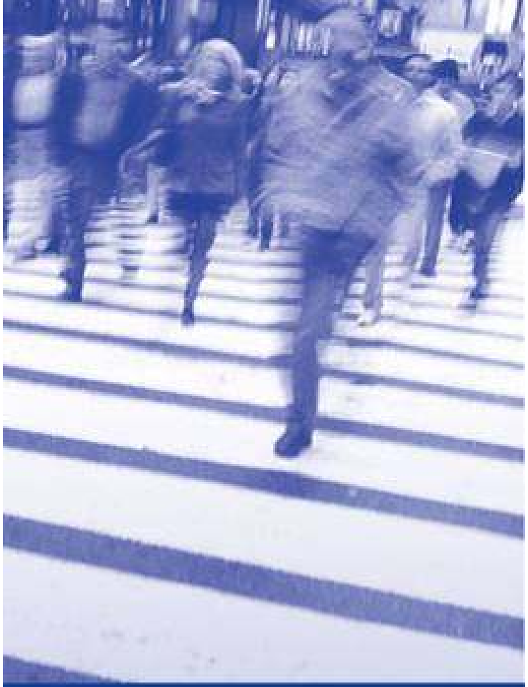

CIVITAS
Cleaner and better transport in cities

ARCHIMEDES
AALBORG • BRIGHTON & HOVE • DONOSTIA - SAN SEBASTIÁN • IAŞI • MONZA • ÚSTÍ NAD LABEM

Donostia – San Sebastian

R4.1 – Study of alternative fuel options in Donostia –San Sebastian

Donostia – San Sebastian

September 2011

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Author	Eduardo González
Quality Control	Alan Lewis
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1. Introduction

1.1 Background CIVITAS

CIVITAS - cleaner and better transport in cities - stands for CIty-VITAlity-Sustainability. With the CIVITAS Initiative, the EC aims to generate a decisive breakthrough by supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies that should make a real difference for the welfare of the European citizen.

CIVITAS I started in early 2002 (within the 5th Framework Research Programme);
CIVITAS II started in early 2005 (within the 6th Framework Research Programme) and
CIVITAS PLUS started in late 2008 (within the 7th Framework Research Programme).

The objective of CIVITAS-Plus is to test and increase the understanding of the frameworks, processes and packaging required to successfully introduce bold, integrated and innovative strategies for clean and sustainable urban transport that address concerns related to energy-efficiency, transport policy and road safety, alternative fuels and the environment.

Within CIVITAS I (2002-2006) there are 19 cities clustered in 4 demonstration projects, within CIVITAS II (2005-2009) 17 cities in 4 demonstration projects, whilst within CIVITAS PLUS (2008-2012) 25 cities in 5 demonstration projects are taking part. These demonstration cities all over Europe will be funded by the European Commission.

Objectives:

- to promote and implement sustainable, clean and (energy) efficient urban transport measures
- to implement integrated packages of technology and policy measures in the field of energy and transport in 8 categories of measures
- to build up critical mass and markets for innovation

Horizontal projects support the CIVITAS demonstration projects & cities by :

- Cross-site evaluation and Europe wide dissemination in co-operation with the demonstration projects
- The organisation of the annual meeting of CIVITAS Forum members
- Providing the Secretariat for the Political Advisory Committee (PAC)
- Development of policy recommendations for a long-term multiplier effect of CIVITAS

Key elements of CIVITAS

- CIVITAS is co-ordinated by cities: it is a programme “of cities for cities”
- Cities are in the heart of local public private partnerships
- Political commitment is a basic requirement
- Cities are living ‘Laboratories' for learning and evaluating

1.2 Background ARCHIMEDES

ARCHIMEDES is an integrating project, bringing together 6 European cities to address problems and opportunities for creating environmentally sustainable, safe and energy efficient transport systems in medium sized urban areas.

The objective of ARCHIMEDES is to introduce innovative, integrated and ambitious strategies for clean, energy-efficient, sustainable urban transport to achieve significant impacts in the policy fields of energy, transport, and environmental sustainability. An ambitious blend of policy tools and measures will increase energy-efficiency in transport, provide safer and more convenient travel for all, using a higher share of clean engine technology and fuels, resulting in an enhanced urban environment (including reduced noise and air pollution). Visible and measurable impacts will result from significantly sized measures in specific innovation areas. Demonstrations of innovative transport technologies, policy measures and partnership working, combined with targeted research, will verify the best frameworks, processes and packaging required to successfully transfer the strategies to other cities.

1.3 Participant Cities

The ARCHIMEDES project focuses on activities in specific innovation areas of each city, known as the CIVITAS corridor or zone (depending on shape and geography). These innovation areas extend to the peri-urban fringe and the administrative boundaries of regional authorities and neighbouring administrations.

The two Learning cities, to which experience and best-practice will be transferred are Monza (Italy) and Ustí nad Labem (Czech Republic). The strategy for the project is to ensure that the tools and measures developed have the widest application throughout Europe, tested via the Learning Cities' activities and interaction with the Lead City partners.

1.3.1 Leading City Innovation Areas

The four Leading cities proposed in the ARCHIMEDES project are:

- Aalborg (Denmark);
- Brighton & Hove (UK);
- Donostia-San Sebastian (Spain); and
- Iasi (Romania).

Together the Lead Cities in ARCHIMEDES cover different geographic parts of Europe. They have the full support of the relevant political representatives for the project, and are well able to implement the innovative range of demonstration activities proposed.

The Lead Cities are joined in their local projects by a small number of key partners that show a high level of commitment to the project objectives of energy-efficient urban transportation. In all cases the public transport company features as a partner in the proposed project.

2. Donostia – San Sebastian

The city of Donostia -San Sebastian overlooks the sea and, with a bit more than 180,000 inhabitants, keeps a human scale. Some people consider the balanced combination of small mountains, manor buildings, and sea as the setting for one of the most beautiful cities in the world. We have a tradition in favouring pedestrians, cyclists and public transport.

For about twenty years, the city has been enforcing a strong integrated policy in favour of pedestrians, bicycles and public transport. Considering walking and cycling as modes of transport, has led to the building of a non-motorised transport network for promoting this type of mobility around the city.

Likewise, the city has extended its network of bus lanes. The city holds one of the higher bus-riding rates, with around 150 trips per person per year.

2.1 Objectives in CIVITAS

The CIVITAS project is a perfect opportunity to expand our Sustainable Urban Transport Strategy. With the package of CIVITAS measures Donostia-San Sebastian wants to:

- Increase the number of public transport users
- Decrease the number of cars entering in the city centre
- Increase the use of the bicycle as a normal mode of transport
- Maintain the high modal share of walking
- Reduce the number of fatal accidents and accidents with heavy injuries
- Reduce the use of fossil fuels in public transport.

3. Background to the Deliverable

The present deliverable refers to Measure number 4, Biofuels and Clean Vehicles in Donostia – San Sebastián.

As part of this measure CTSS has been working on the Task 1.5 Public Transport Biofuels and Clean Vehicles.

The results of this research deliverable are very important to get the key for the biofuels and engine technologies policy (present and future) in the Municipal Bus Company.

3.1 Summary Description of the Task

CTSS has subcontracted a comparative study into different alternative fuels (bio-ethanol, hydrogen, hybrids and second generation biodiesel). The study supports the bio-fuel demonstrator in Donostia - San Sebastián as well as the future introduction of other alternative fuel types and propulsion technologies. The study has been completed by Month 12. (Milestone 11.1.3)

4. Study of alternative fuel options

4.1 Description of the Work Done

The study consists in a very complete analyse of the present and future fuel options alternatives for transportation in combination with the new traction technologies. The final balance and conclusions given are specially oriented for application in the Municipal Bus Company of San Sebastian, with its own present fleet characteristics, facilities location, and proximity of fuel suppliers.

The extrapolation of these conclusions for other fleets (buses, trucks, cars…) would need a new particular study.

Anyway the study will give to the reader a deep vision of the "Alternative fuel options" subject, starting from the environmental present situation and policies description passing through the general description of the alternative fuels and technologies and later particularizing for its application at the Municipal Bus Company of San Sebastián.

4.2 Summary of the Study

This summary of the study presents the analysis of the current "Alternative fuel options" from the point of view of the Municipal Bus Company of San Sebastián (CTSS).

The main technical points of the study are covered in sections 4.2.2 – 4.2.6. Using this information CTSS have carried out a multicriteria analysis, the results of which are contains in section 4.2.7 and 4.2.8. The categories considered are contained within the tables presented in these sections. The scoring system was developed in house by CTSS. It's a comparative scoring system where some of the factors are subjective and others more objective. As such it is suited to the needs of CTSS, but should not be taken as an overall guideline; i.e. the priorities / objectives of other bus companies or municipalities may differ, leading to different weightings and outcomes.

4.2.1 Introduction

The methodology used to develop this project consists on the following phases:

- The beginning of the study was based on the information compiled form within the company and on its own knowledge.
- The next step was the consultation with public and private research institutions and companies as well as fuel suppliers, vehicle manufacturers and urban transport companies.
- Finally, the information is summarized, written and organized to give form to this project.

The information presented in this deliverable is a summary of the full study report which is available at: http://www.dbus.es/descargas/estudios-e-informes/5-biofuels-and-new-technologies-for-dbus.pdf

4.2.2. Criteria for the Selection of More Energetically Efficient Fuels

One of the principal aims is the evaluation of different propulsion systems for road vehicles applicable to urban transport, with special attention to their energetic efficiency.

Public transport in Europe, both urban and inter-city, has been based for several decades on the utilization of diesel engines as the propulsion system, and therefore this is taken as the point of reference for the comparative analyses.

From the beginning of the 1990s, one of the other big factors for the selection of propellants in the urban transport has been pollutant emissions, specifically oxides of nitrogen (NOx), unburnt hydrocarbons (HC), carbon monoxide (CO), and the solid particles in suspension (PM). This problem for the local environment, as well as the need to diversify energy sources, has led in recent years to the utilization of other alternative systems of propulsion such as liquefied petroleum gas (LPG), compressed natural gas (CNG), and the almost nominal application of electrical buses, and some application of hydrogen and fuel cells.

From the beginning of the year 2000, attention has also turned to the effect of global warming of the planet, provoked by the greenhouse gases (Protocol of Kioto and successive). Considering that one of the principal gases causing the above-mentioned effect is CO_2, coming from the normal combustion of the fuels, the principal management consists of improving the energetic efficiency of these, because with the reduction of consumption comes an equivalent reduction of CO_2. The chemical composition of each fuel determines the quantity of carbon atoms that the fuel has, which is also linked to the index of emission of CO_2 from combustion.

Obviously, and considering that the global warming is as the name suggests a global effect, the analyses of energetic efficiency will appear worldwide, and not only at the point of utilization of the vehicle. The analysis is often known as "well to wheels", and takes into consideration all the processes where losses of energy take place. This analysis is especially important for the comparison of liquid fuels (for which the principal transformation takes place on board the vehicle), with others such as electricity (where the principal losses of efficiency take place during the process of generation and transport and the performance on board of the vehicle is much better).

In the analysis traditional liquid fuels (diesel and petrol as reference), liquid fuels processed from vegetable derivatives (biodiesel and ethanol), gaseous fuels (LPG and natural gas), as well as the application of electricity and hydrogen as an energy source have been contemplated.

4.2.3 Analysis "Well to Tank"

WELL TO TANK							
Type of fuel	Extraction (%)	Process (%)	Transport (%)	Conversion (%)	Distribution (%)	Charge (%)	Global (%)
Diesel	96,8	90,2	98,4	--	99,6	99,7	85,3
Gasoline	96,8	92,3	98,4	--	99,6	99,7	87,3
Natural Gas	96,8	97,6	97,3	--	99,2	95,0	86,6
LPG	96,8	93,5	97,8	--	99,4	98,5	86,7
Biodiesel	»	»	»	»	99,6	99,7	70,0
Ethanol	»	»	»	»	99,6	99,7	70,0
Hydrogen	--	--	--	60,0	99,0	92,0	54,6
Electricity							
* from Gas Natural C.C.	96,8	97,6	97,3	56,0	92,0	98,0	46,4
* from Carbon	99,4	90,0	97,5	33,4	92,0	98,0	26,3
* from Fuel Oil	96,8	90,2	98,4	32,5	92,0	98,0	25,2
* Nuclear	99,4	97,6	97,5	30,0	92,0	98,0	25,6
* Hydroelectric	--	--	--	85,0	92,0	98,0	76,6
* Wind	--	--	--	80,0	92,0	98,0	72,1

Source: Study on behalf of TMB, Barcelona (Municipal transport company)

Table 1: Well to Tank Analysis Chart

Liquid Fuels

We consider in this paragraph the reference fuels (being those of more universal application in road transport), diesel and petrol. (The latter is not applied in heavy transport, but serves as value of reference to other fuels that must be used in Otto cycle engines.)

The traditional liquid fuels are obtained from crude oil and therefore have to pass through the processes of extraction of the well, transport (petroleum ships or pipelines), refining, distribution to the service stations and loading to the vehicle's tank. They are not renewable fuels and are subject to depletion of their reserves.

As can be seen in the preceding table, the energy that is consumed in all these processes is relatively low in relation to the potential energy of the fuel, and therefore the efficiency of the set of processes from the well to the tank is relatively high, in the order of 85-87 %.

- The level of emission of CO_2 is of 0.70 kg/kWh

Gaseous Fuels

Gases that are usually associated with crude oil, in joint or exclusive deposits, or (in the case of LPG), obtained during the process of distillation at an oil refinery are considered in this section. They are not renewable fuels

As for liquid fuels, values of well to the tank energetic efficiency are quite high, similar at around 85-86 %. It is worth highlighting that the natural gas has a major efficiency in process terms because it does not need to be refined, but on the other hand it needs major consumption of energy during the process of loading into the vehicle, because it has to be compressed to 200 bar to store it within a manageable volume.

- The level of emission of CO_2 is 0.44 kg/kWh for natural gas, for having a molecule with the minimal possible proportion of carbon,
- The level of emission of CO_2 is 0.70 kg/kWh for the LPG

Vegetable-Derived Liquid Fuels

These fuels are obtained by a process of chemical transformation of certain derivatives of agricultural products, isolated from the food chain.

Biodiesel is obtained by a process of transesterification of oils of diverse vegetable seeds (principally rape, soybean, sunflower or palm), whereas ethanol is an alcohol derived from products such as the corn or the sugar cane.

The energetic efficiency of the cultures and processes of transformation is very variable, depending on the type of cultivable land, on the level of artificial manure and so on. As a conventional norm, an efficiency of 70% is attributed to the "well to tank" processes of these fuels.

The emissions of CO_2 from the use of “Vegetable-Derived Liquid Fuels” in conventional engines is similar to the conventional liquid fuels, but it is considered that the plants necessary to produce these fuels absorb 80 % of this emissions, so that the "well to tank" index would be 0.14 kg/kWh

Hydrogen

Hydrogen is a fuel which has as a principal characteristic that it not found in nature, and therefore has to be produced by chemical means. It can be considered to be therefore an energy carrier, capable of being stored on board a vehicle to produce electricity "in situ".

The principal ways to obtain hydrogen are to break water molecules by means of electrical current (hydrolysis), or by decomposition of hydrocarbons that contain hydrogen in their molecules (natural gas or methanol are most commonly used).

These processes, which involve the decomposition of stable molecules, require a high consumption of energy, so the "well to tank" stage for hydrogen has a low efficiency, in the order of 50-60 %. If we add that the process of loading into the vehicle, because it has to be compressed the vehicle is also a great consumer of energy, on having to be stored in cylinders to 350 bar, the overall process has an efficiency of 52-55 %.

Another consideration is the CO_2 emitted during this production process of Hydrogen.

Electricity

Electricity is the cleanest energy carrier in its utilization, because its index of emission in the vehicle is 0, so for the local emissions, as for CO_2. Its principal problem is the storage on board the vehicle, because it needs the use of batteries (which can be in a variety of diverse technologies from the traditional lead batteries to the newest lithium – ion types) or ultracondensers, but in any case it has high weight and low range.

Nowadays, given the available battery technologies, it is not possible to consider use of electricity in buses of any more than 7 metres in length and approximately 25-30 passengers, because for buses of bigger capacity, the large battery volume necessary makes the application unviable. Linked to this, the great problem for electricity is the range. The available buses have a range between recharge of approximately 80 km working, whereas a typical urban bus covers approximately 200 km per day.

Another important factor to consider for electricity as an energy carrier is the efficiency in the process of production and transport of the electricity. In the Table 1 we can see the efficiencies of the different methods of electricity production, for which the output efficiencies vary from the 25 % of nuclear power stations and of fuel oil, to 77 % for the hydroelectric plants. For the mix of electric power production in Spain in 2007, the average efficiency for the Spanish electricity grid was 32,9 %.

The emission factor of CO_2 is therefore variable depending on the origin of the electricity, being between the emission 0 of the hydroelectric or nuclear plants, up to the 1,45 kg/kWh for the coal plants.

- the average for the Spanish electricity mix is 0.50 kg/kWh.

4.2.4 Analysis “Tank to Wheel”

TANK TO WHEEL (urban cycle)

Type of fuel	Motor (%)	Automatic change (%)	Transm. (%)	Global (%)
Diesel	26,0	85,0	97,0	**21,4**
Gasoline (injection)	17,0	85,0	97,0	**14,0**
Natural Gas Stoichiometric	18,0	85,0	97,0	**14,8**
Natural Gas Lean Burn	20,0	85,0	97,0	**16,5**
LPG	18,0	85,0	97,0	**14,8**
Biodiesel	24,0	85,0	97,0	**19,8**
Ethanol	16,0	85,0	97,0	**13,2**
Hydrogen (combustion)	18,0	85,0	97,0	**14,8**
Electric	80,0	--	97,0	**77,6**

Source: Study on behalf of TMB, Barcelona (Municipal transport company)

Table 2: “Tank to Wheel” Analysis Chart.

This analysis is the traditional one for energetic efficiency of a vehicle, because it considers the real energy used in moving the wheels, in comparison with the potential energy of the fuel consumed, without reference to which type of fuel is stored on board.

The table above shows data for vehicles that use only one type of energy, leaving for a joint analysis those vehicles that incorporate on board the utilization of two or more types of energy (for example diesel - electric hybrid), or those that use any type of mechanism for recovery of the energy released on braking.

Even for these individual vehicle types the results are highly variable, depending on the technologies or components used by the manufacturer, so the values of efficiency that are given are averages commonly accepted on the market.

Vehicles Using Liquid Fuels

The most common reference point is the bus, of 12 metres in length and up to 19 tonnes Gross Vehicle Weight (GVW) equipped with diesel engine, and with automatic gear change (of universal use in urban transport).

Modern diesel engines of Euro III technology and higher, equipped with turbocharger and intercooler, have efficiency levels between 36 and 41 % in the full power range. Nevertheless, in a "heavy" urban cycle, as is common in the big cities of dense traffic (Barcelona, Madrid, Valencia, etc.), with commercial speeds of approximately 12 km/h., the efficiency falls to very low levels, because of the continuous need to stop and start both to pick and drop of passengers and due to traffic conditions. The sudden starts / stops force the engine to work at transitory rate of acceleration and to very partial loads. The average output of the engine for this application it is about 26 %, which, combined with the typical output of an automatic gearbox (85 %), and the transmission of the vehicle, takes us to a reference efficiency of 21.4 %.

Petrol engines, which work with a Otto type combustion cycle (or spark ignition), have a much lower thermodynamic output level, maximums up to 29 %, and on average in a heavy urban cycle about 17-18 %. Combined with the rest of transmission system of the vehicle this leads to overall vehicle outputs of about 14 %.

Vehicles Using Gaseous Fuels

Vehicles that use only gaseous fuels (LPG, natural gas or biogas), have to burn it in an Otto cycle engine, because the properties of gaseous fuels do not allow use in diesel engines.

As we have already seen for the petrol engines, the Otto cycle has a much lower thermodynamic output than the diesel one, and presents maximum outputs of 29 %, which in urban heavy cycle come down to 18 %. In the table 2 we can verify that this takes us to overall vehicle outputs of buses using these fuels of about 15 %.

Instead of burning the gaseous fuels in stoichiometric mixture (proportion of air and gas adapted in order that it reacts with the whole fuel), we do it with a mixture with more air quantity, and therefore poor in fuel (Lean Burn), we manage to increase the output of the engine to thresholds of 20 %, and of the vehicle about 16.5 %.

Vehicles Using Vegetable Derived Liquid Fuels

These fuels are used in the same vehicles and engines as for the equivalent oil derived fuels, i.e. the biodiesel in diesel engines, and the ethanol in petrol engines, except for unusual exceptions.

With this we can say that the outputs of the engine are very similar to its original equivalent, with slightly less output due to the fact that the energy contents of the vegetable derivatives are slightly lower than the oil derivatives.

In urban heavy cycle we have engine outputs of 24 % for biodiesel, and of 16 % for ethanol with the overall vehicle outputs of 19.8% and 13.2% respectively.

Hydrogen

This section deals exclusively with the use of the hydrogen as a direct fuel for the vehicle, leaving for the analysis of complex vehicles its utilization in fuel cells.

Used in this way hydrogen behaves in a very similar way to the rest of gaseous fuels in an internal combustion engine. It must be used in Otto cycle engines, and be stored on board at high pressures of 350 bar, due to its low energetic density, which requires the storage of a bigger quantity to have a reasonable vehicle range.

Hydrogen doesn’t have any carbon within its chemical composition and so, when used as a fuel in an internal combustion engine, the index of CO_2 emitted is 0.

In urban cycle a hydrogen powered combustion engine has outputs of 17-18 %, and therefore overall vehicle outputs of 15 %.

Electricity

Electricity is the most efficient energy carrier once it is stored on board, since the efficiency of electrical engines is highly superior to the internal combustion engines. For these vehicles we have engine outputs of 75-80 %, and the added advantage that the electrical engine does not need to use a gear box. This takes us to overall vehicle outputs higher than 75 %, which separate it clearly from the other fuels.

4.2.5 Combined efficiency analysis "WELL TO WHEEL"

For the combined "Well to Wheel" analysis of the energetic efficiency of every type of propulsion we consider two types of vehicles:

"Simple" vehicles, with only one type of energy system on board.

"Complex" vehicles, which combine on board at least two energy systems, which can use also energy recovery systems.

Simple Vehicles

WELL TO WHEEL (Simple vehicles)

Type of fuel	Well to Tank	Tank to Wheel	Global (%)
Diesel	85,3	21,4	**18,25**
Gasoline (injection)	87,3	14,0	**12,22**
Natural Gas Stoichiometric.	86,6	14,8	**12,82**
Natural Gas Lean Burn	86,6	16,5	**14,29**
LPG	86,7	14,8	**12,83**
Biodiesel	70,0	19,8	**13,86**
Ethanol	70,0	13,2	**9,24**
Hydrogen	54,6	14,8	**8,08**
Electric	32,9	77,6	**25,53**

Source: Study on behalf of TMB, Barcelona (Municipal transport company)

Table 3: Simple vehicles "Well to Wheel" Analysis Chart.

For these vehicles the determination of the global output is calculated by combining the output of the well to the tank, with the one of the tank to the wheel.

As we see, the reference level of the most widespread technology nowadays, the bus with diesel engine using diesel, it has a global output of 18.25 %.

It is possible to verify, using the summary table, that any other liquid or gaseous fuel has very low global output levels compared to diesel vehicles, with ranges that go from 14.3 %, for vehicles using natural gas with a lean burn mixture, to an extremely low global output for hydrogen combustion, with 8.08 %.

This does not mean that fuels with lower global energy efficiencies are going to be overlooked, because urban public transport it is subject to other strategic considerations, such as the minimization of the local emissions the diversification of energy sources (use of gas and of biofuel to follow European union policy), and the diversification and use of agricultural surpluses (for biofuels). In other words the choice of fuel will be for strategic reasons and not of energetic efficiency.

The results suggest that there is a great increase in the energetic efficiency for electric vehicles. Taking into account the Spanish electrical mix and the overall efficiency of an electric vehicle, we have an energetic global efficiency of 25.53 %, which represents an improvement of 40 % in efficiency terms compared to the reference diesel bus. This implies that the option of pure electrical vehicles is one of the alternatives to take into account, in spite of its limitations in terms of capacity and range. These limitations become topics which will require the evolution of battery technology.

4.2.6 Complex Vehicles

WELL TO WHEEL – Complex Vehicles

Hybrid type	Well to tank (%)	GENERATION ON BOARD			TRACTION			Recup. (%)	Global (%)
		Motor (%)	Generador (%)	Almac. (%)	Motor (%)	Generador (%)	Almac. (%)		
Diesel orig. - Electric	85,3	32,0	90,0	98,0	80,0	--	97,0	115,0	**21,5**
Diesel optimiz. - Electric	85,3	35,0	90,0	98,0	80,0	--	97,0	115,0	**23,5**
Diesel orig. - Vol. Inercia	85,3	--	--	--	26,0	85,0	97,0	110,0	**20,1**
Pila C. - Elect. with battery	54,6	45,0	--	98,0	80,0	--	97,0	115,0	**21,5**
Pila C.Full Power - Elect.	54,6	35,0	--	99,0	80,0	--	97,0	--	**14,7**

Source: Study on behalf of TMB, Barcelona (Municipal transport company)

Table 4: Complex vehicles “Well to Wheel” Analysis Chart

From within the complex vehicle group, in which we include vehicles with two or more energy sources and vehicles that can be combined with energy recuperating devices, we consider hybrid and fuel cell vehicles in the following sections.

Diesel – Electric Hybrids

A hybrid vehicle is a vehicle that takes its power from more than one source. Annex 1 contains more information about the basic configurations of hybrid buses.

In the case of a diesel electric hybrid vehicle, these two power sources are the traditional diesel engine and the battery. These are basically electric vehicles, equipped with their standard energy storage systems (batteries or supercondensers), but which additionally have a diesel engine and a generator to create electrical power on board in order to recharge the batteries while in operation. By doing this it is possible to radically increase the range of the vehicle.

In traditional vehicle design, the engineer has had to design the vehicle for ‘peak demands’ i.e., the vehicle has to be able to climb a one in four gradient, fully laden on a hot day. Using diesel electric hybrid technology means the designer can size the base engine for a demand which is nearer the average. Peak demand can still be supplied using a top up from the batteries.

They can be derived from the original diesel vehicle, so that the diesel engine is the same as the conventional bus, and improve the output of this diesel engine by making it work at fixed regime for the generation of electricity, without using the transitory ranges involved in starting and stopping and consequent accelerations to which the diesel engine is submitted when it directly powers the vehicle.

By using batteries or storage condensers, these vehicles can incorporate electric power recovery mechanisms during braking. In a conventional bus, when the driver depresses the brake pedal, after the retarder has done its work, the brakes are activated which relies on friction between the brake disc and pad to slow the vehicle down. This action of friction between the pad and disc generates significant amount of energy which is lost as heat as is the energy lost through the action of the retarder.

In a hybrid vehicle, before the brakes are activated, the electric motor which is connected to the driving wheels turns into a generator and is powered by the road wheels to generate electricity which is stored in the batteries for later use. Unlike a retarder, which cannot operate effectively at low speed, the hybrid system can brake the vehicle to a complete stop. In this way, a sensible bus driver can negotiate a route without having to touch the brakes although of course they are always there and ready to be used. In driving this way, the driver can capture almost 100% of the brake energy.

It is this capture of regenerative brake energy and the way that the vehicle handles this ‘free’ energy which dictates the overall efficiency of the hybrid vehicle. This energy recovery can, in heavy urban service with many stops, lead to an approx. 15 % improvement in energy output.

If the typical output of a diesel engine working exactly at the optimal fixed point, about 32 %, is combined with the electricity generation outputs and with the electrical vehicle traction outputs, the "tank to wheel" efficiency for this type of vehicle is calculated to be 25.2 %. When combined with the "well to tank" of diesel, we obtain a global efficiency of 21.5 %, which represents an improvement of 18 % compared to the diesel reference vehicle.

Being able to downsize the base engine saves around 25% of the overall savings. The remaining 75% of the savings comes through capturing free energy through regenerative braking.

Instead of starting from the original diesel vehicle, if a specific vehicle is designed with a much smaller diesel engine, which is just big enough for the level of electricity generation needed, the output of the diesel engine rises to an average of 35 %, and the overall vehicle "well to wheel" output reaches 23.5 %, which is an improvement of 29 % compared to the diesel reference vehicle.

The Benefits of Hybrid Buses

In a series hybrid (see annex 1), the diesel engine is de-coupled from the road wheels and can operate independently of road speed. It can run in its most efficient operating range and is not subject to the rapid rpm changes which are prevalent in normal bus operation. This allows it to achieve better fuel consumption as well as also improving the emissions of NOx and particulates. This too comes from the rpm being held within certain bands of the engine’s operating range. In effect, the engine can stay in its ‘sweet spot’.

As the final drive is electric there is no gearbox and hence no gear changes so the drive is smooth and stepless.

As the engine tends to be operating in a narrow “rpm” band, the units used for buses tend to be quieter in operation than the traditional diesel version. Furthermore, as the traction power needed to move the vehicle doesn’t all come directly from the diesel engine, it can be sized smaller than in a diesel vehicle of the same characteristics.

Buses with hybrid technology are now available and as the prime mover is a diesel engine which is the same core component as a traditional bus, it is seen as being more reliable than some of the alternative fuel options.

The Potential Weaknesses of Hybrid Buses

On the other side of hybrid operation, the weight of the battery, motor and generator is greater than the weight of the gearbox that it displaces.

Hybrids do introduce a new high voltage element into the bus depot environment. Whilst the systems are inherently safe, there are perceived concerns with high voltage safety. As a result of this there is a further training requirement for operation of these vehicles.

Fuel-cell Vehicles

These vehicles cannot be considered to be fully hybrids, but they can be considered complex vehicles as they combine electric traction with generation of the electricity on board by fuel cell, but without using intermediate storage of batteries.

As there is no intermediate electrical storage (between generation and consumption), the “Fuel cell” has to be sized to be able to generate at every moment as much electrical power as needed to move the vehicle in any conditions.

For a bus of 12 metres and 19 tonnes this maximum power rises to values of approximately 210 kW. Therefore the nominal capacity of the “Fuel Cell” must match this value (in contrast to the average power of 70-80 kW for an equivalent hybrid).

This big dimension of Fuel Cell has two principal problems: the most important is the price, as their cost is directly proportional to their nominal power. The second problem consists of the fact that, as it has to work at transitory state in a constant way, the average efficiency of the “Fuel Cell” is less than in stationary state reaching values not higher than 35 %.

The analysis of these vehicles from well to wheel provides global values of efficiency of 14.7 %, which this reduces their interest from the energetic point of view, and currently there is no manufacturer of buses who has this model of vehicle in development.

4.2.7 Short Term Solutions (2009-2012)

CTSS currently has a fleet of 119 vehicles, with a prepared infrastructure for the increase of 6 more buses, giving a total of 125.

Within the studied fuels we will firstly reject those that present high barriers (technological, economical…), as explained below:

- LPG - fossil Fuel with few applications in public and / or private transport. The main problem for CTSS is the lack of a nearby supplier that can offer a service adapted to the needs of the company.
- CNG - fossil Fuel used in the EMT of Madrid and Barcelona with favourable results on a mechanical level and with environmental improvements linked to the low carbon content of the fuel that reduce the emission of CO_2 to the atmosphere. Its major handicap for CTSS is the need to do a civil work both in facilities and in fixed assets that would cost, according to Naturgas, €1,250,000 in addition to the purchase of the vehicles prepared to use CNG, which are more expensive than conventional vehicles. (A bus of 12m to CNG has a price of €300,000 compared to a diesel vehicle with the same characteristics that costs €240,000.)
- Bioethanol - Biofuel with a great experience in Brazil and a few similar services to the biodiesel. Its utilization is marked by the need to use it in vehicles of “Otto” cycle. This rules out its use in the short term because of the need for the company to buy new vehicles - an investment that would affect the customer through the price for trip.
- Electricity - The use of electrical vehicles in the public transport is not viable yet, as the electrical vehicles possess a low range and the high weight of the batteries means that it can only be used for minibuses.
- Hydrogen – A fuel that is excellent in terms of local emissions, but worldwide the study shows a high current economic and environmental cost.

The chart on the next stage summarises these conclusions.

VALUE

*		**
1	Very low	5
2	low	4
3	medium	3
4	high	2
5	Very high	1

	ASPECTS	**Diesel Euro VI**	**GLP**	**Ethanol + ICE**	**Bio 1ª generation + ICE**	**Bio 2ª generation + ICE**	**GNC + ICE**	**H2 + ICE**	**H2 + Fuel cell**	**Hybrid (Diesel - Electric)**	**Electric**
*	*Technology development*	5	4	4	4	2	4	3	3	3	2
*	*Disp. Resources*	5	3	3	4	4	4	3	3	4	3
*	*Emission reduction (local)*	3	3	4	4	4	4	5	5	5	5
*	*Environmental benefit (global)*	2	2	3	3	4	3	3	4	4	5
*	*Social acceptance*	3	3	4	4	4	4	4	4	5	5
**	*Acquisition/resource costs*	3	3	3	4	4	2	3	3	3	3
**	*Implementation costs*	5	3	3	5	5	2	2	2	4	4
**	*Functional extra charges*	5	2	2	4	4	3	2	2	3	2
**	*Mechanical problems*	5	4	4	5	5	4	3	2	2	1
		36	**27**	**30**	**37**	**35**	**30**	**28**	**28**	**33**	**30**

Given all this information we consider the best option for the company for the period 2009-2012 is to use diesel and biodiesel fuels in new Diesel Internal Combustion Engines with low emission levels. We would hope to combine use of both fuels to a level in excess of the proportion B20, used at present by several bus models within the company, in part to investigate the possible mechanical problems in the vehicles.

These options are closely followed by the use of 2nd generation biodiesel in the actual Internal Combustion Engines but this on the technical development of these fuels and on a reduction in their production costs.

4.2.8 Medium to Long Term Solutions (2012-2050)

In the same way, conclusions will be supported by the chart bellow:

VALUE

*		**
1	Very Low	5
2	Low	4
3	medium	3
4	High	2
5	Very High	1

	ASPECTS	**Diesel Euro VI**	**GLP**	**Ethanol + ICE**	**Bio 1ª genetion + ICE**	**Bio 2ª generation + ICE**	**GNC + ICE**	**H2 + ICE**	**H2 + Fuel cell**	**Hybrid (Diesel - Electric)**	**Electric**
*	*Technology development*	5	5	5	5	5	5	5	5	5	5
*	*Disp. Resources*	2	2	4	4	5	3	5	5	4	5
*	*Emission reduction (local)*	1	1	2	2	3	2	4	5	4	5
*	*Environmental benefit (global)*	1	1	2	2	3	2	3	4	4	5
*	*Social acceptance*	1	1	3	3	3	2	4	5	5	5
**	*Acquisition/resource costs*	2	2	3	3	3	2	3	3	3	5
**	*Implementation costs*	4	3	3	5	5	2	2	2	4	4
**	*Functional extra charges*	5	4	4	4	4	4	5	4	4	5
**	*Mechanical problems*	5	5	5	5	5	5	5	4	4	5
		26	**24**	**31**	**33**	**36**	**27**	**36**	**37**	**37**	**44**

The considered solutions for a medium - large period of time are:

- Pure Electric Vehicles, because of having a good global efficiency, and in spite of the fact that today they could only be considered for minibuses and for reduced range operations.
- Diesel-Electrical Hybrid Vehicles, preferably with optimized diesel engine for the application, for presenting an important improvement of the output and for being a technology that can be applied to any size of bus, from the minibuses up to the articulated buses.
- Hybrid Vehicles and Fuel Cell Vehicles, in spite of nowadays not being optimized alternatives because of the level of costs and current efficiency, represent a future option that should be taken into account.

4.3 Problems Identified

The main problem identified through the development of the study have been access to and reliability of the latest news on controversial themes such as: real environmental problems; the biofuels food versus fuel controversy; emissions cycle results analysis. These are topics that have as many supporters as prosecutors, so it is difficult to find the factual information. As many sources of information as possible had to be compared for each of the topics developed in the study.

4.4 Risks and Mitigating Activities

The risks of the study become in the time to put into practice the conclusions that have been reached. The application of the alternative fuel chosen is open and depends on operational experiences in terms of over consumption and mechanical maintenance.

This information will be available as soon as ARCHIMEDES task **Task 7.5 "Public Transport Bio-Fuels"** is developed. Then, there will be an interesting source of information to set the basis for the upscaling of the study conclusions.

4.5 Dissemination Activities

The complete study, which is summarised in this deliverable, has been placed on the CTSS website (www.DBUS.es).

4.6 Future Plans

The "fuel alternatives options" subject is a live topic that is progressing day to day with the latest research and development news. So this study is valid as a current snapshot while new greener fuel options appear, or new technology developments occur that improve global and local emissions results, production costs and social impacts.

This means that in a short time the study would need to be refreshed and reviewed with the latest information to keep its conclusions valid. Until that time CTSS has identified its strategy for the duration of ARCHIMEDES and will proceed further on that basis in measure 4.

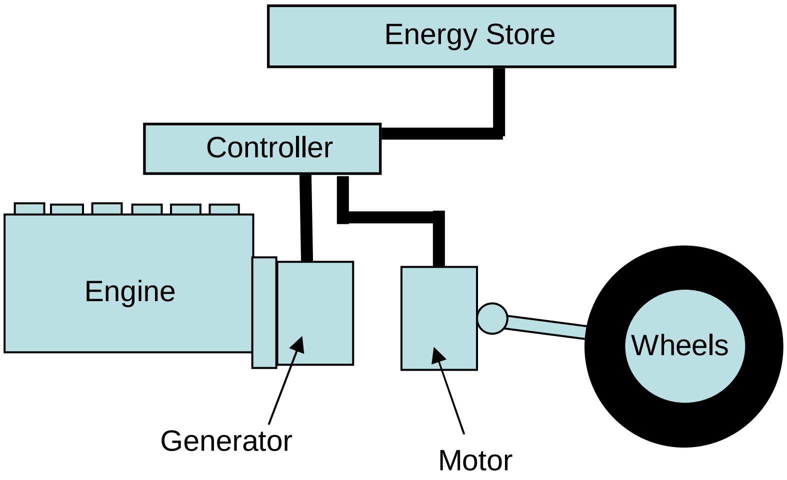
Annex 1: Basic Configurations of Hybrid Buses

Diesel – Electric Hybrid Vehicle designs

There are two types of hybrids in operation, the series and parallel systems.

A) Series Hybrids

The Series hybrid system is shown below:



It can be seen there is no physical connection between the engine and road wheels. A good way of visualising this set up would be to consider it to be an electric vehicle with its own on board electricity generation system.

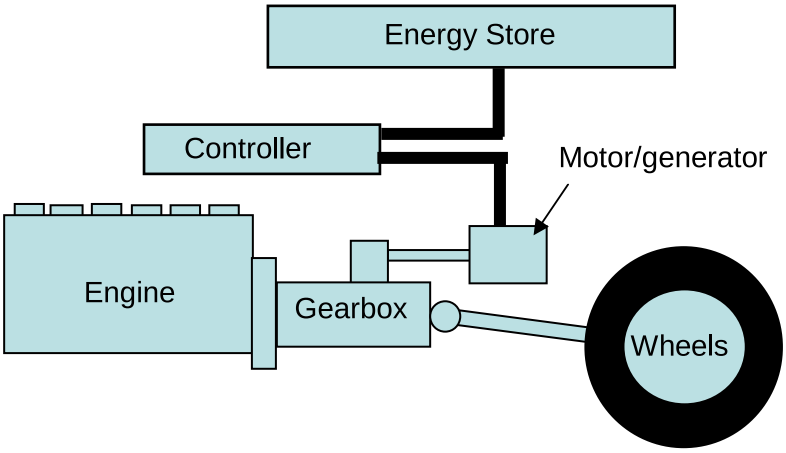
In this system, the engine powers a generator which generates electricity which can be used to either charge the batteries or be used to power the road wheels.

As there is no link between the engine and the roadwheels, it is easier to operate this system in a 'zero emission' mode where the engine can be switched off for periods. This has the advantage of offering zero kerbside emissions but at some time of the duty cycle, the energy used up during this period needs to be generated, probably with the associated higher kerbside emissions, but at a different location. Operating the vehicle in this way will also potentially reduce the life of the batteries.

The series system is believed to be well suited to the UK bus operation with the relatively low speed of operation and the intensive stop start duty cycle.

To date, most vehicle manufacturers have opted to integrate proprietary components into their own system as there are not many integrated system suppliers at present. There are a number of proprietary hybrid parts manufacturers such as Siemans, Enova, UQM, MST and a number of ‘spin offs’ from various military programmes.

B) Parallel Hybrids



In the parallel hybrid, the system retains a physical connection between the engine and the roadwheels through a mechanical transmission with an electric motor in parallel to it. This allows the system controller to typically pull away from rest using the electric motor and subsequently blend in diesel power from the engine when the engine is operating in its ‘sweet spot’.

This system is good when long distance high speed operation may be required as it allows the diesel engine to be used independently of the electrical system when it is efficient to do so thus not using any electrical power. Regenerative braking is achieved using the electric motor as a generator to capture electrical energy during braking,

Many of the current parallel systems are being developed by the gearbox manufacturers which could be interpreted as an attempt to retain their market share in the public vehicle sector. As such, these systems tend to be supplied by them as a ‘turn key’ system.

Diesel hybrids

In rigor, these vehicles should not be named hybrids because they used an only type of traction energy, but they are named by this way because of its complexity of the mechanical systems of recovery of energy in the braking.

Basically there are two types of mechanisms where energy is stored:

- Flywheels, which turn the recovered energy in the braking into kinetic energy, making turn to great speed a steering wheel of an big mass, which returns partof this energy in the way of traction force in the acceleration moments.

- The “radioidales” springs, that recover the braking energy in the way of tension or potential energy, compressing a radial spring, which gets loosen and returns this energy in the way of traction force.

It is considered in average terms that these systems are capable of recovering approximately 10 % of energy, proportion in which they improve the global output.

Applying this output improvement to the conventional diesel vehicle, it is taken to global efficiency of 20,1 %, which without being bad, does not make the system in a priority aim of analysis, and specially bearing in mind that does not exist any bus in development with these systems, existing only prototypes to very experimental levels.

Fuel-cell hybrids - Electric

They have a similar configuration to the hybrid electrical diesel, that is a electrical traction vehicle with a energy generating system on board, but in whichthe above mentioned generator is not a diesel engine connected to an alternator, but a hydrogen fuel cell is used for the generation of the electricity on board.

The fuel cell is a chemical reactor habitually composed by polymeric membranes, who feeds with pure hydrogen from one end of the membrane, and with the oxygen of the air from the other end. Inside the mentioned reactor, the hydrogen decomposes in a hydrogen proton and an electron. The proton crosses the membranes to join with the oxygen of the air, giving as a result steam of water, whereas the electron is gathered in the terminals of the battery, constituting the electrical current that it is sent to the batteries.

The fuel cell gives the electrical power necessary in average, work at stationary state, that is by a constant way generating an constant electrical power, and can have an output about a 45 %.

Provided that hydrogen is the primary energy, for the calculation of global efficiency we start from the " well to tank " of the hydrogen, from a 54,6 %, combined with the own output of the battery and with the output of the traction of an electrical vehicle. The set of " well to wheel " gives us values of 21,5 % of total efficiency, which places the system as interesting from the energetic point of view.

The global output deteriorates notably if the energy used to produce the hydrogen is an electric power for electrolysis, as there would be necessary to add to the calculation the own output of the electrical production.

Definitively, the system deserves to taking into account for its analysis, but without forgetting that nowadays the costs of production of the hydrogen make the the system economically unviable.