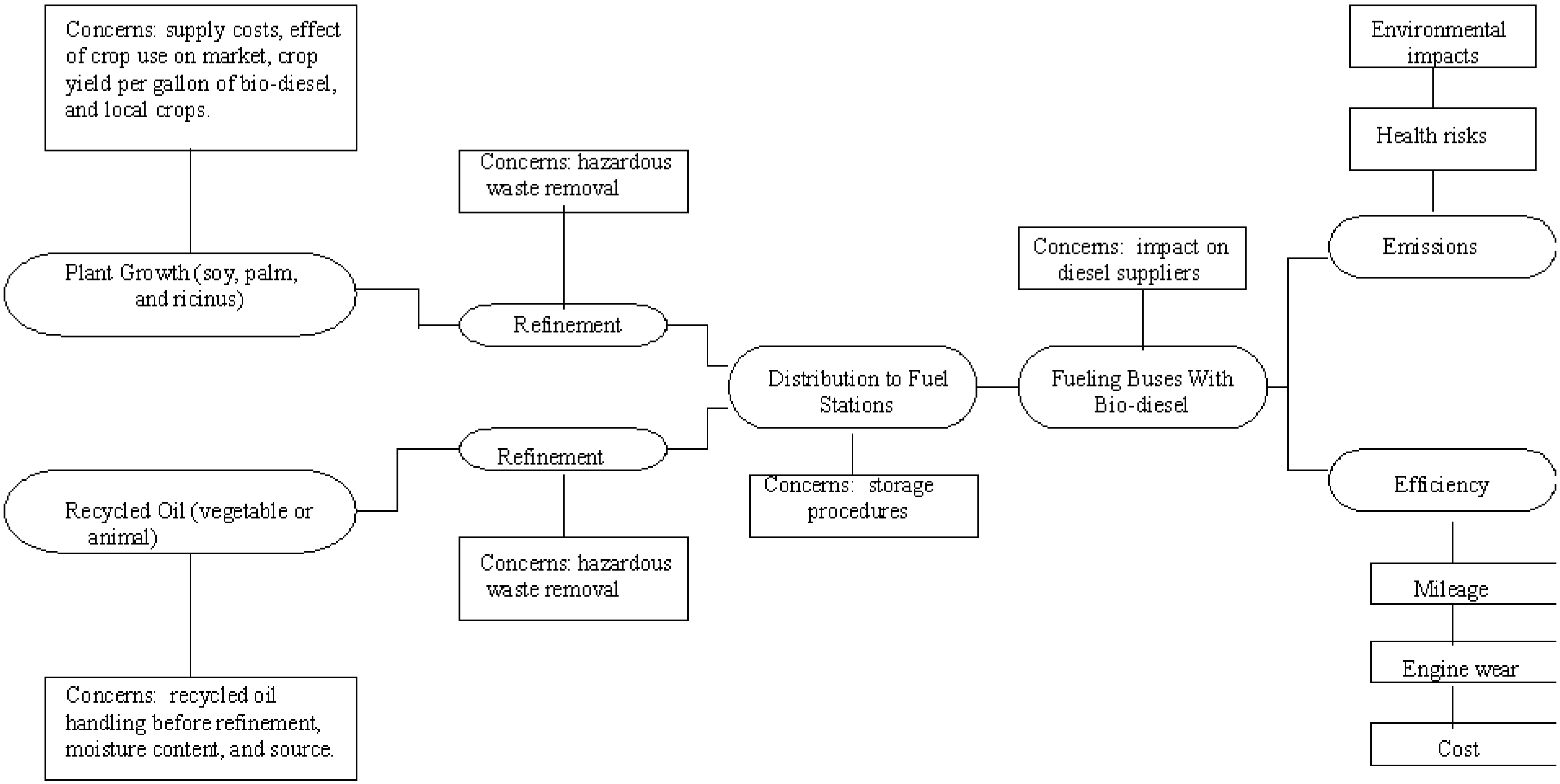


Figure 2: Life Cycle Analysis of Bio-diesel Fuel

2.3 Emissions and Health Impacts: Bio-diesel vs. Diesel

The use of both diesel and bio-diesel fuels produce by-product emissions which have an effect on the environment and living organisms. The difference in severity and toxicity of the emissions differentiate the two fuels. There are several different types of chemical compounds that can be used to compare emissions:

1. *Carbon Monoxide (CO)* is considered a toxic gas because it blocks oxygen intake for people and animals. (Mittelbach and Remschmidt, 2004).
2. *Hydrocarbons (HC)* are compounds which originate from unburned or partially burnt fuel and lubricating oil compounds and are considered hazardous because they are carcinogenic.
3. *Volatile Organic Compounds (VOCs)* are carbon based compounds that readily evaporate into the atmosphere. They are known greenhouse gases and can be toxic to plant and animal life.
4. *Nitrogen Oxides* (NO_x) are produced in the engine and are toxic in very high concentrations (Kemp, 2006)
5. *Particulate Matter (PM)* are tiny particles of solid or liquid suspended in gas, and the PM in diesel exhaust can cause adverse health effects in even small concentrations (McCormick *et al*, 2005).
6. *Sulfur Dioxide* (SO_2) is a gas which is known to contribute to respiratory illness, aggravate existing heart and lung diseases and cause acid rain which corrodes plants and man-made structures (EPA, 2007).
7. *Carbon Dioxide* (CO_2) is another frequently cited emission due to its effect on global warming.

Although there have been some conflicting studies conducted as to the emissions comparisons between bio-diesel and diesel, it has been generally found that the combustion of bio-diesel fuels produces less emissions than diesel (Mittelbach and Remschmidt, 2004).

In particular, bio-diesel is credited with producing less carbon dioxide, carbon monoxide, hydrocarbons, and particulate matter (Mittelbach and Remschmidt, 2004). Sulfur dioxide emissions from the combustion of bio-diesel fuels are negligible. The levels of NO_x on average have increased 3% when using B100 bio-diesel fuel (McCormick *et al*, 2005). The reasons for this increase are still not known (Mittelbach and Remschmidt, 2004). Conversion to even small blends of bio-diesel fuels has shown the ability to reduce all types of emissions except for nitrogen oxides (McCormick *et al*, 2005). The benefits of bio-diesel fuels compared to conventional fossil fuels are numerous, because bio-diesel fuel consistently displays marked reductions in all relevant emission categories (McCormick *et al*, 2005).

The effect on public health due to fossil fuels, in particular diesel emissions, is one reason that bio-diesel feasibility has been investigated. In 2002, the United States Environmental Protection Agency (EPA) published a comprehensive survey on studies investigating potential health effects on the public due to exposure to diesel exhaust. Summing up their results, the EPA concluded that humans are likely to be subjected to both acute and chronic respiratory hazards from exposure to diesel fuel exhaust emissions (Mittelbach and Remschmidt, 2004).

In 1997 a study was done in Costa Rica and later published in 2000, which assessed the effect on public health due to atmospheric pollution. The study, done by Dr.

Carlos Santos Burgoa for the World Bank and later published by publishers Astorga, A.G.; Astorga, Y.E.; Hernandez, G.N.; Mora, J.P; Torres, I.C; Alfonso, F.A.; and Lopez, R., evaluated public health data from 1991 to 1996. The study found many adverse health impacts on the populations of Costa Rica as a whole and in particular downtown San José due to atmospheric pollution. The results indicated that in that five year span, cases of cancer, heart disease and lung disease increased noticeably. For example, death by heart attacks increased 78%; and chronic respiratory mortality increased 75-85% in people over 60 years of age and was linked to the presence of hydrocarbons, sulfur dioxide and particulate matter (Burgoa, 1997). The conclusions drawn for downtown San José, the country's most polluted city, were even more significant. It was found that the risk of dying by acute respiratory illness was three times greater if one lived downtown compared to the suburbs of San José. The risk of developing lymphoma and leukemia was 70%, almost 13 times greater when compared to other densely populated cities in Costa Rica (Burgoa, 1997). In Costa Rica as a whole, the total direct and indirect costs for health care due to atmospheric pollution were estimated at $27 million (Burgoa, 1997).

In May of 2007, Dr. Sergio Musmanni, the director of the San José CNP+L branch spoke to this project team about the Central American Norm on Diesel and Bio-diesel standards. He said that this initiative recently standardized the diesel quality all across Central America. The implication of this initiative, according to Dr. Musmanni, increased the diesel quality for all the countries in Central America except for Costa Rica, whose quality of diesel due to the standardization actually decreased. The reason for the decrease in quality came from the increased sulfur content in the fuel which results in more SO_2 being released into the air. This development was a step back in the effort to better the air quality of San José and Costa Rica as a whole.

2.4 Fuel Types: Benefits and Comparisons

This section compares standardized fuel properties between diesel and bio-diesel. It is important to make these comparisons to ensure that bio-diesel is a feasible substitute for diesel. Diesel fuel is a common fuel and large amounts of research have been conducted on it. Diesel fuel is a distillation by-product of crude oil (Kemp, 2006). Diesel fuel is the most commonly used fossil fuel for heavy-duty engines such as hauling trucks and buses. Diesel fuel engines operate on a direct injection system which leads to more complete combustion of the fuel compared to gasoline engines (Garrett, 1994). Also, diesel engines produce fewer emissions than gasoline engines (Pahl, 2005). This is one of the reasons why Costa Rica fuels its public transit buses with diesel fuel rather than gasoline.

Another benefit to using diesel fuel is its compatibility with different fuel additives (Garrett, 1904). Recent global concern with green house emissions and decreasing fossil fuel supply has encouraged investigation of alternate fuel sources. Bio-diesel is one of the primary alterative fuel sources being promoted at this time (Pahl, 2005). Costa Rica is looking into bio-diesel in particular because it can be blended with diesel fuel or used alone in existing engine systems with minimal modifications (Pahl, 2005).

Bio-diesel is a fuel source produced from plant and animal fatty acids. Fuel sources are any fatty vegetable such as soy, sunflower, safflower, palm, or recycled fryer oil and animal fat (Vern *et al.*, 2006). Fatty acids (triglycerides) react with an alcohol catalyst, causing the fat to re-bond with a new alcohol forming esters (bio-diesel). This process is defined as transesterification (Vern *et al.*, 2006). The end product is fatty acid methyl esters (FAME) or bio-diesel. Purified FAME when combined with diesel fuel is labeled as follows B5, B10, B20, or B100. B stands for bio and the following number represents the percent bio-diesel to diesel fuel ratio. For example, B5 is 5% bio-diesel and 95% diesel (Zhang *et al.*, 2003). See Figure 3.

Bio-Diesel Abbreviations

Diesel= 100% Diesel Fuel

B100= 100% Bio-Diesel Fuel

B15= 15% Bio-Diesel, 85% Diesel

Figure 3: Example of Bio-diesel Abbreviations

Bio-diesel performance is commonly evaluated against diesel fuel properties in scientific studies. There are two common grades of diesel fuel, No. 1 and No. 2. Diesel No. 1 is more expensive and blended with No. 2 in cold climates to prevent freezing. The American Society for Testing and Materials (ASTM) is the most commonly used international source for fuel standards (Fernando *et al.*, 2007). Five parameters are usually used to provide fuel characteristics for both diesel and bio-diesel and these parameters were used in the life cycle analysis. They are: flash point, cetane number, energy production, viscosity, and cloud point. These values are used to understand the chemical properties of the fuel and its operating quality in vehicles. The definitions and purpose of the five parameters are as follows:

1. *Flash point* is the lowest heat at which combustion occurs. A high flash point means that the fuel is safer to handle and store because it is less likely to spontaneously combust. However, if the flash point is too high it will not ignite in the engine (Vern *et al.*, 2006).
2. *Cetane number* is the measure of the ignitability of a fuel. A high cetane number means that the fuel is easy to combust, combustion will be more complete, and the fuel will burn cleaner. If the cetane number is too high or too low the engine will run rough leading to uneven wear and poor piston firing (Garrett, 1994).
3. *Energy production* is the measure of potential energy fuel contains (Btu/gal). Potential energy translates into gas mileage and engine efficiency (Vern *et al.*, 2006). If a fuel has a high energy production it will most likely get more miles to the gallon.
4. *Viscosity* is the time it takes for a certain volume of fuel at a particular temperature to flow a set distance under the influence of gravity. If the viscosity of fuel is too low it will leak through cylinders and cause gumming of engine parts. On the other hand, a high viscosity causes the engine to run hot and fail to start in cold weather conditions (Garrett, 1994).

5. *Cloud point* in relation to diesel is the temperature at which wax separates from fuel causing it to gel. Gelling of fuel leads to plugged filters, deposits on the injection system, and stalling. A similar phenomena occurs with bio-diesel except fat comes out of solution rather than wax (Garrett, 1994).

Table 1 depicts the flash point, cetane, energy production, viscosity, and cloud point for diesel No. 2, ASTM Standards for diesel No. 2, three bio-diesel blends, and ASTM Standards for B100. This table shows that all these fuels meet ATSM standards which allow them to be used in engines. Throughout this report qualities of bio-diesel fuel are related to these standards.

Table 1: Diesel Fuel Properties Compared to Bio-diesel and ASTM Standards

Fuel	Flash Point (°C)	Cetane Number	Energy (Btu/gal)	Viscosity (centistokes)	Cloud Point (°C)
No. 2 Diesel	52	48	140,000	3	< -15
ASTM No.2	52	40	-	1.9 to 4.1	-
B5	59	49	139,500	3.1	-14
B20	78	50	138,000	3.3	-12
B100	130	55	130,000	5.7	0
ASTM B100	130	47	-	2 to 6	-

Adapted from (Vern *et al.*, 2006 & Shrestha, 2007)

2.5 Characteristic of Bio-diesel Production Feedstock

The first step in our life cycle analysis is identifying the bio-diesel feedstock. Bio-diesel fuel can be made out of any substance with a high enough fat content, particularly the content of free fatty acids (Pahl, 2005). When deciding on bio-diesel feedstock, the primary considerations are availability of supply, cost of purchasing, cost of refining, and refined fuel quality. Different fuel feedstocks have varied properties when the FAME (Fatty Acid Methyl Ester) reaches its final refinement stage (Fernando *et al.*,2007). Therefore, the desired fuel characteristics are generally the deciding factor when determining the fuel source. In addition, as seen in Figure 2 choosing an appropriate feedstock has an effect on the rest of the bio-diesel life cycle. Different feedstocks have varied refinement process, properties that affect distribution, affects on the engine, etc. The project team evaluated soybean oil, palm oil, recycled fryer oil, and castor oil as potential fuel sources and assessed their potential use through the stages of the life cycle. It was done because Consorcio Operativo, the public transportation provider the project team worked with, fueled their buses with bio-diesel made from the first three sources and planned on using castor oil.

2.5.1 Potential Bio-diesel Feedstock for Costa Rica

Soybean oil, palm oil, recycled fryer oil, and castor oil were the four primary bio-diesel fuel feedstocks which were evaluated. Each source is available in Costa Rica without importing. First, soy is one of Costa Rica's smaller crops (FAO, 2004a). The soybean is a plant grown for either food consumption or oil production. Oil production grade soybeans are rounder and larger than food stock soybeans. The plant can grow in most soils but prefers a temperate climate (Berk, 1992).

Second, palm trees are a tropical plant which flourishes in well drained yet moist soil. In Costa Rica most palm plantations are found on the Central and South Pacific Coasts. Palm trees are a fruit bearing plant which has a high fat content (Poku, 2002). It generally takes 3 to 40 years for a palm tree to mature and produce fruit (FAO, 1998). Palms grown specifically for agriculture are bred to have shorter germination times, but a wide range still exists. Palm oil (*Elaeis guineensis*) can be extracted from the mesocarp (fleshy part) or kernel (seed) of palm fruit (see Figure 4). Both contain 50% fat by weight (Poku, 2002). When used in agriculture, palms are grown in a plantation and the fruit is harvested. Furthermore, palm trees are specifically bred to produce more mesocarp for oil production (FAO, 1998).

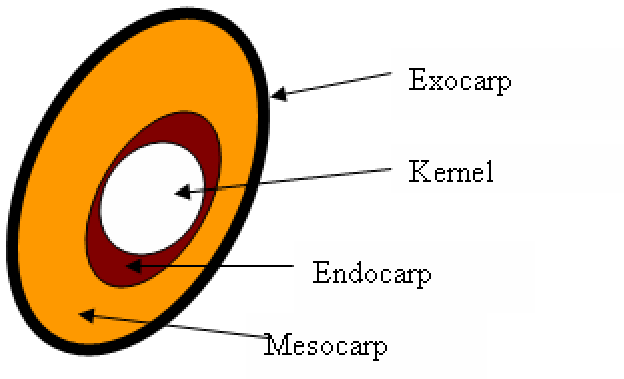


Figure 4: Diagram of Palm Tree Fruit
(Source: Poku, 2002)

Recycled fryer oil (RFO) is also an option for producing bio-diesel. Both vegetable and animal sources are types of waste oil which can be refined and used for other processes. Recycled fryer oil is a type of oil which has been used in cooking but is no longer usable for food preparation (Kemp, 2006). Quality RFO is only used in food preparation until it becomes off color and begins to thin (Kato *et al.*, 2004). Animal oil generally comes from meat processing plants (Reyes and Sepulveda, 2006). Any animal waste which is not fit for consumption can be cooked down and the fat removed for recycling (Mittelbach, 2004). The quality of animal fat depends on similar characteristics as recycled fryer oil. However, in evaluating quality more emphasis is placed on storage conditions. Energías Biodegradables collects its RFO from local restaurants (Musmanni, 2007).

Lastly, castor oil is an evolving feedstock for bio-diesel fuel production. Castor oil is processed from beans growing on the Ricinus plant. The ricinus plant produces poisonous beans which are also high in fat content (Conceicoa, 2007). The beans are ideal for bio-diesel production because they are rarely used in food based products (Osava, 2003).

2.5.2 Evaluation of the Physical Properties of Potential Feedstocks

Several physical properties affect the quality of bio-diesel feedstock. A higher quality feedstock leads to more products with less wasted material (Phal, 2005). Soy, palm, recycled fryer oil, and castor oil all exhibit different fat contents which means that they produce different yields of bio-diesel per raw feedstock used (Mittelbach, 2004). This affects the "land use resources and consumption" phase of our life cycle (see Figure 1). Less potential food supply is wasted when a higher yield crop is used. In addition, higher fat content will raise the cloud point, the viscosity, and glycerin by-product amounts while lowering the cetane which results in better quality bio-diesel (Kemp, 2006). Depending on the fuel qualities needed physical properties of FAME might make certain feedstock non-feasible for Costa Rica.

First, soy contains less oil by weight than palm and recycled fryer oil. It is a less efficient crop to refine (Pahl, 2005). The soybean contains about 20% fat when bred specifically for oil production. This means that one acre is required to produce 48 gallons or 182 liters of bio-diesel fuel (Addison, 2007). This is a lower yield when compared to other feedstocks. Costa Rica imports its soy feedstock from the US (Musmanni, 2007).

Aside from the production costs, bio-diesel fuel made from soy has ideal physical properties (see Table 2). The cetane number, flash point, viscosity, and cloud point are all comparable to diesel No. 2 as seen in Table 1 (Fernando *et al.*, 2007). Bio-diesel fuel with comparable properties to diesel No. 2 will operate similarly (Fernando *et al.*, 2007). In addition, the bus driver using bio-diesel fuel can expect the engine to turn over at the same rate as it would with diesel No. 2 (Leevijit *et al.*, 2007).

Second, palm oil is high in fatty acids which makes it an ideal candidate for high yield bio-diesel fuel production (Mittelbach, 2004). Also, palm is a more conservative crop regarding land use. This is an important point for the life cycle analysis because palm does not use as much land and agricultural space is limited in Costa Rica (FAO, 2004a). Increases in palm plantations lead to deforestation of Costa Rica. There is a threshold in which the deforestation surpasses the improved fruit yield of palm. Costa Ricans will have to determine when to supplement demand for palm oil. Bio-diesel yield for palm fruit is about 635 gallons or 2,404 liters per acre (Addison, 2007). This is significantly greater than that of soy (48 gallons or 182 liters per acre). The annual palm acreage for Costa Rica is 98,842 acres (Pomereda, 2003). Most of the production is done on small independent farms and privately owned plots of land (FAO, 1998). If palm were used for bio-diesel it would stimulate the private agriculturalists. Costa Rica could produce, 62,764,670 gallons or 237.6 million liters of fuel from one year worth of palm oil based on crop yields in 2006. In addition, the physical properties of palm oil are also comparable to diesel No. 2 and surpass the standard for diesel cetane number (see Tables 1 and 2).

Recycled fryer oil and animal oil both have similar physical properties to fatty virgin vegetable oil, such as palm (Mittelbach, 2004). However, the fat content varies depending on the source of the recycled oil. Fryer waste is generally a vegetable oil, containing about 0 to 7% fat (Kemp, 2006). Animal oil tends to have a higher fat content at about 10 to 15% fat (Reyes and Sepulveda, 2006). The fat content of recycled oil does provide some variance in expected bio-diesel yields. A typical refinement yield is 0.8 to 0.95 gallons (3.02 to 3.59 liters) of fuel per 1 gallon (3.79 liters) recycled feedstock, making recycled fryer oil another high yield fuel source (Kato *et al*., 2004).

Restaurants are the biggest producer of fry oil and the number of restaurants depends on population. San José has a population 309,672 within city limits and 885,000 including suburbs (Rico Tours, 2007). This translates to 1,327,500 gallons (5.03 million liters) of waste oil annually for the greater San José area which can be used for refinement (Zhang *et al.*, 2003a). As of 2007 recycled fryer oil was the lowest cost raw fuel source for Energías Biodegradables (Musmanni, 2007). In addition, RFO is still comparable to diesel No. 2.

Castor oil seed contains about 47 to 49% fat by weight making it the second best crop for oil production. Castor oil seeds yield 141 gallons (534 liters) of fuel per acre (Forest Law Farm Press Editorial Staff, 2006). Ricinus plants also exhibit high crop yields and short germination times (Forest Laws Farm Press Editorial Staff, 2006). The Costa Rican climate is ideal for Ricinus plants. A farmer could expect to receive 2.5 growing cycles per year (Ramirez, 2007). Therefore, one acre of land could potentially produce 353 gallons (1,336 liters) of bio-diesel fuel a year.

The chemical characteristics of bio-diesel fuel produced from castor oil are slightly different than soy, palm, and recycled fryer oil. The flash point and viscosity for castor oil are significantly higher. The flash point is 167 °C and the viscosity is 13.34 mm^2/s (Cvengros *et al.*, 2006). These values indicate that the oil may need to be thinned before use. The vehicle can experience difficulty starting due to the thickness of castor oil. On the other hand, the cloud point (-23 °C) and cetane number (44) are more desirable (Cvengros *et al.*, 2006). These two values meet ASTM standards.

2.5.3 Summary of Feedstocks and Application in Costa Rica

Overall, each feedstock has its benefits and weaknesses for use in Costa Rica. At the time of this project Energías Biodegradables was using a blend of palm oil, soy oil and RFO. The percentages of each vary, but Energías Biodegradables was attempting to increase the amount of RFO used. In Costa Rica the temperature does not drop below freezing so cetane numbers and cloud point values do not have a great effect on fuel performance. Due to the climate, cost and availability are the primary deciding factors when choosing a feedstock for bio-diesel fuel refinement. It is important to minimize the expense of fuel for the buses. Choosing a high yield yet low cost bio-diesel feedstock keeps costs lower.

Table 2 below summarizes each potential fuel source that was evaluated, its current global market cost as of 2007 and their physical properties compared to ASTM standards (Fernando *et al.*, 2007). The flash points, cloud points, viscosities and cetane numbers are relatively similar so the primary factors in choosing feedstock are the current availability and price. Currently, crude oil sells for about $650.00 per tonne in U.S. dollars. This value is comparable to renewable raw feedstock.

Table 2: Summary of Feedstock Cost and Physical Properties

Source	Cost ($U.S./tonne)	Yield	Cetane	Viscosity (mm^2/s)	cloud point (˚C)	Flash Point (˚C)
Soy	$502.00	48 gal/acre	51	2	0	<130
Palm	$612.00	635 gal/acre	65	4.8	13	≤130
Recycled Oil	$412.00 to $825.00	.8 to .95 gal/1gal raw	35 to 40	5	10 to 16	≤130
Castor Oil	$855.00	141 gal/acre	44	13.3	-23	167
ASTM Standard	—	—	47	2 to 6	—	≤130

(Sources: Frenando *et al.*, 2007; Behr, 2005; Krishnan, 2007; Cvengros *et al.*, 2006; Osava, 2003;& USDA, 2007)

This table demonstrates that the different bio-diesel raw stocks are comparable to each other and diesel. Palm, recycled oil, and castor oil might be the better bio-diesel raw stock options for Costa Rica due to their higher yield when compared to soy.

2.6 Refinement Practices for Feedstock and Costs

The next step in the life cycle process is to evaluate the refinement of bio-diesel fuel. It is important to make sure that refinement is both environmentally friendly and financially feasible. There are three primary refinement processes which have been researched for industrial use. These processes are called alkali-catalyzed transesterification, acid-catalyzed transesterification, and ozone (Mittelbach, 2004). Each process corrects unique impurity issues. Refining recycled fryer oil (RFO) requires slightly different processes than virgin oils because impurities within the oil must be considered. The food particles, hydration and free fatty acid content of RFO have the greatest impact on refinement methods (Kemp, 2006). Furthermore, some methods are more cost effective than others for specific feedstock. After refinement bio-diesels from different raw feedstocks can be mixed.

2.6.1 Alkali-Catalyzed

Alkali-catalyzed refinement uses a base to produce the FAME. A base is a substance with a pH of greater than 7. Alkali-catalyzed is the predominately used process in industry. Reactions occur more quickly than with acid-catalyzed and ozone treatments. However, there are more steps involved and greater quantities of hazardous waste are produced (Zhang *et al.*, 2003a). In addition, alkali-catalyzed refinement works best with virgin oil because the process is highly sensitive to free fatty acids (Mittelbach, 2004). Generally two transesterification cycles are sufficient to produce 95-97% oil conversion which is the industrial grade specified by the American Society of Testing and Materials (ASTM) for resale (Kemp, 2006).

2.6.2 Acid-Catalyzed

Acid-catalyzed refinement involves similar stages to alkali-catalyzed. The primary differences between alkali-catalyzed transesterification and acid-catalyzed are, time for reaction, stages involved in refinement, and waste production. Acid-catalyzed transesterification is not as commonly used in industry because more reaction time is necessary (Zhang *et al.*, 2003a). A typical batch can take 69 hrs to produce 90% conversion to methyl esters and an additional 240 minutes to reach 97% FAME (Zhang *et al.*, 2003a).

One advantage of acid-catalyzed transesterification is that pre-treatment is not necessary. Acid processes are less sensitive to hydration and free fatty acids (Zhang *et* *al.*, 2003a). Therefore, less hazardous waste is produced (glycerin, methanol, and acid water). Reduced number of processes also means that there are reduced equipment purchases and maintenance.

2.6.3 Ozone

Ozone treatment has been studied less than the other two processes. The cost of ozone treatment is greater than that of transesterification. However, some regions like Japan are studying ozone use because they have less land to work with and waste management is a greater concern (Kato *et al.*, 2004). Ozone treatment does not require any pretreatment and glycerin is not separated from the oil. Fatty acids are attacked by ozone creating hydrocarbons without releasing glycerin. Therefore, fuel recovery from feedstock is almost 100%. This may be an option for Costa Rica; however, more case studies should be performed before implementation on a full production scale.

2.6.4 Cost Analysis of the Refinement Processes and Feasibility for Costa Rica

In 2003 Y. Zhang, M.A. Dube, D.D. McLean, and M. Kates performed an economic assessment on the use of alkali-catalyzed transesterification and acid-catalyzed transesterification for waste oil and virgin oil (see Table 3). Their economic assessment was for the year of 1999 and is helpful when presenting the financial aspects of our bio-diesel life cycle. Zhang and his associates found that neither refinement method was profitable. Tax incentives would be needed to turn a profit because costs of raw feedstock and operational costs at the time were greater than the amount of revenue that was able to be generated. Alkali-catalyzed production had a deficit of $2,280,000 and acid-catalyzed was slightly better with a $350,000 deficit. Results of the study indicated that the break-even cost per tonne for bio-diesel was lower when acid-catalyzed processes were used ($644.00). The findings demonstrate that refining bio-diesel on site might be more costly than purchasing diesel fuel. Minimizing expenses for operating the public transit system is important. Therefore, the expense of refinement will factor into the cost between using diesel fuel and bio-diesel fuel.

Table 3: Costs Comparison for Alkali-catalyzed and Acid Catalyzed FAME Production

	Alkali-catalyzed	Acid-catalyzed
Cost of Chemical Processes		
Esterification	$80,000	0
Transesterification	$290,000	$168,000
FAME Distillation	$157,000	$168,000
Cost of Manufacturing		
Oil Feedstock	$1,680,000	$1,650,000
Waste Disposal	$284,000	$280,000
Total Direct Manufacturing	$4,750,000	$3,280,000
Total Indirect Manufacturing	$830,000	$710,000
Total Profit-After Tax	($2,280,000)	($350,000)
Break-even Price	$884 per tonne	$644 per tonne

Adapted from (Zhang *et al.*, 2003b)

2.7 Bio-diesel Storage and Distribution Evaluation

Following refinement processes in the life cycle, bio-diesel fuel is stored and distributed. The quality of fuel as it leaves the production plant must be the same as when it is consumed. The San José public transit system needs fuel which meets standards in order to insure proper interaction between the engine and the fuel (Fernando *et al.*, 2007). Improper engine wear and decreased efficiency can result from poor quality fuel (Kemp, 2006). ASTM standards are internationally recognized and most bio-diesel fuels meet them regardless of production country. After the refined fuel leaves the production plant there is debate as to its degradation rate and appropriate storage conditions (Leung, Koo, & Guo, 2006).

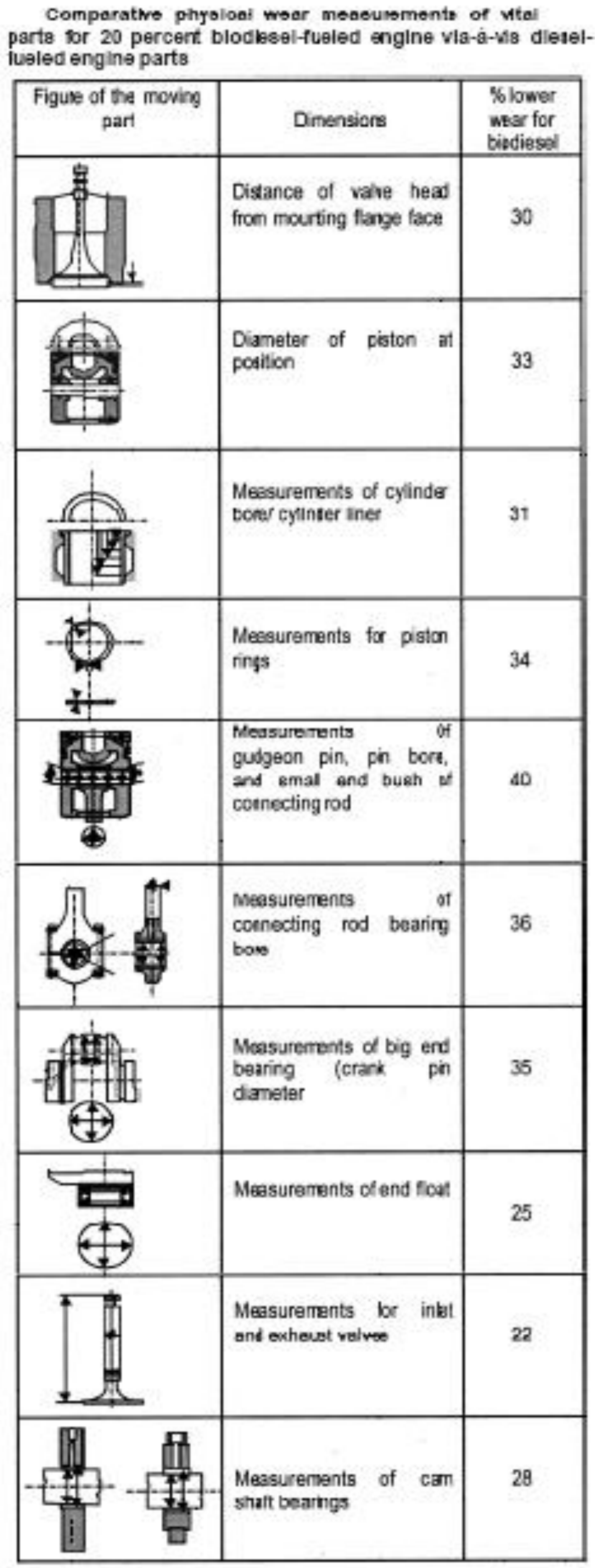
This debate pertains to Costa Rica in particular. Costa Rica is a tropical climate with high humidity and high temperatures. One concern with bio-diesel fuel is its susceptibility to bacterial growth during storage, particularly in warm, moist conditions. There are anti-bacterial fuel additives to kill microorganisms which are effective in diesel and bio-diesel fuel, but the microorganisms can hinder fuel quality if untreated (Kemp, 2006). In addition, bio-diesel fuel is an organic material. Organic materials are biodegradable substances which will naturally experience accelerated decay when exposed to air, light, and high temperatures. Bacteria thrive in this environment, creating storage issues. This means that bio-diesel is more susceptible to rapid decomposition than fossil diesel fuel (Zhang *et al.*, 2003a). The potential affect of temperature and humidity on bio-diesel fuel is a concern for Costa Rica.

A study conducted by D.Y.C. Leung, B.C.P. Koo, and Y. Guo in 2006 addressed the issue of humidity and determined it does not have an effect on fuel quality if the bio-diesel is stored in an air tight container. Therefore, the study suggests that if properly stored, degradation will not be an issue in Costa Rica. This was important when designing and conducting the fuel efficiency study because fuel quality will determine how accurate fuel efficiency results are.

2.8 Bio-diesel Engine Wear and Maintenance Compared to Diesel

An important factor in the relative benefits of diesel vs. bio-diesel is the impact of the fuel on the engine. This includes whether or not the use of these fuels is hazardous to the life of the engine being used. According to an extensive study comparing a diesel fueled engine to that of a bio-diesel fueled engine, the bio-diesel fueled engine is better in many different aspects involving engine wear. Figure 5 shows many of the vital diesel engine components with a percentage of wear that is lower when using a bio-diesel engine compared to a diesel engine (Argalwal *et al.*, 2003).

As shown in the graphs in Figure 6 on the following page, the wear deposits measured in the lubricating oil were all lower in the bio-diesel engine than in the diesel engine. The concentrations of ash, iron, copper, zinc, chromium, magnesium, cobalt and lead were evaluated (Argalwal *et al.*, 2003).



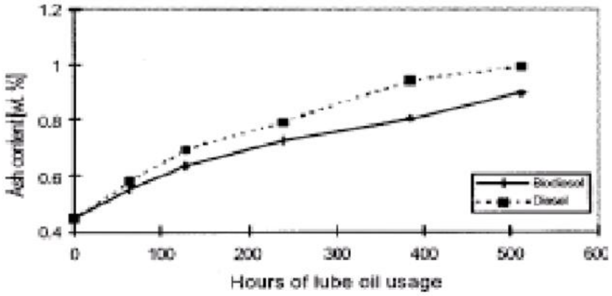
Comparative physical wear measurements of vital parts for 20 percent biodiesel-fueled engine vis-à-vis diesel-fueled engine parts

Figure of the moving part	Dimensions	% lower wear for biodiesel
	Distance of valve head from mourting flange face	30
	Diameter of piston at position	33
	Measurements of cylinder bore/ cylinter liner	31
	Measurements for piston rings	34
	Measurements of gudgeon pin, pin bore, and small end bush of connecting rod	40
	Measurements of connecting rod bearing bore	36
	Measurements of big end bearing (crank pin diameter	35
	Measurements of end float	25
	Measurements for inlet and exhaust valves	22
	Measurements of cam shaft bearings	28

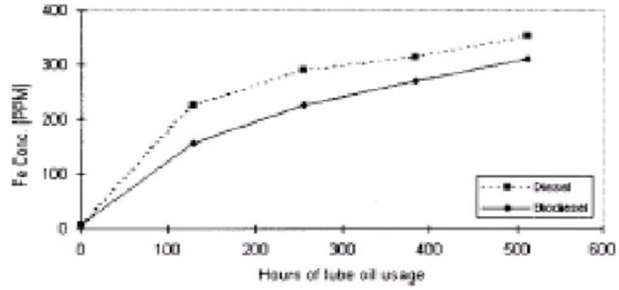
Figure 5: Engine Wear Data
(Source: Argalwal *et al.*, 2003)

Ash content is basically the wear debris of metal from the engine use (Argalwal *et al.*, 2003). From the first graph in Figure 6, one can see that the ash content is less in the 100% bio-diesel engine than in the diesel engine, showing less wear to the engine overall. The iron concentration content signifies wear on the piston, cylinder liner, rings, valves, valve guides, gears, shafts, bearings, and crankshaft (Argalwal *et al*., 2003). From graph 2 in Figure 6, one can see that the iron concentration was also less in the bio-diesel engine than in the diesel engine, which means less wear. The copper concentrations are due to the wear of bushings and bearings (Argalwal *et al.*, 2003). Graph 4 shows that the copper concentration was also less in the bio-diesel engine than in the diesel engine, which means less wear again. The chromium, magnesium, cobalt, lead, and zinc all are evidence of other engine parts and for all of the samples the bio-diesel engine turned out to show less wear on all of the parts of the engine (Argalwal *et al*., 2003).

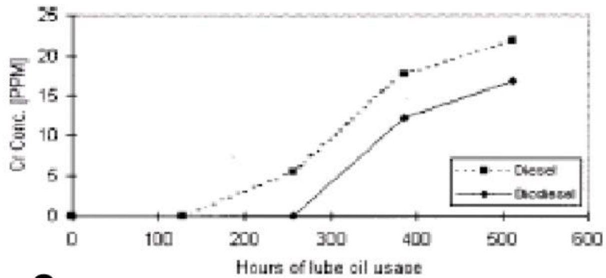
In terms of our project, the results of this research provided strong evidence that using the bio-diesel fuel would be beneficial to the life of the engine.



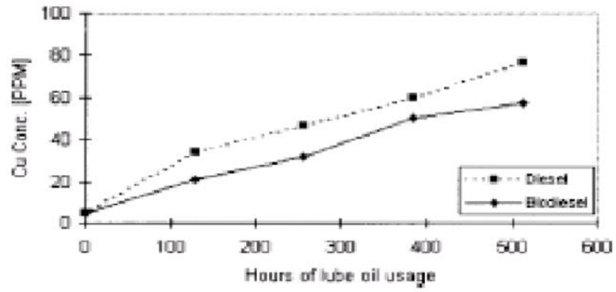
1 Ash content versus hours of lube oil usage



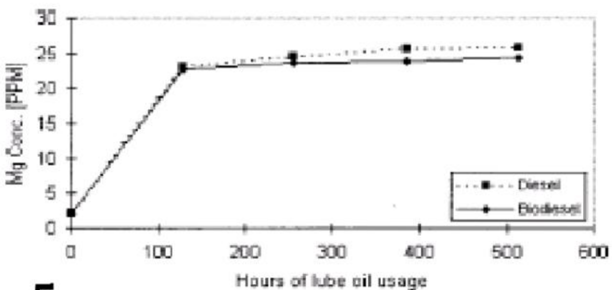
2 Iron concentration as a function of lube oil usage



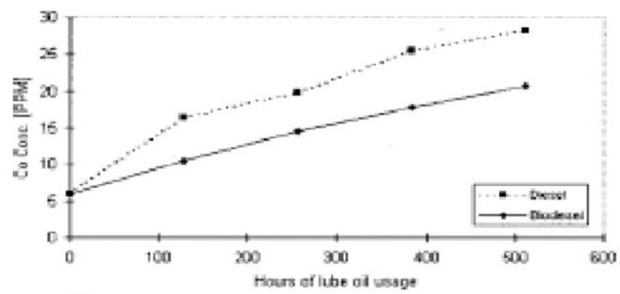
3 Chromium concentration as a function of lube oil usage



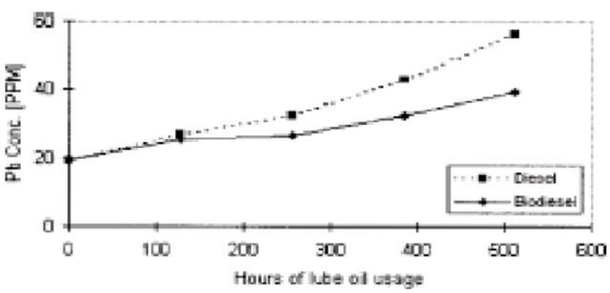
4 Copper concentration as a function of lube oil usage



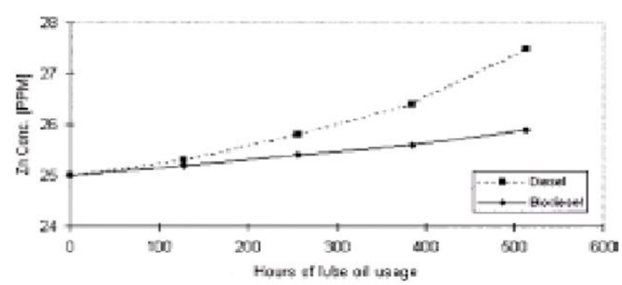
5 Magnesium concentration as a function of lube oil usage



6 Cobalt concentration as function of lube oil usage



7 Lead concentration as a function of lube oil usage



8 Zinc concentration as a function of lube oil usage

Figure 6: Graphs Showing Factors in Engine Wear
Source: (Argalwal et al., 2003)

2.9 Summary

As Costa Rica begins to form policies regarding bio-diesel fuel it is important for CNP+L to evaluate the complete life cycle of bio-diesel. One of the motivating forces for switching to bio-diesel is that it may reduce environmental impacts. The project team's analysis of bio-diesel fuel helped support this. Furthermore, the analysis will demonstrate costs vs. benefits for switching to bio-diesel fuel. Aside from direct production costs numerous studies have been conducted proving that bio-diesel reduces emissions. This may also impact cost-based decision making because health expenses may decrease for Costa Rica. However, fuel stock production, refinement, fuel storage, and engine mechanics all factor into the decision to switch transportation buses to bio-diesel fuel. Previously conducted studies discussed in this Chapter demonstrate that bio-diesel fuels have shown enough benefits to warrant conducting a full scale study on San José public transportation buses.

After completing the background research the project team had a knowledge base to establish relevant research questions. There are three primary topics addressed in the Methods Chapter. The first evaluates the fuel efficiency of Consorcio Operativo buses in San José. The second topic calculates the cost of using solely bio-diesel in San José buses. Finally, the third topic evaluates the relationship of several social aspects with using bio-diesel.

3.0 Methods

The objective of this project was to research the feasibility of bio-diesel use within the context of San José, Costa Rica. In order to meet this objective the project team posed three research questions. Section 3.1 introduces the research questions and describes the methodology in detail.

3.1 Research Variables and Methodology

There are three central research questions which the project team addressed in this chapter. The three avenues of research address technical, economic, and social issues. The three research questions are:

- What is the fuel efficiency of bio-diesel compared to diesel in public transit buses for the San José area?
- What is the cost difference for the use of bio-diesel versus diesel in the public transit sector of San José?
- What impact will bio-diesel have on the economy, environment, and society and how are these impacts interrelated?

The first research question considered the relative fuel efficiencies of B15 bio-diesel, B30, B100, and diesel. B15 was the blend that Consorcio Operativo was using at the time of this project. In order to determine these relative efficiencies the project team conducted an experiment by running buses in San José with different fuel blends and compared data such as kilometers traveled and fuel consumption.

In an investigation of economic issues, the project team calculated the cost of converting the use of diesel in public buses to pure bio-diesel. To calculate the conversion cost, a proportion was achieved that compared a liter of diesel to the equivalent amount of bio-diesel, based on the calorific study. The project team also considered the partial molar volume of bio-diesel/diesel blends. This consideration took into account a possible fluctuation in the density of the bio-diesel-diesel mixtures when blended.

Finally, the project team decided to evaluate the effect of bio-diesel use in San José from three perspectives: the economy, environment and society. The project team evaluated the economic feasibility and impact of bio-diesel by using the data collected on bio-diesel conversion costs and considering a plan that would allow the Consorcio Operativo bus company to operate on fuel grown and refined in a closed-loop operation. The second perspective considered the environmental impact. In order to do this, the project team contacted agencies in Costa Rica that had done studies on air pollution caused by fossil fuel use. The team then used Consorcio Operativo's opacimeter to compare the particulate matter emissions in bio-diesel and diesel exhaust. The project team also looked into the implications of reduced greenhouse gas emissions on climate change. Finally, the project team evaluated the relationship between bio-diesel and society focusing on health implications. Information on air pollution trends and corresponding healthcare issues were researched with the intent of finding correlations between the two. A second societal impact considered was public opinion and attributes relating to bio-diesel fuel and air quality. This was done by conducting a survey of pedestrians at different locations around San José.

3.1.1 What is the fuel efficiency of bio-diesel compared to diesel in public transit buses for the San José area?

When designing this project's fuel efficiency study the project team referenced a similar study conducted by Dr. C. Chen and associates of Shanghai Academy of Environmental Sciences (2007). Chen and associates performed a fuel efficiency study using hauling trucks. The methodology and reasoning for using specific methods was published in *Atmospheric Environment* in 2007. The project team evaluated Chen's methods to assist in designing a procedure.

Dr. C. Chen and associates began by randomly selecting nine hauling trucks which were less than five years old and representative of the most commonly used engines in Shanghai. They then established one hauling route all trucks traveled on and specified the time of day all trucks began the route at. According to the study these procedures reduced the number of variables. For their study they recorded both emissions and fuel efficiency using the following table (see Appendix B). The results were evaluated by averaging all of the trucks' fuel efficiencies together. The resulting data was the total average fuel consumption, and average emissions.

This project used a similar methodology as in the study by Dr. Chen; however, there were more resource constraints in this study. The limiting factors the project team faced were time and equipment. Time constraints and the lack of an electronic fuel efficiency gauge limited the type and quantity of data collected. The procedures follow:

1. The first step in the fuel efficiency study was to meet with Señor Orlando Ramirez, an owner of Consorcio Operativo, and discuss the objectives of the research. The project team had predicted that the engine make, passenger load, driver, and time of day the bus operated would all have an effect on the efficiency. Señor Ramirez offered to work with the team to minimize variation. He recommended six buses with Mercedes Benz engines based on the following criteria:
    a. The Mercedes Benz buses were the newest of the fleet containing engines from 2004. They were equipped with on-board global positioning system devices (GPS) which record kilometers traveled, passenger loads, and routes traveled. This enabled the project team to record accurate kilometers traveled.
    b. Mercedes Benz buses were also chosen because they have required minimal maintenance in the past and adapted to bio-diesel use without complications.
    c. Lastly, the buses were assigned a single driver. The drivers for the Mercedes Benz buses were considered to be the best among all drivers and the most experienced. Also, when a bus driver was not working on a particular day, his assigned bus was generally not used. This approach eliminated a possible variation due to the drivers.

d. There were eleven Mercedes Benz buses, and the project team selected six out of the eleven. The decision was based on availability of archival data for each bus. The project team looked at a full week's worth of data for all eleven buses and chose six based on complete and consistent documentation for driver, mileage, and fuel consumed per shift worked.

2. An evaluation of fuel efficiency using the B100 and diesel was conducted after the B15 blend runs. Due to supply constraints with bio-diesel, Consorcio Operativo could only run three buses at a time with B100. The other three were filled with diesel fuel. At the end of a seven day sample period the B100 buses were then fueled with diesel for the next seven days and vice versa. The first two days were used to flush out any remaining previous fuel from the buses' combustion system. For the next five days data was collected for the relevant fuel. The total liters of fuel consumed, kilometers traveled, and driver were recorded on Consorcio Operativo data sheets. Then, the average fuel efficiency for each blend and standard error were calculated for each bus. Buses 5, 6, and 18 operated on diesel from June 2-9 and then switched to B100 for June 11-18. Buses 27, 32, and 55 began on B100 (June 2-9) and were run on diesel fuel for June 11-18. See Table 4 for a sample of the data collection for each bus.

Table 4: Sample Data Collection Chart

	Bus # 5			
B15	Day	Distance (km)	Consumption (L)	Efficiency (km/L)
	1			
	2			
	3			
	4			
	Average			
	Bus # 5			
B100	Day	Distance (km)	Consumption (L)	Efficiency (km/L)
	1			
	2			
	3			
	4			
	Average			
	Bus # 5			
Diesel	Day	Distance (km)	Consumption (L)	Efficiency (km/L)
	1			
	2			
	3			
	4			
	Average			

3. Data for the B15 and B30 study ware obtained from official log sheets kept on each bus. Log sheets recorded the date, bus number, conductor, route traveled, odometer reading (km), and the liters of fuel put in the tank. Log sheets are also stored as a permanent record for several years. The project team transferred data from log sheets into Microsoft Excel in order to calculate fuel efficiency. B15 information was obtained from May 20-25, 2007. B30 data was recorded for November 2-15, 2006. Drivers for the 6 Mercedes Bens buses were the same for both time periods.

3.1.2 What is the cost difference for the use of bio-diesel versus diesel in the public transit sector of San Jose?

In order to evaluate the cost for utilizing bio-diesel in San José the project team answered several sub-questions:

- What is the energy content of diesel, biodiesel, and fuel blends?
- How much diesel fuel is used by bus companies per year?
- What are the costs for bio-diesel and diesel fuel during the month of June 2007, in San José?

The first step in determining the cost of using bio-diesel was to find a direct comparison between the energy content of each fuel. This difference in energy content was crucial in determining an equivalency for a conversion from liters of diesel to liters of bio-diesel. This was done by bomb calorimetry. A bomb calorimeter is a strong sealed metal vessel used to measure energy content (Answers.com, 2007). The first step was to combust a fuel inside the bomb calorimeter. The energy given off by the combustion heated up water trapped inside an insulated chamber that surrounded the reaction chamber (Helmenstine, 2007). The change in water temperature allowed for the energy content of the fuel to be calculated. The equations which yielded the energy content of the fuel were:

$$Step\ 1: q_{bomb\ calorimeter} = (specific\ heat\ capacity)_{bomb\ calorimeter} \bullet m_{bomb\ calorimeter} \bullet \Delta t$$

$$Step\ 2: q_{water} = 4.18 \frac{J}{(g\ C^{o})} \bullet m_{water} \bullet \Delta t$$

$$Step\ 3: q_{fuel} = -(q_{water} + q_{bomb\ calorimeter})$$

Specific heat capacity is a constant value for different materials and it is the amount of energy required to raise one gram of substance one degree Celsius. In these equations the variable *q* represents energy in Joules (Helmenstine, 2007). In Step 1 the amount of energy the bomb calorimeter absorbed needed to be considered. This was done by multiplying the calorimeter's specific heat capacity and its mass (fixed values) by the change in temperature of the water. Step 2 calculated the energy content absorbed by the water. Finally, Step 3 determined the energy of the fuel. The team then converted the Joules to British thermal units (Btu) in order to make more standardized energy comparisons. One Joule is equal to 0.000948 Btu.

The project team contacted Professor Julio Mata to have B100, B30 blend, and B15 blend and diesel fuel combusted in a bomb calorimeter at the University of Costa Rica. The energy content was found for the fuel types. After determining the energy content of the fuels, a relative volumetric ratio was determined between B100 and diesel using a relationship which the project team created:

$$\frac{\text{Energy of Diesel}}{\text{Energy of Bio-Diesel}} = \frac{\text{1 Liter of Diesel}}{\text{X Liters of Bio-Diesel}}$$

$$\text{X Liters of Bio-Diesel} = \frac{\text{Energy of Bio-Diesel} * \text{1 Liter of Diesel}}{\text{Energy of Diesel}}$$

Figure 7: Energy - Volume Conversion Ratio

An additional experiment was conducted that accounted for a particular phenomenon that occurs with the blending of certain chemically similar liquids. Partial molar volume is a phenomenon that occurs when the measured volume of a mixture is different than the sum of the individual volumes. The mixed substances interact on a molecular level and the resulting volume is either greater or less than expected.

Dr. Musmanni informed the project team about an example of this phenomenon which occurs between ethanol and water. When mixing ethanol and water, the resulting volume is less than the sum of the original volumes of water plus ethanol. Because water and ethanol are chemically similar, the individual molecules of the substances are attracted to each other. The result is a final volume that is less than expected (Musmanni, 2007). Dr. Musmanni had mentioned this occurrence to the project team and requested an experiment investigating blending bio-diesel and diesel fuel. This was significant because if the volume of a bio-diesel/diesel blend did fluctuate, it would affect the density and in turn this would affect the energy per unit mass of a bio-diesel/diesel blend. In order to determine if this phenomenon occurred in blends of bio-diesel and diesel, the project team did a volumetric analysis at the University of Costa Rica.

The analysis consisted of taking known volumes of both bio-diesel and diesel for preplanned blends and comparing the actual volume of the resulting mixture with the expected volume. The expected volume was simply the sum of the two initial volumes of bio-diesel and diesel.

After determining the physical properties of bio-diesel, diesel, and blends, the cost of replacing diesel in public transportation buses was calculated. In order to determine the cost it was necessary to find the total amount of diesel consumed by the entire public bus fleet in San José. This was done by contacting RECOPE, the national diesel provider and distributor in Costa Rica. This amount of diesel was converted to the equivalent amount of bio-diesel using the relationship in Figure 7. After calculating how much bio-diesel it would require to run the fleet, the cost of said bio-diesel was determined by multiplying the number of liters required of bio-diesel by the current market price of bio-diesel (See Figure 8).

Energy Content Analysis → Diesel to Bio-Diesel Equivalency

Diesel to Bio-Diesel Equivalency + Diesel Consumption Data → Total Bio-Diesel Required

Total Bio-Diesel Required + Current Bio-Diesel Cost → Cost of Using Bio-Diesel

Figure 8: Summary of Methods 3.2.2

3.1.3 What impact will bio-diesel have on the economy, environment, and society and how are these impacts interrelated?

By answering this third research question, the project team was able to assess the implications of implementing a bio-fuel program. The assessment process required a view from three perspectives:

- Economy:
    - ⇒ Cost Comparison of diesel vs. bio-diesel in Costa Rica
    - ⇒ Case study of the Ramirez bio-fuel plan
- Environment:
    - ⇒ Emissions
    - ⇒ Climate Change
- Society:
    - ⇒ Health Effects

⇒ Public Opinion

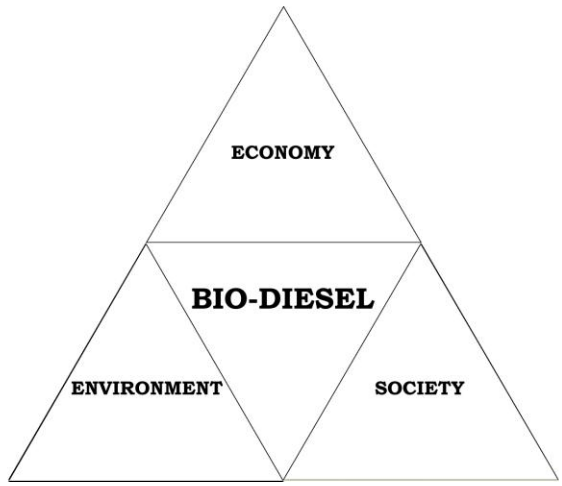


Figure 9: Economic, Environmental, and Societal Relationship

Evaluating these three perspectives allowed the project team to assess the full spectrum of bio-diesel implications.

In looking at economy, this project team evaluated a case study of a plan to run a bus transportation company completely on bio-fuel (See Figure 10).

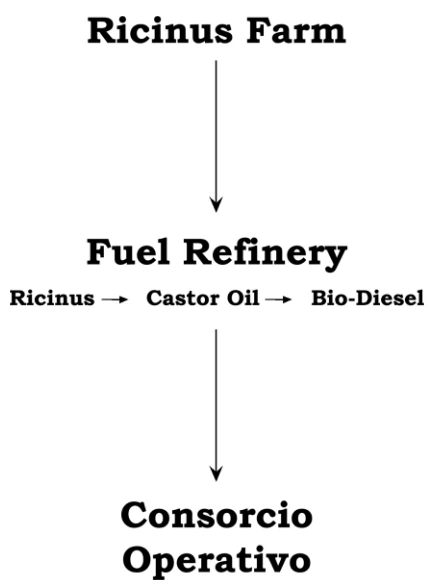


Figure 10: Ramirez Bio-Diesel Plan

At the time of this project, Orlando Ramirez and his family were using bio-diesel through their bus company, Consorcio Operativo, and were major shareholders of the bio-diesel refinery that supplied the buses. They also initiated a plan to convert some of the agricultural land that they own to produce castor oil as a bio-diesel raw-stock. The project team studied this plan and evaluated the economic possibilities of the Ramirez enterprise. The project team also performed archival research on issues concerning domestic fuel crop production in relation to the Ramirez enterprise. The cost comparison and evaluation of this case study allowed for conclusions to be drawn in regard to the feasibility of a bio-diesel initiative from an economic standpoint.

Another important factor the project team wanted to consider was the environmental benefits of using bio-diesel fuel. To look at this environmental factor, the project team studied the impact of emissions caused by the combustion of bio-diesel and diesel. It is generally accepted that bio-diesel reduces the total amount of harmful emissions. However, the project team wanted to evaluate the impact of reduced emissions for San José specifically. In order to complete this evaluation the project team found reports by government organizations and private organizations in Costa Rica that had done research on this topic. The findings consisted of the collected emissions data, specifically the amount and type of particulate matter and harmful compounds (CO, CO_2, NO_x, HC and SO_2) released from each type of fuel. Next, the project team used an opacimeter to determine the difference in particulate matter between bio-diesel exhaust and diesel exhaust. The team used two Consorcio Operativo buses, one running on B100 and the other on diesel, and used an OPUS 50 model opacimeter to measure the particulate matter in each bus's exhaust. The project team also evaluated the effect on climate change by using the total diesel consumption data and an equation developed by the Department for Environment, Food, and Rural Affairs, UK to determine the amount of CO_2 emissions resulting from that consumption. The amount of CO_2 was found by using a conversion table located on the Department for Environment, Food, and Rural Affairs website (www.defra.gov.uk). This table gave an equation to find the value of CO_2 emitted per liter of diesel fuel:

$$(Liters\ of\ Diesel) \times (2.63) = kg\ of\ CO_2\ emitted$$

This number allowed the project team to look at the amount of CO_2 emitted by the buses per year in San José and compare the number to the corresponding emissions for the same amount of bio-diesel. CO_2 is a greenhouse gas and reducing the total emissions could have positive implications in the area of climate change. This calculation, in conjunction with the other emissions data, gave the project team the information needed to draw conclusions on the potential environmental impact of using bio-diesel in Costa Rica.

Finally, the project team was concerned with investigating the impact on society. This impact was evaluated by looking at the health effects of the combustion of fossil fuels on the population, its costs and the current public opinion in regard to bio-diesel use. In order to evaluate the health effects of using diesel fuel, the group contacted the Ministry of Health in Costa Rica that had done research on this topic. These contacts gave the project team information necessary to draw conclusions comparing the health effects with respect to the economy and the environment. Finally, the project team conducted a short survey of one hundred randomly selected pedestrians in four locations. (See Appendix C for the survey) The survey was conducted at the University of Costa

Rica, Avenida Central (Central Pedestrian Avenue), the National Theatre, and Parque Morazon. The questions that were asked in the survey were:

- Do you think the air in San José is healthy?
- How would you rate the air quality in San José?
- What kind of an impact do you believe public buses have on the air quality of San José?
- Are you familiar with the word "Bio-Diesel"?
- What type of impact do you think bio-diesel fuel would have on the air quality in San José?
- Would you be willing to pay another 5 colones for a bus using bio-diesel fuel?

The results of this survey allowed the project team to take into account the opinion of the population that would be subject to the changes resulting from the use of bio-diesel fuels.

3.2 Summary

Methods for the team's empirical study and archival research were explained in this chapter. In what follows, the project team reports results for each of the three research questions outlined above. The results will be presented in Chapter Four. The project team closes this report with our findings and recommendations in the subsequent chapters five and six.

4.0 Results

4.1 Fuel Efficiency Study

The project team's fuel efficiency study evaluated diesel fuel, B15 blend, B30 blend, and B100. The results are provided in the subsequent sections. After the project team evaluated the results for each fuel type, a statistical comparison was performed (Petruccelli, 1999) to compare diesel fuel and each bio-diesel blend.

4.1.1 Diesel Fuel Results for the Six Mercedes Benz Buses

Fuel efficiency data for diesel, B15, B30, and B100 are presented in Appendix D for each bus. The efficiency averages and statistical data are shown in Figure 11 for each fuel type. The project team determined that buses running on diesel fuel had an average fuel efficiency of 2.94 km/L and a standard error of 0.4 as shown in Figure 11. Standard error indicates how much a sample set deviates from the average, so the six buses may exhibit fuel efficiencies of 0.4 km/L greater or less than the average. For example, the maximum and minimum fuel efficiency for diesel fuel ranges between 3.34 km/L and 2.54 km/L within a 95% confidence interval. These confidence interval values are used in further comparisons.

4.1.2 B15 Results for the Six Mercedes Benz Buses

The fuel efficiency using B15 blend was similar to the fuel efficiency using diesel fuel. The average fuel efficiency for the six Mercedes Benz buses was 3.00 km/L (see Appendix D). There was a 2% improvement with B15 blend over diesel fuel. Despite the difference in average fuel efficiencies, the two fuels were still statistically similar. B15 demonstrated a standard error of 0.23. The maximum and minimum fuel efficiencies for B15 were 3.15 km/L and 2.85 km/L. These values fell within the same data range as diesel fuel.

4.1.3 B30 Results for the Six Mercedes Benz Buses

The six Mercedes Benz buses demonstrated an average fuel efficiency of 2.73 km/L when operating on B30 blend. The standard error was found to be 0.12. The maximum and minimum fuel efficiencies were 2.85 km/L and 2.61 km/L. Both of these values fall between diesel fuel's maximum and minimum efficiencies of 3.34 km/L and 2.54 km/L. This meant that diesel fuel and B30 blend did not exhibit significantly different fuel efficiencies.

4.1.4 B100 Results for the Six Mercedes Benz Buses

Fuel efficiencies for B15 blend and B30 blend remained statistically similar to diesel fuel. This meant that there is no significant difference between diesel fuel, B15 blend, and B30 blend

B100 followed the same relationship. The average fuel efficiency was 2.49 km/L with a standard error of 0.47. B100 exhibited a maximum fuel efficiency of 2.96 km/L which was similar to that of the other fuels. However, the minimum fuel efficiency was 2.02 km/L which was lower than the other fuel types. Figure 11 depicts how each fuel type relates to one another and provides a visual representation of standard error (the black bars). As seen in Figure 11, the error bars for B15, B30, and B100 fall within the error bars for diesel fuel. As a result, all fuel types are statistically similar.

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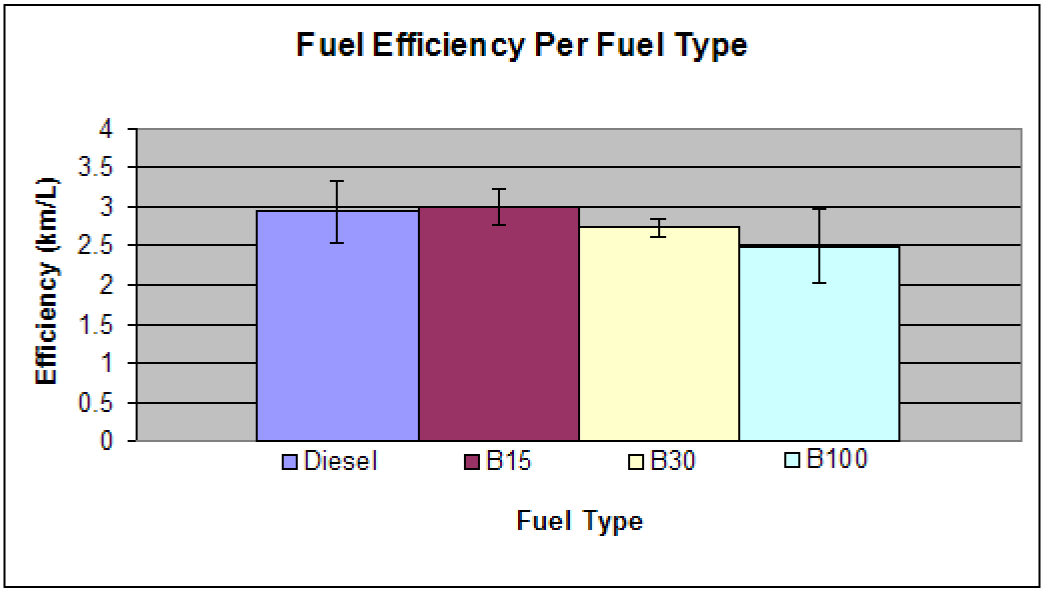


Figure 11: Summary of Fuel Efficiencies

4.2 Cost Difference of Diesel vs. Bio-Diesel

4.2.1 Calorific Experiment

Professor Julio Mata at the University of Costa Rica performed the calorific energy determination and reported to the project team that diesel had 44.5 MJ/kg, B15 blend contained 43.7 MJ/kg, B30 contained 43.1 MJ/kg and B100 contained 39.2MJ/kg of energy. These values translate to 42,200 Btu/kg; 41,400 Btu/kg; 40,900 Btu/kg; and 37, 200 Btu/kg respectively.

4.2.2 Molar-Volume Experiment

The project team received the results of the Molar Volume experiment on June 22nd, 2007 from the University of Costa Rica. The results showed no expansion or contraction in the bio-diesel/diesel mixture volumes. Bio-diesel and diesel have a 1:1

molar ratio and are not affected by internal forces. Within an error of two percent, it was found that the final volume of a mixture of bio-diesel and diesel was equal to the sum of the two original volumes.

4.2.3 Cost Calculations

The project team with the help of Dr. Sergio Musmanni obtained information from RECOPE, the national fuel distributor, and learned that the projected amount of diesel consumed by Costa Rica for transportation purposes in 2007 was 715, 277,000 liters. The team could not obtain the amount of diesel consumed by public bus companies but determined the total diesel consumed for transportation purposes in Costa Rica 2007. The project team took the value of diesel consumed and multiplied it by the energy of diesel over the energy of bio-diesel.

$$715{,}277{,}000\ \textit{Liters of Diesel} \times \left(\frac{42{,}200\ \textit{Btu/kg of Diesel}}{37{,}200\ \textit{Btu/kg of Bio-Diesel}} \right) = 811{,}124{,}000\ \textit{Liters of Bio-Diesel}$$

This equation determines how much bio-diesel would be needed to replace diesel on an annual basis. Once the total required bio-diesel consumption for the year 2007 had been determined, the total cost for the fuel based on current market prices was calculated. The project team found that Energías Biodegradables sold bio-diesel to Consorcio Operativo for $1.1 or 568.7 colones per liter. Using the price of 568.7 colones per liter, the team determined that it would have cost $892,236,400 or ¢461,286,218,800 colones to use B100 for transportation purposes in Costa Rica in 2007. An important lesson in this scenario is that the majority of the cost of the fuel would remain in Costa Rica if the bio-diesel were produced in this country as opposed to supporting foreign oil producers.

4.3 The Relationship Between the Economy, Environment, and Society

The following sections report the results for the methodology of section 3.1.3. Results include data on the Ramirez plan, environmental impacts, as well health effects, and public opinion results.

4.3.1 Case Study of Ramirez Bio-Fuel Plan

An example of a bio-diesel initiative in Costa Rica is the Ramirez bio-fuel plan. Orlando Ramirez's family owns a farm which they plan on using for bio-diesel raw stock production, and Mr. Ramirez is also a co-owner of the bio-diesel production company Energías Biodegradables. He is also an owner of the bus company Consorcio Operativo.

In an effort to decrease raw feedstock costs and increase the amount of bio-diesel generated, Señor Ramirez and his family opted to start growing their own bio-diesel raw stock. In an interview with Orlando Ramirez on May 24, 2007, the project team learned that the Ramirez family planned on converting 1,000 hectares (2471 acres) from cattle pastures to growing ricinus. The objective is to produce castor oil from higuerilla, which is a particular type of ricinus (Figure 12). The reason for ricinus is based on its high yield, fast growth and low management.

Figure 12: Ricinus: Higuerilla used in Ramirez Plan
(Source: Eladio Madriz)

Because ricinus is not a local crop, there had been no previous data on ricinus growth in Costa Rica. Ramirez researched how ricinus is grown in Brazil and Columbia when considering which raw stock to use. Ramirez planned on experimenting with several types of seeds in order to determine which would produce the largest yield in Costa Rica. O. Ramirez (personal communication, May 24 2007) told the project team that with the right ricinus seed he was planning to produce 2,500 liters of bio-diesel for every hectare and have two crop cycles per year. So in a given year, the farm could produce around 5 million liters of bio-diesel. Since Consorcio Operativo's annual fuel consumption was 2.4 million liters, the ricinus farm could produce twice as much castor oil for bio-diesel than is needed for Consorcio Operativo's entire fleet to run on 100% bio-diesel. Although these yields are higher than what the project team found in literature, ricinus might grow better in Costa Rica.

Ramirez is also a major share holder in Energías Biodegradables, a company that refines raw feedstocks into bio-diesel and supplies Consorcio Operativo with bio-diesel fuel. At the time of this project, the refinery was operating at about 10% capacity (250,000 liters per month) due to high costs of raw materials and the level of demand.

They were using primarily palm oil, soy oil, and RFO as feedstocks. Energías Biodegradables needed to compete for these raw materials with other industries which used the same feedstocks for other products (Ramirez, 2007). Ramirez plans to run the refinery at full capacity (three million liters per month) when full scale ricinus production begins. Although the feasibility of this model is not possible to determine at this time, the possibility of ricinus becoming a high yielding bio-diesel raw stock warrants further investigation.

Another consideration was determining if enough land existed for growing bio-diesel raw stock. According to E. Madriz, manager and co-owner of Energías Biodegradables, Costa Rica would need about 400,000 hectares of bio-diesel raw stock producing land to match their current crude oil needs (personal communication, June 26 2007). Figure 13 shows current land distribution in Costa Rica as of 2005.

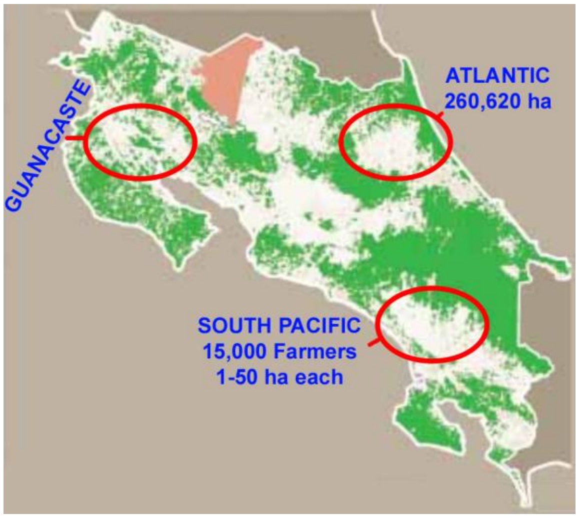


Figure 13: Land Distribution
(Source: Eladio Madriz)

The north Atlantic region contains 260,620 hectares of flat, usable farmland and the South Pacific region holds 15,000 farmers owning 1 to 50 hectares each. Many of the farmers already grow certain crops but could potentially be contracted to grow bio-diesel raw stock. Both of these regions are potential bio-diesel raw stock producing areas. The Guanacaste region in the northwest also has copious flat, usable land. Prospects for growing bio-diesel in this region are slim due foreign purchase of the land for development. This development has caused the cost of land near Guanacaste to be very high. The potential to grow enough bio-diesel raw stock exists. The issue becomes the displacement of other crops and the implications of those displacements. The project team addresses this issue in Chapter Six. Depending on the yields of ricinus, those implications might be less of a concern.

One economic benefit of using bio-diesel comes directly from the lower emissions. Andres Arenas, the general director of operations at Consorcio Operativo, informed the project team of a particular advantage to using bio-diesel (personal communication, May 25 2007). Periodically, buses were taken out of circulation due to failing the random governmental emissions testing (see Section 2.1), and it would take one to two weeks to have the license plate returned so the bus could resume operations. Since on average a bus earns between ¢90,000 ($174) and ¢200,000 ($387) a day, the company would lose between ¢630,000 ($1219) and ¢2,800,000 ($5416) depending on when the bus would return to circulation. When Consorcio Operativo began using bio-diesel blends in all their buses, one and a half years ago, the instances of license plates being revoked due to failed emissions tests significantly decreased (Arenas, 2007). Although Arenas could not provide the team with exact figures on savings, he did state that the bio-diesel fueled buses almost never failed the emissions testing. Due to the fact that bio-diesel was more expensive than diesel at the time of this project, Consorcio

Operativo needed to balance the higher cost of bio-diesel with this financial benefit of using bio-diesel (Arenas, 2007). They found that balance by using a B15 blend.

4.3.2 Emissions Findings

Emissions data was gathered from two Consorcio Operativo buses from the efficiency study. One bus ran on diesel fuel and the other ran on B100 bio-diesel The resulting emissions of particulate matter showed the bio-diesel bus emitted fewer emissions in both trials (See Appendix H for raw data).. At high RPM's the bio-diesel bus emitted 31% fewer emissions. At low RPM's the bio-diesel bus emitted 89% fewer emissions. The results also showed that both buses emitted less particulate matter when running at lower RPM's; in addition, the difference between the emissions of the diesel and bio-diesel bus was also greater when running at lower RPM's. The differences are shown on Figure 14 (low RPM) and Figure 15 (High RPM).

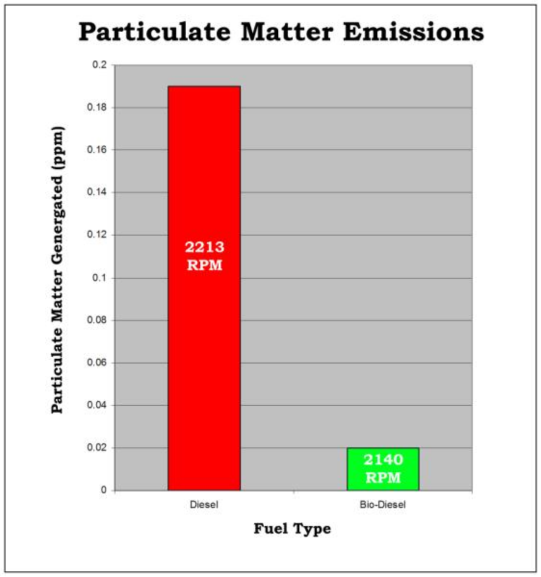


Figure 14: PM Emissions at Low RPM

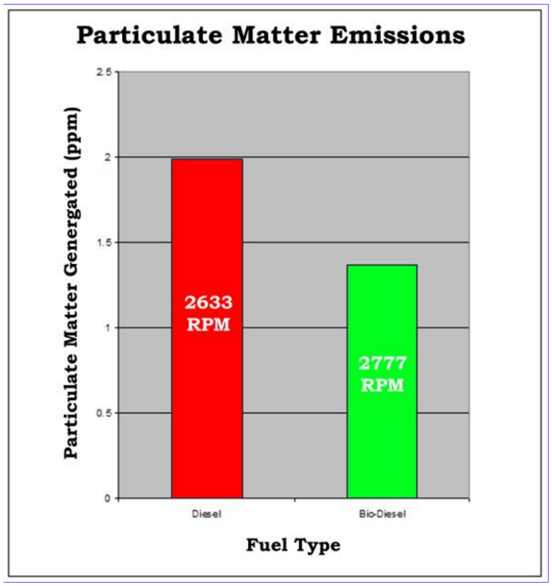


Figure 15: PM Emissions at High RPM

These contaminants have implications on a larger scale as the following Figure demonstrates. Figure 16 shows only the amount of PM10 contamination present in the city of San Jose due to vehicular flow, which accounts for 75% of all particulate matter.

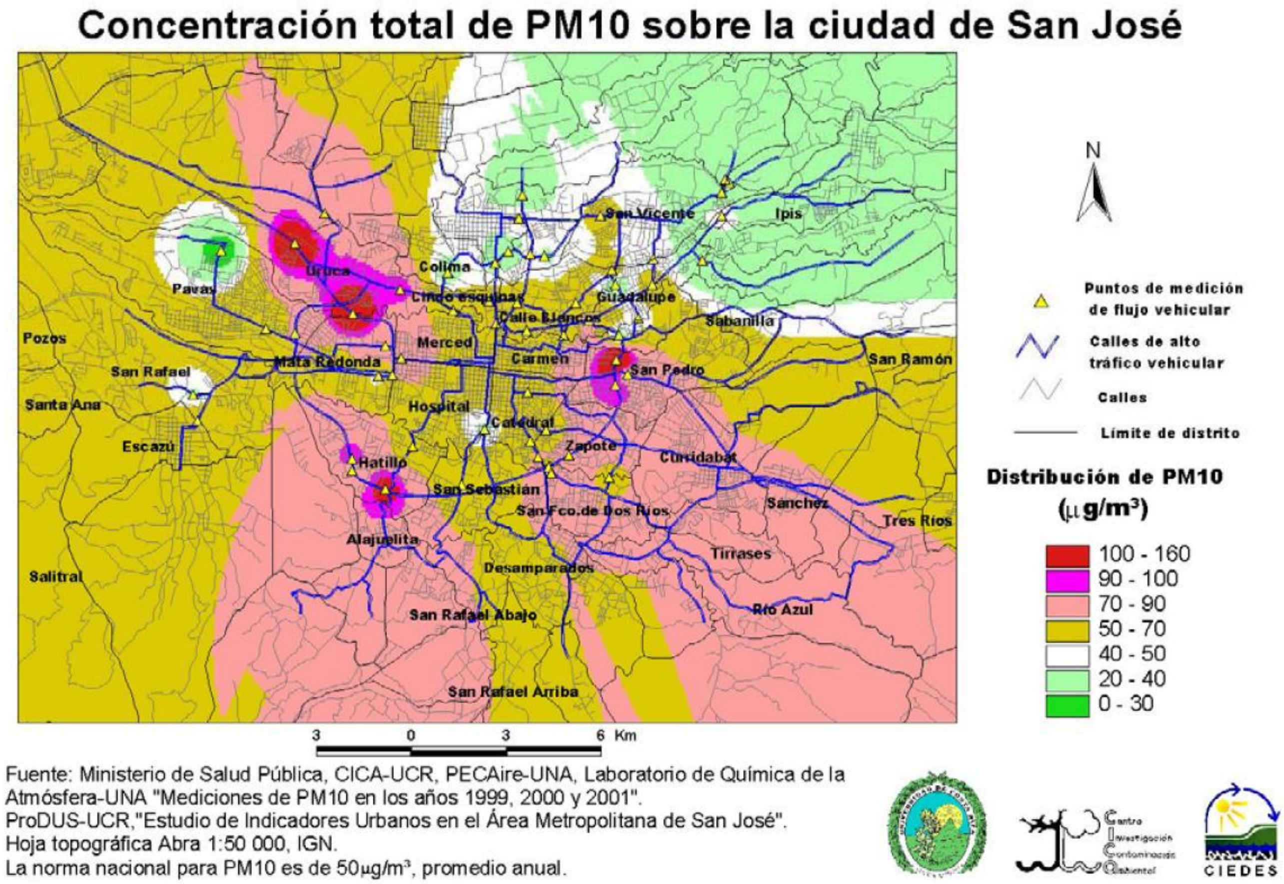


Figure 16: Total PM10 Concentrations Around the City of San José
(Source: Allen *et al*., 2005)

Sources not included are natural factors like dust from the ground, as well as fixed pollution sites (Allen *et al*., 2005). Uruca, the area south of Hatillo, and San Pedro are three of the most effected areas (Allen *et al*., 2005). These areas are in the 100-160 range of micrograms per cubic meter. The severity of these high levels can be related to the national norm of 59 micrograms per cubic meter. The high concentrations are also affected by the factors of wind patterns, precipitation, temperature, and pressure (Allen *et al*., 2005).

According to Allen *et. al*., the concentration of PM10 in Costa Rica is much larger than those of other countries (2005). Austria has a total annual concentration of 26 $\mu g/m^3$, France has a concentration of 23.5 $\mu g/m^3$, and Switzerland has a concentration of 21.4 $\mu g/m^3$ compared to the concentration of 59 $\mu g/m^3$ in Costa Rica (Allen *et al*., 2005). Costa Rica's levels are almost triple those of other more developed countries. The major reason for the higher level of pollutant is due to the transportation industry. Austria, France, and Switzerland have a fifth of the concentration of PM10 when compared to Costa Rica's 44.3 $\mu g/m^3$. See Appendix E for complete data.

The fuel projections shown in Figure 17 illustrate that year after year the diesel fuel consumption for the transportation sector is rising. The increased consumption correlates to the growth of the transportation sector. This increasing consumption of diesel fuel to support public transportation will result in increasing emissions, making the current air contamination problem even worse (CNP+L, 2005).

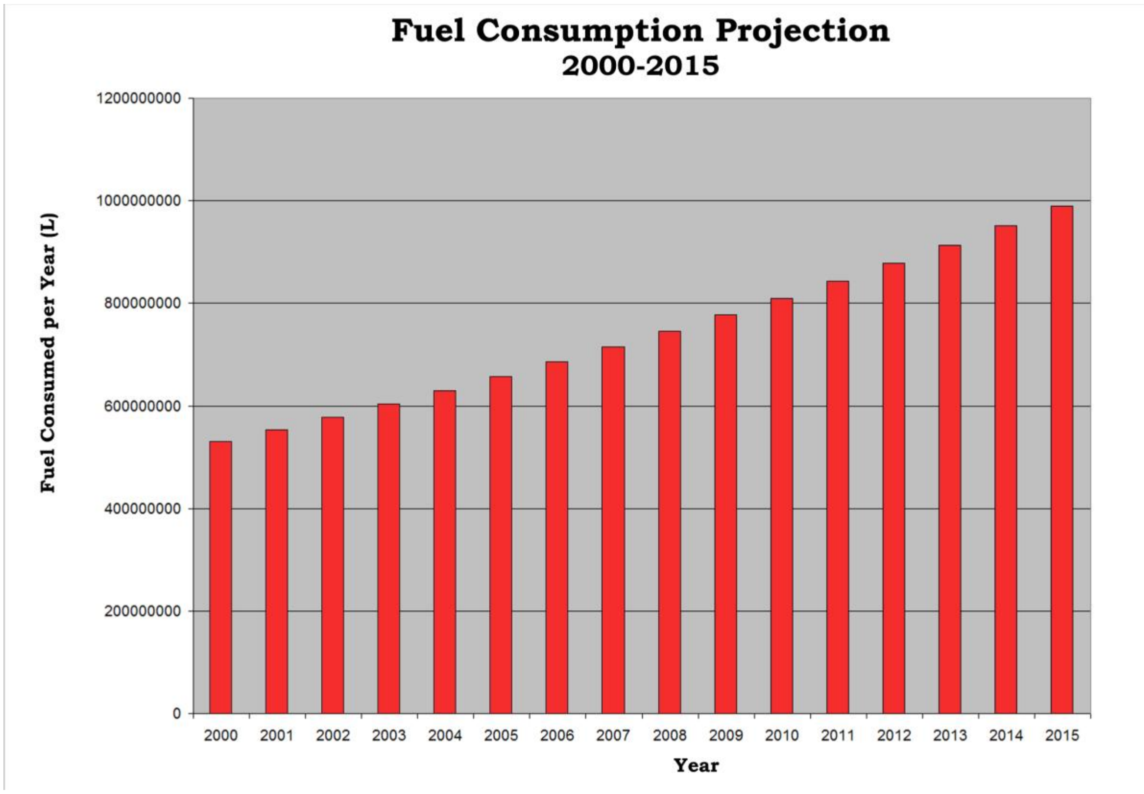


Figure 17: Diesel Consumption Projections from 2000-2015
(Source: CNP+L, 2005)

4.3.3 Climate Change

In order to calculate the greenhouse gas emissions for Costa Rica, the project team determined the amount of diesel fuel consumed on an annual basis. RECOPE projected that Costa Rica would consume 715, 277,000 L of diesel fuel in 2007 (Centro Nacional de Producción más Limpia, 2005). The subsequent kilograms of CO_2 emitted into the atmosphere in 2007 will be 1,881,178,510 kg. This value was calculated using the equation from the Department for Environment Food and Rural Affairs (2005).

$$Liters\ of\ Diesel \times 2.63 = Total\ kg\ CO_2$$

The total kilograms of CO_2 emitted indicate the amount of greenhouse gas that Costa Rica will produce in 2007. If San José were to operate the public transportation buses on

B100 the direct CO_2 emissions would be similar to diesel. However, when evaluating the full life cycles of diesel fuel and B100 a significant difference in CO_2 is found. B100 produces 75% less CO_2 than diesel over the course of a complete life cycle (Union of Concerned Scientists, 2005). Growing and producing plant based bio-diesel in Costa Rica would reduce CO_2 to 470,294,628 kg in 2007. The process of climate change could be slowed with the use of bio-diesel in public transportation buses.

4.3.4 Health Effects

The impact on public health due to airborne pollutants has been documented in several research studies done in Costa Rica. In a study done by the World Bank, Doctor Carlos Burgoa found several adverse health trends.

During a five year study conducted between 1991 and 1996, Burgoa found that the occurrence of several illnesses caused by atmospheric pollution had increased in number as well as their respective mortality rates. In the general population of Costa Rica, leukemia and lymphoma increased 17% between 1996 and1997 (Burgoa, 2000). These illnesses had a particularly strong showing in San José where the risk of developing leukemia and lymphoma was 78%.

In addition, cases of heart disease, acute respiratory illness, chronic respiratory illness and asthma went up all over Costa Rica. The risk of cardiovascular disease was found to be 50-75% in downtown San José. Cases of chronic respiratory illness were 30% greater and death by acute respiratory illness was found to be 3 times greater in downtown San José than metropolitan San José.

When compared to other countries, the death rate caused by exposure to PM10 is higher in Costa Rica. (Allen *et al.*, 2005) The death rates when compared to other countries such as Austria, France, and Switzerland are greater in Costa Rica. See Appendix E for full data. The countries had death rates of 374, 349, 337, and 475 people per million respectively, making Costa Rica's death rate 24% greater (Allen *et al*., 2005). This trend continues for bronchitis cases in children under 15 years of age. Costa Rica's bronchitis cases were 81% higher in children under 15 years of age than the other countries (Allen *et al*., 2005). The health of the Costa Rican population is in danger due to the air pollution caused by diesel emissions. The opinion of the public in relation to these dangers is demonstrated in the next section.

4.3.5 Public Opinion

In order to gauge public opinion, the project team conducted a six question survey aimed at evaluation public awareness of both the air quality in San José and of bio-diesel fuel.

Eighty-six percent of those surveyed about air quality and public buses responded that they believed that the air was not healthy (See Figure 18).

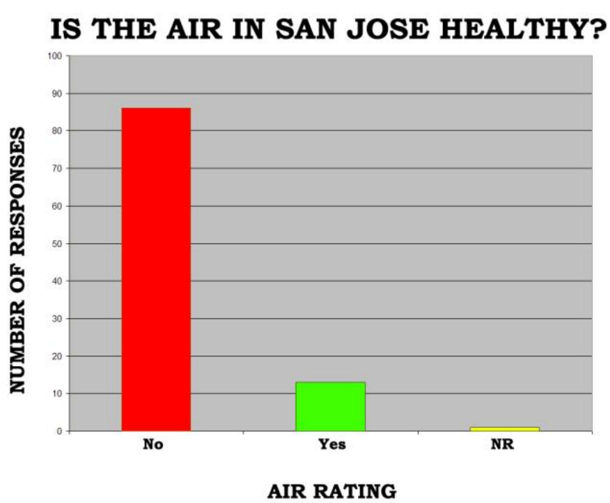


Figure 18: Public Responses to Healthiness of San José Air

Fifty-five percent of the participants indicated that the air quality was either "bad" or "less than sufficient", and only five percent indicated that the air quality was "more than sufficient" or "excellent".

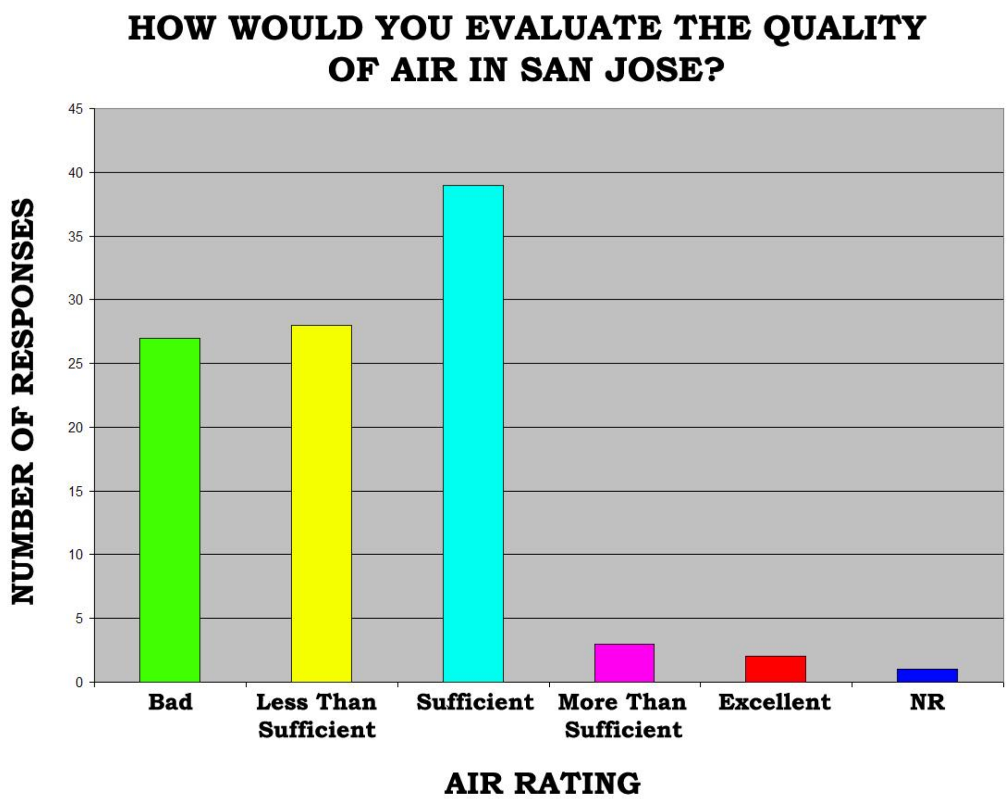


Figure 19: Public Evaluation of San José air quality

Ninety-three percent of the participants indicated that they believed that the public buses have a negative impact on quality of air.

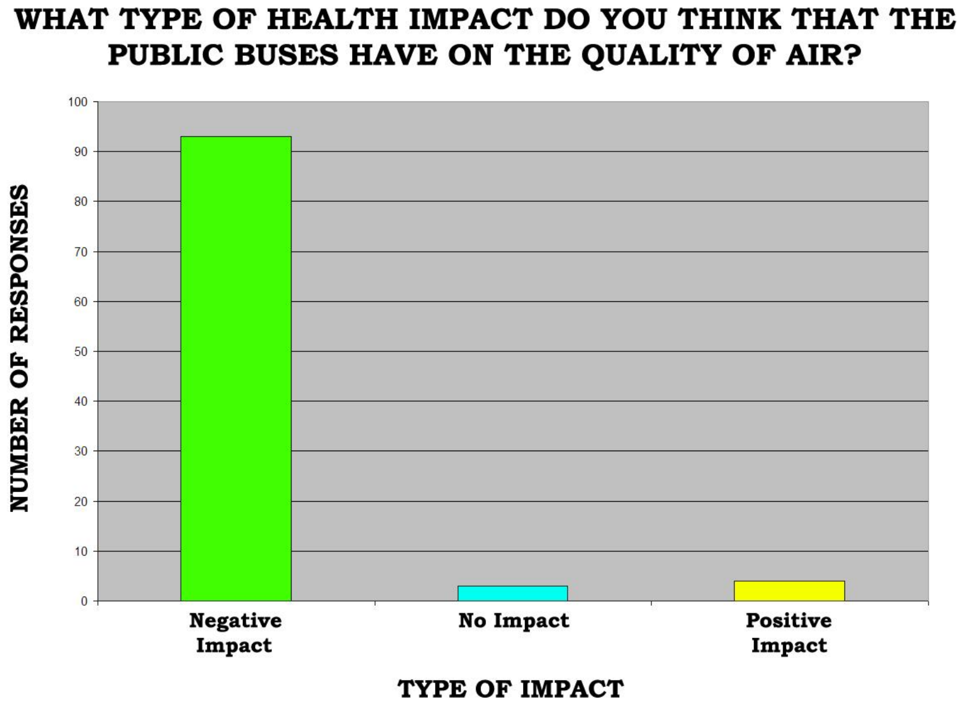


Figure 20: Public Evaluation of Bus Impacts

Eighty-one percent of participants indicated that they thought that using bio-diesel would better the air quality.

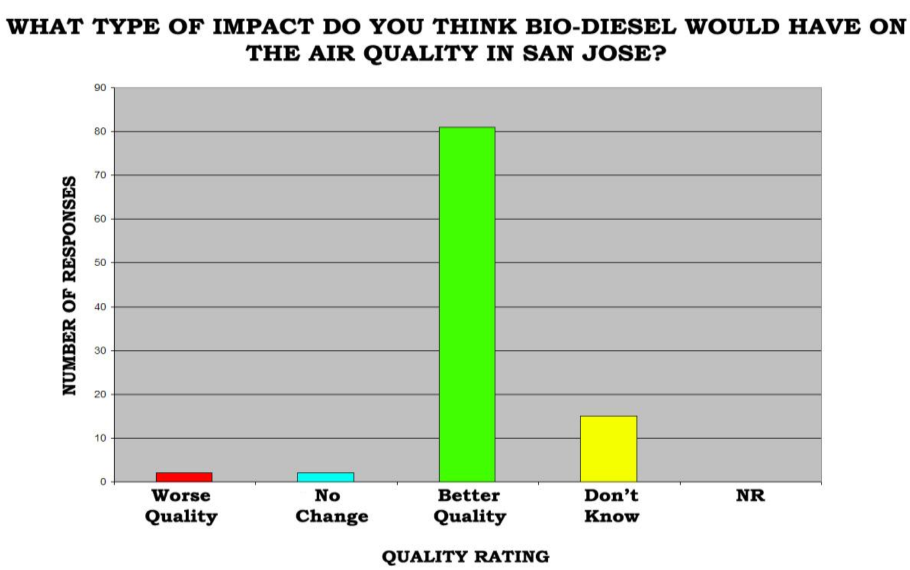


Figure 21: Public Evaluation of Bio-Diesel Impact

Sixty-eight percent of the participants said that they were familiar with the term "bio-diesel".

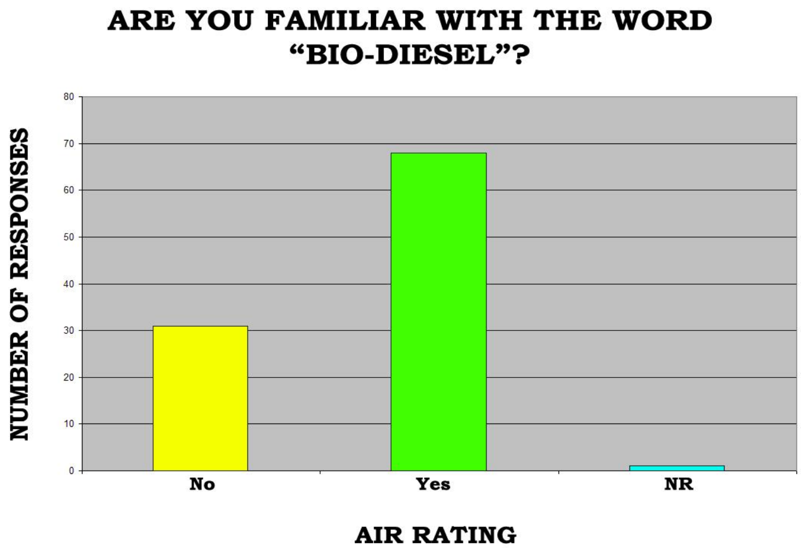


Figure 22: Public Awareness of Bio-Diesel

Finally, participants were asked whether or not they would be willing to pay 5 more Colones for a bus that used bio-diesel fuel. Ninety-four percent of the participants indicated that they would indeed pay the extra 5 Colones.

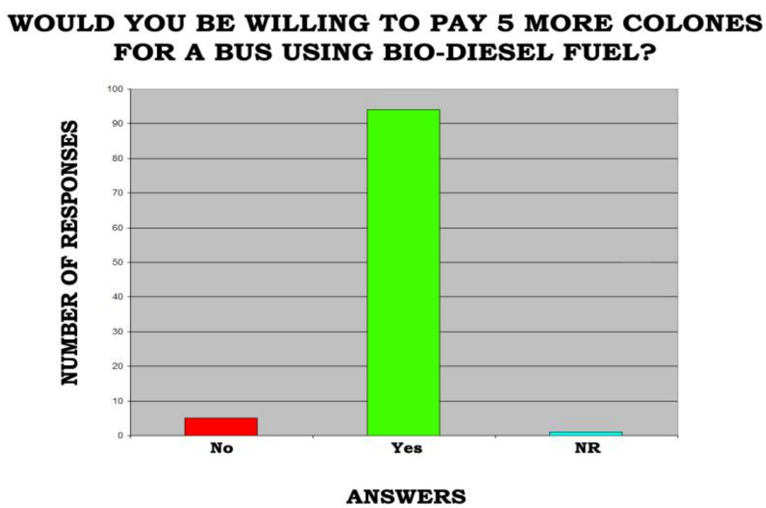


Figure 23: Public Willingness to Pay for Bio-Diesel

5.0 Discussion of Results

5.1 Economic, Environmental, and Societal Effects

This section discusses the results based on economic, environmental and societal impacts of using bio-diesel.

5.1.1 Economic Considerations: Efficiency Discussion

The fuel efficiency study indicated that there was no significant difference between diesel fuel, B15 blend, B30 blend, and B100. Compared to the diesel fuel efficiency, B100 was 15% lower on average. Based on the project team's findings, it was determined that concerns about lowered fuel efficiency should not be a deciding factor when choosing bio-diesel fuel over diesel fuel. Factors such as traffic, age of the bus, operator, route traveled, passenger load, etc. seem to have a more profound impact on fuel efficiency than the fuel itself. Based on the high error, the project team concludes that these other factors have a larger impact.

Benefits to using bio-diesel in San José are numerous. Bio-diesel has the potential to reduce emissions, stimulate the economy, and slow adverse heath effects due to pollution. Since the fuel efficiencies are not statistically different, any slight increase in fuel costs would be balanced by these positive factors.

5.1.2 Economic Considerations: Domestic Fuel Production

From an economic standpoint, investment in bio-diesel programs would be a step in the right direction towards reduced dependence on foreign oil. Instead of purchasing diesel fuel, in-country production of bio-diesel raw stock could create a system where energy spending would bolster Costa Rica's economy. The support of local agricultural efforts to produce bio-diesel raw stocks and new or expanded refineries could mean new jobs, new exports, and a new source of revenue for the country.

In order for successful implementation, certain factors need to be addressed. One factor that has caused the failure of bio-fuel initiatives in the past has been the sharp decline in oil prices after record highs. In recent history bio-fuel sustainability has depended on high oil prices. Robert James Woolsey Jr., a former CIA director, talked about strategies for pricing bio-fuels in a piece for *The Futurist*. He stated that in the 1980's when oil dropped to $5 a barrel, bio-fuels startups went bankrupt and the same situation occurred in the early to mid 1990's (2007). In order to curb this trend and sustain interest in bio-fuels, Woolsey states that government subsidies should fluctuate with oil prices (2007). By fluctuating subsidies, governments would be able to maintain the vitality of bio-fuels by keeping prices competitive with that of oil. Another action governments could take would be to place a flexible tariff on imported oil. Similar to subsidies, this action would allow locally produced fuel to remain competitive with foreign oil.

In an article for *Foreign Affairs*, Runge and Senauer wrote about many drawbacks of bio-fuels. They emphasize the point that increased food costs due to bio-fuel production hurts poorer populations (2007). In the United States political lobbying has influenced crop choices despite drawbacks such as lower efficiency. An example they cite is that lobbyists have pushed for a certain food stock, corn, even though there are more efficient sources (2007). Focus on that one particular raw stock has caused corn prices to rise sharply. Land used for other crops was converted to growing corn resulting in higher prices for those other crops as well. These drawbacks they cite are not insurmountable. If food crops need to be used as bio-fuel raw stock, it is important to diversify which raw stocks are being used and not focus on one in particular. Besides diversifying raw stocks used in bio-diesel production, responsible land management is critical in order to manage prices of crops.

Using a fuel crop that is not a food staple would be ideal. This would avoid increases in cost of food staples, as well as avoid the cyclic behavior of consumption crops. S. Musmanni told the project group that one of the problems with using the palm grown in Costa Rica as a raw stock is the cyclic behavior of its availability and cost (personal communication May 24 2007). When demand for palm exceeds supply, the price of palm goes up. Farmers, seeing the increased price, grow more palm to capitalize on the situation. This eventually causes supply to exceed demand, resulting in a surplus. The surplus causes prices to drop, causing farmers to grow less palm. At a certain point demand again exceeds supply, starting the cycle over again. Figure 24 demonstrates this visually.

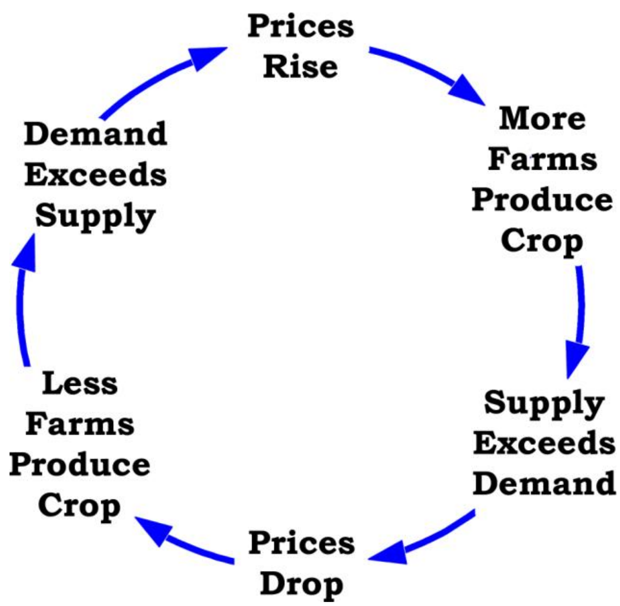


Figure 24: Cyclic Behavior of Consumption Crops

Industrial energy needs cannot survive on a supply situation which constantly fluctuates in price and availability. If Cost Rica intends to grow its own bio-diesel raw stock supply, there needs to be land set apart for fuel crop production. The production should maximize crop yields annually while taking into account crop needs and any detrimental effects to the local soil and water supplies.

Having taken some of these concerns into account, the Ramirez bio-fuel plan is an example of how the use of bio-diesel fuel might become a sustainable enterprise that turns a profit for producers and stimulates the local economy. By using ricinus which is not a food staple, food price hikes are avoided. It also shows responsible land management because they are converting cattle grazing land for ricinus production. This will not result in additional deforestation because it is already usable, cleared land. This has the potential of producing around 5 million liters of bio-diesel yearly, and will allow for the entire fleet of Consorcio Operativo to run on B100. Excess bio-diesel could be sold to other companies and industries for profit. Besides the reductions in emissions, increased investments in raw stock production and refinement will result in economic benefits for Costa Rica instead of foreign oil suppliers. Harvesting 1,000 hectares of ricinus plants will require more farmhands than grazing cattle would need, creating new jobs. Energías Biodegradables was operating at only 10% capacity due to insufficient supply of feedstocks. They could operate at capacity with the ricinus harvests. This increase in capacity has the potential to create more jobs and to strengthen local industry.

If cost of diesel continues to rise as it has in the past fifteen years, (See Figure 25) then an investment in bio-diesel raw stock production and refinement on a national scale for Costa Rica could provide a less expensive alternative fuel when diesel prices overtake bio-diesel prices.

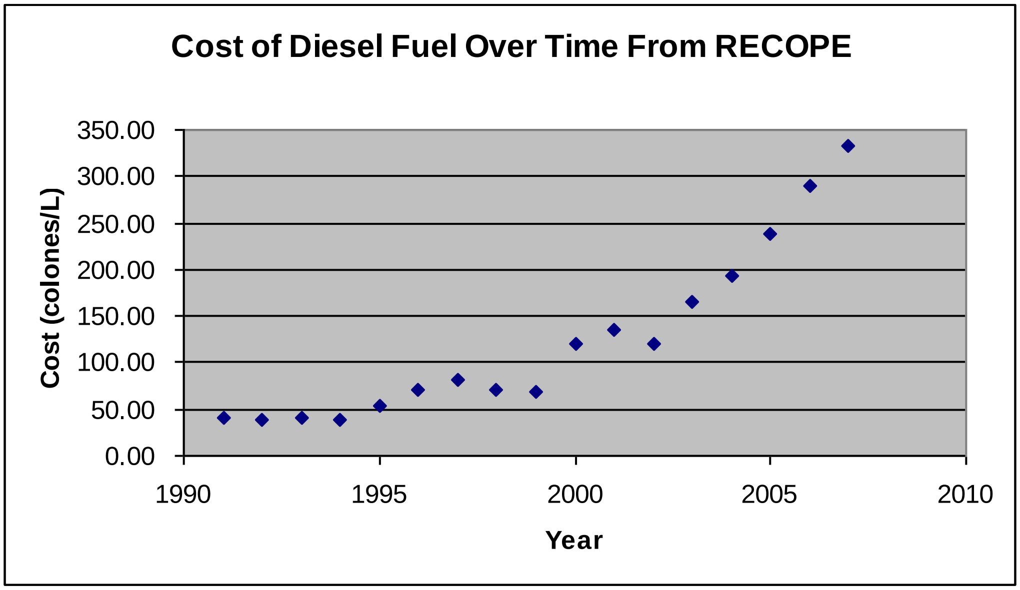


Figure 25: Increase in Diesel Price Since 1990

5.1.3 Environmental Effects: Climate Change

Climate change is an altering of weather patterns due to various airborne particles. Some of the more influential particles from fossil fuel emissions are VOC's, NO_x, PM, and CO_2. These particles are categorized as greenhouse gases (Air Quality Expert Group, 2006). According to the Air Quality Expert Group, the volume of CO_2 produced is usually much larger than the other particles, causing a greater impact on climate change (2006). Climate change can occur when radiation from the sun is reflected by greenhouse gases towards the Earth rather than passing through the upper atmosphere out to space (see Figure 26). The reflected radiation causes the air to become heated (Air Quality Expert Group, 2006). Impacts of this heated air depend on region and local climate.

Tropical climates and humid regions tend to experience more severe side affects (EPA, 2006).

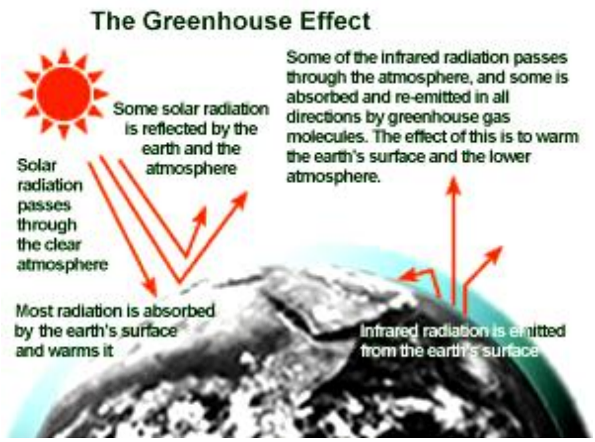


Figure 26: The Greenhouse Effect
(Source: EPA, October 2006)

San José is likely to experience more severe climate change effects because it is a city with a higher elevation and has frequent cloud cover during the rainy season. Regions with higher elevation are closer to the upper atmospheric levels. This means that refracted rays carry more energy (EPA, 2006). In addition, cloud cover caused by high humidity retains more airborne particles. The result is a greenhouse gas layer that reflects more radiation back to the earth (Air Quality Expert Group, 2006).

Side effects from climate change are predictable, but the specific impact on San José is not yet known. The region would either become more tropical or more arid. Both possibilities affect agricultural growing cycles, crop yield, crop growth, and agricultural threats such as insect species (EPA, 2006). Public health risks would also change. Should the temperature increase in San José, the severity of air pollution, water pollution, and infectious parasites would also increase (EPA, 2006). Warmer air encourages pollutants to linger lower in the atmosphere, making it more likely to be inhaled by citizens. Health risks associated with inhaling airborne pollutants include asthma, chronic respiratory illness, and cancer (Burgoa, 2000). Warmer climates are also more susceptible to water pollution in the form of algal contamination and diseases such as cholera (EPA, 2006). Similarly, infectious parasites can be contracted through contaminated water and agricultural products irrigated with contaminated water (EPA, 2006).

In 2007, approximately 1,881,178,510 kilograms of CO_2 will be emitted in Costa Rica. Each year the amount of greenhouse gas continuously increases because CO_2 remains in the atmosphere for up to 150 years (EPA, 2006). If only B100 was used, the number of kilograms would be 470,294,628; which is a reduction of seventy-five percent. The reduction in climate change is attributed to growing fuel sources rather than burning fossil fuels. Plants consume CO_2 during the growth process, counteracting emissions created from burning bio-diesel (Union of Concerned Scientists, 2005). Overall, bio-diesel has a lifecycle which slows the process of climate change. It is important to prevent damage to the environment from becoming worse.

5.1.4 Societal Implications: Public Awareness

After conducting the survey, the project team found that the people of San José were aware of the poor air quality in the city. It was also found that many people were familiar with bio-diesel and believed that substituting it for diesel would have a positive impact on air quality.

The project team believes that San José would be very responsive to a bio-diesel fuel initiative. The responses showed that a large percentage of the respondents felt that the air quality is lacking and many felt that public buses cause the air quality to be poor.

This response showed that most of the respondents are aware that the buses emit a lot of harmful emissions into the air.

In addition, many participants responded that they had heard of bio-diesel before. An even greater amount of participants believed that using bio-diesel would better the air quality. The reason for this greater response could be attributed to participants having heard of the beneficial effects of bio-diesel in the media but not knowing enough to consider themselves “familiar” with it.

Finally, 94% percent of the participants indicated that they would pay an extra 5 Colones in order to ride a bus that used bio-diesel fuel. Based on this high response, the project team believes that a bio-diesel initiative would be well received.

All in all, the results of this survey indicated that the public felt the air quality lacking in San José and will be receptive to the use of bio-diesel to help alleviate this problem.

5.2 Relationships Between Impacts

5.2.1 Relationship between Emissions and Health

The Background Chapter of this report presented studies which discussed San José as the public transportation hub of the country. The majority of public buses pass through Avendia Central in downtown San José. See Appendix F for bus routes. The emissions from these primarily diesel fueled buses contribute to the air pollution problem already prevalent in the city of San José. The air pollution problem is illustrated by the Figures in 4.3.3. These Figures show higher concentrations of pollutants in downtown San José than surrounding areas. Also according to the health research, the probability of adverse health effects occurring due to air pollution in residents of downtown San José is greater when compared to surrounding regions. Therefore, these correlations suggest that public bus emissions play a role in adversely affecting public health. Using bio-diesel fuel will reduce the amount of harmful emissions generated from public buses. In particular, sulfur dioxide (SO_2) emissions are negligible. Lack of sulfur dioxide would remove the foul smell prevalent on busy roads and according to the EPA; reduce cases of respiratory illness (2007).

5.2.2 Relationship between Health and Economy

Cost Rica has universal health care which means that the government pays for the health care for the entire populace. Based on the project team's research, emissions caused by diesel buses contribute to the air pollution. This pollution causes diseases such as bronchitis, asthma, chronic respiratory illnesses, and acute respiratory illnesses. Burgoa (2000) estimated that direct and indirect healthcare costs due to respiratory illnesses caused by airborne pollutants averaged $27 million between the years 1991-1996. Because emissions from diesel buses cause adverse health effects, they contribute to the financial burden on the nation due to these illnesses. This project team predicts that using bio-diesel will reduce harmful emissions in the area, thus reducing cases of respiratory illness and reduce the health care costs.

6.0 Conclusions and Recommendations

Based on the findings, the project team has provided a set of conclusions and recommendations.

Based on the fuel efficiency study conducted in this research project, we conclude that the fuel efficiencies for B100, biodiesel blends, and diesel are statistically similar. Therefore, the efficiency is not a determining factor in the decision to switch to bio-diesel.

Currently, the cost of using bio-diesel is greater than using diesel, but if oil prices continue to rise, alternative fuels will become an economic necessity for small countries like Costa Rica. As the bio-diesel industry matures, the cost of bio-diesel may become more competitive with diesel. Currently, Costa Rica has enough farm land to supply bio-diesel raw stock to match its crude oil needs. Also, the funds spent in obtaining and processing the fuel would mostly stay in the country, adding jobs and strengthening the economy. Therefore, a switch to bio-diesel would be economically viable and important to the Costa Rican economy.

The city of San José has a major problem with air pollution, attributed in large part to transportation sources. Because bio-diesel releases significantly less emissions, a switch to using bio-diesel would help alleviate this problem. Our findings also showed a direct correlation between the polluted air and the rise in the number of cases of serious health problems. Again, a switch to using bio-diesel would help to alleviate this problem. Therefore, a switch to bio-diesel would better the environment as well as the health of the population.

Finally, our findings from the survey give anecdotal evidence that the population of San Jose is aware of the problems with air quality and believe that the replacement of diesel with bio-diesel would have a beneficial effect. Therefore, we predict that a switch to bio-diesel would be well received by the population of San José.

Based on this research project, the project team recommends the following:

- Support should be given to already existing bio-diesel initiatives.
  - Costa Rica should give route preference to bus companies which use bio-diesel.
  - Costa Rica should mandate a blend of bio-diesel, intending to increase the blend annually and with the goal of eventually reaching B100
- Further research should be done to:
  - Identify an appropriate raw stock for Costa Rica that produces a high energy yield.
  - Determine how to grow adequate bio-diesel raw stock without displacing major food staples or causing deforestation.
  - Determine the economic environment needed for a successful bio-diesel industry.

Appendix A

Integrando el ambiente al proceso productivo

CNP+L
COSTA RICA

February 5, 2007

Susan Vernon Gertenfeld
Director
Costa Rica Project Center
Worcester Polythechnic Institute

Dear Mrs. Vernon:

The National Cleaner Production Center in Costa Rica is presenting the following project profile to be considered as a potential Global Perspective Program Initiative in our country.

Project Tittle: **Fuel Efficiency Monitoring in a Public Transportation Enterprise: Diesel vs Biodiesel.**

Background Information: The transportation sector is the main energy consumption activity in Costa Rica and the emissions caused by the use of fossil fuels the largest contributor to the Green-House Gases reported by the country to the UNFCCC. One of the key issues regarding the use of biodiesel and other biofuels is the reduced performance measured by an indicator like L/100 Km or Km / L, mainly by the energy content of the alternative fuel vs the fossil courterparts. Other factors can affect the actual behavior of the alternative fuels disrupting the linear behavior between heat content and performance.

Objectives: 1) Research the information regarding biodiesel content (B100 and lower mixtures eg B20) and performance; 2) Define control parameters for performance measurement; 3) Select 5 test vehicles and one route within the public transportation enterprise; 4) Perform the data analysis for the vehicles and fuel type; 5) Present the findings using graphical mears and supporting the results. (The use of a computer on-board system like the Siemens ECO EDM is suggested to the enterprise)

We will be honored to have a team from Worcester Polytechnic Institute in our organization for the 2007 period and we are sure the interaction will be valuable for all the parties involved.

Sincerely,

Sergio Musmanni
Executive Director
CNP+L Costa Rica

Appendix B

Data Points Recorded in the Shanghai Study

Truck parameter		Arterial road	Highway	Residential road	All roads
Number of measurements		17,216	4,595	15,444	37,255
Speed (km h^{-1})	Average	22.9	36.3	19.9	23.3
	Maximum	68.5	84.2	64.1	84.2
Time (%)	Idling	18.7	4.7	18.0	16.5
	Acceleration	24.1	34.4	24.4	25.5
	Cruise	29.3	34.2	29.4	30.0
	Deceleration	27.9	26.7	28.2	27.9
Vehicle distance driven (km)	Idling	0.0	0.0	0.0	0.0
	Acceleration	44.8	14.2	32.6	91.7
	Cruise	31.7	20.0	25.9	77.6
	Deceleration	33.2	12.1	26.8	72.2
Fuel consumption (L h^{-1})	Idling	1.25	1.75	1.17	1.24
	Acceleration	11.65	7.23	8.89	9.80
	Cruise	3.34	5.94	2.74	3.45
	Deceleration	1.87	2.82	1.48	1.81
Fuel economy (L/100 km)		19.8	14.7	18.1	18.2
CO emission rate (mg s^{-1})	Idling	12.5	20.7	12.1	12.7
	Acceleration	93.3	54.5	53.0	70.7
	Cruise	24.4	43.8	19.0	24.8
	Deceleration	17.6	23.9	12.4	16.2
THC emission rate (mg s^{-1})	Idling	7.8	12.6	7.8	8.1
	Acceleration	23.5	14.0	19.3	20.2
	Cruise	9.8	15.3	9.9	10.6

Truck parameter		Arterial road	Highway	Residential road	All roads
	Deceleration	8.9	11.1	8.5	9.0
NO_x emission rate (mg s^{-1})	Idling	15.5	25.5	15.7	16.1
	Acceleration	104.6	70.3	84.1	90.6
	Cruise	32.8	58.7	28.6	34.6
	Deceleration	21.7	33.6	19.3	22.1
CO emission rate (g km^{-1})	Acceleration	8.65	6.06	6.12	7.35
	Cruise	3.88	3.44	3.32	3.58
	Deceleration	2.55	2.41	2.01	2.33
	All	5.79	4.07	4.38	4.96
THC emission rate (g km^{-1})	Acceleration	2.18	1.56	2.22	2.10
	Cruise	1.57	1.20	1.73	1.53
	Deceleration	1.29	1.12	1.39	1.30
	All	1.96	1.35	2.07	1.88
NO_x emission rate (g km^{-1})	Acceleration	9.69	7.82	9.71	9.41
	Cruise	5.22	4.61	5.01	4.99
	Deceleration	3.15	3.39	3.13	3.18
	All	6.87	5.39	6.73	6.54

(Source: Chen, 2007)

Appendix C

Bio-Diesel Survey

The purpose of this survey is to gauge public opinion on the air quality of San José. This survey will only take **one minute.**

1) **Do you believe that the air in San José is healthy?**

No Yes

2) **How would you rate the air quality in San José?**

1	2	3	4	5
Poor	Worse than Sufficient	Sufficient	Better than Sufficient	Excellent

3) **What kind of a health impact do you believe public buses have on the air quality of San José?**

1	2	3
Negative Impact	No Impact	Positive Impact

4) **Are you familiar with the word "Bio-Diesel"?**

No Yes

5) **What type of impact do you think Bio-diesel fuel would have on the air quality in San José?**

1	2	3	4
Worse Quality	No Change	Better Quality	Don't Know

6) **Would you pay 5 more Colones for a bus that uses bio-diesel?**

No Yes

In Spanish

Bio-Diesel Encuesta

Esta es una encuesta para evaluar el opinión de la gente de San José sobre la calidad del aire de San José. Esta encuesta tomará **un minuto** de su tiempo. ¡Gracias!

1) **¿Piensa qué el aire en San José es saludable?**

No Sí

2) **¿Cómo evaluaría la calidad del aire de San José?**

1	2	3	4	5
Malo	Peor que Suficiente	Suficiente	Mejor que Suficiente	Excellente

3) ¿Qué tipo de impacto sobre de salud cree Ud. que tienen los buses públicos sobre la calidad del aire?

1	2	3
Impacto Negativo	No Impacto	Impacto Positivo

4) ¿Está Ud. familiarizado con la palabra "bio-diesel"?

No Sí

5) ¿Qué tipo de impacto piensa que podría tener el bio-diesel en la calidad del aire de San José?

1	2	3	4
Calidad Peor	No Cambio	Calidad Mejor	No sé

6) Podría Ud. pagará cinco colones más por un autobús que usó bio-diesel?

No Sí

Appendix D

Diesel								
Bus Number	Bus Operator	Route	Date	Distance (km)	Fuel (L)	Efficiency (km/L)	Avg. Eff. (km/L)	Standard Error
5	No Data							
6	Solis Juan Carlos	Granadilla	6/5/2007	129	72.00	1.79	3.09	1.01
6	Solis Juan Carlos	S. Pedro	6/6/2007	137	53.00	2.58		
6	Solis Juan Carlos	S. Pedro	6/7/2007	151	44.84	3.37		
6	Solis Juan Carlos	S. Pedro	6/8/2007	177	62.80	2.82		
6	Solis Juan Carlos	S. Pedro	6/9/2007	191	39.19	4.87		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/7/2007	180	82.18	2.19	2.11	0.90
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/8/2007	86	67.36	1.28		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/9/2007	178	62.01	2.87		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/13/2007	134	45.28	2.96	2.72	0.46
27	Gutierrez Torres Noel Antonio	Sabanilla	6/14/2007	189	58.84	3.21		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/15/2007	204	92.05	2.22		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/16/2007	192	61.75	3.11		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/17/2007	~	~	~		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/18/2007	265	125.89	2.11		
32	Coulson Perez Eustace Welsmin	Sabanilla	6/17/2007	174	53.82	3.23	4.13	1.77
32	Coulson Perez Eustace Welsmin	Sabanilla	6/18/2007	133	26.41	5.04		
55	Arauz Quesada Wilfredo	x. Pisto	6/13/2007	151	40.31	3.75	3.03	0.40
55	Arauz Quesada Wilfredo	x. Pisto	6/14/2007	167	64.78	2.58		
55	Arauz Quesada Wilfredo	x. Pisto	6/15/2007	139	51.41	2.70		
55	Arauz Quesada Wilfredo	x. Pisto	6/16/2007	~	~	~		
55	Arauz Quesada Wilfredo	x. Pisto	6/17/2007	239	76.09	3.14		
55	Arauz Quesada Wilfredo	x. Pisto	6/18/2007	143	47.88	2.99		
Group	------	------	------	------	------	------	**2.94**	**0.4**

B15								
Bus Number	Bus Operator	Route	Date	Distance (km)	Fuel (L)	Efficiency (km/L)	Avg. Eff. (km/L)	Standard Error
5	Ramirez Garro Miguel Angel	Granadilla	5/21/2007	176	58.57	3.00	2.72	0.22
5	Ramirez Garro Miguel Angel	Granadilla	5/22/2007	146	54.48	2.68		
5	Yanicelly Cascante Giovanni	Granadilla	5/23/2007	132	48.48	2.72		
5	Ramirez Garro Miguel Angel	Granadilla	5/24/2007	189	76.44	2.47		
6	Solis Juan Carlos	Granadilla	5/21/2007	124	41.92	2.96	2.74	0.22
6	Solis Juan Carlos	Granadilla	5/22/2007	244	69.07	3.53		
6	Solis Juan Carlos	Granadilla	5/23/2007	116	48.63	2.39		
6	Solis Juan Carlos	Granadilla	5/24/2007	104	50.25	2.07		
18	Sanchez Carmona Marvin Enrique	C. x San Pedro	5/21/2007	123	48.89	2.52	2.46	0.09
18	Sanchez Carmona Marvin Enrique	C. x San Pedro	5/22/2007	180	73.60	2.45		
18	Sanchez Carmona Marvin Enrique	C. x San Pedro	5/23/2007	123	52.46	2.34		
18	Sanchez Carmona Marvin Enrique	C. x San Pedro	5/24/2007	152	59.54	2.55		
27	Gutierrez Torres Noel Antonio	Sabanilla	5/21/2007	284	76.25	3.72	2.99	1.04
27	Gutierrez Torres Noel Antonio	Sabanilla	5/22/2007	132	32.78	4.03		
27	Gutierrez Torres Noel Antonio	Sabanilla	5/23/2007	119	50.10	2.38		
27	Gutierrez Torres Noel Antonio	Sabanilla	5/24/2007	138	75.63	1.82		
32	Coulson Perez Eustace Welsmin	Sabanilla	5/21/2007	166	51.07	3.25	2.68	0.62
32	Coulson Perez Eustace Welsmin	Sabanilla	5/22/2007	132	45.34	2.91		
32	Coulson Perez Eustace Welsmin	Sabanilla	5/23/2007	132	47.45	2.78		
32	Coulson Perez Eustace Welsmin	Sabanilla	5/24/2007	133	74.67	1.78		
55	Arauz Quesada Wilfredo	C. x Zapote	5/21/2007	185	60.28	3.25	3.05	0.54
55	Arauz Quesada Wilfredo	C. x Zapote	5/22/2007	161	60.41	2.67		
55	Arauz Quesada Wilfredo	C. x Zapote	5/23/2007	168	45.11	3.72		
55	Arauz Quesada Wilfredo	C. x Zapote	5/24/2007	150	58.89	2.55		
Group	------	------	------	------	------	------	3.00	0.23

B30								
Bus Number	Bus Operator	Route	Date	Distance (km)	Fuel (L)	Efficiency (km/L)	Avg. Eff. (km/L)	Standard Error
5	Ramirez Garro Miguel Angel	Cedros	11/2/2006	125	56.97	2.19	2.72	0.27
5	Ramirez Garro Miguel Angel	Granadilla	11/3/2006	179	52.39	3.42		
5	Ramirez Garro Miguel Angel	Granadilla	11/4/2006	174	69.96	2.49		
5	Ramirez Garro Miguel Angel	Granadilla	11/6/2006	139	50.34	2.76		
5	Ramirez Garro Miguel Angel	Granadilla	11/7/2006	159	59.68	2.66		
5	Ramirez Garro Miguel Angel	Granadilla	11/8/2006	141	53.57	2.63		
5	Ramirez Garro Miguel Angel	Granadilla	11/9/2006	156	48.30	3.23		
5	Ramirez Garro Miguel Angel	Granadilla	11/10/2006	142	67.27	2.11		
5	Ramirez Garro Miguel Angel	Granadilla	11/12/2006	190	62.83	3.02		
5	Ramirez Garro Miguel Angel	Giana	11/13/2006	107	41.57	2.57		
5	Ramirez Garro Miguel Angel	Giana	11/14/2006	148	69.06	2.14		
5	No Name	Parquco	11/15/2006	119	34.37	3.46		
6	Solis Juan Carlos	CxS.Pedro	11/2/2006	124	30.42	4.08	2.78	0.30
6	Solis Juan Carlos	CxS.Pedro	11/3/2006	168	82.21	2.04		
6	Solis Juan Carlos	CxS.Pedro	11/4/2006	170	61.26	2.78		
6	Solis Juan Carlos	CxS.Pedro	11/6/2006	153	59.47	2.57		
6	Solis Juan Carlos	CxS.Pedro	11/7/2006	111	41.51	2.67		
6	Solis Juan Carlos	CxS.Pedro	11/8/2006	167	49.52	3.37		
6	Solis Juan Carlos	CxS.Pedro	11/9/2006	125	56.20	2.22		
6	Solis Juan Carlos	CxS.Pedro	11/10/2006	168	59.24	2.84		
6	Solis Juan Carlos	CxS.Pedro	11/12/2006	164	63.97	2.56		
6	Solis Juan Carlos	CxS.Pedro	11/13/2006	126	44.15	2.85		
6	Solis Juan Carlos	CxS.Pedro	11/14/2007	152	54.32	2.80		
6	Solis Juan Carlos	CxS.Pedro	11/15/2006	108	41.99	2.57		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/2/2006	105	41.99	2.50	2.75	0.26
27	Gutierrez Torres Noel Antonio	Sabanilla	11/3/2006	177	53.40	3.31		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/4/2006	135	55.25	2.44		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/6/2006	104	47.22	2.20		

27	Gutierrez Torres Noel Antonio	Sabanilla	11/7/2006	177	66.92	2.65		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/8/2006	106	47.10	2.25		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/9/2006	135	56.25	2.40		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/10/2006	120	38.10	3.15		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/12/2006	120	39.45	3.04		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/13/2006	134	39.17	3.42		
27	Gutierrez Torres Noel Antonio	Sabanilla	11/14/2006	177	61.21	2.89		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/2/2006	125	66.51	1.88	2.36	0.23
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/3/2006	120	41.11	2.92		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/6/2006	135	58.37	2.31		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/7/2006	88	36.32	2.42		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/8/2006	173	82.81	2.09		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/9/2006	129	44.61	2.89		
29	Cisneros Monestel Jose Jimmy	S. Ramon	11/10/2006	134	64.66	2.07		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/12/2006	192	68.60	2.80		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/13/2006	120	47.98	2.50		
29	Cisneros Monestel Jose Jimmy	Sabanilla	11/14/2006	116	51.00	2.27		
29	Lihsztain Arias Ronald Fernando	Sabanilla	11/15/2006	148	81.21	1.82		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/2/2006	127	41.66	3.05	2.84	0.29
32	Coulson Perez Eustace Welsmin	Sabanilla	11/3/2006	135	46.36	2.91		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/5/2006	192	50.06	3.84		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/6/2006	120	53.55	2.24		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/7/2006	197	73.82	2.67		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/8/2006	120	47.20	2.54		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/9/2006	92	32.92	2.79		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/10/2006	120	36.01	3.33		
32	No Name	Parquco	11/12/2006	134	39.14	3.42		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/13/2006	138	62.05	2.22		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/14/2006	183	65.20	2.81		
32	Coulson Perez Eustace Welsmin	Sabanilla	11/15/2006	120	52.85	2.27		
55	Arauz Quesada Wilfredo	xS.Pedro	11/2/2006	172	87.75	1.96	2.89	0.38
55	Arauz Quesada Wilfredo	xS.Pedro	11/3/2006	173	61.98	2.79		

55	Arauz Quesada Wilfredo	xS.Pedro	11/5/2006	262	81.29	3.22		
55	Arauz Quesada Wilfredo	xS.Pedro	11/6/2006	153	55.92	2.74		
55	Arauz Quesada Wilfredo	xS.Pedro	11/7/2006	172	60.50	2.84		
55	Arauz Quesada Wilfredo	xS.Pedro	11/8/2006	167	57.52	2.90		
55	Arauz Quesada Wilfredo	xS.Pedro	11/9/2006	169	36.35	4.65		
55	Arauz Quesada Wilfredo	xS.Pedro	11/10/2006	172	84.30	2.04		
55	Arauz Quesada Wilfredo	xS.Pedro	11/11/2006	211	75.91	2.78		
55	Arauz Quesada Wilfredo	xS.Pedro	11/13/2006	166	59.40	2.79		
55	Arauz Quesada Wilfredo	xS.Pedro	11/14/2007	155	57.54	2.69		
55	Sanchez Carmona Marvin Enrique	xS.Pedro	11/15/2006	200	62.13	3.22		
Group	------	------	------	------	------	------	**2.73**	**0.12**

B100

Bus Number	Bus Operator	Route	Date	Distance (km)	Fuel (L)	Efficiency (km/L)	Avg. Eff. (km/L)	Standard Error
5	Ramirez Garro Miguel Angel	Granadilla	6/12/2007	155	53.5	2.90	2.67	0.48
5	Ramirez Garro Miguel Angel	Granadilla	6/13/2007	158	74	2.14		
5	Ramirez Garro Miguel Angel	Granadilla	6/14/2007	173	65	2.66		
5	Ramirez Garro Miguel Angel	Granadilla	6/15/2007	156	71	2.20		
5	Ramirez Garro Miguel Angel	Granadilla	6/16/2007	205	89	2.30		
5	Ramirez Garro Miguel Angel	Granadilla	6/17/2007	244	79	3.09		
5	Ramirez Garro Miguel Angel	Granadilla	6/18/2007	122	33.4	3.66		
6	Solis Juan Carlos	Granadilla	6/12/2007	178	64	2.78	2.43	0.22
6	Solis Juan Carlos	S.P. Curri	6/13/2007	136	60	2.27		
6	Solis Juan Carlos	S. Pedro	6/14/2007	122	47	2.60		
6	Solis Juan Carlos	S. Pedro	6/15/2007	136	52	2.62		
6	Solis Juan Carlos	S. Pedro	6/16/2007	146	56	2.61		

6	Solis Juan Carlos	S. Pedro	6/17/2007	~	~	~		
6	Solis Juan Carlos	S. Pedro	6/18/2007	129	62	2.08		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/12/2007	116	63	1.84	2.35	0.32
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/13/2007	172	61	2.82		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/14/2007	123	69	1.78		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/15/2007	165	70	2.36		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/16/2007	140	59	2.37		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/17/2007	~	~	~		
18	Sanchez Carmona Marvin Enrique	S. Pedro	6/18/2007	179	74	2.42		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/2/2007	191	88	2.17	2.47	0.65
27	Gutierrez Torres Noel Antonio	Sabanilla	6/4/2007	133	78	1.71		
27	Gutierrez Fernandez Carlos Humberto	Sabanilla	6/5/2007	175	74	2.36		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/6/2007	133	57	2.33		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/7/2007	147	65.1	2.26		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/8/2007	119	56	2.13		
27	Gutierrez Torres Noel Antonio	Sabanilla	6/9/2007	203	50	4.06		
32	Coulson Perez Eustace Welsmin	Sabanilla	6/4/2007	268	111	2.41	2.50	0.58
32	Coulson Perez Eustace Welsmin	Sabanilla	6/5/2007	189	61	3.10		
32	Chaves Masis William	Giano	5/7/2007	176	81	2.17		
32	Coulson Perez Eustace Welsmin	Sabanilla	5/8/2007	175	78	2.24		
55	Arauz Quesada Wilfredo	X. Pista	6/4/2007	193	50.5	3.82	2.46	0.73
55	No Name	Parqueo	6/5/2007	68	58	1.17		
55	Arauz Quesada Wilfredo	C. Sicus	6/6/2007	153	47	3.26		
55	Arauz Quesada Wilfredo	Granadilla	6/7/2007	153	69	2.22		
55	Arauz Quesada Wilfredo	Granadilla	6/8/2007	150	59	2.54		
55	Arauz Quesada Wilfredo	Granadilla	6/9/2007	260	84	3.10		
Group	------	------	------	------	------	------	**2.49**	**0.47**

Appendix E

Tabla No. 2: Estimación del efecto en salud (RR) y los incrementos en la línea basal epidemiológica por cada 10 $\mu g/m^3$ de PM_{10} y 1 Mill. de habitantes ($D10$, $D10_{Inf}$, $D10_{Sup}$)

Resultado en salud	Efecto estimado Riesgo Relativo (±95% IC)	Incremento fijo a la base (D10) por 10 $\mu g/m^3$ PM10 y 1 por millón de habitantes Casos D_{10} (D_{10Inf} - D_{10Sup} basado en estimaciones con un ±95% de IC)			
		Austria	Francia	Suiza	Costa Rica
Mortalidad General (adultos ≥ 30 años)	1,043 (1,026-1.061)	374 (226-524)	340 (206-476)	337 (204-473)	475 (287-673)
Egresos Hosp Causas Respiratorias (todas edades)	1,0131 (1,001-1,025)	228 (24-433)	148 (16-282)	133 (14-253)	550 (42 - 1050)
Egresos Hosp Causas CV (todas edades)	1,0125 (1,007-1,019)	449 (234-668)	212 (112-315)	303 (157-450)	266 (149--404)
Bronquitis Crónica (≥ 25 años)	1,098 (1,009-1,194)	413 (37-821)	394 (35-784)	431 (38-858)	12.638 (1160-25018)
Bronquitis (personas < 15 años)	1,306 (1,135-1,502)	3.196 (1.409-5.774)	4.830 (2'129-8'728)	4.622 (2.037-8.352)	22.117 (13.671-50.835)
Días de incapacidad (adultos ≥ 20 años)[1)]	1,094 (1,014-1,102)	208.355 (175.399-241.754)	263.696 (221.987-305.966)	280.976 (236.533-326.016)	71.565 (18.675-127.377)
Episodios de asma[2] (personas < 15 años)	1,044 (1,027-1,062)	2.325 (1.430-3.231)	2.603 (1.600-3.617)	2.404 (1.478-3.341)	9.601 (5.891-13.528)
Episodios de asma[2] (adultos ≥ 15 años)[2)]	1,039 (1,019-1,059)	6.279 (3.058-9.564)	6.192 (3.016-9.431)	6.366 (3.101-9.697)	9.450 (4.604-14.296)

1 Días de incapacidad: total días persona por año
2 Episodios de Asma: total de días-persona- con episodios de asma
Fuente: Swisscontact – Unidad de gasto y Financiamiento; Dirección de Desarrollo de la Salud, Ministerio de Salud. 2005

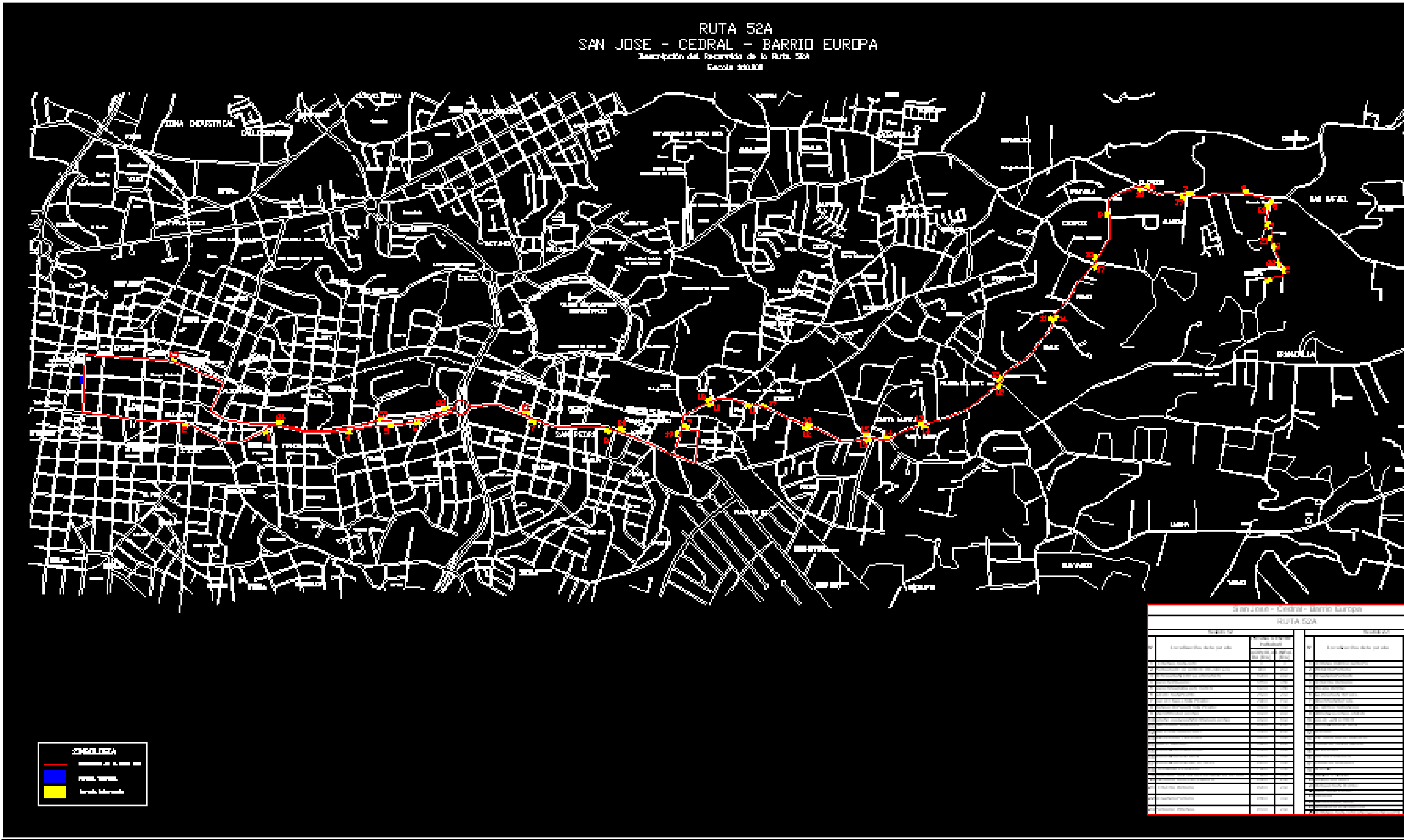
Promedios ponderados de exposición al PM10
(calculados con los valores originales del mapa)

	Concentración de PM10 en µg/m³ *(promedio anual)*			
	Austria	**Francia**	**Suiza**	**Costa Rica**
PM10 Total	26,0	23,5	21,4	59,00
PM10 sin fracción atribuible al transporte automotor	18,0	14,6	14,0	14,70
PM10 atribuible a Transporte Automotor	8,0	8,0	7,4	44,30

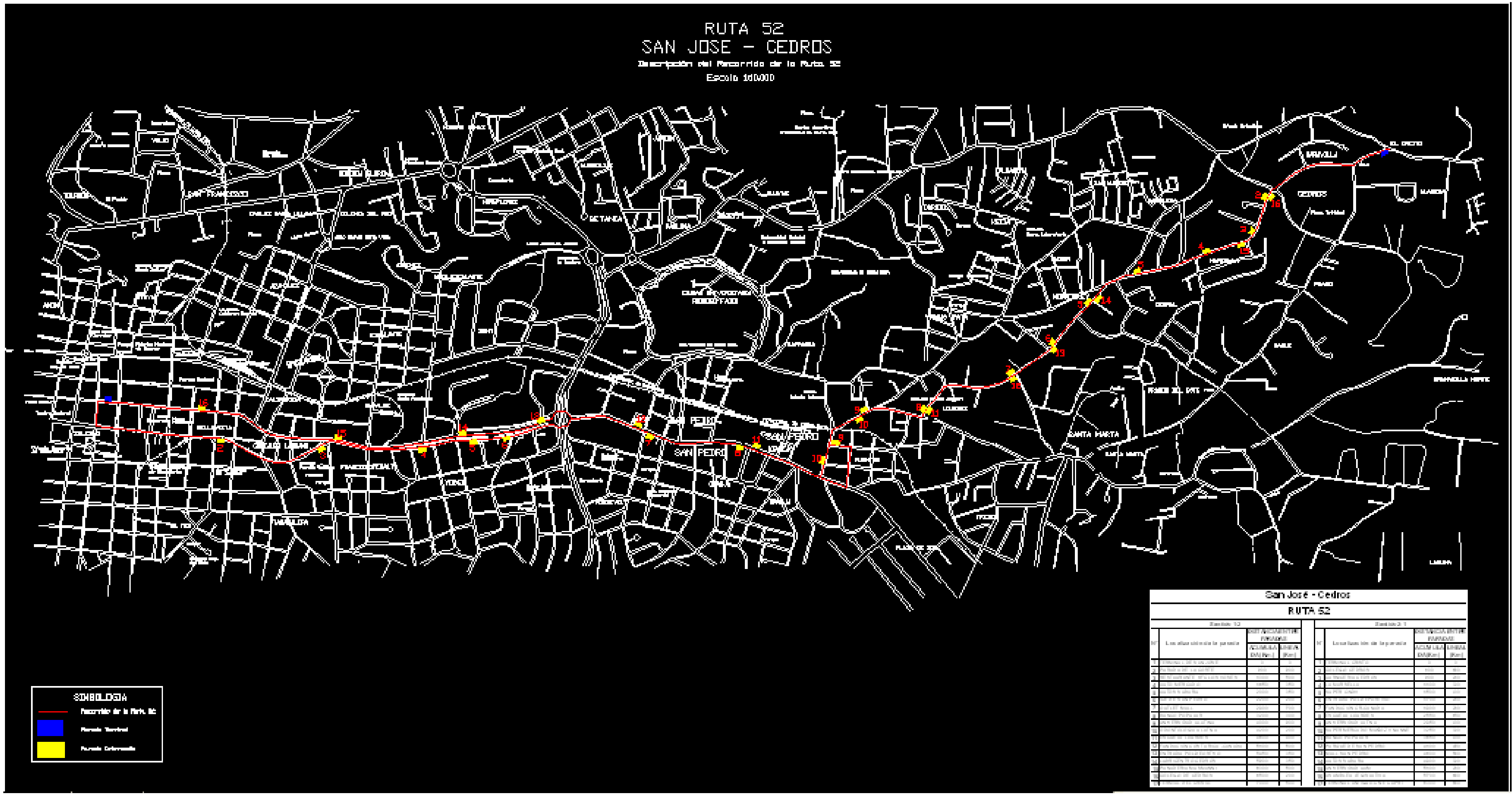
Fuente: SuissContact, Unidad de gasto y Financiamiento, DDS, M.S. 2005

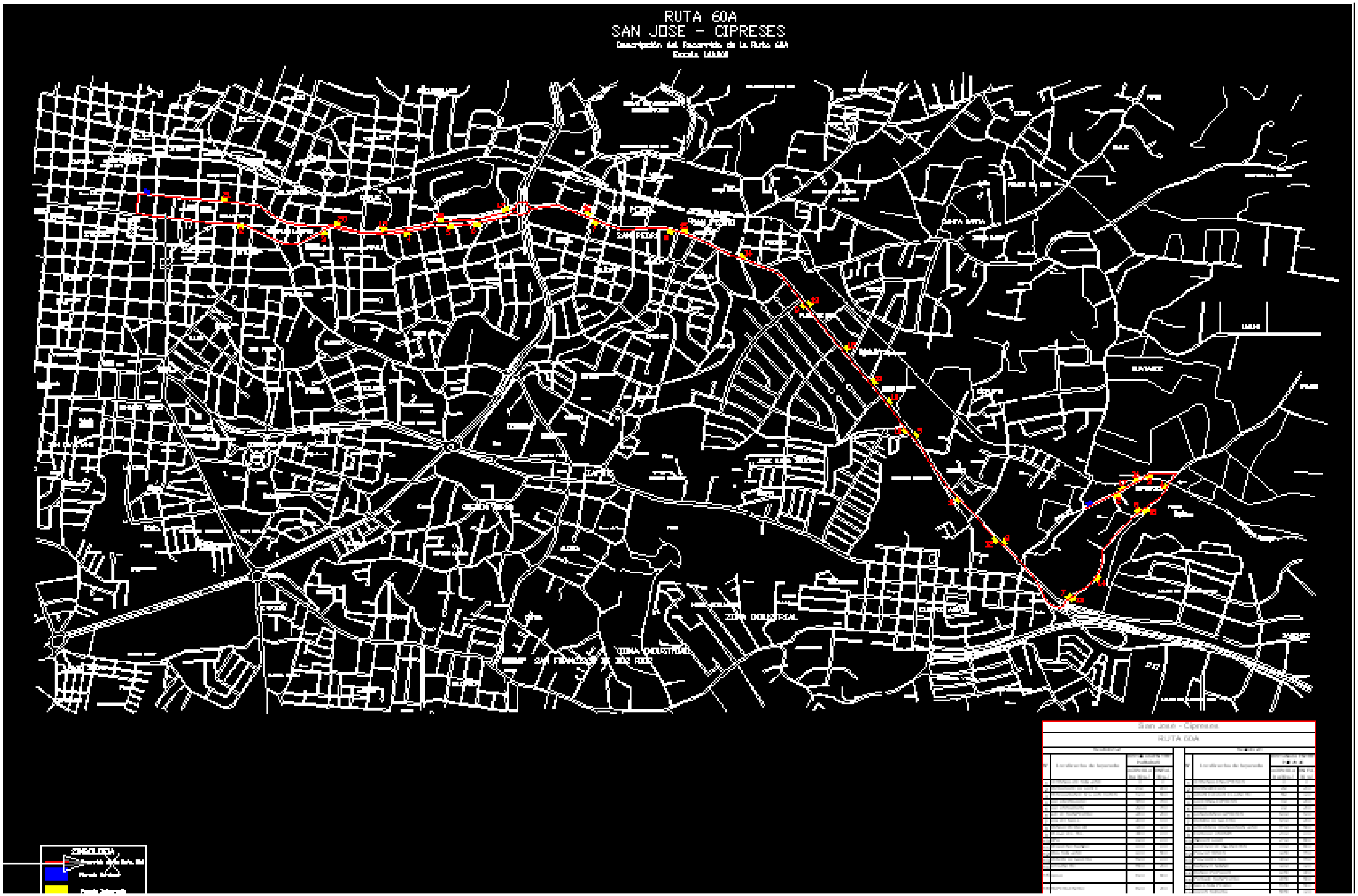
Appendix F

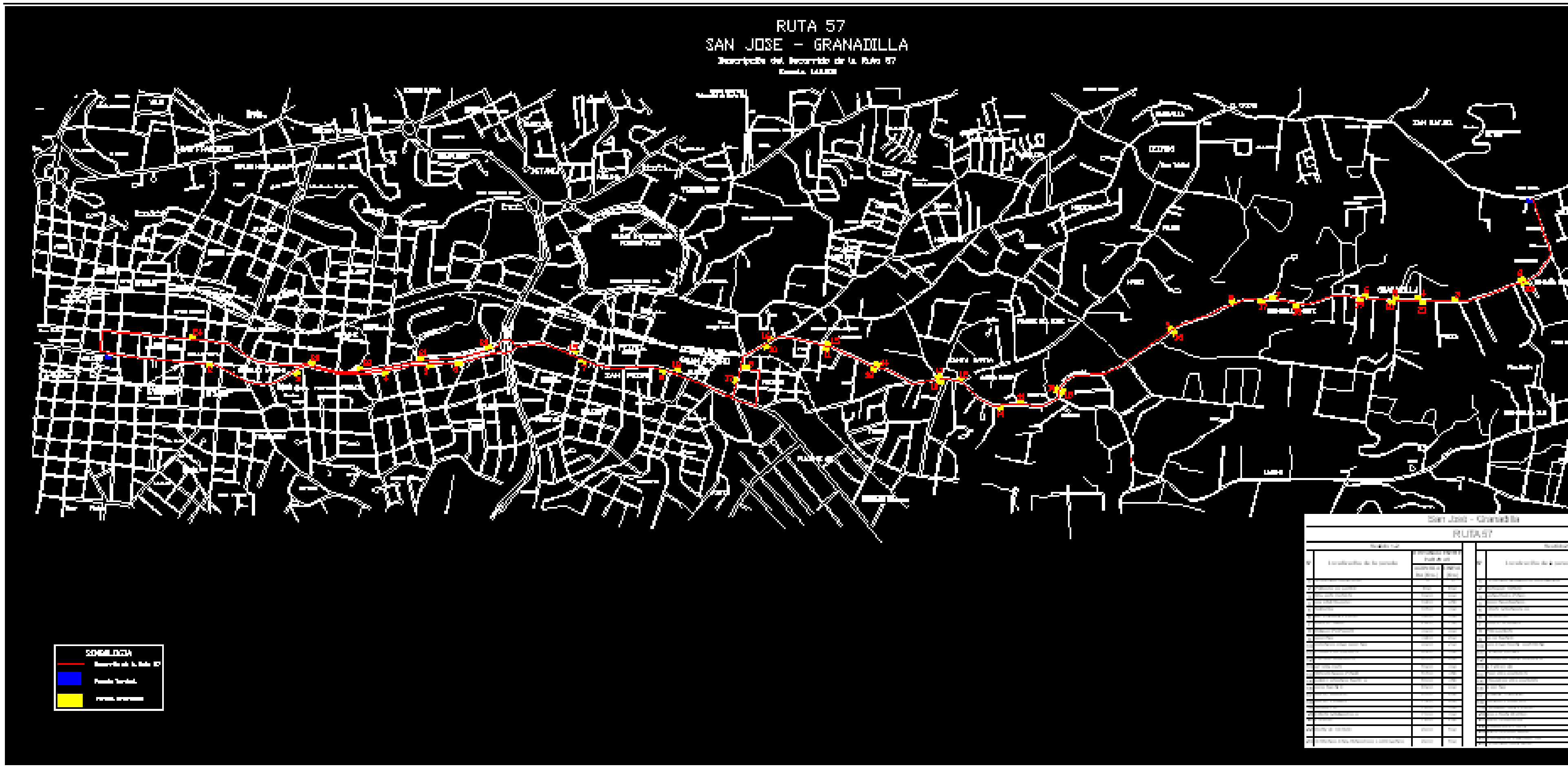

Parque Nacional
AVENIDA 1
ELADIO PRADO SAENZ
CALIFORNIA
24
AVENIDA CENTRAL
Plaza Democracia
Museo Nacional
BELLAVISTA
2
GONZALEZ LAHMANN
3
SOLEDAD
AVENIDA 6
Tribunal Supremo de Elecciones
Corte Suprema de Justicia
Colegio Sagrado Corazon
Piscina
Parque
Paseo Ruben Dario
AVENIDA 8



RUTA 52A
SAN JOSE - CEDRAL - BARRIO EUROPA
Descripción del Recorrido de la Ruta 52A
ZONA INDUSTRIAL
SAN PEDRO
SAN RAFAEL
GRANADILLA
San Jose - Cedral - Barrio Europa
RUTA 52A
SIMBOLOGIA


RUTA 52
SAN JOSE - CEDROS
San José - Cedros
RUTA 52
SIMBOLOGIA
SAN PEDRO
CEDROS


RUTA 60A
SAN JOSE - CIPRESES
San José - Cipreses
RUTA 60A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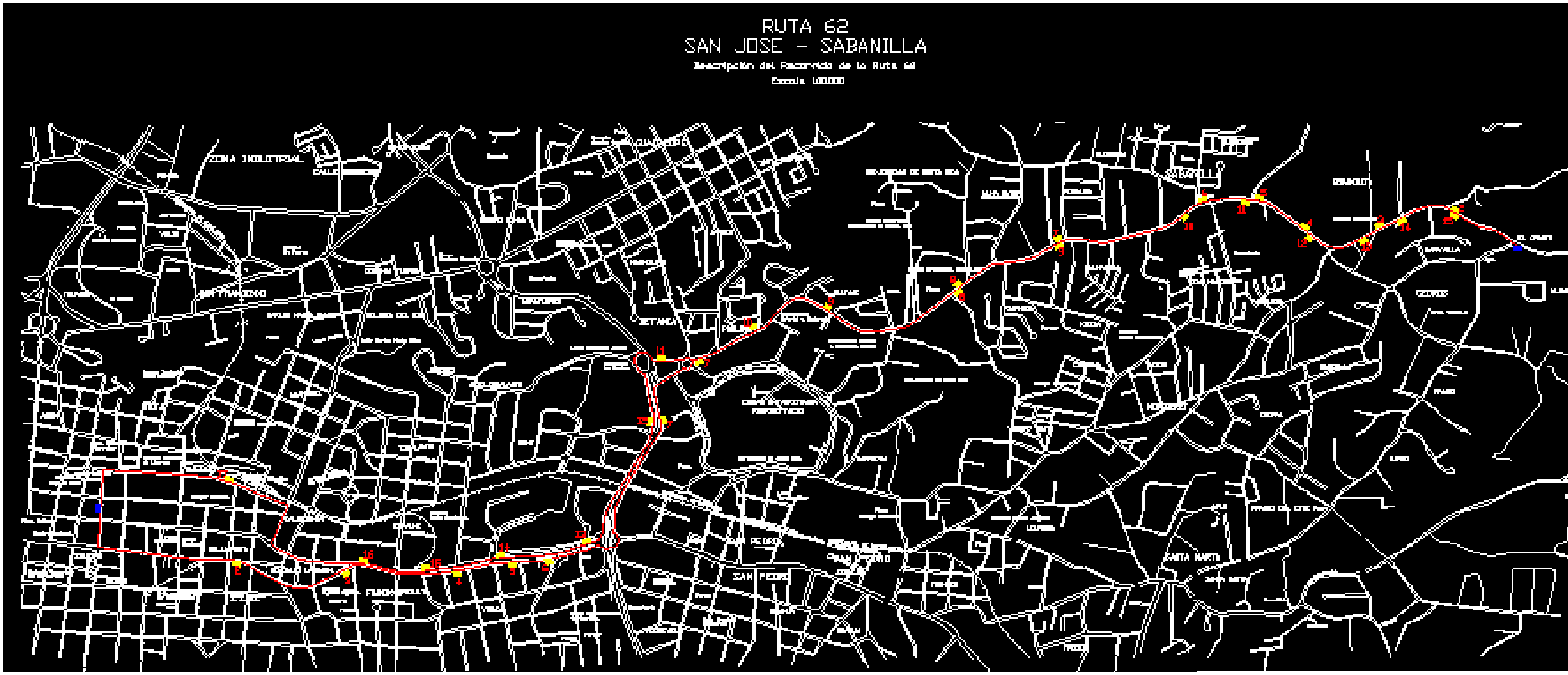
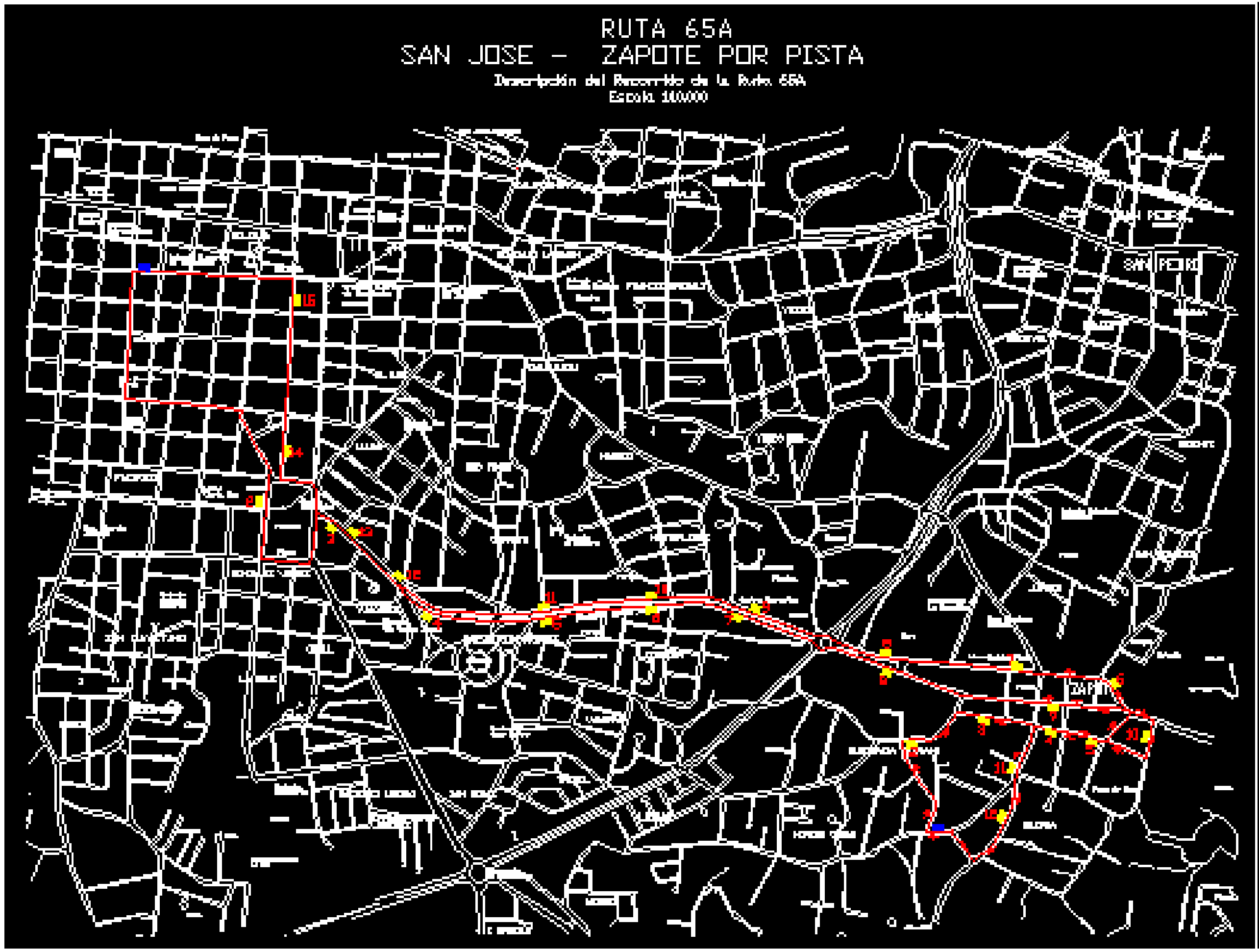
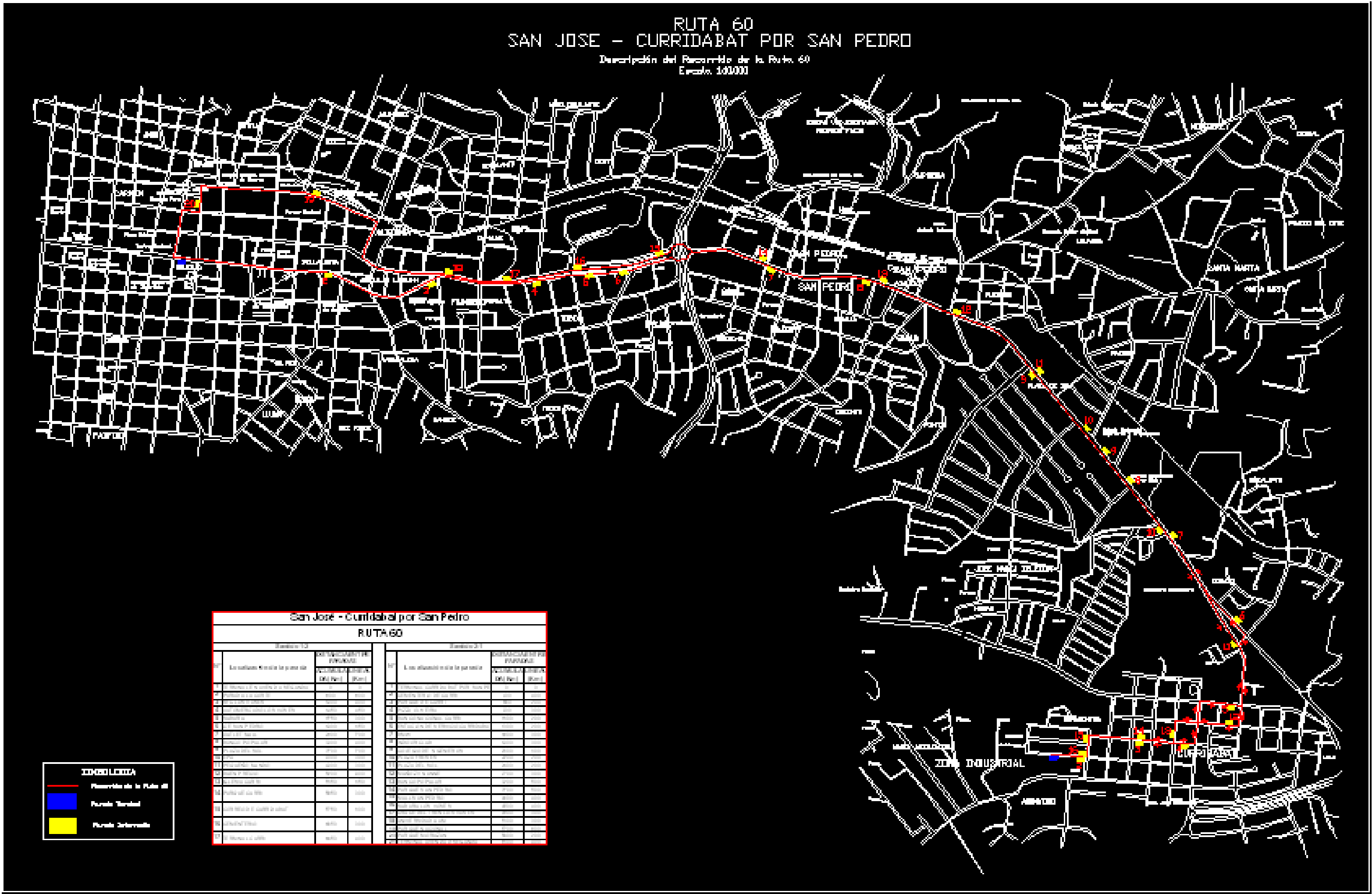
SAN JOSE - GRANADILLA


RUTA 62
SAN JOSE – SABANILLA


RUTA 56
SAN JOSE - SAN RAMON


RUTA 65A
SAN JOSE - ZAPOTE POR PISTA
ZAPOTE
SAN PEDRO


RUTA 60
SAN JOSE - CURRIDABAT POR SAN PEDRO
San José - Curridabat por San Pedro
RUTA 60
SAN PEDRO
CURRIDABAT
ZONA INDUSTRIAL

Appendix G

Press Release

US Students Conduct Bio-Diesel Fuel Study in San José

- A team of engineering students from Worcester Polytechnic Institute in Massachusetts (USA) are conducting a four month research project on the use of bio-diesel fuel in San José buses
- Project is sponsored by the Centro Nacional de Producción Más Limpia
- Data is being collected in conjunction with the Consorcio Operativo bus company
- A comparative case study on the fuel efficiency and emissions of buses fueled by bio-diesel (B15, 30 and 100 blends) versus diesel fueled buses; a review of published scientific literature to investigate relationships between climate change, health, and diesel versus bio-diesel fuels.
- Topics of interest:
    - Fuel efficiency and economics of bio-diesel
    - Agricultural sources of bio-diesel in Costa Rica
    - Fuel refinery in Costa Rica
    - Public transit (buses) in San José
    - Air pollution
    - Global warming
    - Health effects
- Presentation of findings and research report available July 2, 2007

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Appendix H

	Diesel	Bio-diesel	Diesel	Bio-diesel
RPM	2,633	2,777	2,213	2,140
PM (mm3/g)	1.99	1.37	0.19	0.02
Opacity (%)	56	44.4	8.1	1.2

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