# Sustainable Transportation for San Diego

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# List of Abbreviations

**Organizations**

COASTER – San Diego Coast Express
MTDB – Metropolitan Transit Development Board
MTS – San Diego Metropolitan Transit System
NCTD – North County Transit District
SANDAG – San Diego Association of Governments
SDTI – San Diego Trolley, Inc.

**Transportation Terminology**

BPS – Battery Power System
$CH_4$ – Methane
CNG – Compressed natural gas
CO – Carbon Monoxide
$CO_2$ – Carbon Dioxide
Euro3 – Diesel fuel with lower sulphur emotions mandated by the European Union, often called *clean diesel*
$gCO_{2eq}$ – Greenhouse gas carbon dioxide equivalent – a measure of how much global warming a type of type and amount pollutant may cause, using the functional equivalent amount or carbon dioxide as the reference.
GHG – Green House Gasses
$N_2O$ – Nitrous Oxide
$O_3$ – Ozone
PAH – Polycyclic aromatic hydrocarbon
$PM_{2.5}$ – Fine particulate matter such as soot or smoke
SO – Sulphur Monoxide
$SO_2$ – Sulphur Dioxide
VMT – Vehicle Miles Travelled represents the total miles travelled in a one year period by all the motor vehicles in a specific geographic area

# Abstract


The aim of this paper is to understand the current status of the San Diego transportation system and, by the analyses of viable development, implementation and alternatives, suggest possible solutions to improve its reliability and sustainability. Due to the diversity of the topics studied, considerations are carried along chapter by chapter for a more fluent discussion.

First of all, background research was conducted on the three major transit services (MTS, NCTD and Amtrak). The outcomes were that bus fleets are powered by both diesel and compressed natural gas (CNG) engines while three of the four rail systems are running on diesel. Only the MTS trolley is electrified on its entire line.

Second, projections were analysed for both population growth and movements in the San Diego area. The population is predicted to increase by more than one million by 2050. This will impact the already dramatic number of people on the road. Approximately 86% of the population commutes to work by driving cars, which contribute to more than 60 million vehicle miles travelled within the county every day.

Third, the research is divided into two central chapters and suggests solutions for a reliable and sustainable system. In the first chapter, some proposed solutions include an active priority light system; increased frequency; and user friendly GPS-tracked transits with relative mobile; and online applications will develop the current transportation system and adapt it to people's needs. On the other hand, the latter analysed the possibility of switching diesel to CNG engines in order to reduce carbon emissions by about 10%; however, costs were not justified. Moreover, the electrification of the railway system was proposed as an effective way of reducing carbon emissions by 20 – 35%, improving reliability by 29 – 57% and reducing costs.

Finally, the modes of transportation used by San Diegans were thought to be more of a "status symbol" then a real necessity. Work needs to be done to change the mind set of San Diego residents.

# Introduction

The introduction of this report focuses on three main aspects. First of all, a background of the current public transportation system is given by dividing it into the different services available in the San Diego County and by giving some brief information about the different fleets and their history. Secondly, the public transportation system is shown graphically by means of a detailed map of the area. Finally, the aims and objects of the report are stated.

## 1.1 Background: currently available transit options

### 1.1.1 MTS – Metropolitan Transit System

California senate Bill 101 created the Metropolitan Transit Development Board (MTDB) in 1975 which became operational on January 1, 1976 when the MTDB came into existence. Only later in 2005, the name was changed to the current MTS when it incorporated the San Diego Trolley, Inc. (SDTI) (MTS, 2012a, 2011a).

Both bus and light-rail services are provided by MTS. Moreover, private and services for disabled are also available.

#### 1.1.1.1 Bus

The MTS bus service includes 93 fixed routes that provide direct and relatively frequent service to the most densely populated areas in the southern San Diego County. Of those routes, 26 are served directly by the operator and the remaining 67 by private contractors. The total fleet operates in the cities of San Diego, Chula Vista, Coronado, El Cajon, Imperial Beach, La Mesa, National City, and Spring Valley. It serves about two million people (MTS, 2011a). Fixed routes are usually run every 12 to 15 minutes (reduced service over week-ends and bank holidays), and they include the following services:

**Figure 1.1: MTS bus. Model: NABI 60-BRT**
**Source:** MTS, 2012b

- Urban and local bus service (Fig. 1.1)
- Rural bus service
- Commuter and express bus service

Moreover, par transit for people with disabilities is also available on request as required by the federal Americans with Disabilities Act.

#### 1.1.1.2 Light Rail

Light rail is operated by SDTI owned by MTS. It consists of three lines (MTS, 2011b):

- Blue: 18.8 miles connecting the Old Town Transit Centre and San Ysidro Transit Centre.
- Orange: 20.7 miles connecting the 12th and Imperial Transit Centre and Gillespie Field.
- Green: 19.3 miles connecting the Old Town Transit Centre and Santee Town Centre.
- Silver: only serving during special events; mostly running in a downtown loop.

**Figure 1.1: MTS Trolley Model: Siemens S70.**
**Source:** Metro Cincinnati 2010

Trains are operated by electrical engines as it can be seen by the example in Figure 1.2.

### 1.1.2 NCTD – North County Transit District

The NCTD began operations in southern California in 1975 by serving the northern part of the San Diego County. It started as a regular bus service and it developed by including a commuter rail line, the Coaster, in 1995. In 2008, a light rail line called Sprinter was also added to the fleet (NCTD, 2008).

#### 1.1.2.1 BREEZE

The BREEZE bus service operates in the northern part of the San Diego County where the MTS service does not or where it works in a limited way. It consists of 30 major fixed-route lines served by 144 buses and serves an area of over 1,020 square miles with 2,600 bus stops (NCTD, 2012a, 2007).

**Figure 1.2: BREEZE Bus Model: New Flyer D40LF.**
**Source:** NCTD, 2008

Moreover, for rural and not easily accessible areas where BREEZE is not available, FLEX is in operation. It operates on two secondary zones in Southwest Carlsbad and Ramona, and it runs only on request. It can be easily booked by phoning the company 30 minutes in advanced. Finally, as for the MTS, a Para transit service for passengers with disabilities that prevent them from using regular bus or train service is also in operation (LIFT service) (NCTD, 2012a, 2012b).

Of the 144 buses in operation, 90 are run on compressed natural gas and the remaining 54 run on diesel fuel (example available in Fig. 1.3).

#### 1.1.2.2 COASTER

The San Diego Coast Express Rail serves three major coastal areas of southern California between Downtown San Diego (Santa Fe Depot) and Oceanside with eight stops (NCTD, 2012c). Twenty-two (22) trains are available on weekdays with four (4) trains extra on Friday nights. Twelve (12) trains run on Saturdays and eight (80 on Sundays. Special-event trains are also in operation. The fleet includes three types of locomotives (example of EMD F40PH-2C train in Fig. 1.4) all run by diesel engines (NCTD, 2009).


**Figure 1.3: COASTER Train Model EDM F40PH-2C**
**Source: NCTD, 2008**

#### 1.1.2.3 SPRINTER

The SPRINTER is a light rail train service which serves a 22-mile area between Oceanside and Escondido with 15 stations. About 455 trains run weekly (NCTD, 2012d).

The fleet consists of 12 light rail diesel multiple unit passenger trains (example in Fig. 1.5) (NCTD, 2012d).


**Figure 1.4: SPRINTER Train**
Source: NCTD, 2008

### 1.1.3 Amtrak: the Pacific Surfliner

Amtrak (Fig. 1.6) is the major national rail service, which started its service in 1971 as a governmental corporation. In particular, the Pacific Surfliner, part of Amtrak California, connects Downtown San Diego (Santa Fe Depot) and San Luis Obispo (Amtrak, 2012a).

The service consists of 12 round trips stopping at 30 stations along a 350-mi route. In particular, it

**Figure 1.5: Amtrak Pacific Surfliner Train**
**Source:** 3D Trains, 2012

serves San Diego County between the Santa Fe Depot in downtown San Diego and the San Clemente station (one way route is about 63 miles). The fleet uses diesel engines.

## 1.2 The San Diego Public Transportation Network

Figure 1.7 shows a detailed map of the San Diego public transportation system. This includes all the above discussed services.


**Figure 1.6: San Diego County Transportation Map** (Include All Services Listed in Chapter 2)
**Source:** MTS, 2011c

## 1.3 Aims and Objectives

The aim of this study is to analyse and understand the current public transportation system of the San Diego County in order to give methods of improvement.

This part gives an introduction that includes the history and the fleets of the different services available in the county.

Secondly, an analysis of the San Diego County is necessary in order to understand the trend, the habits and the projection of the area, the population and the public transit development.

Thirdly, suggestion are given from both a social and an environmental point of view where the public transportation needs to be more reliable; and, at the same time, needs to be more environmentally friendly with regard to carbon, and other pollutants, emissions.

Finally, discussions and conclusions are given in order to summarise and like the different aspects that were taken into consideration.

# Population and Transport: Trends, Projections and Impacts

This part of the report gives a general overview of the current situation of the San Diego County with regard to its public transportation system, which is influenced by many different factors. First of all, population growth, its travelling habits and projections for the future are of major importance in order to create a development plan for the area and the transits available. Secondly, the current scarcity and unreliability of public transportation drive the local population to rely on private vehicles. This has a greater impact on the carbon, and generally greenhouse gas, emissions into the environment with local and global consequences. Finally, the thoughts and needs of people are also taken into consideration in order to better understand and evaluate what are the necessary changes needed.

## 2.1 Population Growth and City Development

Population growth and its geographical distribution play an essential role in the planning of an effective transportation system. In particular, people tend to want to live close to their workplaces and they need to have a good connection between their home and workplace. Figure 2.1 shows 2008 and projected trends of the San Diego population, the amount of jobs available and the number of housing.

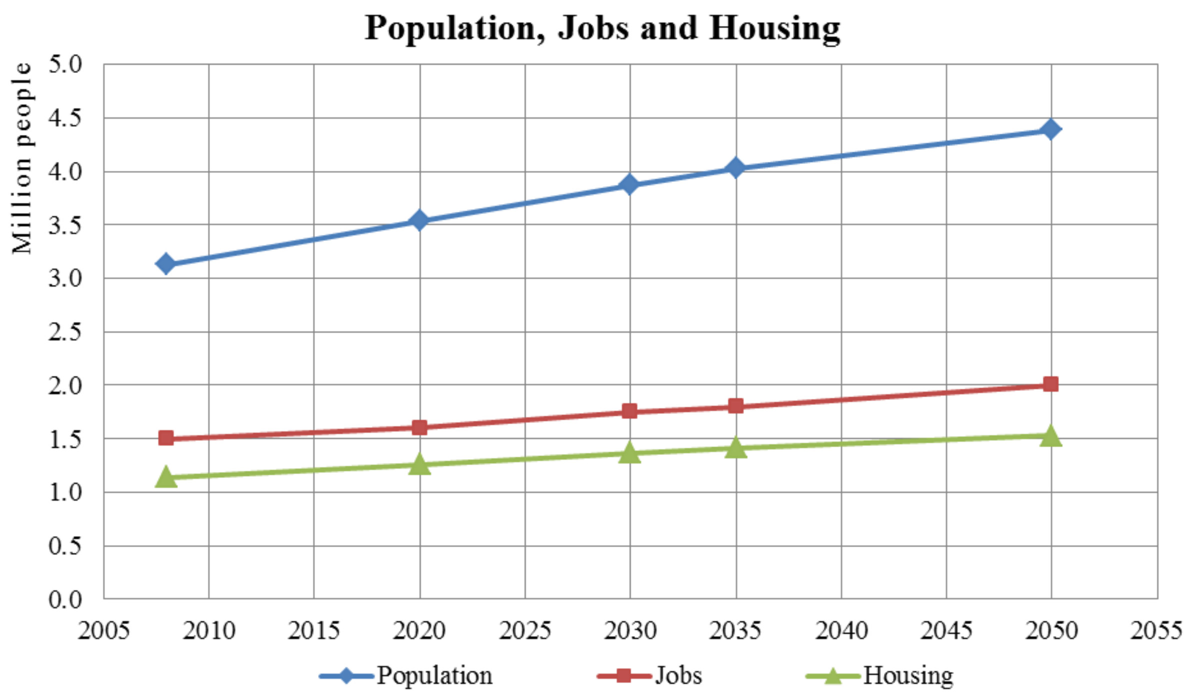


**Figure 2.1: Numbers (in millions) of People, Jobs and Housing present in San Diego County.**
**Source:** Author, with data from SANDAG, 2010a
**Note:** Actual data for 2008. Projected data for 2020, 2030, 2035 and 2050. Numbers used are available in Appendix (Tab. A1)

Notice that the increase in population is greater than the increase in jobs and housing, which seem to have the same growth rate. This means that more people will be living in the San Diego County in the future and that the length of commute travels will increase with a consequent effect on both on-road traffic and public transportation congestion. The economic development of the city is also clear in Figure 2.2, where housing is highlighted on a map. This same trend also affects job distributions (Appendix, Fig. A1).

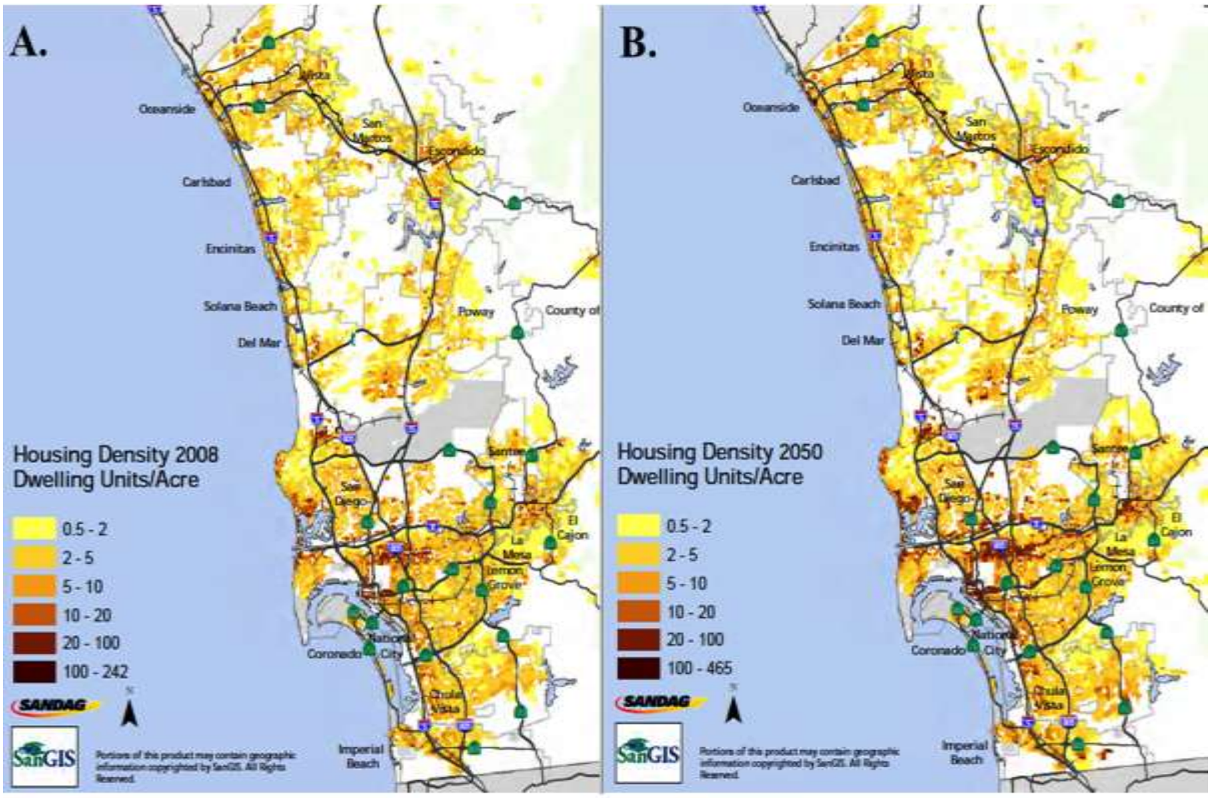


**Figure 2.2: San Diego County Housing Density Map – 2008 and 2050**
**Source:** Modified from SANDAG, 2010a

It can be easily seen that both housing and job distribution develop mostly in the following three areas served by public transits:

- Along Coronado Bay: The trolley’s blue line runs from the Mexican border to Downtown
- Between Old Town and El Cajon: Areas served by the trolley’s green line (also partially served by the orange line)
- Between Oceanside and Escondido: Areas served by the NCTD Sprinter Light Rail service.

Furthermore, the importance of public transportation in the development of the city has also been deeply studied by Duncan (2009) who states that the price of housing is significantly higher the closer a house is to a trolley or train station. The price decreases until it becomes insignificant at a distance from the public transportation station of about 3000 feet of 0.6 miles (an example of the decreasing price of houses can be seen in Appendix, Fig. A2).

## 2.2 Travel Trends

In the future, San Diego County will see its population increase by over one million people (1,253,315 according to forecasts; SANDAG, 2010a). It is important to better understand the traveling trends of those people. This section of the report will show how the San Diego transportation system is particularly, and negatively, focused on the use of private vehicles. This has a major impact on the global and local environment and on the city itself.

### 2.2.1 Transportation Habits

Figure 2.3 shows how the San Diego population commutes to work. It is immediately clear that the preferred transportation method is driving. In fact, "driving alone" and "carpooling" account for the 86% of the total.

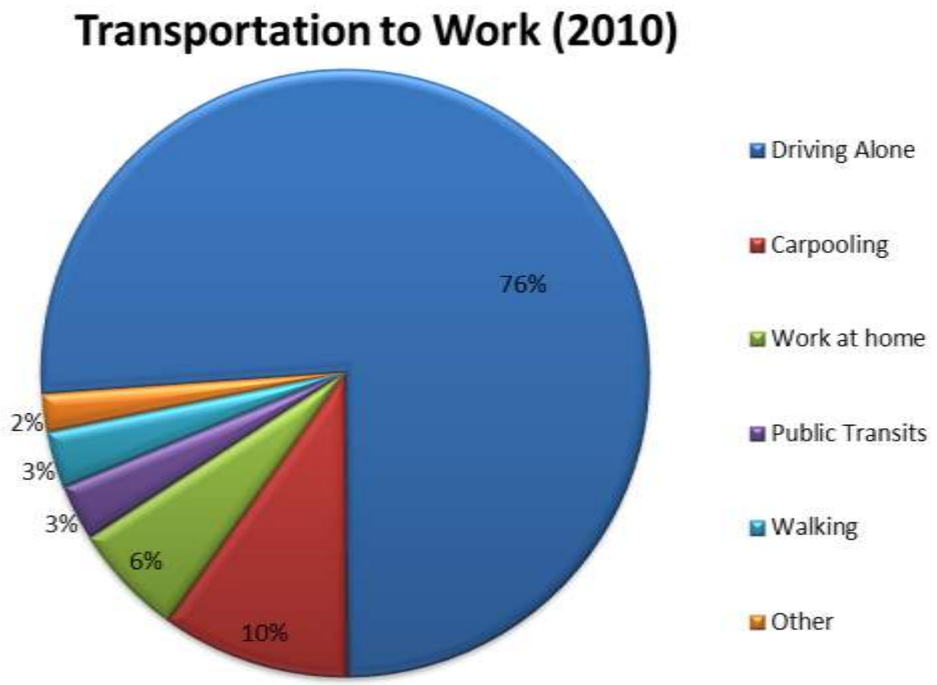


**Figure 2.3: 2010 Transportation Modes Used in San Diego to Commute to Work**
**Source**: Author, with data from the Equinox Centre, 2011a

If "work at home" is not considered, this percentage increases even more. Analyses of data show that this trend has slightly increased over the past 20 years (Appendix, Fig. A3). Nevertheless, the percentage of people who decide to use public transportation to commute to work has stayed constant at only 3%, despite the continuous improvement of the public transportation network.

This information is a warning sign and must be taken into account over the whole project: public transits are currently available. The question is: Why do people prefer to drive to work? Moreover, this trend is even more dramatic when compared to other major American cities (Fig. 2.4).

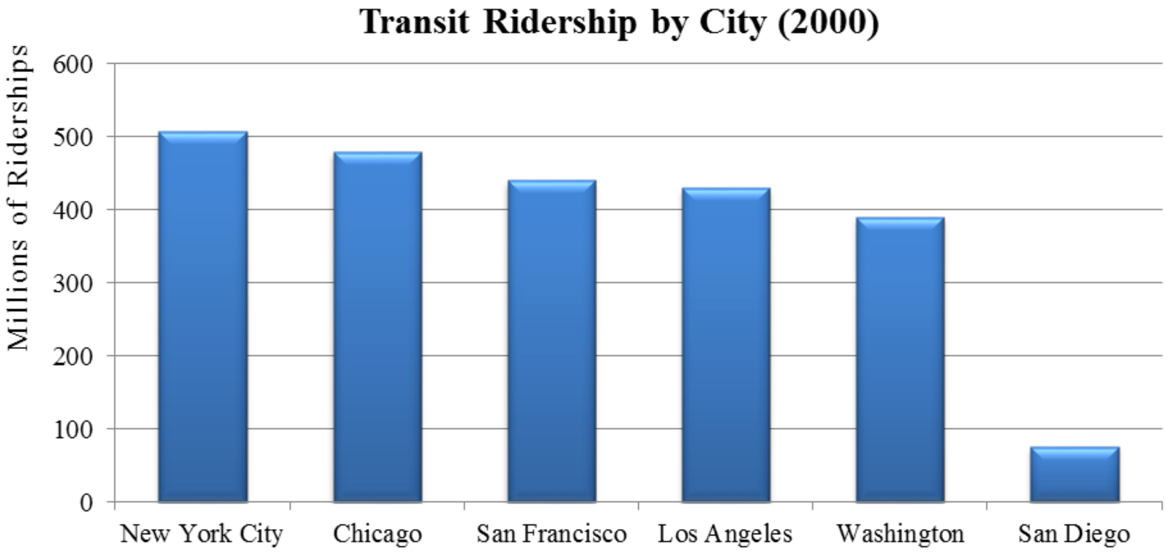


**Figure 2.7: Public Transit Ridership in 2000 for San Diego and Five Major US Cities**
**Source:** Author, with data from the Dunphy, 2005
**Note**: Data used is available in Appendix, Table A2

### 2.2.2 Vehicle Mile Travelled (VMT)

San Diego is a city based on privately-owned vehicles. It is a city based on cars and on its efficient and extensive highway system. Cars may be the fastest and most effective form transportation; however, they are also much more polluting and much less environmentally friendly than public transportation. It is important to understand and quantify the actual number of cars on the road in San Diego and, more importantly, the VMT associated with them before studying the pollution and the environmental impacts that drivers have on the local area of San Diego.

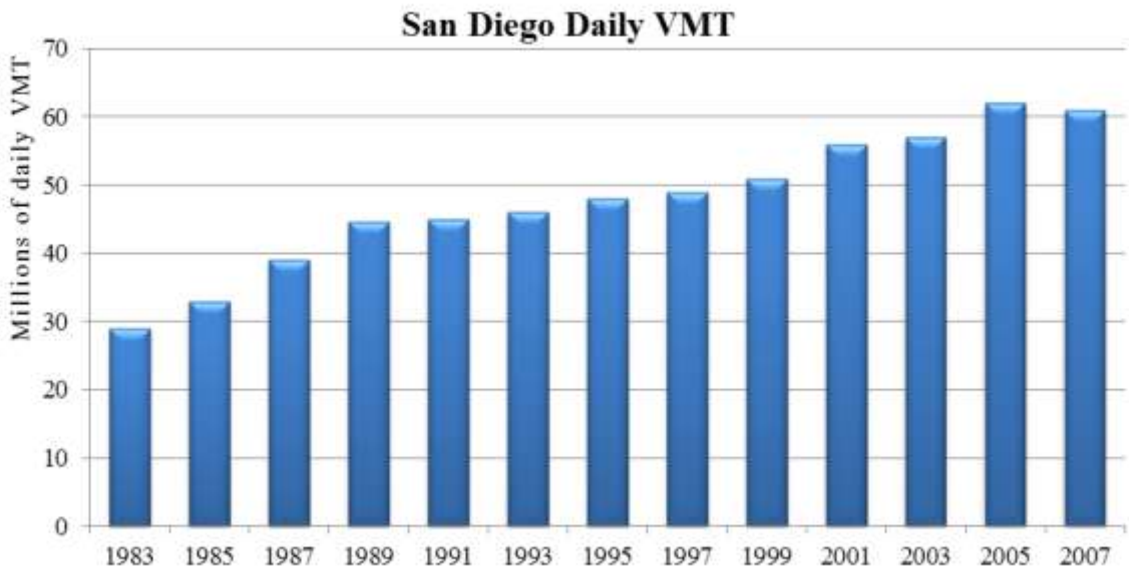


**Figure 2.8: Daily Vehicle Mile Travelled in Diego County – 1983 to 2007**
**Source:** Author, with data from the Schrank and Lomax 2009
Note: Data used available in Appendix, Table A3.

Figure 2.5 sh7ows the daily VMT between 1983 and 2007. Despite a slight decrease in 2007, most likely due to the dramatic increases in fuel price, it is clear that the trend is rapidly increasing, reaching over 60 million VMT in 2011.

Simply stated, more cars on the roads means that fewer people are using public transportation. Furthermore, Figure 2.4 shows San Diego is behind other major American cities in the use of public transit. Figure 2.6 shows that San Diego has the highest VMT per capita among the major Californian cities.

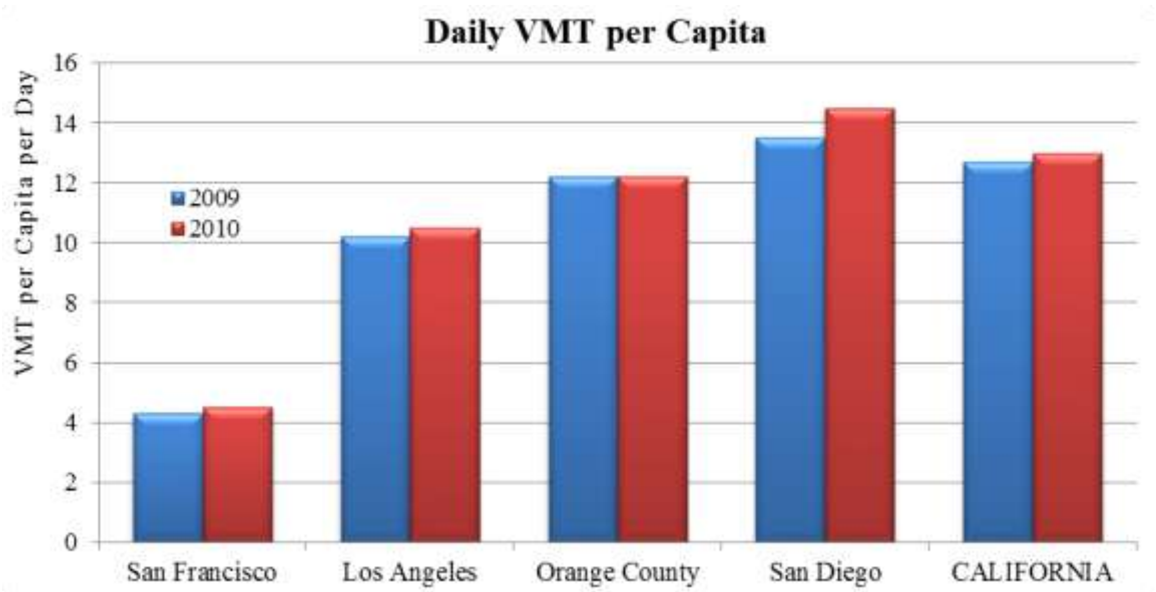


**Figure 2.9: Daily VMT per capita Mary California Counties and Average Values for California in 2009 and 2010**
**Source:** Author, with data from the Equinox, 2011b
**Note:** Data used available in Appendix, Table A4.

## 2.3 Environmental Impacts of Private Vehicles

On-road transportation has a major impact on pollution emissions into the atmosphere. Those emissions are mostly $CO_2$, CO, $NO_X$ and in minor quantity $SO_2$ from diesel engines and particulate matter. $NO_X$, $SO_2$ and PM may cause severe health problems for those people who spend most time outdoors. In California, every day the followings occur (SANDAG, 2004):

- 17,000 people die prematurely
- 55,000 people are hospitalised
- 1,300,000 asthma attacks
- 3,300,000 people lost days of work.

$NO_X$ stands for both NO (nitric oxide) and $NO_2$ (nitrogen dioxide). In 2009, San Diego had, on average, 184 total tonnes per day of $NO_X$ emitted into the atmosphere. Out of them, the 93% (171 tonnes per day) came from only mobile resources. On the same year, the amount of $PM_{2.5}$ emitted into the atmosphere daily was of 42 total tonnes per day. Of those, the 21% (9 tonnes per day) came from mobile sources. Figure 2.7 shows how mobile sources emit pollutants.

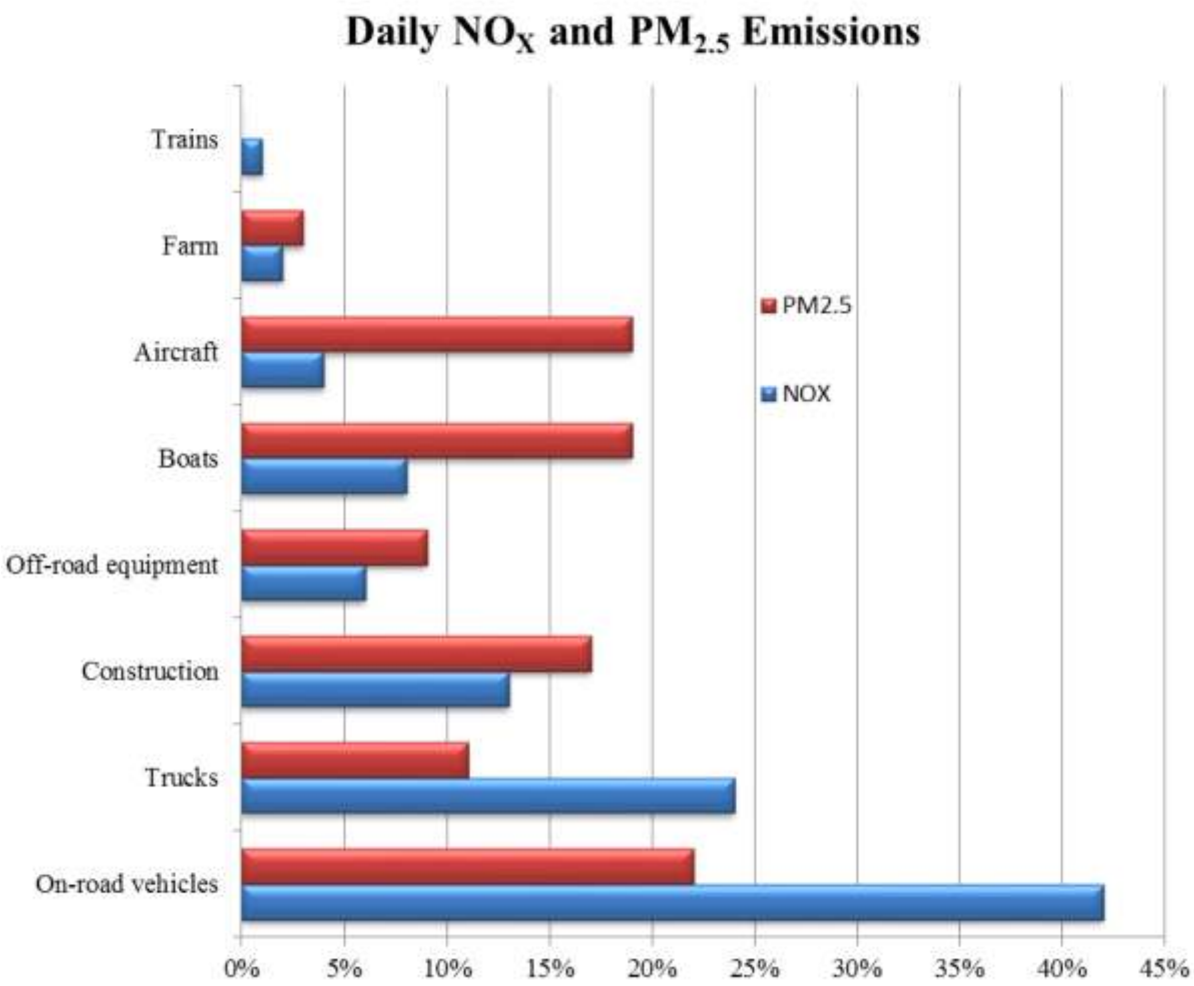


**Figure 2.7: Daily $NO_X$ and $PM_{2.5}$ Emissions into the Atmosphere in 2009.**
**Source:** Author, with data from the California Environmental Protection Agency, 2011

As it can be seen from the two graphs above, on-road vehicles have a major impact in hazardous-to-health pollutions.

In addition to those just analysed, there are other pollutants (such as $CO_2$ and CO) which, even though not as dangerous for human health, have a severe effect on the environment. The reason for this is that they are characterized as GHG emissions and cause the homonymous environmental effect. Major GHGs such as water vapour, $CO_2$, $CH_4$, $N_2O$ and $O_3$ are already present in the environment. GHG effects and impact are measured as carbon dioxide equivalent ($CO_2e$). Table 2.1 shows the emissions of GHG for the area of San Diego during 1990, 2006 and the projections for year 2020.

**Table 2.1: San Diego County GHG Emissions in 1990, 2006 and Projections for 2020**
**Source:** Author, with data from the Equinox Centre, 2011b

| | $CO_2e$ (tonnes) | | |
|---|---|---|---|
| **CATEGORY** | **1990** | **2006** | **2020** |
| **Electricity** | 1,035,005 | 1,391,224 | 1,897,370 |
| **Natural Gas** | 477,695 | 463,741 | 620,957 |
| **On-Road Transports** | 2,740,000 | 2,923,373 | 3,471,505 |
| **Off-Road Vehicles** | 175,889 | 200,955 | 275,981 |
| **Waste** | 143,308 | 108,206 | 155,239 |
| **Other Fuels** | 222,924 | 170,039 | 224,235 |
| **Wildfire** | 200,000 | 300,000 | 300,000 |
| **Agriculture** | 145,000 | 62,000 | 30,000 |
| **TOTAL** | **5,139,821** | **5,619,538** | **6,975,287** |

To better understand the importance of data in Table 2.1, the contribution of each category has been calculated as a percentage and plot in Figure 2.8.

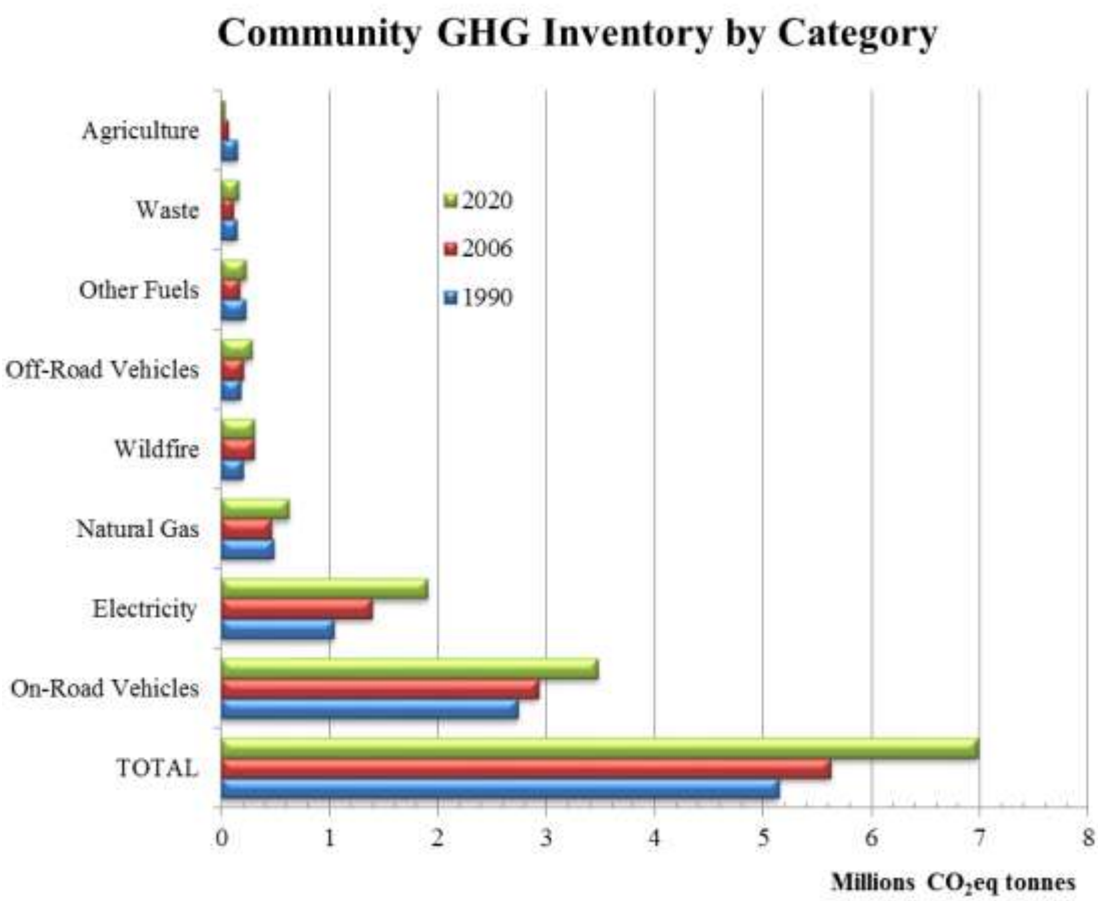


**Figure 2.10: Community GHG Inventory by Category for 1990 and 2006; Projections 2020.**
**Source:** Author, data found in Equinox Centre, 2011b

As indicated above atmospheric pollutions generate by on-road transportation have major impact on GHG production and emission into the atmosphere. Between 1990 and 2020, this impact has and will slightly decrease; nevertheless, it is still the major cause. GHGs have effects both locally and globally. Locally, the temperature rises and other pollutions are trapped and do not spread around maintaining high concentrations. Globally, they are thought to be the major cause of global warming.

It is clear from this section of the report that many and severe environmental issues that affect San Diego County are directly connected to the transportation system. In particular, on-road vehicles play the major role. The following chapters of the report try to find a solution to implement and further develop the San Diego public transportation system as the best way to take the population off the many highways in the area and, by using public transit, help the environment and the county itself.

# Proposed Improvements for a Reliable and Effective System

The San Diego County public transportation system is in constant evolution. Nevertheless, the local population tends to prefer the use of private vehicles rather than using public transits. This section of the report aims to better understand what people's needs for a better public transportation are and tackle them by trying to give a solution. Moreover, SANDAG, together with the San Diego local jurisdictions, are constantly working to solve this issue and development plans are already under study, if not already in operation.

## 3.1 Need for Better Public Transportation

Figure 2.3 shows that 76% of people commuting to work drive alone. Another 10% carpools, taking the total to 86% of people on the road and only 3% using public transportation. SANDAG (2008) conducted a survey in which the San Diego population was asked different questions about travelling and to rate the likelihood of occurrence. A summary of the survey can be found in Figure 3.1.

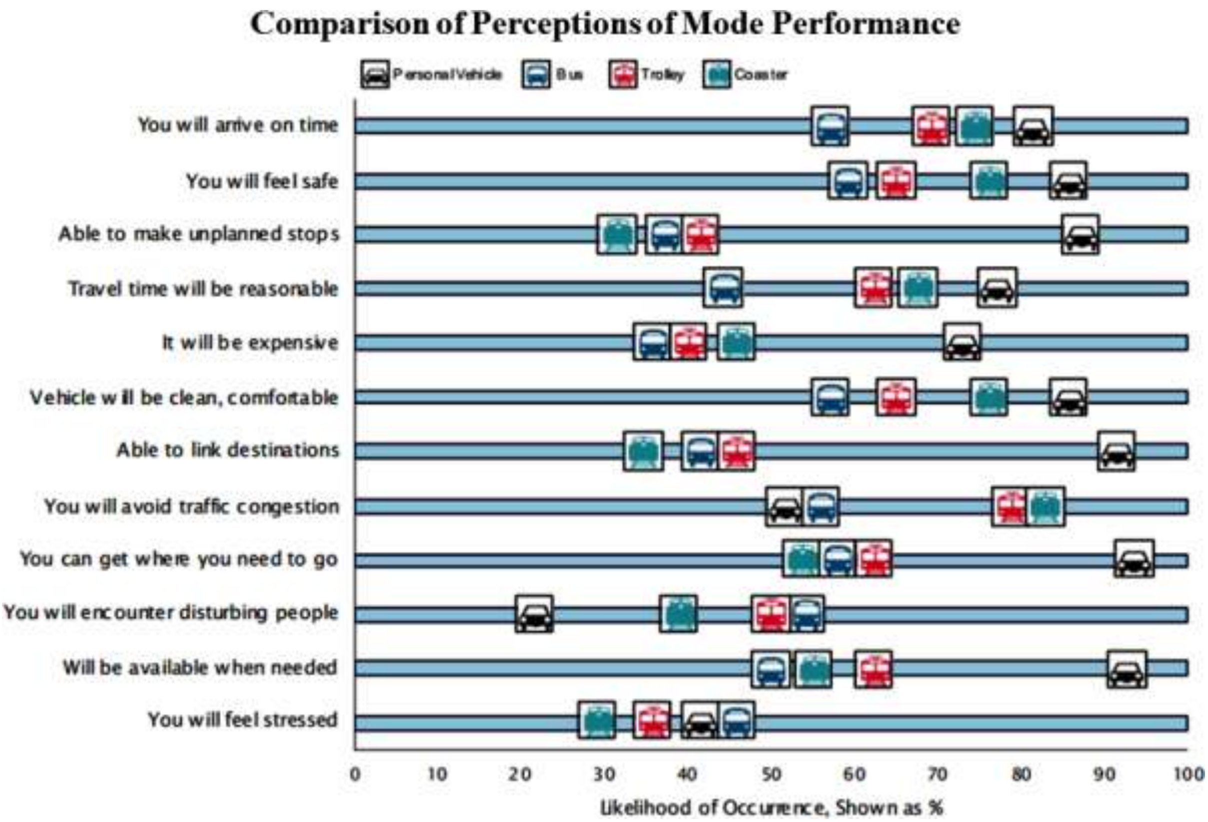


**Figure 3.11: Comparison of Perceptions of Transportation Mode Performance**
**Source**: SANDAG, 2008
Note" Data available in Appendix, Table A5.

Once again, it is clear that the use of private vehicles is preferred to public transportation. When the population was asked why public transportation is not the chosen mode of commuting to work, they gave the following answers (Fig. 3.2) were found.

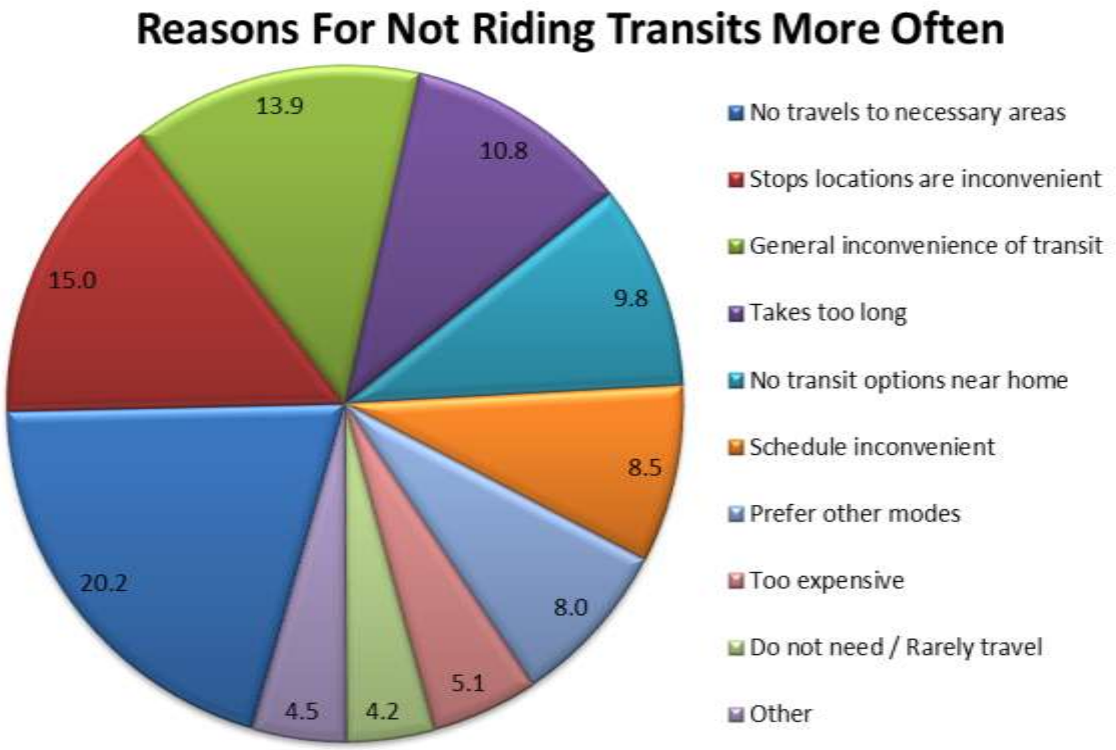


**Figure 3.2: Reasons for Not Riding Public Transit More Often**
**Source:** Author, with data from SANDAG, 2008

From these surveys, the data that emerges the most are the following

- Public transportation systems are not well-developed with regard to the land use. In particular, people have difficulties in using it because either the area where they live or where they work is not properly connected and served. This problem is related to the wide and spread-out layout of the San Diego County and to the not enough developed public transportation system.
- Public transportation options are not adequate to people's needs. For instance, they are slow, not frequent enough and not reliable.

## 3.2 Land Use and Public Transportation

It is of fundamental importance to analyse land use in San Diego County before planning developments for its transportation systems.

San Diego, as with California in general, is an area rich in highways. Not only are they numerous and efficient in connecting San Diego to the surrounding cities; but, they constitute a dense network that connects every part of the county. This is the main reason why San Diego residents prefer to drive rather than using public transportation. Moreover, San Diego County has a hilly topography that complicates linear development. In fact, the cities in the county have very spread-out configurations. This makes reaching every area very difficult and challenging for public transportation.

Population forecasts predict an increase of about 1.2 million people in the next 40 years and a consequent increase in the number of houses and jobs (SANDAG, 2010a). If the trends for private vehicle usage stay the same, very soon the county's roads will be severely congested.

One solution is the development of an improved public transportation system able to serve efficiently the majority of people living in the county. According to the survey conducted for SANDAG (2008), there is a general unhappiness about the limitations of the existing public transportation system that does not serve the areas where people live, work or both. Therefore, public transportation systems must spread around the county to serve as many people as possible. Existing trolley lines need to develop further, and different transportation systems need to be connected to each other by strategically positioned interchange stations. Figure 3.3 shows the 2050 transit map projection, developed by SANDAG (2011) that shows how the major, long-distance transportation systems are used to connect the different areas of San Diego County. Each area is then served by local bus services which do not appear on the map to make any destination available to the public with no more than two and preferably possibly just one, interchange.

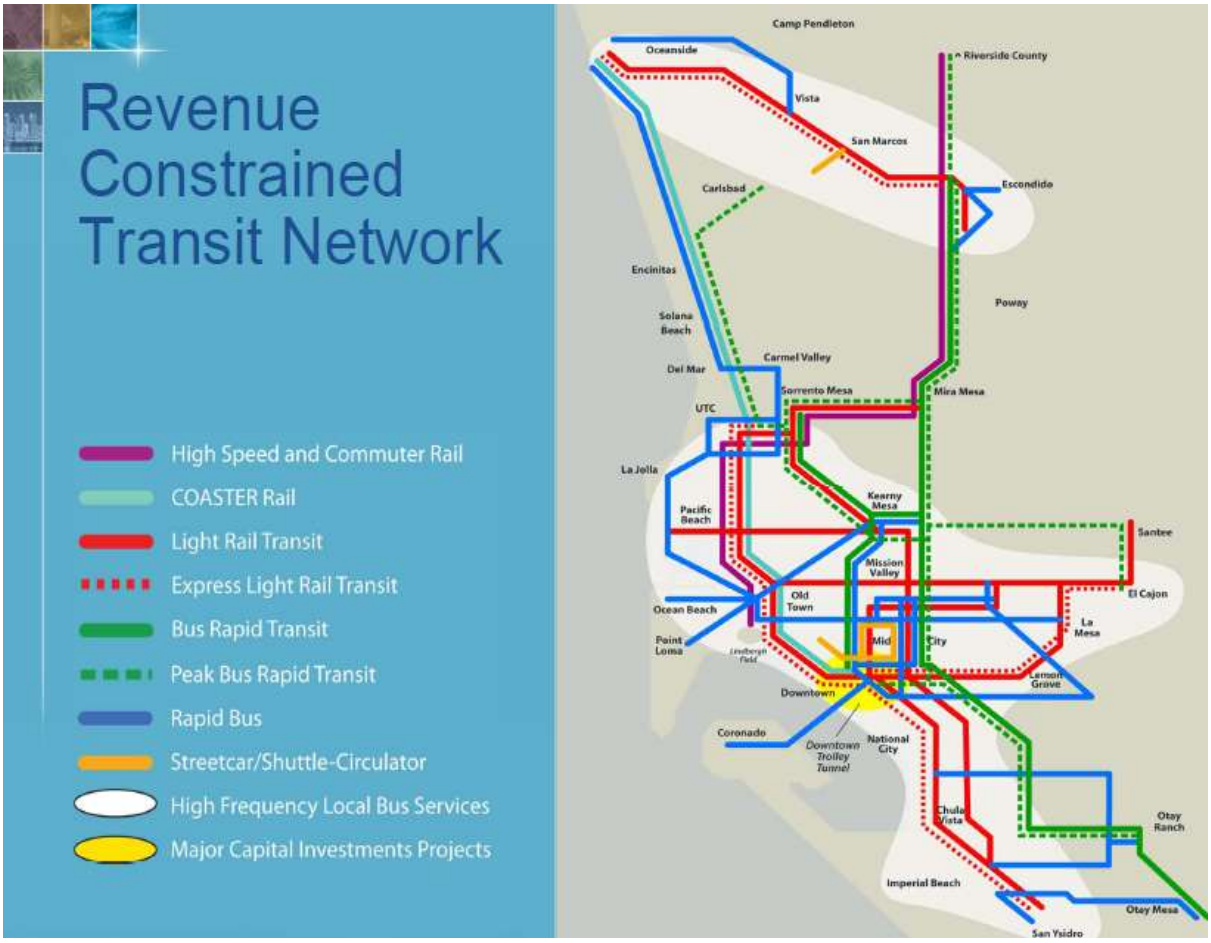


**Figure 3.3: Revenue Constrained Transit Network – Future development of San Diego Public Transportation System.**
**Source**: SANDAG, 2011

Both the 2030 and 2050 Regional Development Plans (SANDAG, 2007, 2011) take into account the economic and social development of the region in order to maximise the efficiency of the service and the number of people being served by it.

## 3.3 Faster and More Frequent Transits for Reliable Service

This part takes examines and tries to find a solution for some of the problems the San Diego population believes its public transportation has.

### 3.3.1 Fast Transit: Bus Lanes and Priority Lights

According to the survey on public transportation (SANDAG, 2008), more 10% of the people i10% interviewed believe that public transportation systems are too slow. Many large cities, such as San Francisco, Los Angeles, Orlando, London, and Paris,


**Figure 3.12: Bus Lane on M4 Highway in London.**
**Source:** Human Transit, 2010

use priority bus lanes that prohibit access to private vehicles. For instance, downtown Orlando has streets running through the city where only buses are allowed. In major street connections in London (example of bus lane on M4 highway in Fig. 3.4), one lane is always forbidden to private vehicles traffic and can be used only by buses and taxis. This has the advantage of reducing the time that buses spend in traffic, especially in very congested areas such as the downtown area, city centres and highways. Furthermore, the development of bus lanes on highways would potentially allow the further development of the public transportation system by the implementation of high speed transit, which could compete with rail system and be more accessible to people.

Another aspect that needs further analysis is the urban organisation of traffic lights. The San Diego trolley runs through the city centre and through many traffic lights and pedestrian crossings, which slow down its route. The current system can be considered as "passive," meaning that it is based on data analyses and time prediction models. For instance, if the trolley prepares to leave a red light five seconds before it turns green, then it allegedly would find all green lights on its way to the next station (Li *et al*., 2009). However, if for any reason the trolley needs to stop on the way, then it most likely will encounter a red light with a consequent time loss on its schedule. Moreover, when the trolley stops at a station, although ready to leave and on a green light, it has to wait until the next green light in order to meet the priority light system. This makes the trolley schedule variable and unreliable.

For instance, the blue line has been studied on its route through downtown San Diego between 12th and Imperial Transit Centre and America Plaza. Figure 3.5 shows the list of the crossings (pedestrian and non-) with traffic lights where the trolley could potentially have to stop at; the duration of the red light has been timed for each light.

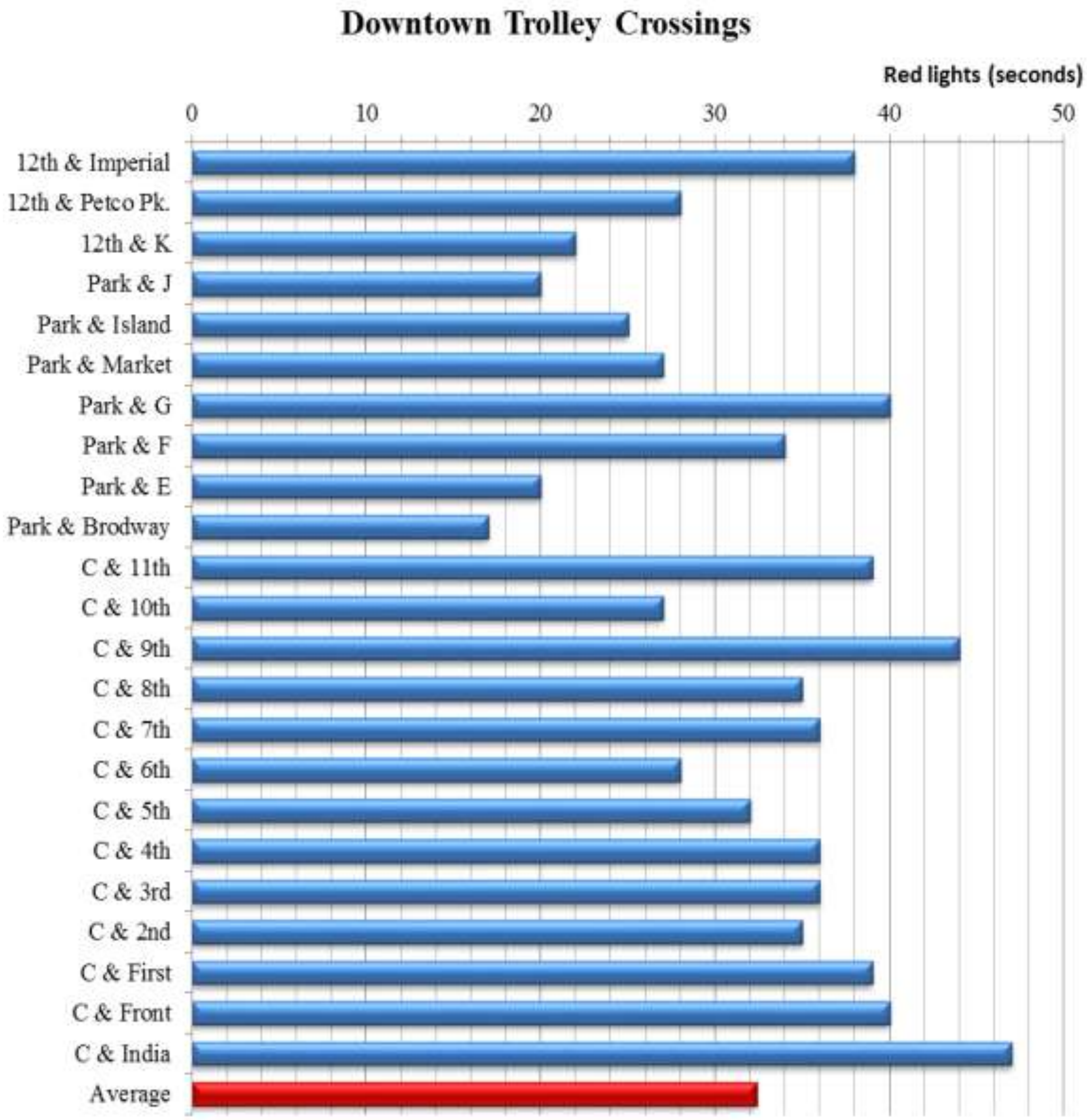


**Figure 3.5: Blue Line Trolley Crossings with Traffic Light and Red-Light Duration.** (Measured on 03 August 2012 between 3:30 PM and 4:30 PM)
**Source**: Author

With a potential average loss of 32.4 seconds per stop, without accounting for slowing and accelerating, the trolley could accumulate an important delay on its route from one side to the other of downtown. For this reason, it is advisable to adopt an "active" signal priority system as it is in use in the city of Zurich (Carrasco, 2011). Furthermore, not only would the adoption of an active system be beneficial for the time saving and the punctuality of trolleys, it would also benefit the traffic congestions. In fact, several times, especially during peak hours, trolleys are formed by too many carriages which do not fit the length of a whole block and extend into the crossing. This affects traffic congestion for cars on perpendicular lanes and it is dangerous for the safety of pedestrian which have to walk on the car lanes to cross the street.

### 3.3.2 More Frequent Transits: Flexible Schedule and Night Transits

Frequency is an important aspect of a reliable public transportation system. San Diego transits run on average every 15 to 20 minutes; this is a too long wait for most people (SANDAG, 2008) and, together with the actual travel time, it makes driving and other modes faster and more convenient. For those reasons, more frequent transits are needed. Large cities that rely on a strong public transport network, such as New York and London, have transits every few minutes during busy hours. For instance, Figure 3.6 shows the timetable of the bus line 159 in London at one of its stations.

**Monday - Friday**

| Midnight to 00:30am | 00:30 to 1am | 1 to 2am | 2 to 4am | 4 to 5am | 5 to 6am | 6 to 8am | 8am to 7pm | 7pm to Midnight | Midnight to 1am |
|---|---|---|---|---|---|---|---|---|---|
| 00 20 | 00 32<br>00 44<br>00 56 | 01 08<br>01 20<br>01 39<br>01 59 | At these minutes past the hour 19 39 59 | 04 19<br>04 39 | 05 00<br>05 20<br>05 28<br>05 36<br>05 44<br>05 52<br>05 59 | about every 3-5 minutes | about every 4-8 minutes | about every 8-12 minutes | 00 08 |

**Saturday (also Good Friday)**

| Midnight to 00:30am | 00:30 to 1am | 1 to 2am | 2 to 3am | 3 to 4am | 4 to 5am | 5 to 6am | 6 to 8am | 8 to 9am | 9am to 7pm | 7pm to Midnight | Midnight to 1am |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 00 23 | 00 35<br>00 47<br>00 59 | 01 11<br>01 23<br>01 41 | 02 01<br>02 21<br>02 41 | 03 00<br>03 19<br>03 39<br>03 59 | 04 19<br>04 39 | 05 00<br>05 20<br>05 32<br>05 44<br>05 56 | about every 9-12 minutes | about every 6-10 minutes | about every 5-8 minutes | about every 8-12 minutes | 00 11 |

**Sunday and other Public Holidays**

| Midnight to 00:30am | 00:30 to 1am | 1 to 2am | 2 to 3am | 3 to 4am | 4 to 5am | 5 to 6am | 6am to Midnight | Midnight to 1am |
|---|---|---|---|---|---|---|---|---|
| 00 23 | 00 35<br>00 47<br>00 59 | 01 11<br>01 23<br>01 41 | 02 01<br>02 21<br>02 41 | 03 00<br>03 19<br>03 39<br>03 59 | 04 19<br>04 39 | 05 00<br>05 20<br>05 32<br>05 44<br>05 56 | about every 10-13 minutes | 00 08 |

**Figure 3.6: Timetable of Bus Line 159 in London at Kennington Park Post Office Stop**
**Source:** modified from TfL, 2012a

During busy period, the schedule does not give a specific time as it may not be accurate in the city traffic. Instead, the average frequency is given. It is also significant to see the high frequency of 3-5 minutes on weekdays during rush hours (6am to 8am) and 4 -8 minutes during the rest of the day. When walking in San Diego, few buses can be seen on the road. In comparison, London is crowded with its red double-deck buses (Fig. 3.7) which advertise themselves by showing that the service is efficient and always available.


**Figure 3.13: London Buses**
**Source:** Modified from *Pollution Free Cities*, 2011

An increased frequency of transit would increase people's willingness to using public transportation and would help change the driving mentality of the San Diego population.

Another aspect to be considered by looking at Figure 3.6 is the fact that San Diego does not have any sort of public service running at night. For big cities, a night service is of fundamental importance for the following reasons:

- It gives more visibility and increases the reliability of the public transportation system.
- People who need public transportation at night and purchase monthly passes may be willing to use it also during the day and vice versa.
- People who work late shifts can still commute to work by public transportation.
- People who go out partying at night do not have the risk of driving after having drunk alcohol.

### 3.3.3 User Friendly Transit: GPS-tracked Transits and Mobile Applications

Trying to encourage people to use public transportation in an environment where private vehicle culture is so deeply-rooted is a challenge. For this reason, public transportation not only needs to be reliable and efficient, but also user friendly. Timetables are often missing at transit stops and, where they are present, they are sometimes unreliable and inaccurate. Figure 3.6 shows how London tackles this problem by giving an average frequency rather than an exact time.

Furthermore, London has a GPS system in operation for both trains and buses. Every bus is has GPS tracking that allows user to know exactly when the next bus is arriving. Figure 3.8 shows the electronic GPS arrivals panel at a London bus stop. All the buses arriving at that stop are listed on order of arriving time and the predicted time is given, as well as the destinations.


**Figure 3.8: Electronic GPS Arrivals at a Bus Stop in London.**
**Source:** modified from The London Bus Blog, 2011

This approach to scheduling bus service very convenient and user friendly. Not only can bus arrivals be seen at bus stops, they can also be checked on the TfL (Transport for London) website or by the means of applications for smartphones or tablets. Figure 3.9 shows the screen of a smartphones running two of these applications. The availability of GPS live tracker and the on-line live planner are tools to make the public transportation system more accessible to the public. In fact, people can plan their trips very quickly without need to wait at the bus stop for unknown periods of time.


**Figure 3.9: Screenshots of Two Applications for iPhone/iPad. Left: London Bus Checker by FatAttitude. Right: London Bus Live Countdown by MobiSpector.**
**Source:** modified from Apple Inc. UK, 2012

One last aspect to consider is the physical status of transits and their maintenance. Some of the San Diego buses are very old; they make a lot of noise; and make travelling unpleasant. The trolley blue line is run by old trains which sometimes break down and cause travel delays.

# Proposed Improvements for a Clean and Sustainable System

This part of the report aims to analyse and find smart solutions that can improve the San Diego County public transportation system with regard to the pollution emitted by exhausts, to the energy consumption and, generally, to environmental impacts.

## 4.1 Exhaust Effects: Diesel vs. Compressed Natural Gas

The major and most harmful pollutants deriving from the exhausts of vehicles are summarised in Table 4.1.

**Table 4.1: On-road Vehicle Pollutants and Their Health and Environmental Effects**
**Source:** Author, based on Wargo, Wargo & Alderman 2006; TEC 2005

| Pollutant | | Description |
|---|---|---|
| **Carbon Dioxide** | $CO_2$ | It is the major product of hydrocarbon combustion reactions. It has negligible effects on human health, but major impact on the environment (GHG effect and global warming). |
| **Carbon Monoxide** | CO | It derives from partial combustion reaction, especially when a deficiency of air occurs. It is toxic and it has severe impacts on human health. |
| **Nitrogen Oxides** | $NO_X$ | Nitrous oxide and nitrogen dioxide usually derive from high combustion temperature or from rich fuels. They are acidic compounds that promotes acid rains. Moreover, they undergo photochemical reactions that form ozone and smog. |
| **Sulphur Oxides** | $SO_X$ | Sulphur monoxide and sulphur dioxide derive from fuel rich in sulphur. They are toxic to human health, and they lead to acidification of the atmosphere and consequent acid rains. |
| **Particulate Matter** | PM | Particulate matter derives from hydrocarbon chains that do not reach complete combustion. They take the form of ash or dust. They may be toxic. They have severe impacts on human health. |
| **Organic Compounds** | | Derived from the combustion of hydrocarbons, major compounds are benzene, formaldehyde and polycyclic aromatic hydrocarbon (PAH). Those have toxic and/or carcinogenic effects on human health. |
| **Ozone** | $O_3$ | Usually not directly produced by vehicle, ozone is the major by-product deriving from $NO_X$ and PAH. |
| **Lead** | Pb | Lead was added to fuel to improve its performance. It has dramatic poisoning effects on human health. |

Exhausts have major impacts both on the environment and on people's health. The former is affected by two major events:

- Greenhouse gas effect and consequence on global warming
- Acidification and consequent acid rain

The latter is affected by a variety of pollutants emitted by different vehicles. Even though the whole population can suffer, there are susceptible groups that are more likely to be adversely affected (Tab. 4.2):

**Table 4.2:- Summary of Groups and Diseases Affected by Air Pollution from Vehicles' Exhausts.**
**Source:** Author, based on Wargo, Wargo & Alderman 2006**.**

| Affected Groups an Diseases | Causes and/or Effects |
|---|---|
| **Children** | Particularly affected by high $O_3$ and particular PM levels. |
| **Elderly** | At risk of cardiovascular and respiratory diseases. |
| **Asthma** | Can be harmed by exhaust that can cause allergic reaction on their respiratory ways. |
| **Chronic obstructive pulmonary disease** | Sufferers of this are at risk when in an environment with high level of $O_3$ and $PM_{10}$. |
| **Cardiovascular disease** | Problems are very common in people working in heavy traffic or living near major highways |
| **Cancer** | Cases derived from air pollution accounts for half the cases deriving from outdoor activities. PAH play a fundamental carcinogenic role. |
| **Diabetes** | Mortality is associated with rising levels of air pollution. |

As described in *Chapter 2*, the San Diego transportation system relies on a mixture of bus, light rail and rail systems. Most buses and rails are powered by diesel engines and only some buses powered by CNG. This section compared these two fuels with regard to their environmental emissions and gives a better understanding of the policies and trends of public transports.

First, classic emissions from buses powered by diesel fuel are compared to buses powered by CNG engines. Moreover, many different types of engines and many different types of end-of-pipe cleaning technologies are available; this makes comparison a challenging operation. Figure 4.1 summarizes emissions of CO, $NO_X$ and PM for early CNG and *Euro3* Diesel engine buses. The graph shows how emissions produced from CNG combustion are cleaner than Diesel emissions – CO reduction is 25.45%; $NO_X$ reduction is 28.45%; and reduction of PM is 98.12% (Appendix, Tab. A6).

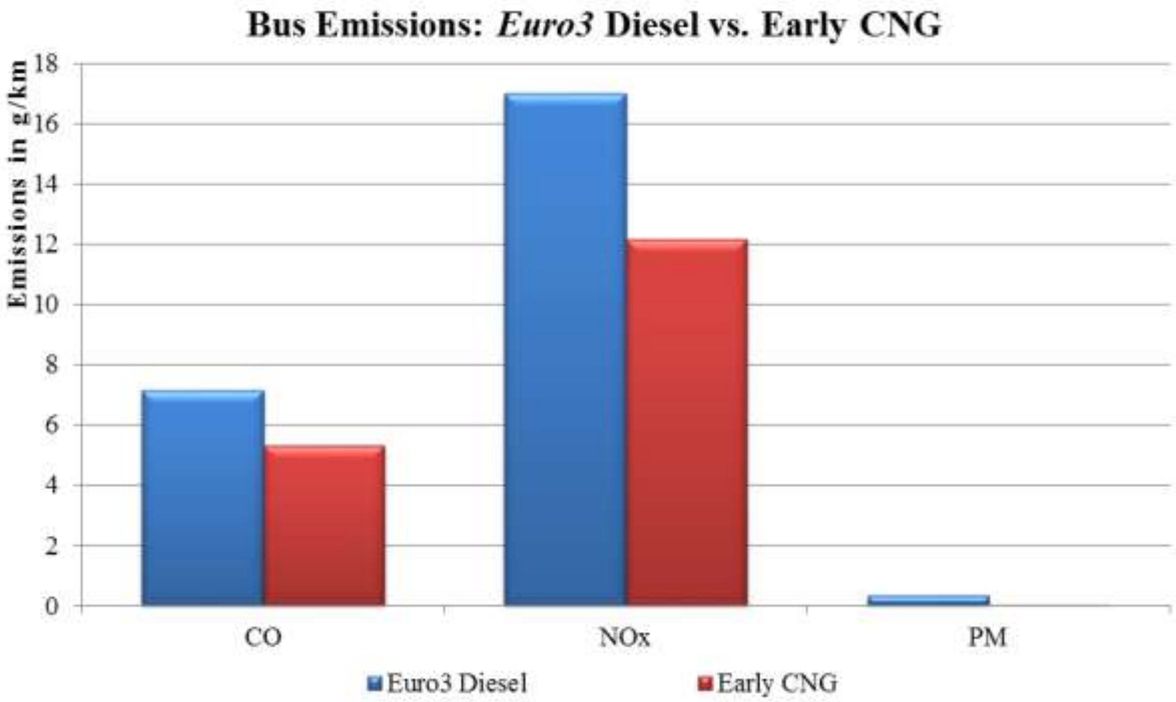


**Figure 4.1:- Emissions of Buses Powered by *Euro3* Diesel and Early CNG engines.**
**Source:** Author, with data found in Beer *et al.*, 2000
**Note:** Data used are available in Appendix (Tab. A6).

Nevertheless, when both diesel and CNG are retrofitted with cleaning technologies, the differences showed in Figure 4.1 are minimized and can be considered negligible from many points of view (Hesterberg, Bunn & Lapin, 2009). For instance, emissions can be reduced by 10 folds simply by installing articular filters and can achieve a 1,000-fold reduction by adding a catalysed muffler to each vehicle (Nylund *et al.*, 2004). As an evidence of this, Table 4.3 shows the outcome of two different studies that compare the emissions from buses powered by clean Diesel and CNG. Even though CNG is once again the cleaner technology, the difference in emissions (summarized in total grams of $CO_2$ equivalent per kilometre) is less than 10%.

**Table 4.3: Comparison of g$CO_2$eq Emission by Buses powered by Diesel and CNG Wngines.**
**Study 1 source:** Beer *et al.*, 2004**. Study 2 source:** Sliva *et al.*, 2006

| | Emissions (g$CO_2$eq/km) | | |
|---|---|---|---|
| | **Diesel** | **CNG** | **Reduction** |
| **Study 1** | 1759 | 1604 | -8.81% |
| **Study 2** | 2277 | 2070 | -9.09% |

It can be concluded that CNG is cleaner than diesel. Nevertheless, when newer technologies are added to clean the exhausts, the differences come to a value less than 10%. On the other hand, costs of both fuel engines need to be accounted for. Table 4.4 breaks down the incremental annual cost of moving from the old, standard Diesel to both the newer clean diesel and CNG.

**Table 4.4: Cost Comparison of CNG to Clean Diesel**
**Source:** Author, data found in DEER, 2003
**Note:** Numbers are given per bus and per a 200-bus fleet

| | CNG ($) | | Clean Diesel ($) | |
|---|---|---|---|---|
| **Cost Element** | Per Bus | Per Fleet | Per Bus | Per Fleet |
| Incremental CNG Fuel | 2,860 | $0.6 \times 10^6$ | - | - |
| CNG Fuel Station Maintenance | - | $0.9 \times 10^6$ | - | - |
| Incremental Bus Maintenance | 5,200 | $1.0 \times 10^6$ | - | - |
| Incremental Cleaning Technology | - | - | 1,040 | 208,000 |
| Diesel Fuel Station Maintenance | - | - | - | 92,000 |
| Clean Technology Replacement | - | - | 137 | 27,400 |
| Annual Technology Cleaning | - | - | 670 | 134,000 |
| **TOTAL** | | **2,500,000** | | **461,400** |

Overall, diesel powering classic engines is the less desirable fuel from an environmental point of view. However, there are different and conflicting opinions when CGN is compared to Clean Diesel. From this study it seems that, despite the little differences in environmental polluting emissions, Clean Diesel wins over CNG for economical and logistic reasons.

## 4.2 Electrification of the Rail System

Rail is an integrated part of the San Diego public transportation system. The Coaster and Sprinter by NCTD and the Amtrak's Pacific Surfliner are used on a daily basis and their diesel engines consistently generate pollution. Table 4.5 summarises the above three services.

**Table 4.5: Summary of Rail Systems powered by Diesel engines and Running in San Diego County**
**Source:** Author; data found in Amtrak 2012b, NCTD 2012c, 2012e
**Note:** Pacific Surfliner travel considered only for the San Diego County between Santa Fe Depot and San Clemente

| Service | Company | Travel (mi) | Weekly Trips | Yearly Travel (mi) |
|---|---|---|---|---|
| Coaster | NCTD | 41 | 46 | 98,072 |
| Sprinter | NCTD | 22 | 132 | 151,008 |
| Pacific Surfliner | Amtrak | 63 | 154 | 504,504 |
| **Total** | | | | **753,584** |

This section of the report suggests electrification of the rail systems operating in the San Diego County (Tab. 4.5) as a way of:

- Reducing environmental impacts
- Improving the reliability of the service
- Increasing the capacity of trains
- Reducing maintenance, fuel and wear and tear costs

Electrified rail does not produce direct emissions but the electricity production processes needed to power it do. However, the pollution coming from electricity production can come from a variety of plants (hydrocarbons as well as renewables) that can control emissions in a better way and on an industrial scale. For this reason, electrified rail is considered green as it does not have any sort of emission at the point of use and, therefore, does not influence local pollution levels (for example, city centres or particularly traffic-congested areas). Figure 4.2 shows average emissions of $CO_2$ for both a diesel and an electric train.

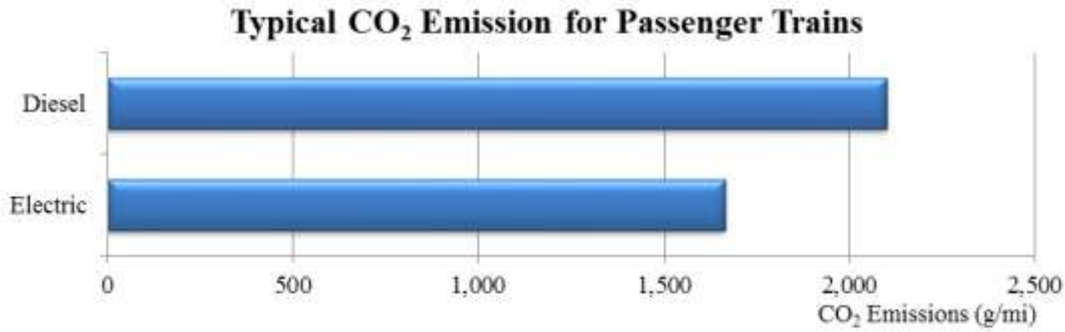


**Figure 4.14: Typical $CO_2$ Emissions Per Mile for Passenger Trains Powered by Diesel and Electric Engines.**
**Source: Author, data found in Atkins, 2007**

On average, an electric train emits about 20 – 35% less carbon dioxide per mile than a diesel one (DfT, 2009). Figure 4.3 shows the impacts that different modes of transportation have with regard to carbon emissions. The study was conducted for a trip from London to Manchester in the United Kingdom; this distance is comparable to a trip from San Diego to Santa Barbara in California.

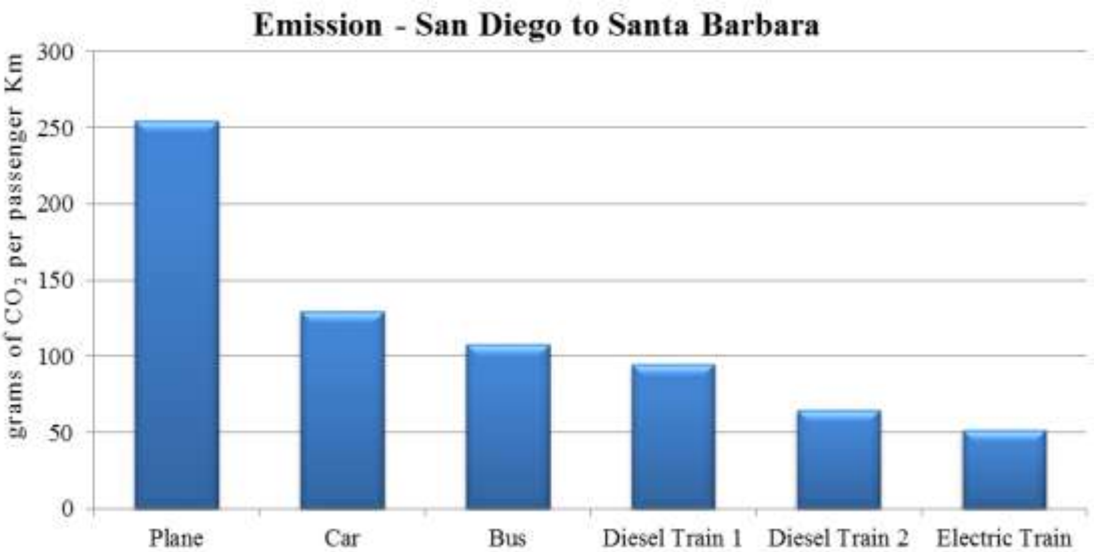


**Figure 4.3: Comparison of Different Transport Modes $CO_2$ Emissions – Travel from San Diego to Santa Barbara**
**Source:** Author, data found in DfT, 2009
**Note:** Train 1 refers to Meridian; train 2 to HST. The electric train considered is a Pendolino. Data used are available in Appendix (Tab. A8).

Second, the reliability of electric trains can be compared to that of diesel trains. Figure 4.4 shows the average distance travelled before failure for both diesel and electric trains. As can be seen, electrification would improve the reliability of trains: calculations give an improvement of 28.8% and 57.4% respectively for intercity and regional trains.

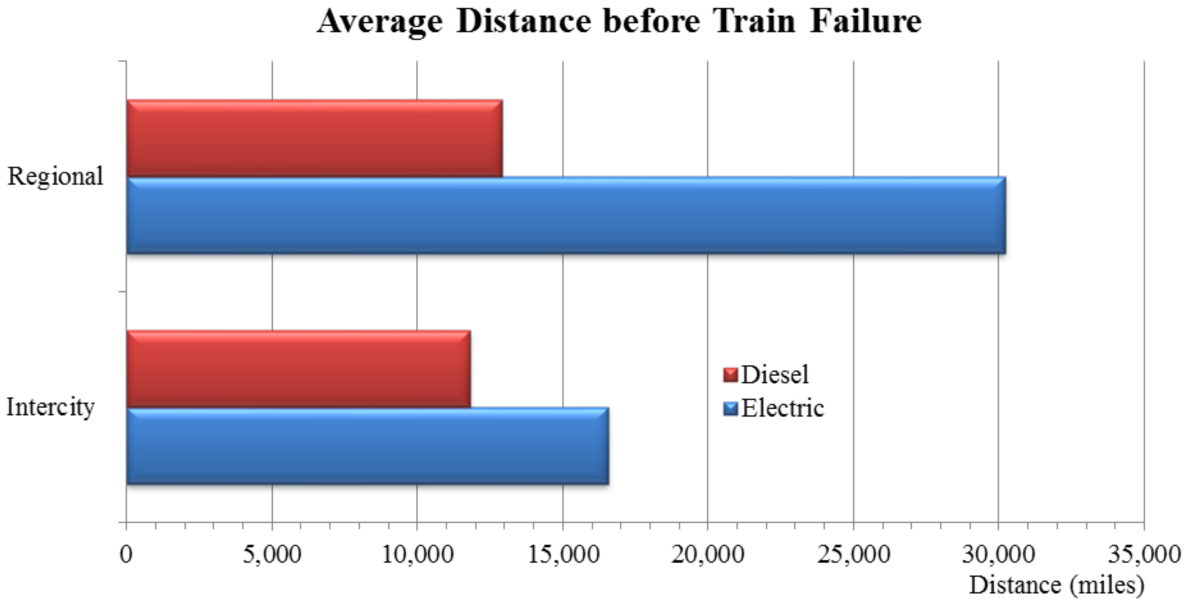


**Figure 4.4 - Reliability of Diesel and Electric Intercity and Commuter Regional Trains – Average Distance (Miles) Between Failures**
**Source:** DfT, 2009
**Note:** Failures are considered only when they cause delays of five (5) minutes or more. Data used and improvement calculation results are available in Appendix (Tab. A9)

Third, in order to promote and further develop the railway system as a cleaner and more environmentally-friendly travel mode, train capacity can be implemented. Diesel engines are larger and generate more noise than electric engine. For this reasons, rail electrification can result in larger seat availability in the power cars (Dft, 2009). Moreover, electric engines are lighter and do not require the presence of fuel tanks. For this reason, despite slight reduced performance, trains can travel faster and would require less maintenance, which would result in an increase fleet availability – 88% availability for diesel engines compared to 91% of a typical electric fleet (Network Rail, 2009).

Finally, costs of electrification can be accounted for. The operation costs of electric trains are normally cheaper than those for classic diesel trains by about 35% (DfT, 2009). Reasons for this are that electric trains:

- Require less maintenance.
- Need less maintenance and that fuel costs are cheaper. However, fuel cost was studied from an English point of view, where cost of fuel is higher than in the US.
- Are lighter; therefore, the wear and tear of rail tracks are reduced, which reduces the cost of track maintenance.

- Cost less to purchase by 20% than a diesel engine (DfT, 2009).

Table 4.6 summarises the cost for both Diesel and electric trains.

**Table 4.62: Cost Ccomparison for Diesel and Electric Trains**
**Source:** Yahoo! Finance, 2012; Network Rail, 2009
**Note:** Monetary value were converted from GBP (exchange rate checked on 18 August 2012: $1 = £1.5694)

| Cost Description | Diesel Trains | Electric Trains |
|---|---|---|
| Maintenance cost per vehicle mile | 94.2¢ | 62.8¢ |
| Fuel cost per vehicle mile | 73.8¢ | 40.8¢ |
| Track wear and tear cost per vehicle mile | 15.4¢ | 13.3¢ |
| Lease cost per vehicle per annum | $172,629 | $141,242 |

Overall, the electrification of the rail system is an advantage for San Diego County from all the points of view analysed.

## 4.3 Regenerative Braking and Automated Rail Systems

The electrification of the rail system is a serious and expensive matter that usually involves more than local authorities to achieve an effective transformation. On the other hand, there are some strategies or technologies that can be added to existing diesel or electric trains to make them more reliable, efficient and environmentally friendly.

Regenerative braking have been expanding and becoming more and more popular in the past decade. When a train accelerate, the source of energy used by the engine (electricity in case of electric trains or fuel for Diesel engines) transforms into mechanical energy and, as the train speeds up, into kinetic energy. When the train brakes, this accumulated kinetic energy dissipates on the brake system in the form of heat. Regenerative brakes prevent this energy waste by transforming the kinetic energy in electricity that can be reused by the train when it accelerates; can be stored by batteries for different use (for example, electricity sockets for customers, lights, etc.); or can simply be transmitted into the grid (in the case of an electric train) (DfT, 2009; CVEL).

Figure 4.5 summarises the mechanism behind regenerative braking and how they can be used to maximise the efficiency of electric transportation. The figure shows the difference between acceleration and braking operations. When braking the engine, the electric motor generates a negative torque (i.e. in the opposite direction of when accelerating) and, by doing so, it acts as a generator which can recover the energy otherwise dissipated.

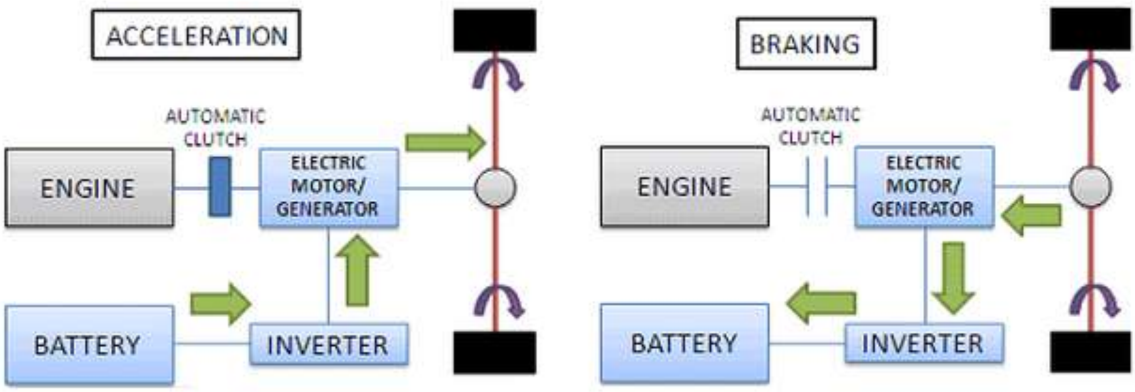


**Figure 4.15: Flow of Energy During Acceleration (Left) and Braking (Right) Operations**
**Source:** CVEL

This technology is very convenient, especially for those transportation modes that use electric engines and make several stops on their route. Therefore, this technology is suggested as a viable way of reducing carbon emission in San Diego County. It could potentially be adopted by any transit. The trolley would benefit the most from it. The reason for this is that it is already electrified and connected to the city grid. However, in the event of rail electrification, the Coaster, the Sprinter and the Pacific Surfliner would also benefit from adopting this innovative technology. Figure 4.6 shows a schematic of how the trolley could use regenerative brakes to save energy, and therefore to reduce its environmental impacts, by adopting BPS and utilizing the recovered energy to power its accelerating operations.

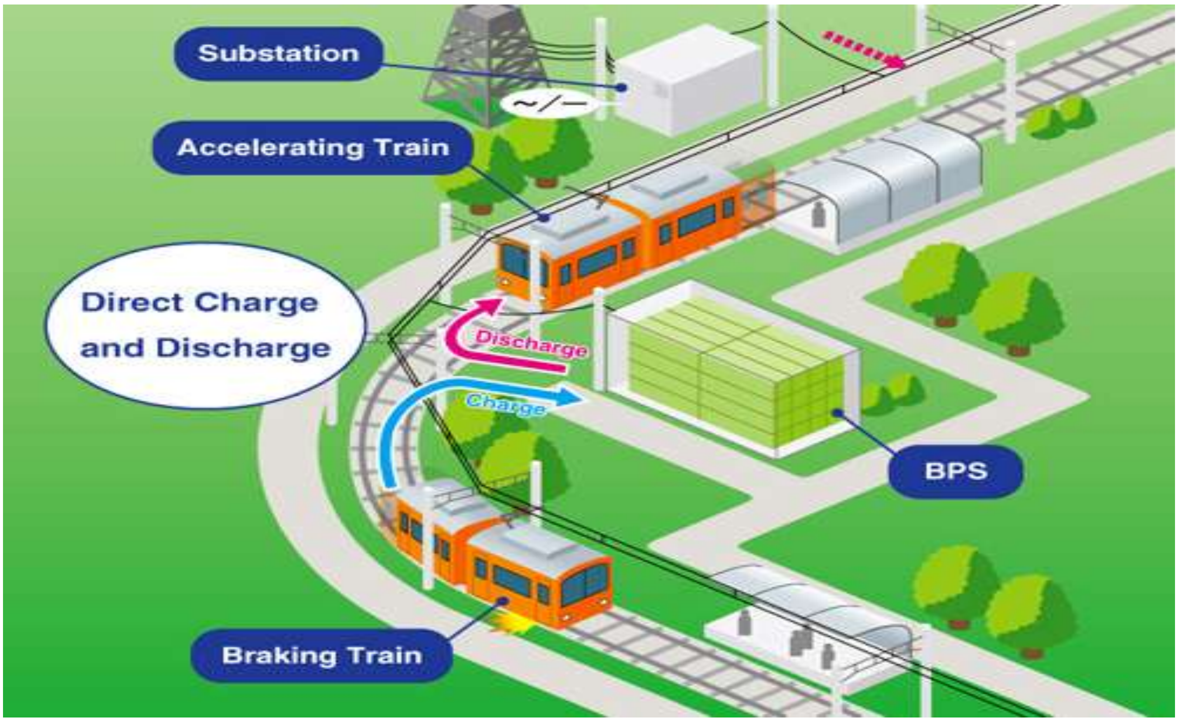


**Figure 4.16: Battery Power System (BPS) for Railways**
**Source:** Kawasaki, 2012
**Note:** The energy recovered from braking is stored in batteries which release it for the train's accelerating operations.

Buying brand new and efficient trains requires an investment of capital that a city or a county do not want to make. Nevertheless, there are other technologies that can be adopted and some can be retrofitted to existing trains. As an example, ZTR offers alternatives for locomotive modernization (ZTR Control System LLC, 2012):

- NEXSYS III-i is a locomotive control system that improves the adhesion of trains (29 to 44%) for reducing stress and extending trains' lives.
- SmartStart IIe provides fuel and emission reduction by improving trains' idling.
- Bolt on Adhesion gives 73 to 80% adhesion improvement to old locomotives.

Further studies can also be conducted on automated train system regulations in order to improve transportation efficiency and performances and reduce fuel or energy consumption and environmental impacts. Each train has a driver, and, depending on that driver, the riding pattern of the train changes. Changing the following simple operations could potentially result in saving energy and reducing impacts:

- Acceleration pattern
- Velocity variations
- Speed decision
- Idle operations
- Braking pattern

Moreover, signalling can be improved and a better human or automated interpretation and response can sometimes help, together with what just analysed, the following:

- Reduce energy consumption
- Reduce emissions
- Reduce environmental impacts
- Increase transits' efficiency
- Reduce operating costs
- Reduce wear and tear costs
- Extend transits' lives

## 4.4 Bicycling and Walking

A way of reducing carbon and other pollutant emissions is to promote cycling and walking. San Diego County has a warm weather and low amounts of rain. For this reason cycling and walking could potentially be developed further.

Currently in San Diego there are different roads or path available for cycling categorised in different classes as in Table 4.7 (SANDAG, 2010b):

**Table 4.7: San Diego current available ways for bicycles.**
**Source:** Author, data found in SANDAG, 2010b

| Class | Type | Description | Miles | % |
|---|---|---|---|---|
| 1 | Bike Path | Consist of paths completely separated from normal roads where only bicycles and/or pedestrian have access. These are considered the preferred and safest ways. | 159.3 | 11.9 |
| 2 | Bike Lane | Consist of one-way lanes for bicycles only on the side of normal roads or highways. They are usually separated by a continuous line which does not allow cars and other motorized vehicles to cross. | 890.2 | 66.4 |
| 3 | Bike Route | Consists of roads that are shared with other motorized vehicles. There are no designated bicycle lanes. These are the least desirable and most dangerous ways | 243.9 | 18.2 |
| - | Freeway Shoulders | Not considered as biking ways, but available and used by cyclists. These are very dangerous. | 47.4 | 3.5 |
| | **Total** | | **1340.8** | 100 |

According to the above classification, San Diego County needs to develop and implement bike paths to make cyclists feel safe and increase their willingness to consider cycling as a way of commuting to work. Considering that the majority of the population commutes to work by car (86%), and adding the fact that they usually drive alone (76%), convincing one driver to switch to a bicycle would mean, generally speaking, taking one car off the road.

Because of the topography of the county, it is not convenient or possible for people to ride a bike to their workplace. In this case, a possible and effective alternative would be to provide each neighborhood with bike paths or bike lanes to allow people to reach the closest public transportation station, safely store their bicycles, and continue from there by public transportation.0.

San Diego is working on the development and implementation of bicycles on the road. Nevertheless, other cities are doing much more. For instance, London saw bicycle user doubled in the decade between 2000 and 2010. Moreover, the London Cycling Revolution Plan (Tfl, 2010) has projection of a 400% increase by 2026. It should be noted that the weather in London is much worse than that in San Diego. Therefore, San Diego has, at least in theory, more potential from this point of view. One of the strategies adopted by London's authorities is develop an intense and efficient bike hiring system. Around the city centre, there are 400 hiring points (Fig. 4.7), where customers and have


**Figure 4.7: A London Docking Station for Renting a Bike**
**Source:** Barrett, 2010

different option to rent one of the 6,000 available bikes (TfL, 2010). Once the bike is rented, it can be given back at any hiring point with an available bike slot. In this way, it is very easy for user to rent a bike close to home and give it back at a point close to their workplace. The same is done for their way home. Figure 4.8 shows a map of the current available bike rental points in central London.


**Figure 4.17: Bike Docking Stations in Central London.**
**Source:** TfL, 2012b

In conclusion, San Diego has the potential to decrease the environmental impact of private vehicles by promoting cycling as a viable alternative. However, much more work is needed in order to change people habits.

# Further Discussions: Fighting a Status Symbol

The large majority of San Diego's population commutes to work by driving their private vehicles and, most of the times, they drive alone. The reason for this is the unreliability of San Diego's public transportation system, which not only runs too few routes but has a an infrequent service schedule. In fact, people do not want to wait; they want a fast and, most of all, direct service which can take them to work quickly, efficiently and without too many intermediate stops.

However, while studying, analysing and understanding the San Diego community, it became evident that sometimes the above is not just a *reason*, but an *excuse* not to use public transits. San Diego, as California and as the whole United States of America in general, relies on private transportation. Most people's mentalities do not consider public transportation as an option, regardless its effectiveness. In San Diego, people who use public transportation do so because they have to (for example, they do not own a private vehicle) or because driving is too inconvenient (for example, there are no parking options close to their work place or the parking options available are too expensive).

Many times, driving a car is a status symbol. People want to own and to use their cars and they want them big and powerful even though this is not always necessary.

I believe the San Diego County's authorities need to follow the example of many European cities (for example, London, Paris and Zurich) and a few American cities (San Francisco and Ney York City) and do what is necessary to improve the transportation system as part of addressing people's perceptions and their way of thinking. In order to achieve this, not only does public transportation need to work efficiently and be user friendly, but it needs to be a great system that the population is proud of and uses regularly. Therefore, local authorities should expand the transportation system to reach more areas of the city and provide more frequent service. Public transportation vehicles need to be all over the city so that people can constantly see them and understand that they could be a viable and efficient alternative to driving their own cars.

As described in this report, many actions can be taken and many technologies can be adopted in order to improve the efficiency of public transportation and to reduce the carbon impact that those have on the local, and to a bigger extent, the global environment. All of those described would potentially bring some improvement that all together, will create a great public transportation the population would be proud of.

# Conclusions

The San Diego public transportation system is in a state of constant development. However, the available services do not meet the population's requirement and, for this reason, the 86% of people prefer to use their own vehicles to commute to work. This impacts the road congestion in the county. Moreover, the number of privately-owned vehicles on the city's roads and highways results in more than 60 millionVehicle Miles Travelled a day. This negatively impacts the environment due to polluting exhaust emissions.

The San Diego population is predicted to increase by more than one million people in the next 40 years. Together with this increase, the number of housing and jobs will also increase. If the current trend does not change, roads will be even more congested and the impact on the environment will be dramatic.

Results of public surveys give alarming information on what people think about the public transportation system. More than 86% of those surveyed think that public transportation is inadequate, and they choose not to use it because of its unreliability.

Proposed solutions were given to improve the reliability of public transportation, including:

- An active light system was proposed to reduce the trolley delays in the downtown area.
- Local authorities are advised to follow the example other large cities, in particular London, and increase their reliability by introducing more frequent public transportation system.
- Also based on London's experience, install GPS tracking systems on public transportation vehicles that, working together with online or mobile applications, provide a more user friendly service.

Proposed solutions were also given to improve the environmental impacts of public transportation.

- Eliminating classis diesel engines and switch to CNG or clean diesel engines would result in a substantial reduction in the emissions levels of carbons and other pollutions, which are hazardous to both the environment and the population's health.
- Local rail service, such as the Coaster, Sprinter and Pacific Surfliner systems, should be converted to electric power to reduce carbon emission by 20 – 35%; improve their reliability by about 29 to 57%; and reduce operating costs by 35%.
- Electrified trains should have regenerative brakes and other automated systems installed as energy saving methods.

- Bicycle commuting should be encouraged by developing safer bike paths, bike rental sites and linking the bicycle path network to the public transportation network in order to take people off the roads of San Diego.

In conclusion, the population of San Diego is believed to prefer privately-owned vehicles more as a status symbol rather than as a real necessity. Authorities need to expand and improve the public transportation system as much as possible in order to change people's opinions about public transportation and make them proud public transportation users.

# References


1. 3D Trains 2012, *Pacific Surfliner Trainset*, Accessed on 30 July 2012, <http://www.3dtrains.com/products/trainsets/amtrak_surfliner_screens.shtml>.

2. Amtrak 2012a, *Pacific Surfliner*, Accessed on 30 July 2012, <http://www.amtrak.com/pacific-surfliner-train>.

3. Amtrak 2012b, *Pacific Surfliner Schedule: San Luis Obispo, Los Angeles, San Diego*, Leaflet from Amtrak, Effective 7 May 2012.

4. Apple Inc. UK 2012, *iTunes Preview – App Store > Navigation*, Accessed on 15 August 2012, <http://itunes.apple.com/gb/genre/ios-navigation/id6010?mt=8&letter=L&page=3#page>.

5. Beer, T., Grant, T., Morgan, G., Lapszewicz, J., Anyon, P., Edwards, J., Nelson, P., Watson, H., & Williams, D. 2001. *Study of Life-cycle Emissions Analysis of Alternative Fuels for Heavy Vehicle, Stage 2.* Final Report EV45A/2/F3C. Aspendale, Australia: CSIRO, Australian Greenhouse Office.

6. Beer, T., Grant, T., Brown, R., Edwards, J., Nelson, P., Watson, H. & Williams, D. 2000, *Life-Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles*, Report C/0411/1.1/F2 to the Australian Greenhouse Office, CSIRO Atmosphere Research, March 2000, Table 1.5, p.9

7. California Environmental Protection Agency 2011, *Air Quality and Emissions*, Air Resources Board, Accessed on 06 August 2012, <http://www.arb.ca.gov/html/ds.htm>.

8. Carrasco, N. 2011, *Quantifying Public Transport Reliability in Zurich*, 11th Swiss Transport Research Conference (Ascona, May 11–13, 2011).

9. CVEL (the Clemson University Vehicular Electronics Laboratory), *Regenerative Braking*, Accessed on 19 August 2012, <http://www.cvel.clemson.edu/auto/systems/regenerative_braking.html>.

10. DEER (Directions in Engine-Efficiency and Emissions Research) 2003, *Comparison of Clean Diesel Buses to CNG Buses*, New York City Transit Department of Buses, from August 26, 2003 DEER Conference, Newport, RI.

11. Dept. of Planning and Land Use 2009, *Appendix K: Greenhouse Gas Emission Inventory*, County of San Diego, Land Use and Environmental Group.

12. DfT (Department for Transport) 2009, *Britain's Transport Infrastructure – Rail Electrification*, London.

13. DfT (Department for Transport) 2007, *T633: Study on Further Electrification on the UK Railway*, Atkins Report.

14. Duncan, M. 2011, *The Impact of Transit-oriented Development on Housing Prices in San Diego, CA*, Urban Studies Journal Limited, Vol. 48 (1), 101–127.

15. Dunphy, R. T. 2005, *Developing Around Transit*, Urban Land Institute.

16. Equinox Centre 2011a, *American Community Survey, 2010*, Table C08301.

17. Equinox Centre 2011b, California Department of Transportation, 2011, Department of finance, 2011.

18. Barrett, F. 2010, *All Hail London's Bike-Hire Revolution. Now Let's See More Two-Wheeled Schemes...*, Online article available on Mail Online, Accessed on 17 August 2012, <http://travelblog.dailymail.co.uk/2010/09/all-hail-londons-bike-hire-revolution-now-lets-see-more-two-wheeled-schemes.html>.

19. Hesterberg, T., Bunn, W. & Lapin, C. 2009, *An Evaluation of Criteria for Selecting Vehicles Fueled with Diesel or Compressed Natural Gas*, Sustainability: Science, Practice, & Policy, Spring/Summer 2009, Volume 5 (1).

20. Human Transit 2010, *On Bus Lanes Britain Can Learn from Los Angeles*, Accessed on 15 August 2012, <http://www.humantransit.org/2010/10/london-uk-conservatives-attack-m4-bus-lane.html>.

21. Kawasaki Heavy Industries Ltd. 2012, *Battery Power System (BPS) for Railways*, Accessed on 19 August 2012, <http://www.khi.co.jp/english/gigacell/use/bps.html>.

22. Li, M., Wu, G., Johnston, S. & Zhang, W.B. 2009, *Analysis toward Mitigation of Congestion and Conflicts at Light Rail Grade Crossing and Intersections*, California PATH, University of California, Berkeley and California Department of Transportation in collaboration with SANDAG, San Diego Trolley, Inc. (SDTI), City of San Diego.

23. Metro Cincinnati 2010, *Transit 101: Heavy Rail and Light Rail*, Accessed on 24 July 2012, <http://metro-cincinnati.info/?p=1566>.

24. MTS (Metropolitan Transit System) 2012a, *General Information*, Accessed on 24 July 2012, <http://www.sdmts.com/MTS/About_MTS.asp>.

25. MTS (Metropolitan Transit System) 2012b, *MTS Orders New and Sleek Buses*, Accessed on 24 July 2012, <http://www.sdmts.com/marketing/NABIbuses.asp>.

26. MTS (Metropolitan Transit System) 2011a, *MTS Bus Operations*, San Diego.

27. MTS (Metropolitan Transit System) 2011b, *San Diego Trolley, Inc.*, San Diego.

28. MTS (Metropolitan Transit System) 2011c, *San Diego County, Regional Travel Map, Effective March 2011*, San Diego.

29. MTS (Metropolitan Transit System) 2007, *San Diego trolley Light Rail Vehicles*, San Diego.

30. NCTD (North County Transit District) 2012a, *BREEZE Bus Routes*, Accessed on 30 July 2012, <http://www.gonctd.com/breeze>.

31. NCTD (North County Transit District) 2012b, *BREEZE and FLEX Fact Sheet*.

32. NCTD (North County Transit district) 2012c, *COASTER; Costal Rail: Oceanside – San Diego*, Accessed on 30 July 2012, <http://www.gonctd.com/coaster>.

33. NCTD (North County Transit District) 2012d, *SPRINTER Fact Sheet*.

34. NCTD (North County Transit District) 2012e, *SPRINTER; Inland Rail: Oceanside – Escondido*, Accessed on 18 August 2012, <http://www.gonctd.com/sprinter>.

35. NCTD (North County Transit District) 2009, *COASTER Fact Sheet*, Oceanside.

36. NCTD (North County Transit District) 2008, *North County Transit District (NCTD)*, Accessed on 30 July 2012, <http://www.thebergennetwork.com/na/ca/nctd/index.php>.

37. NCTD (North County Transit District) 2007, *BREEZE Fact Sheet*, Oceanside.

38. Network Rail 2009, *Network RUS – Electrification*, London.

39. Nylund, N., Erkkilä, K., Lappi, M., & Ikonen, M. 2004. *Transit Bus Emission Study: Comparison of Emissions from Diesel and Natural Gas Buses*, Finland, VTT Processes.

40. Pollution Green Cities 2011, *Pollution "Glue" and Congestion Pricing in London*, Accessed on 15 August 2012, <http://pollutionfree.wordpress.com/2012/02/22/pollution-glue-and-congestion-pricing-in-london/>.

41. SANDAG 2011, *2050 Regional Transportation Plan – Our region, Our Future*, San Diego.

42. SANDAG 2010a, *2050 Regional Growth Forecast*, Agenda Item No. 10-02-16, File No. 3100900, Board of Directors.

43. SANDAG 2010b, *San Diego Regional Bicycle Plan – Riding to 2050*, San Diego.

44. SANDAG 2008, *San Diego Region – Public Transit Opinion Study*, Encinitas, True North Research.

45. SANDAG 2007, *2030 San Diego Regional Transportation Plan – Pathways for the Future*, San Diego.

46. SANDAG 2004, *Regional Comprehensive Plan for the San Diego Region*, San Diego.

47. Schrank, D. and Lomax, T. 2009, *2009 Urban Mobility Report*, Texas Transportation Institute, The Texas A&M University System.

48. Silva, C., Goncalves, G., Farias, T., & Mendes-Lopes, J. 2006, *A tank-to-wheel analysis tool for energy and emissions studies in road vehicles. Science of the Total Environment,* 367(1), 441–447.

49. TEC (Total Environment Centre Inc.) 2005, *Diesel vs. Compressed Natural Gas (CNG) in the Sydney Bus Fleet*, Sydney.

50. TfL (Transport for London) 2012a, *Timetable of Bus 159 towards Paddington Basin (W2)*, Accessed on 15 August 2012, <http://www.tfl.gov.uk/>.

51. TfL (Transport for London) 2012b, *Barclays Cycle Hire – Map*, Accessed on 20 August 2012, <https://web.barclayscyclehire.tfl.gov.uk/maps>.

52. TfL (Transport for London) 2010, *Cycling Revolution London*, Lodnon.

53. The London Bus Blog 2011, *New Countdown Clocks at Bus Stops*, Accessed on 15 August 2012, <http://thelondonbusblog1.blogspot.com/2011_10_01_archive.html>.

54. Wargo, J., Wargo, L. & Alderman, N. 2006, *The Harmful Effects of Vehicle Exhaust – A Case for Policy Change*, EHHI (Environment & Human Health, Inc.).

55. Yahoo! Finance 2012, *Currency Centre*, Currency Conversion as $1 = £1.5694, Accessed on 18 August 2012, <http://finance.yahoo.com/currency-converter/#from=GBP;to=USD;amt=1>

56. ZTR Control System LLC 2012, *Locomotive Modernization*, Accessed on 19 August 2012, <http://www.ztr.com/railway-solutions.php>.

# Appendix

**Table A 1: Actual Data (2008) and Future Projections (2020, 2030, 2035, 2050) of the San Diego County Population, Jobs and Housing**
**Source:** Author, data found in SANDAG, 2010a

| Year | Population | Jobs | Housing |
|---|---|---|---|
| **2008** | 3,131,552 | 1,501,080 | 1,140,654 |
| **2020** | 3,535,000 | 1,604,615 | 1,262,488 |
| **2030** | 3,870,001 | 1,752,630 | 1,369,797 |
| **2035** | 4,026,131 | 1,798,372 | 1,417,520 |
| **2050** | 4,384,867 | 2,003,038 | 1,529,090 |

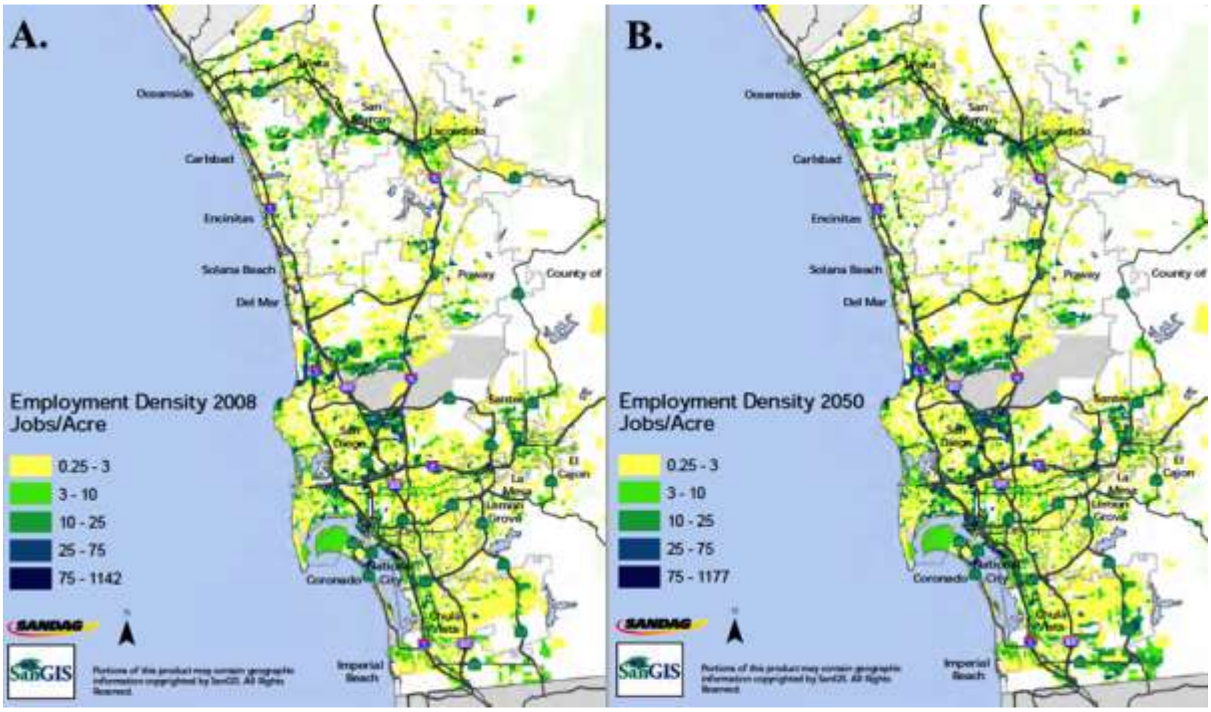


**Figure A 1: San Diego County Employment Density Maps..**
**Source:** Modified from SANDAG, 2010a
Notes: Figure A shows the job distribution measured in 2008 in the considered area; Figure B shows the projections for year 2050.

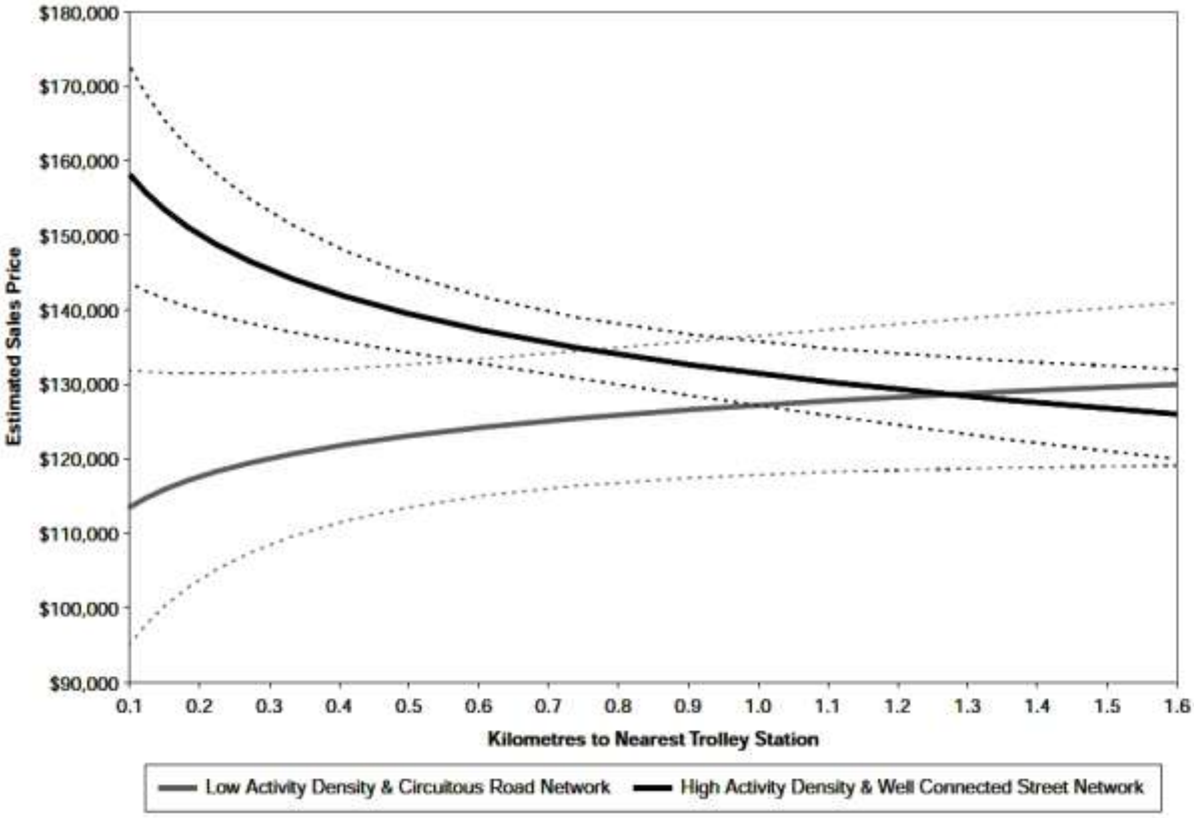


**Figure A 2: Estimated Sale Price of Housing Based on the Distance from a Hypothetical Trolley Station**
**Source:** Duncan, 2011

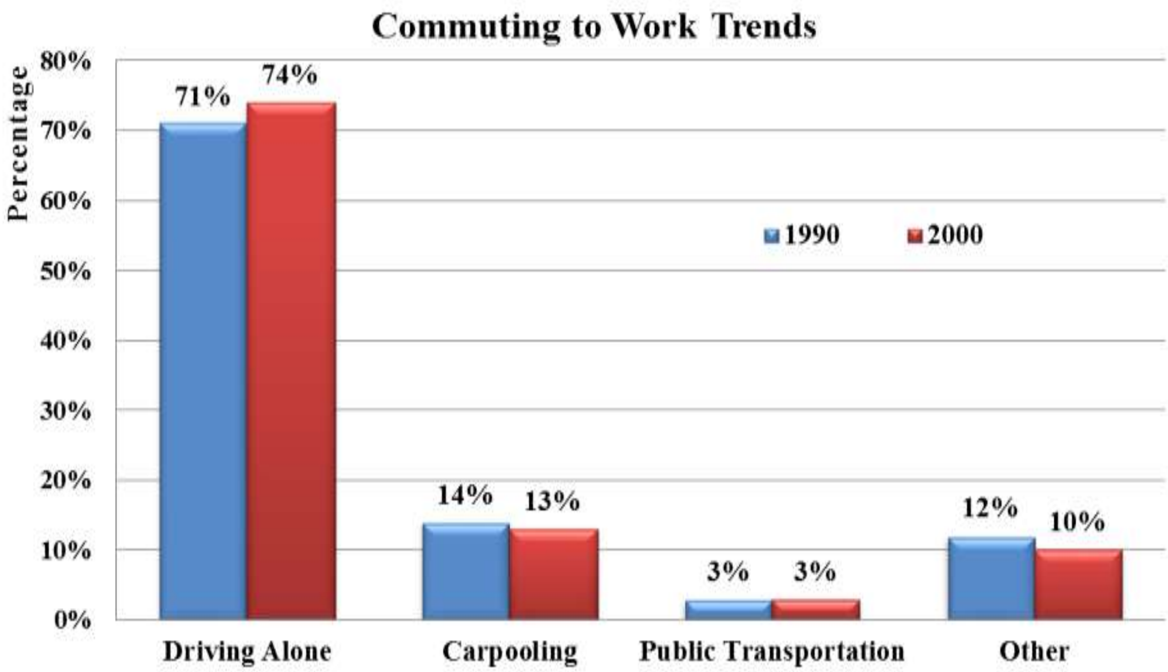


**Figure A 3: Ways of Commuting to Work in San Diego County**
**Source:** Author, with data found in SANDAG, 2004

**Table A 2: 2000 Transit Ridership in Millions for San Diego and Five Major US Cities**
**Source:** Author, with data read graphically from Dunphy, 2005

| City | New York City | Chicago | San Francisco | Los Angeles | Washington | San Diego |
|---|---|---|---|---|---|---|
| **Ridership ($x10^6$)** | 508 | 480 | 440 | 430 | 390 | 75 |

**Table A 3: Daily Vehicle Mile Travelled in the San Diego County – 1983 to 2007.**
**Source:** Author, with data read graphically from Schrank and Lomax 2009

| Year | VMT ($x10^6$) |
|---|---|
| **1983** | 29 |
| **1985** | 33 |
| **1987** | 39 |
| **1989** | 45 |
| **1991** | 45 |
| **1993** | 46 |
| **1995** | 48 |
| **1997** | 49 |
| **1999** | 51 |
| **2001** | 56 |
| **2003** | 57 |
| **2005** | 62 |
| **2007** | 61 |

**Table A 4: Daily VMT Per Capita in Four California Metropolitian Areas and Average Values for California – 2009 and 2010.**
**Source:** Author, with data read graphically from Equinox, 2011b

| | VMT | |
|---|---|---|
| | **2009** | **2010** |
| **San Francisco** | 4.3 | 4.5 |
| **Los Angeles** | 10.2 | 10.5 |
| **Orange County** | 12.2 | 12.2 |
| **San Diego** | 13.5 | 14.5 |
| **CALIFORNIA** | 12.7 | 13 |

**Table A 5: Comparison of Perceptions of Mode Performance.**
**Source:** Author, with data found in SANDAG, 2008

| Question | Personal Vehicle | Bus | Trolley | Coaster |
|---|---|---|---|---|
| Arrive on time | 81.8 | 57.6 | 69.6 | 73.9 |
| Feel safe | 85.6 | 59.9 | 64.1 | 76.6 |
| Able to make unplanned stops | 86.6 | 38.1 | 40.0 | 31.2 |
| Time will be reasonable | 77.2 | 45.2 | 61.9 | 67.0 |
| It will be expensive | 73.2 | 38.4 | 39.0 | 44.2 |
| It will be clean and comfortable | 86.1 | 56.9 | 65.5 | 75.7 |
| Link several destinations | 91.4 | 42.4 | 44.1 | 34.8 |
| Avoid traffic congestion | 52.7 | 53.8 | 80.0 | 81.9 |
| Get where you need to go | 94.0 | 59.6 | 60.2 | 59.2 |
| Encounter disturbing people or behaviours | 21.1 | 53.3 | 52.0 | 39.2 |
| Available when you need it | 93.1 | 50.1 | 62.1 | 54.7 |
| Feel stressed | 42.1 | 45.4 | 37.8 | 29.4 |

**Table A 6: Comparison of Bus emissions from Engines Powered by Euro3 Diesel and Early CNG Fuel**
**Source:** Author, data found in Beer *et al.*, 2000

| | Emissions (g/km) | | |
|---|---|---|---|
| **Engine** | CO | $NO_X$ | PM |
| *Euro3* Diesel | 7.15 | 17.01 | 0.34 |
| Early CNG | 5.33 | 12.17 | 0.02 |
| **Reduction** | 25.45% | 28.45% | 98.12% |

**Table A 7: Typical $CO_2$ Emissions Per Mile from Passenger Trains Powered by Diesel and Electric Engines**
**Source:** Author, with data found in Atkins, 2007

| | Electric | Diesel |
|---|---|---|
| **$CO_2$ per vehicle mile (g)** | 1,664 | 2,100 |

**Table A 8: Comparison of Different Transport modes $CO_2$ emissions for Travel from San Diego to Santa Barbara, CA**
**Source:** Author, with data read graphically from DfT, 2009

| Mode | Emission - San Diego to Santa Barbara (grams of CO2 per passenger kilometre) |
|---|---|
| Plane | 255 |
| Car | 130 |
| Bus | 108 |
| Diesel Train 1 (Meridian) | 95 |
| Diesel Train 2 (HST) | 65 |
| Electric Train (Pendolino) | 52 |

**Table A 9: Reliability of Diesel and Electric Intercity and Commuter Regional Trains – Average Distance (Miles) Between Failures.**
**Source:** DfT, 2009
**Note:** Failures are considered only when they cause delays of 5 minutes or more.

| | Distance (miles) | | Improvement (%) |
|---|---|---|---|
| **Train type** | Diesel | Electric | |
| Intercity | 11,800 | 16,571 | 28.8 |
| Regional | 12,880 | 30,209 | 57.4 |