Survey for the Development of Compressed Natural Gas Systems (CNG) for Vehicles

By

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Declaration

I hereby certify that the material, which I now submit for assessment on the program of study leading to the award of Degree of Master of Engineering is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed.....

ID No: (53122101)

Date: 10/8/**2005**

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First of all I would like to express my heartiest gratitude and profound indebt to my supervisor Dr. Abdul Ghani Olabi, who kept me patiently, forced on my work. My research under his thoughtful guidance has been extremely successful and personally satisfying; I will always be deeply grateful to him.

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A. M. Abulamosha

Abstract

Compressed Natural Gas (CNG) vehicles have been used internationally by fleets for decades. The use of CNG vehicles results in less petroleum consumption, resulting in fewer air pollutants and greenhouse gas emissions in most applications. In Europe, the adoption of CNG among consumers has been slowed by the availability of affordable gasoline and diesel fuel. This investigation addresses the current situation of the CNG vehicle at the manufacturing level and the consumer level in Europe. Based on studies of CNG car manufacturers and vehicle customers, the study reveals the nature of the development of CNG vehicles among the companies. This study also examines vehicle ownership experience, determines the effects of government incentives on the decision to own a CNG vehicle, and considers the European CNG refuelling network in the context of future alternative fuel vehicles (AFVs). CNG car manufacturing companies have detailed some obstacles facing them in developing and implementing CNG technology. CNG vehicle owners have expressed significant dissatisfaction with the public fuelling infrastructure for the vehicles, leading them to choose non-CNG vehicles. Despite these disadvantages, most European CNG vehicle owners have shown their satisfaction with CNG vehicles.

The objective of this study was to gather analyse information that would enable that development of a strategy for the implementation of CNG vehicles around Europe by conducting surveys. Such a strategy need to take account of public opinion on the issues facing CNG development and ascertain what measures need to be taken to ensure success in the development of the CNG programme around Europe by car manufacturers and Original Equipment Manufacturers (OEM).

Chapter 1
Introduction

1.1 Introduction

The use of Compressed Natural Gas (CNG) in vehicles dates from the 1930s in Italy. After the late 1970s, there was a substantial increase in the development and use of CNG in vehicles. There are now approximately 3 million CNG vehicles around the world [1], in more than 50 countries. Figure 1.1 highlights the top six countries in terms of NGV use worldwide today according to the NGV report 2003 [2].

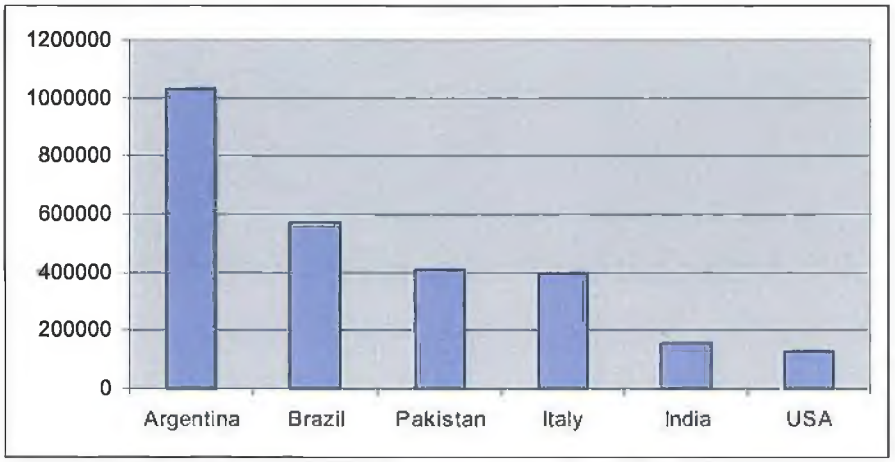


Fig 1.1 Top six countries in terms of NGV use

In recent decades, there has been a noticeable increase in the use of Natural Gas Vehicle fuel due to the following reasons:

- Compressed natural gas is the cleanest burning fuel operating today. This means less vehicle maintenance and longer engine life.
- CNG vehicles produce very low emissions compared to traditional fuels.
- The supply of natural gas is assured for the foreseeable future, at least for the next 160 years [2].
- Some fleet operators have reduced maintenance costs by as much as 40% by converting their vehicles to CNG.
- Intervals between tune-ups for natural gas vehicles are extended from 30,000 to 50,000 miles.

- Natural gas does not react with metals in the way gasoline does, so pipes and mufflers last significantly longer.
- Natural gas gives the same mileage as gasoline.
- Because CNG is already in a gaseous state, NGV's have superior starting and drivability, even under severe hot and cold weather conditions.
- NGV's experience less knocking and no vapour locking.
- Natural gas is on average 15% to 50% cheaper per equivalent gallon than gasoline [3]. Table 1.1 shows European fuel prices by dollars ($) and figure 1.2 shows the average European fuel prices in 2004 [4].

Table1.1 European fuel prices [4]

Country	Premium Gasoline ($ / litre)	Regular Gasoline ($ / litre)	Diesel ($ / litre)	CNG ($ / m3)
Austria (a)	1	0.98	0.87	0.53
Bosnia & Herzegovina	0.74		0.68	0.25
Bulgaria (a)	0.9	0.7	0.65	0.219
Croatia	0.96	1.03	0.78	0.313
Czech Republic(c)	0.937	1.05	1.2	0.41
Egypt(b)		0.133	0.053	0.059
France	1.06		0.82	0.69
Germany (a)	1.24	1.17	0.97	0.48
Iceland (d)	1.24	1.21	0.52	0.91
Italy	1.158	1.158	0.95	0.452
Latvia	0.76	0.7	0.62	0.23
The Netherlands	1.26	1.19	0.84	0.3
Norway	1.2	1.12	0.97	0.46
Poland (e)	0.872	0.721	0.706	0.266
Russia	0.36	0.27	0.24	0.11
Serbia & Montenegro	0.78	0.67	0.55	0.27
Sweden		1.03	0.78	0.27
Switzerland (a)	0.9	0.86	0.86	0.7
Ukraine	0.45	0.34	0.36	0.12
United Kingdom (f)	1.05		1	0.33

In these countries the local gauge unit is ¤/ kg, the conversion factor is 0.73 (normal density of gaseous natural gas)
In Egypt diesel is only allowed in heavy duty engines, buses and trucks.
The excise tax for premium gasoline is not yet incorporated. The excise taxes for gasoline, diesel and CNG are included (¤ 0, 36, ¤ 0, 30 and ¤ 0,07 respectively). Also, 22% VAT is included in the CNG cost.
No taxes on diesel. Owners of diesel vehicles need to pay an extra tax depending on the weight of the vehicle.
There is no excise duty on CNG consumption. VAT is included in the CNG price.
VAT exclusive [4].

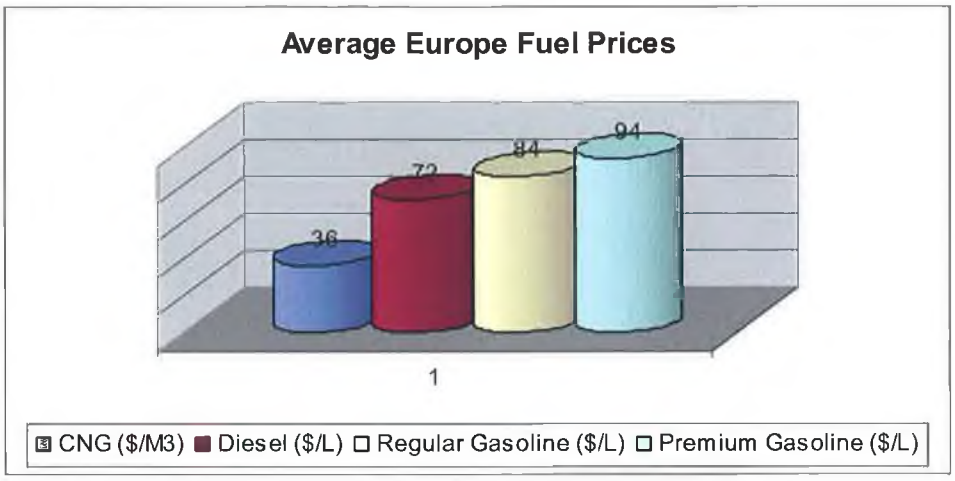


Fig1.2 Average European fuel prices [4]

However, Compressed Natural Gas (CNG) does have some disadvantages such as:

- Driving complaints due to loss of power with CNG. CNG-fuelled vehicles have 10-15% lower power output than petrol engines.
- Increased exhaust-valve wear in CNG-operated vehicles due to the drying effect of the gaseous fuel
- Limited service availability
- High cost of conversion
- Additional weight of CNG cylinders [5].

1.2 Application of CNG in Vehicles

Natural gas is compressed to about 200 bar and is stored on board the vehicle in cylinders installed in the rear, undercarriage, or atop the vehicle. When natural gas is required by the engine, it leaves the tank travelling through a high-pressure pipe to a high-pressure regulator (most often located in the engine compartment) where the pressure is reduced. In carburetted engines, the fuel enters the carburettor (through a special fuel/air mixer) at close to atmospheric pressure through a specially designed natural gas mixer where it is properly mixed with air. In fuel injected vehicles the natural gas enters the injectors at relatively low pressure (up to about 6 bars). In either case, natural gas then flows into the engine's combustion chamber and is ignited by

spark, to create the power required to drive the vehicle. Special solenoid valves prevent the gas from entering the engine when it is shut off. In bi-fuel vehicles, a fuel selector switch controls the flow of either natural gas or petrol. A fuel gauge is provided on the dashboard or it is incorporated into the normal fuel gauge so the driver can determine the amount of natural gas remaining in the fuel tanks. Natural gas also can be stored in a cryogenic, liquid form (LNG) at minus 164 degrees C. It is vaporized and is used as an engine fuel just like CNG [6].

1.3 How Compressed Natural Gas (CNG) Vehicle Systems Work

In CNG vehicles the fuel is stored at pressures of 200 bars in one or more cylinders located under the body or in the trunk of the vehicle. The filling valve is placed near the tank or in the front grille. When the CNG leaves the cylinder tank, it travels through high-pressure fuel lines into one or more pressure regulators, where it is reduced to low atmospheric pressure. Unlike gasoline, which must be vaporized before ignition, CNG is already gaseous when it enters the combustion chamber. When the intake valve opens, the gas enters the combustion chamber, where it is ignited to power the vehicle [7]. Figure 1.3 shows a diagram of the CNG fuel system [2].

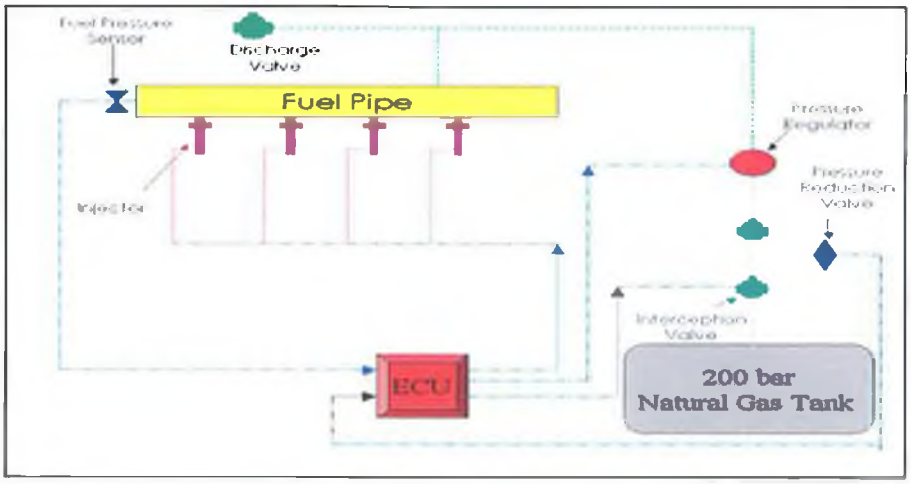


Fig 1.3 Diagram of the CNG Fuel System

Table 1.2 and figure 1.4 show the CNG Camry specifications and a schematic of the vehicle, a dedicated natural gas vehicle. The transmission is the same automatic transaxle as in the base gasoline vehicle. As the engine power is reduced the vehicle acceleration becomes slightly slower [8].

Therefore, the differential gear ratio was selected one rank higher than that of the gasoline vehicle in order to restore the loss in acceleration. A large fuel tank was installed utilizing a portion of the rear seat back and luggage compartment space to maintain luggage space. The exhaust pipe and rear floor pan were redesigned to fit the large, 135L tank.

Table1.2 Camry vehicle specifications

	CNG	Gasoline
Curb Weight	1450Kg	1395Kg
Fuel Tank Volume	135L	70L
Equivalent Gasoline Capacity	43L	70L
Service Pressure	24.8MPa	____
Luggage Space	332L	518L
Final Axle Ratio	4.176	3.944

The fuel tank is composed of a highly reliable light structure reinforced seamless aluminium liner with carbon fibre over wrap. The light weight tank keeps the increase in vehicle weight to a minimum. The remaining fuel volume in the fuel tank is calculated by signal from a pressure sensor placed in the high-pressure fuel pipe and a temperature sensor placed in the in-tank solenoid shut-off valve. At the current stage, the costs of CNG Vehicles are relatively high compared with those of gasoline vehicles, because of small volume production. However, CNG vehicles are fundamentally similar to gasoline vehicles and therefore CNG vehicles have the potential of widespread use in the market compared with Electric Vehicles (EV), especially if the refueling infrastructure and vehicle performance are improved further [8].

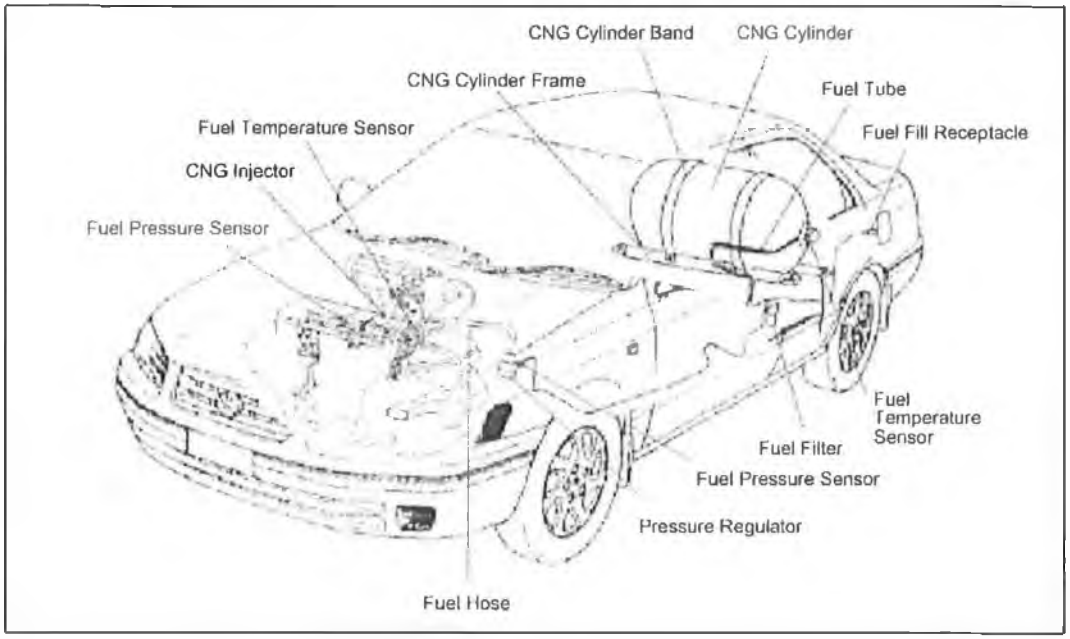


Fig1.4 Example of a purpose built CNG vehicle [8]

1.4 Development of Natural Gas Vehicle Markets

World NGV commercialization activities have been occurring at different paces in different countries since their initial introduction in Italy in the mid-1930s. Each country has a different set of market, economic, gas supply, and political conditions, coupled with the technology development at any give time that causes NGV commercialization to progress at a different rate. A brief overview of the global NGV progress is presented below by giving the number of NGV's currently owned around the world and the number of refueling stations in different countries. Table1.3 shows the spread of NGV's around the world and table 1.4 illustrates the number of refuelling stations present in each country [4].

Table1.3 Worldwide natural gas vehicle numbers [4]

Country	Natural Gas Vehicles				Nm3 Monthly Sales Average
	Total	Cars/LDVs	Buses	Trucks	
Italy	381,250	380,000	1,000	250	36,000,000
Ukraine	55,000	5,000	26,000	24,000	42,800,000
Egypt	53,302				21,790,000
Russia	40,500	2,000	4,500	34,000	11,700,000
Germany	19,600	15,400	1,050	3,150	38,400,000
France	7,200	5,500	1,500	200	
Belarus	5,500				
Sweden	4,238	3,575	472	191	
Bulgaria	1,425	1,300	120	5	2,097,667
United kingdom (e)	875	20	35	820	400,000
Moldavia	800				
Switzerland	800	710	49	12	
Spain	664	17	226	421	120,000
Czech Republic	390	298	90	2	2,000,000
Latvia	310	30	10	270	
Netherlands, the	310	300		10	
Austria	400	300	2	2	12,000
Belgium	300				30,000
Portugal	242	28	213	1	
Slovakia	170	70	100		
Poland	147		31		
Croatia	100	100			750,000
Norway	88		66		100,000
Ireland	81				
Serbia & Montenegro	77	76	1		
Finland	76	2	70	4	
Iceland	44	44			300,000
Luxembourg	25				2,900
Denmark	5				
Bosnia & Herzegovina	1				
Totals	**573,920**	**414,770**	**35,535**	**63,338**	

*Light Duty Vehicles (LDV)

Table1.4 The number of refuelling stations around the world [4]

Country	Refuelling Stations					Refuelling Station Under Construction		
	Total	Public Use (a)	Private Use (b)	Hoses	CNG Capacity (m3/hour)	Total	Public Use	Private Use
Italy	471	454	17			46	46	
Ukraine	140	112	20			20	15	5
Egypt	86					15		
Russia	207	199	8	620	237,500	2	2	
Germany	445	315	130			150	150	
France	105	8	97					
Belarus	24							
Sweden	47	35	12			3		
Bulgaria	9	5	4	25	6,600	6		3
United kingdom (e)	34	7	27			20	5	5
Moldavia	87							
Switzerland	36	30				50	15	
Spain	19		19			2	1	1
Czech Republic	14	7	7	18				
Latvia	4							
Netherlands, the	8	1	7	9	2000	3	2	1
Austria	66	26	40					
Belgium	5							
Portugal	5		5			5		5
Slovakia	7					2		
Poland	21					4	2	2
Croatia	1	1		2	660(f)			
Norway	4							
Ireland	2							
Serbia & Montenegro	1		1			1	1	
Finland	2		2			1	1	
Iceland	1	1						
Luxembourg	5							
Denmark	1							
Bosnia & Herzegovina								
Totals	1,857	1,201	396			330	240	22

Italy has the largest number of NGV's in Europe with 320,000 vehicles (mostly commuter vehicles) and 320 fuelling stations (mostly public stations). The Italians have been the historic leaders in the NGV market (only recently outpaced by Argentina). Today they are embarking on a significant expansion programme to increase both vehicle and fuelling station numbers, with plans to double both in the upcoming five years. The Italians are product leaders worldwide, exporting vehicle conversion systems and compressor station equipment to the Middle East, South America, China, and many other countries around the world.

The German market has developed over the last few years. NGV's now number about 5500+ and they have over 100 fuelling stations. The German government has provided funding, including DM 5 million, (approximately 2,551 million euro) to the city of Augsburg, for NGV development and demonstrations. The German natural gas industry

has created a national NGV development strategy that should drive the market forward for the next five years and beyond, depending upon the success of the current activities.
The UK market is developing steadily, mostly focused on municipalities (about 875 NGV's). There are currently 34 fuelling stations countrywide.
The French are expanding their market steadily, mostly due to efforts by Gaz de France (GdF). GdF now has 3000 vehicles in their own fleet, making it the largest in Europe. They have created a separate marketing entity called *GNVert* to install fuelling stations and sell CNG. The gas company has signed a contract with the government and manufacturers that pledges mutual support for clean vehicles and NGV's. Currently, there are 300 NG buses in France. Moreover, of the new buses sold or on order, 20-25% is NG.
In Sweden there has been some very interesting activity, especially for a country with only a limited natural gas distribution network. The government is environmentally oriented and is working with local government and private industry in the area of biomass, from both agricultural waste and from human waste retrieved (in Stockholm) during the water purification process. Volvo also has been active in leading the development of the NGV market. In 1995 Sweden had just over 100 NGV's; today they have 1500, the growth rate in this small market is impressive [9]. Figure 1.5 illustrates the European refuelling stations, 75% are public stations and 25% are private stations. Figure 1.6 illustrates the European refuelling stations under constructions, 92% are public stations and 8% are private stations. Figure 1.7 illustrates the Europe Natural Gas Vehicles (NGV's) of which 81% are light duty vehicles (LDV's), 12% are trucks and 7% are buses.

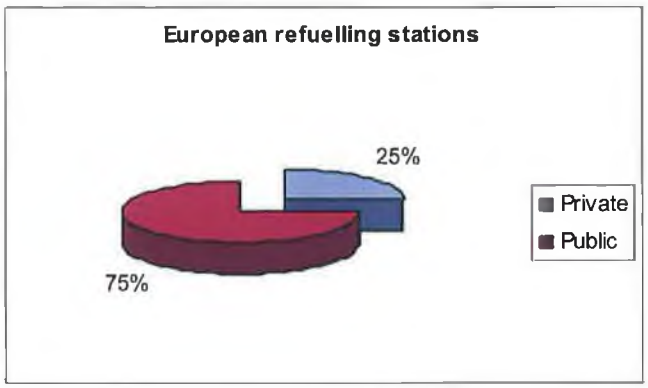


Fig 1.5 European refuelling stations

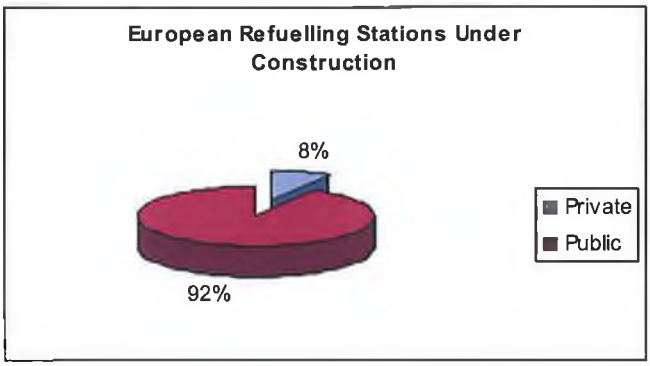


Fig 1.6 European refuelling stations under constructions

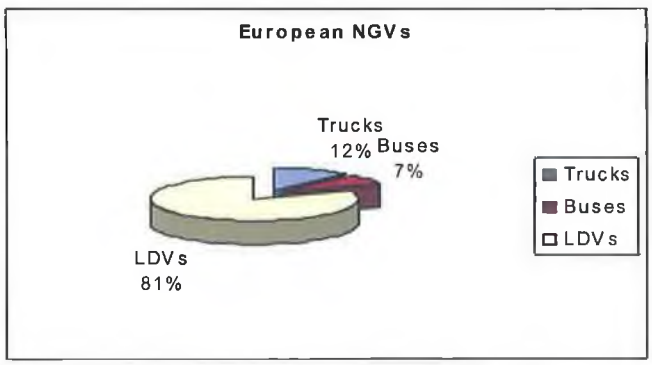


Fig 1.7 European natural gas vehicles

1.5 Factors Influencing the Gas Market

The gas market is influenced by different factors:

1. Demand. From a strong economy follows a growing demand for energy. The use of natural gas in Europe in commercial and industrial sectors has grown substantially in the last decade. Also, a growing demand for electricity, coupled with a desire for cleaner burning fuel and more stringent environmental standards, has resulted in more natural gas being used to generate power.

2. Competing fuel prices. Fuel switching is a temporary change from one fuel to another at a particular facility and acts to limit gas price increases. The choice of which energy form to consume is frequently based on relative prices, relative combustion efficiency, availability or security of supply, emissions and other considerations.

3. Natural Gas Storage. Underground natural gas storage inventories provide suppliers with the means to meet customer requirements during the heating season, especially on peak demand days. The heating season for natural gas markets is considered the five-month period from November through the following March. The other seven months, April to October, become an inventory-building period called either the "non-heating season" or "refill season". In addition to meeting winter demand loads, storage is also used for load balancing on pipeline systems, short-term "parking" of gas until it is needed, and to provide a physical hedge against price volatility.

4. Supplier. The supply response to increased prices differs in the short run and the long run. As demand increases and causes a price to rise, the immediate response is an attempt to provide a larger volume from the existing wells and facilities. Companies with spare capacity generally respond promptly to opportunities for additional sales.

5. Market Psychology. One of the factors that can influence the price of natural gas either in the short or the long-term is the psychology of the market in reacting to the above noted drivers (factors), including drivers such as availability of pipeline transportation capacity. In examining the price of natural gas and how natural gas markets are working, it is important that market psychology be taken into consideration. Market psychology is very difficult to measure as it is an interpretation by traders and analysts of events that may often lead to a price level that otherwise would not have been expected [10].

1.6 Aim of Study

The general aim of this research is to assess the level of the development of Compressed Natural Gas (CNG) in vehicle systems and the level of satisfaction with CNG vehicle consumers. Surveys have been carried out in this research, with the following objectives:

1. To build a strategy to use CNG vehicles in Ireland and other European countries.
2. To determine the obstacles to the adoption of CNG system in the car industry.
3. To determine the obstacles that caused CNG vehicle manufactures and vehicle customers not to convert to CNG.
4. To determine the level of current development in CNG car manufacturing.
5. To determine the desire to adopt the development technology over the next years.
6. To study the effect and incentives influencing CNG vehicle manufacturing and CNG vehicle customers.
7. To study the CNG vehicle ownership experience in order to determine the potential growth and subsequent viability of a CNG vehicle market and help government agencies tailor their programs to meet the needs of current and future owners.

1.7 Thesis Structure

Chapter two contains a literature review which provides the context and environment in which the research was undertaken and the research methodology is discussed in chapter two as well. First analysis and the aim of each question will be discussed in chapter

three. Analysis and discussion of considerable raw data, which is subjected to three analysis processes (Frequency table Technique, Select Cases Technique and Correlation Technique) is presented in chapter four. This thesis then presents discussions of the major conclusions which can be drawn. Finally, recommendations and suggestions for future work are presented in chapter 5. Figure 1.8 shows the schematic diagram of the research.

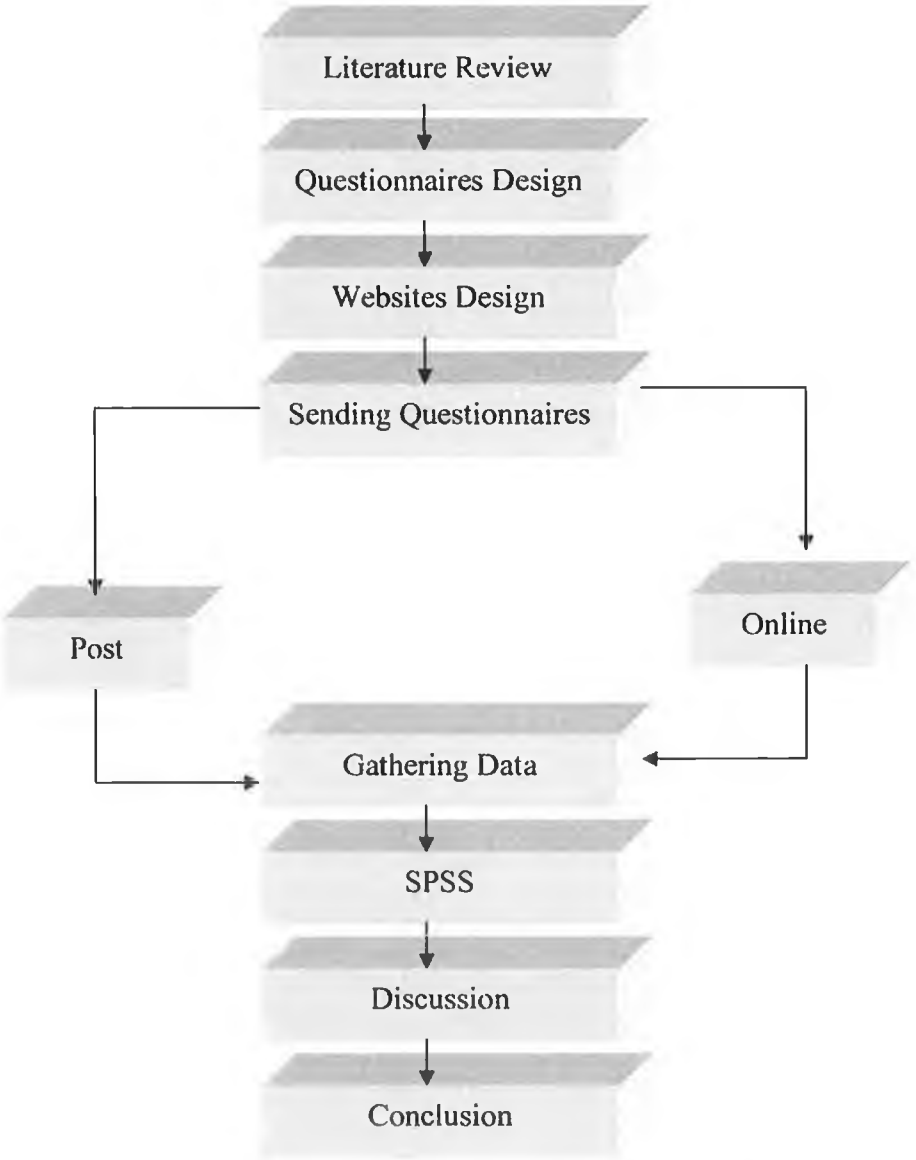


Fig 1.8 Schematic diagram of the research outline

Chapter 2
Literature View

2.1 Introduction

During the research period of this study it was necessary to conduct a literary review to show the application and technological development of natural gas engines including problems encountered over the years and recent solutions. The following represents numerous studies carried out by engineers and scientists in this field. They highlight the most recent advances in the CNG industry.

2.2 Air Pollution

Motor vehicles emit a variety of pollutants into the air. The type and quantity of pollutant emitted depends on the number and type of vehicles present, age, engine type and operating conditions. These emissions impact on the environment in the form of elevated ambient concentrations, which depend on proximity to the roadside and meteorological conditions. Local ambient concentrations are normally compared with limit or guideline values to ascertain whether a pollution problem exists.

2.2.1 Motor Vehicle Emissions

Of the atmospheric pollutants emitted from motor vehicles, those of most concern are carbon monoxide (CO) and carbon dioxide (CO_2), oxides of nitrogen (NOx), especially nitric oxide (NO) and nitrogen dioxide (NO2), particulate matter and volatile organic compounds (VOCs), including hydrocarbons (HCs) such as benzene. The complete combustion of a fuel gives rise to emissions of CO_2 and water only. However in real engines, incomplete combustion also gives rise to emissions of CO, unburnt HCs and particles, while nitrogen oxides are formed by the high-temperature oxidation of nitrogen present in the air. Approximately 50% of NOx, 60% of VOC and 80% of CO emissions originate from transport sources [11]. Most of these pollutants are involved in chemical transformations which cause the composition of pollutants in the air to differ from those emitted from vehicle exhausts. Pollutant emission rates are highly dependent on vehicle operation mode. The highest emission rates for CO and HC occur at the low average speeds typical of urban driving, in which frequent starts and stops, accelerations and decelerations occur. At higher average speeds, engine efficiency improves and

emission rates reduce on a distance-travelled basis. However, as engine temperature increases at these higher average speeds (when fuel consumption per unit time is high), the rate of formation of NOx also increases. The contribution of individual vehicles to overall pollution levels can be expressed in terms of emission factors. These seek to quantify the mass of a pollutant emitted by a given vehicle under a set of operating conditions, and are combined with vehicle activity information in order to obtain emissions inventories [11].

2.2.2 Greenhouse Gas Emissions

Of the three greenhouse gases CO_2, nitrous oxide and methane, only CO_2 is emitted in significant quantities by road transport. Current trends indicate that the rate of increase in total greenhouse gas emissions in Ireland is well above that allowed under the Kyoto Protocol. A report published by the Environmental Protection Agency in 2000 [12], suggested that greenhouse gas emissions from transport increased by 80% between 1990 and 1998 in Ireland. Also, whereas the transport sector was responsible for just under 10% of total greenhouse gas emissions in 1990, this had risen to nearly 15% in 1998. Ireland's Climate Change Strategy [13], contains a commitment to put in place an appropriate framework of taxation, prioritizing reducing CO_2 emissions, from 2002.

2.2.3 Ambient Air Quality

Motor vehicle emissions impact on the atmospheric environment as elevated ambient concentrations. At a local level, regulation of these impacts in future years will be carried out within the EU Framework Directive on ambient air quality assessment and management [14]. They set out limit values for ambient concentrations of a range of pollutants. With respect to vehicle emissions, the most relevant values are those specified for CO, NO_2/NOx, PM10, and benzene. Different dates for the attainment of the limit values are specified. The ways in which the limit values are expressed are related to the mechanisms of their actions on the human body. Since the effects of sulphur dioxide may occur rapidly, a short (15 min) averaging period is employed, whereas an annual average suffices for benzene, for which no such rapid effects occur. Currently, nearly all urban residents in the EU still experience air quality that does not

comply with EU air quality standards. It has been suggested that in recent years, PM10 concentrations in Dublin have been close to the limit values to be attained by 2005, and above those to be attained by 2010. It has also been suggested that ambient NO_2 concentrations in the centre of the city is close to the Directive's limit values [15].

2.2.4 Traffic Management and Air Quality

The following measures can be considered for the management of traffic during high pollution episodes [16];

(i) Environmental road pricing (to encourage modal shift),

(ii) Environmental access control (to prevent access by a proportion of vehicles),

(iii) Traffic re-routing away from pollution 'hotspots',

(iv) Traffic signal control.

(v) Identifying a number of traffic management measures which have the potential to reduce vehicle exhaust emissions, including urban traffic control, parking control, park and ride, mass transit systems and public transport pricing policies. In recent years, demonstration projects of environmental access control measures have been carried out in Paris, Athens and Rome.

2.3 Emission Control and Exhaust Emissions

Many studies have been carried out to demonstrate the development and implementation of CNG systems. Verbeek [17], highlighted the development of NGVs since 1993 and their relative position due to the incredible reduction in emission. Verbeek indicated that all 2003 cars improved in HC/CO emissions. There were marked improvements for all Spark Ignited (SI) cars, as figure 2.1 shows, but the improvement rate is most significant for CNG/LPG due to rapid developments from the original equipment manufacturers (OEM).

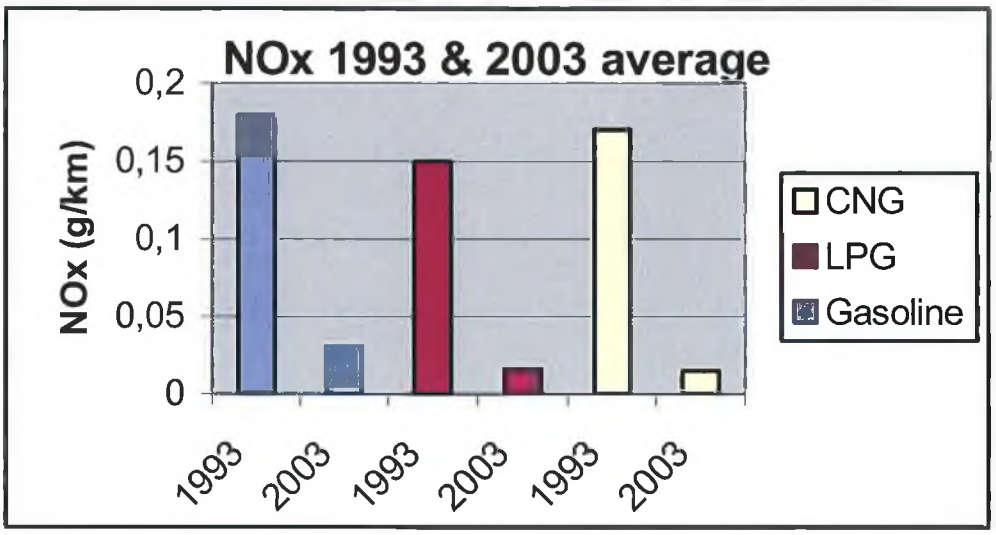


Fig 2.1 Average NOx graph for SI engines in 1993 and 2003 [17]

Verbeek points out that diesel vehicle continue to emit a high percentage of PM, despite the significant progress in reducing overall PM emissions as figure 2.2 shows.

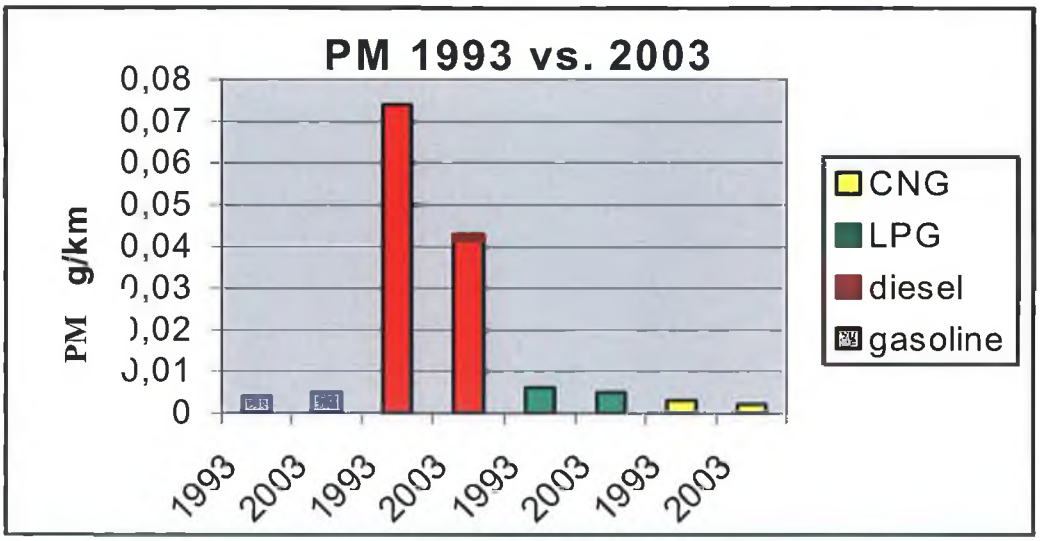


Fig 2.2 Particles in EDW 1993 vs BD 2003 [17]

In a 1999, Kremer's report [18], the average emissions for each pollutant from Light-Duty Truck 1 (LDT1) and Light-Duty Truck 2 (LDT2) classes were compared to the

estimated MOBILE6 ULEV emission factors for that truck class at the same mileage. Figures 2.3 and 2.4 show the comparison.

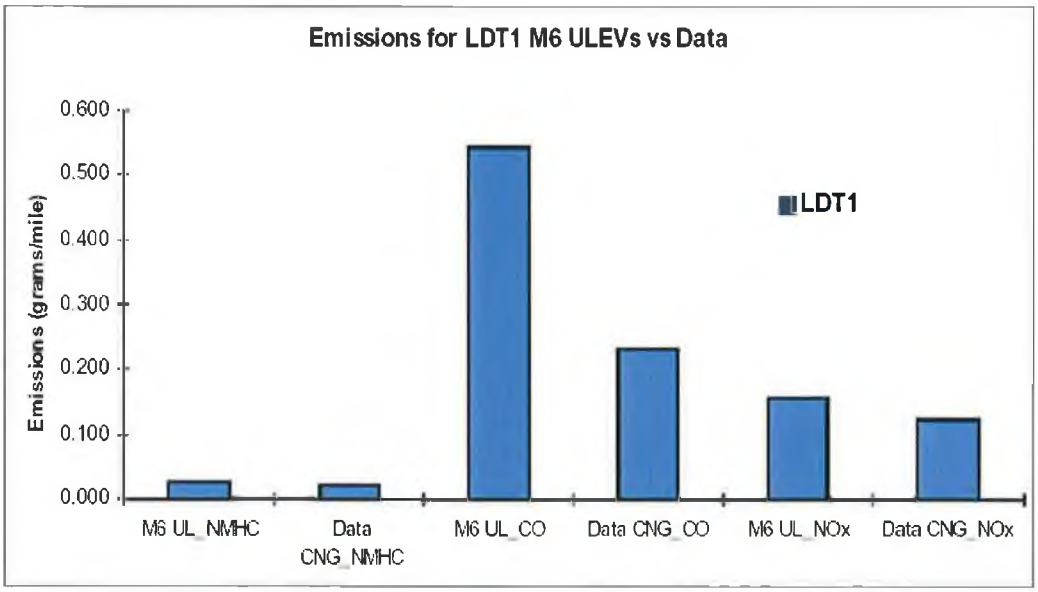


Fig 2.3 Emissions for LDT1 M6 ULEVs vs CNG data [18]

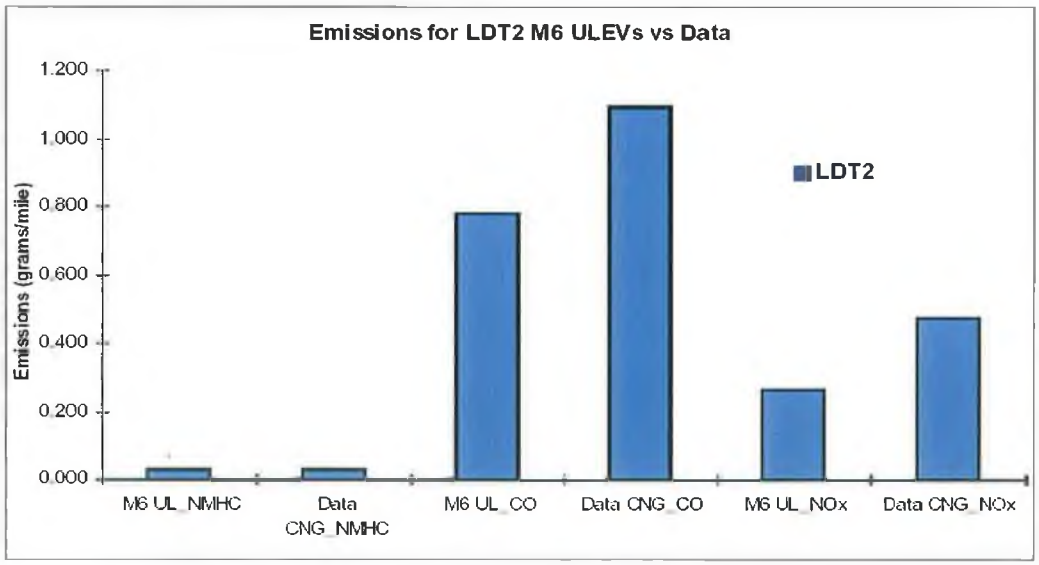


Fig 2.4 Emissions for LDT2 M6 ULEVs vs data [18]

Duggal [19], has indicated that, in 2007 the emission levels for natural gas and diesel engines should reach 0.2g/bhp-hr NOx. Both engine types will be challenged to meet these proposed standards which, from an in-cylinder optimization standpoint, appear infeasible.

In their paper Wang and Watson [20], indicate that the first result of a direct injection (single injector) CNG engine were presented with the following findings:

1. Negligible levels of CO and NOx emissions were preserved with the introduction of CNG and direct injection.
2. HC emissions were reduced by an approximate factor of one third to one half by replacing port inducted propane with port inducted CNG.
3. HC emissions were reduced by a further 100 ppm C6 by using direct injection of CNG instead of port induction.
4. Fuel stratification was minimally achieved by direct injection, although the decrease in exhaust HC is mainly attributed to a reduction in crevice emissions.
5. The evaporative emission control system is unnecessary for CNG vehicles, because a closed fuel system is used. The catalytic converter volumes are also the same as gasoline, 0.7L for the close-coupled converter and 1.3L for the under floor converter. The composition of noble metals in the CNG catalysts were optimized to obtain high conversion rates in catalyst durability tests. The fuel injection is controlled so that the exhaust gas A/F ratio stays as closely as possible to the stoichiometric A/F under any engine operating conditions, utilizing the A/F sensor and heated O_2 sensor. It is expected that when such strategy is implemented, the conversion efficiency of the catalyst can be fully utilized. Gasoline engines usually require increased fuel injection due to wall wetting in the intake port. However, the use of gaseous CNG fuel eliminates this problem. Therefore, as shown in Figure 2.5, cold start ability is good, and because it is possible to set the A/F for stoichiometric A/F, HC and CO emissions are reduced just after engine cold start [8].

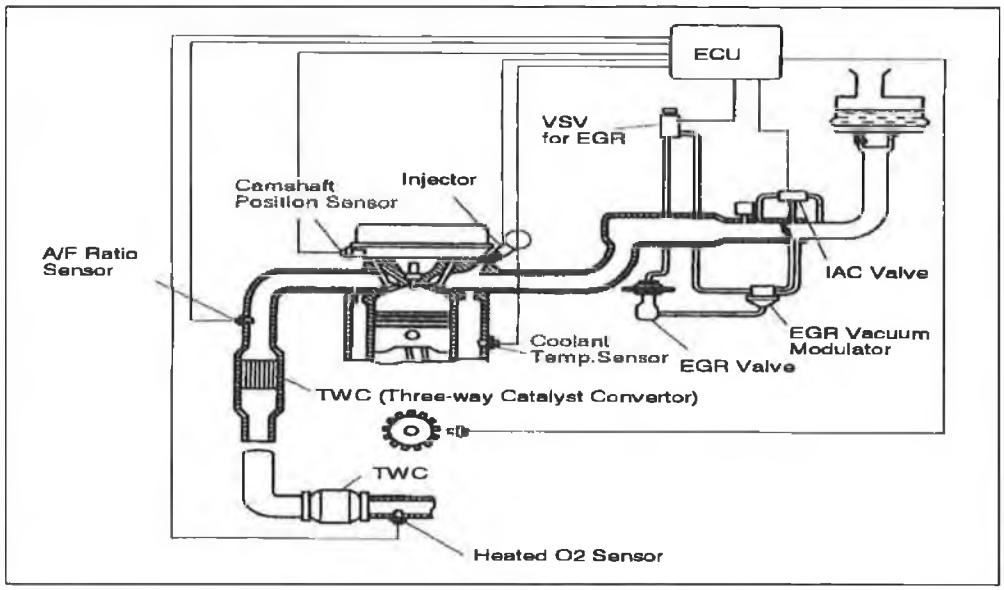


Fig 2.5 Exhaust emission control systems [8]

According to Wang and Watson [20], the significant reduction in CO emissions is one of the major advantages of lean engine operation.

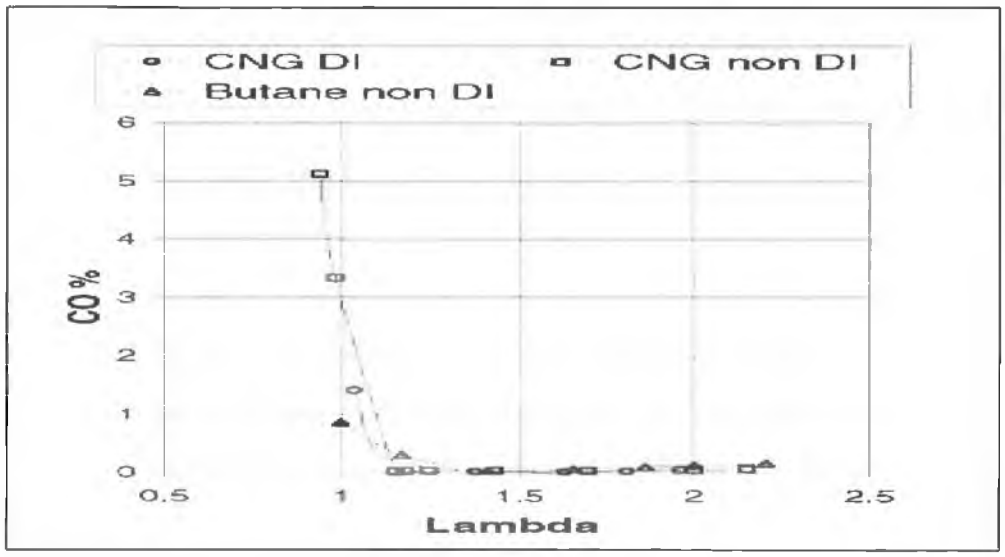


Fig 2.6 NO Emissions vs. Lambda NOx emissions [20]

Figure 2.6 shows that the percentage of CO in the exhaust gas in all cases is very close to zero for $\lambda > 1.2$, where λ is the relative air/fuel ratio, which is obtained by dividing the

actual air/fuel ratio by the stoichiometric air/fuel ratio. This is as expected and is due to the large amount of oxygen available to fully oxidise carbon when running lean. The increase in CO emissions around $\lambda = 1$ is not significant.

Figure 2.7, illustrates the measured HC emissions for the three operating conditions. The operating condition which clearly generates the highest HC emissions in the ultra lean region is port-inducted propane. The difference in compression ratio also has no effect on the validity of the general trends noted, since an increased compression ratio typically increases HC emissions.

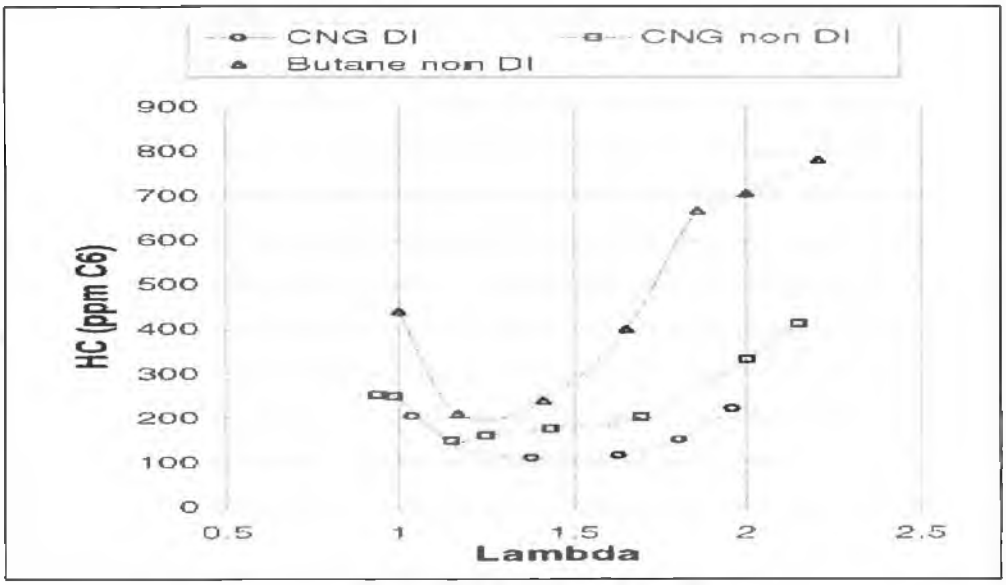


Fig 2.7 HC emissions vs. Lambda [20]

2.4 CNG Alternative Fuel Systems

In recent years there have been considerable advances in technological developments for CNG Engines. The following highlights the latest development in CNG vehicles in terms of wear, fuel, new components and others. Also highlighted are the advances made in crossing over to hydrogen powered vehicles and how natural gas is the near term solution to the implementation of these ultra-low emission vehicles. Ecatania et al, [21] compared the wear mechanisms between gasoline and CNG system. The study demonstrated that all higher temperatures were due to the lack of latent heat of

evaporation created by the oil. There is a gum component in oil which acts as a lubrication device for gasoline system which is not present in CNG. Lewis et al. [22] found that CNG engines have greater wear when valve seat temperatures are lower. Valve seat wear is temperature dependent. Therefore it is necessary to produce alloys that are not susceptible to the same temperature dependencies. In order to secure wear resistance in the dry environment characteristic of gas fuels, the material has improved by adding Co-Mo-Cr to increase the hardens and eliminate the wear effect. Daisho et al. [23], indicated that by increasing intake temperature, total hydrocarbons (THC), CO and NOx are reduced.

Finley and Daly [24], compared the cost of Natural gas and Diesel, the results can be summarized as the following:

- Lower Maintenance Costs due to better training
- Reduced engine wear due to fewer engine deposits,
- Absence of pre-ignition engine knock,
- Lower internal stresses (without compression ignition),
- Better oil life.

Hu et al [25], and Chen et al [26], have both reported that the new CNG engines which have adopted high compression ratios, intake valves with early closed timing, intake and exhaust valves with increased lift and low backpressure muffler, have restored a loss in power. As Lewis [22], mentions, the valve retainer life has been increased 50% and also reductions in pressure variations in the system have been achieved. New wear testing methods have been developed which helps in the identification of new surface treatments processes for valve seat insert applications [27]. Sakai [28], has recently reported a positive effect on wear resistance and self-lubrication using new additive materials. This is as an alternative to hazardous elements such as lead, which were previously used. New lead free, 20% cheaper material, which consisted of 6% CaF_2 additive, has actually been shown to demonstrate better characteristics than that of lead containing valve seat materials.

Dam et al [29], showed that the CNG engine shows a large efficiency improvement as well as cutting Hydrocarbon emissions by nearly 50% compared with port induction of

propane. Furuyama and Yan [30], investigated the premixing of natural gas and air and found it was inadequate due to adverse effects on engine combustion as well as emission characteristics. Studies have developed a two-dimensional CNG mixer with good characteristics. Sato et al [31], have studied the effect of gas fuel on wear mechanisms and have developed and improved the valve seat material resist the wear mechanism produced by the gas fuel. Amorese et al. [32], have introduced a new CNG feeding systems based on the sequential multipoint gas injection. In those systems there is one injector for each cylinder. With respect to the carburetted systems they allow lower fuel consumption, superior stability, better performance and very low emissions in transient.

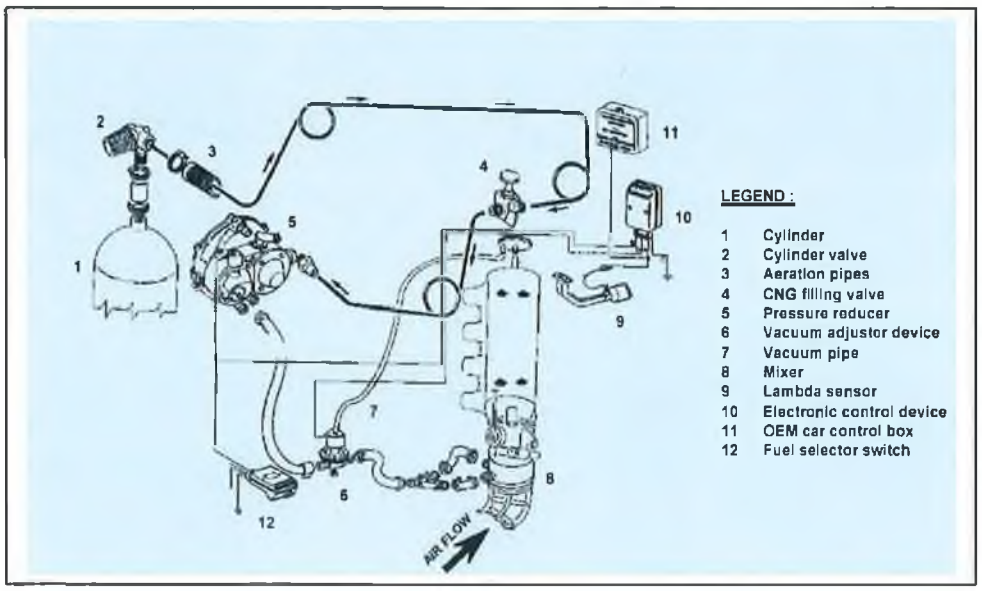


Fig 2.8 Traditional CNG after-market kit (beginning of nineties) [32]

Figure 2.8 shows a traditional CNG feeding system diffused in the retrofit market. In the traditional systems, the CNG is stored in the tank at a pressure ranging between 20 and 200 bar, and from there is delivered to a mechanical pressure reducer. Finally, the fuel flows at a reduced pressure to a value slightly above the manifold air pressure, which would be adjusted with a mechanical element. Obviously, the adjuster senses the manifold air pressure and corrects the fuel dosage depending on the engine load.

Figure 2.9 shows a state of the art fuel feeding system. Before entering the rail where the CNG pressure is reduced to about 10 bars, the ECU controls the signals coming from the throttle, rpm, manifold air pressure, rail pressure and temperature sensors, then calculates the injectors Energising Time and closes the loop with the lambda sensor signal.

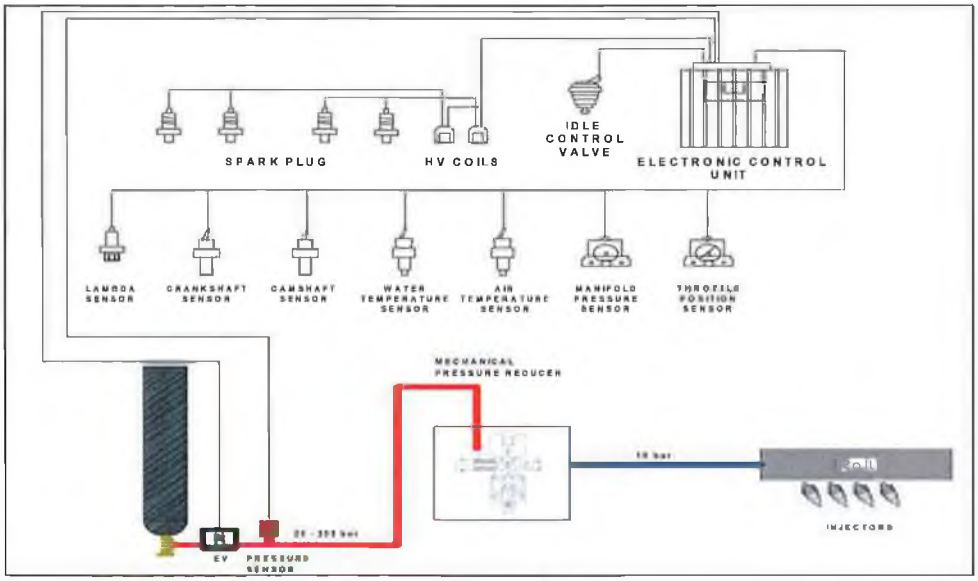


Fig 2.9 First generation of OEM bi-fuel fuel feeding system [32]

2.4.1 Evolution of CNG Feeding Systems

As mentioned in Amorese, et al 2004 [32], there are different points which should be addressed to improve the current CNG fuel system:
First: further pollutant emissions reduction, and
Second: improvement of the engine performance.
To achieve those goals, it is recommended that the different CNG components of the fuel feeding system should be redesigned. The main component could be:

- The shut-off valve;
- The pressure reducer;
- The injectors;
- The electronic control unit.

The core of the new fuel injection system is represented by the chance to control suitably the rail pressure. The scheme of this innovative fuel feeding system is shown in Figure 2.10.

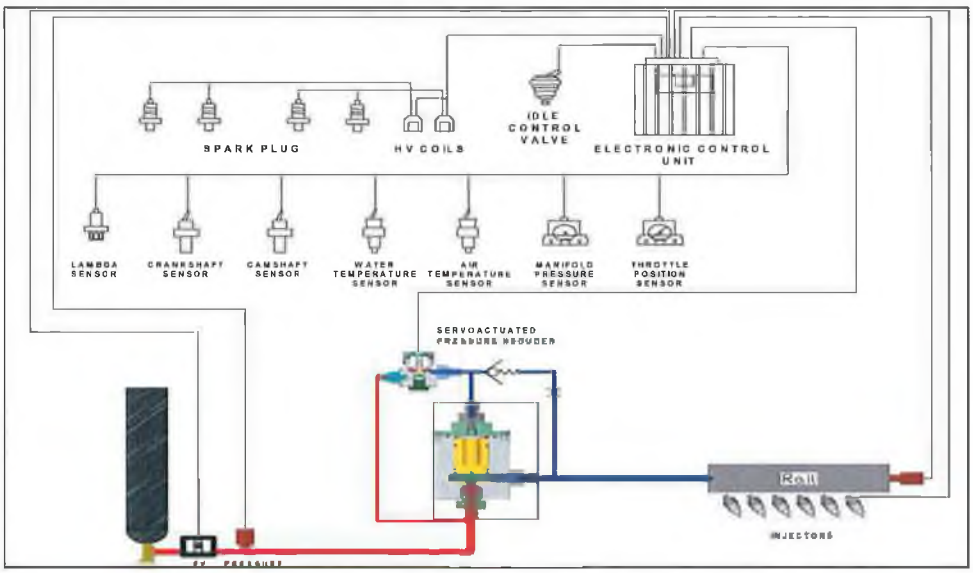


Fig 2.10 Scheme of electronic pressure control [32]

In the proposed system, the CNG tank pressure is measured to give the driver information about the CNG remaining in the tank. The rail pressure and temperature are measured to optimize the fuel metering. This innovative ECU has to be provided with a power output stage to drive the pilot valve. A suitable algorithm has to be developed to control the rail pressure.

From one of the leading European companies in the field of engine and vehicle development, Kahland and Avramopoulos [33] reported in their study that their company *Ingenieurgesellschaft Auto und Verkehr* (IAV), has already usefully developed and implemented for series production a number of concepts for natural gas vehicles. It was also indicated that the production vehicle development currently conducted by the IAV company in the field of gas vehicles for both liquid petroleum gas (LPG) and compressed natural gas (CNG) included the following:-

1. Development of a bivalent LPG vehicle with LPG injection, for the Chinese market,

2. Development of a fork-lift truck with monovalent CNG operation,
3. Development of a fork-lift truck with monovalent LPG operation, and
4. Development of the Volkswagen Golf 2.0-litre Bifuel.

2.4.2 Test Setup of CNG Systems

Hu et al [25], proposed a test setup for a CNG fuelling systems consisting of a fuel tank, pump, fuel supply and return lines, six injectors connected in series, a pressure regulator, an injector power supply and controller. In this investigation, the fuel injection system was fired in the order 3-6-1-5-2-4. The pulse width for each injector was 2.5 ms. The setup can simulate the real working environment of the real fuel injection system mounted on an engine block as can be seen in figure 2.11.

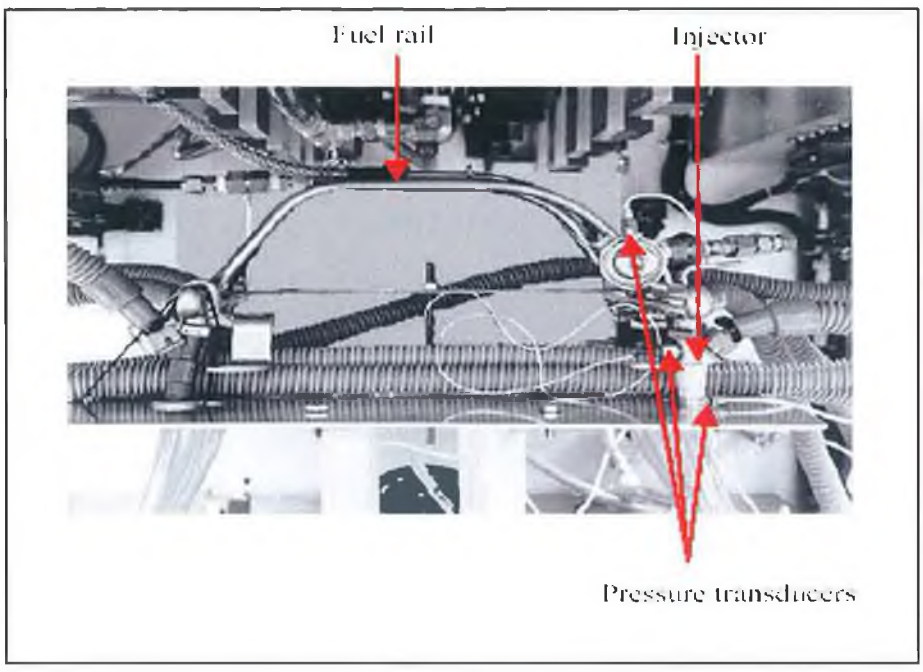


Fig 2.11 Measurement setup on a test bench simulating a real, full-size vehicle [25]

To monitor the pressure fluctuations at various locations of the fuel injection system, several pressure transducers are mounted on different locations in the system including the top and bottom sections of various injectors and a point on the pipeline 2 as shown in figure 2.12.

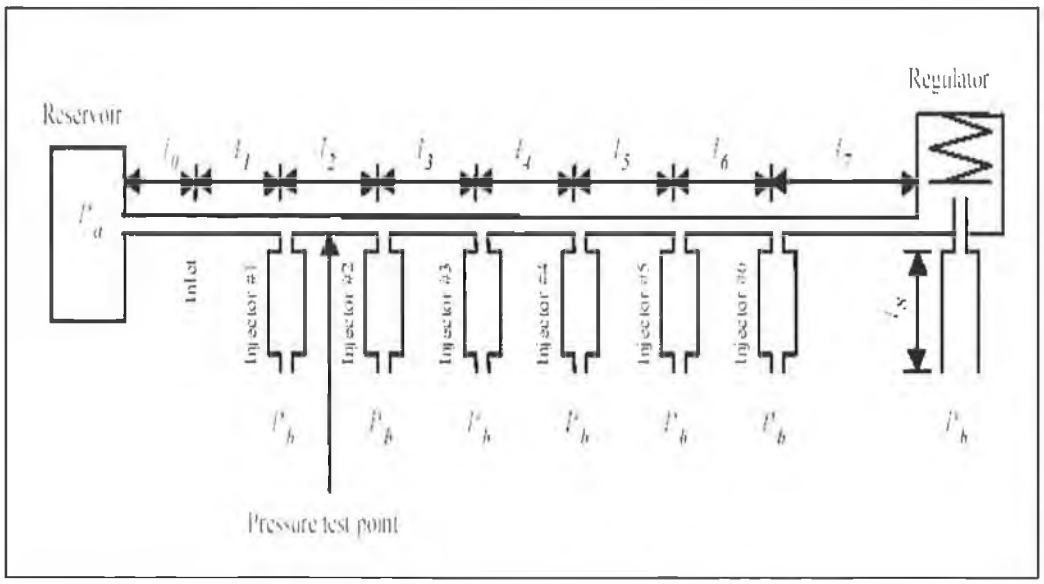


Fig 2.12 Schematic of automotive fuel rail system with six injectors and regulator [25]

2.4.3 Fuel Metering System

In the work of K. Kato et al [8] for Toyota Motor, high-pressure natural gas from the fuel tank is reduced through a pressure regulator before being supplied to each injector, as shown in Figure 2.13. Injection flow rate is controlled by the ECU as in gasoline engines. By using a sequential multi port injection (MPI) system for supplying fuel to each intake port, feedback A/F ratio was precisely controlled and the A/F ratio dispersion among cylinders was reduced and transient response time in fuel metering was improved. In order to realize such an MPI system, the injector and the pressure regulator have been newly developed. The injector is newly designed to supply sufficient flow and overcome the inadequacy of lubricate due to gaseous fuel [8].

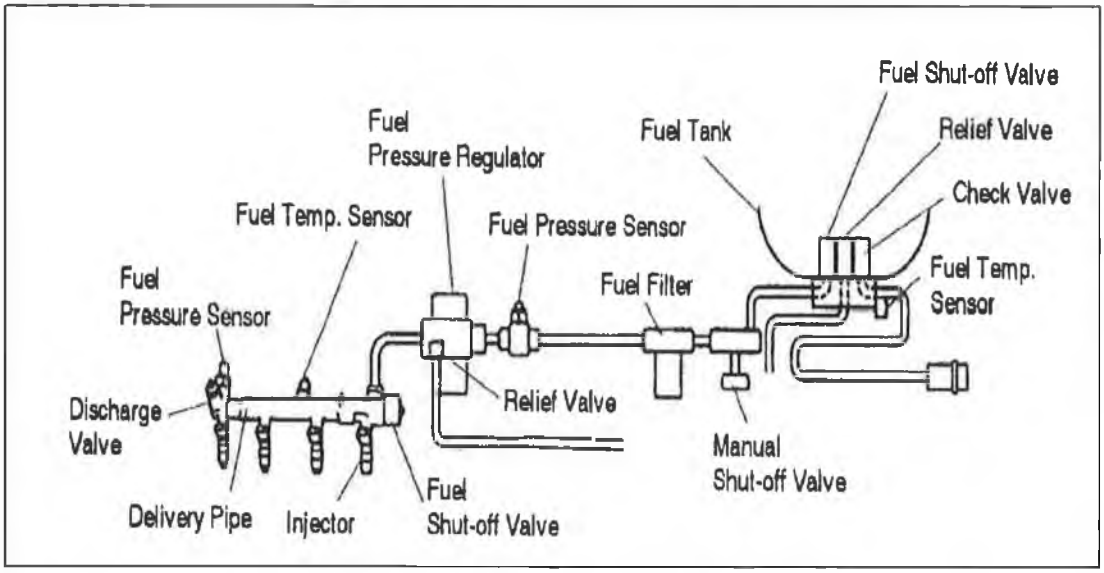
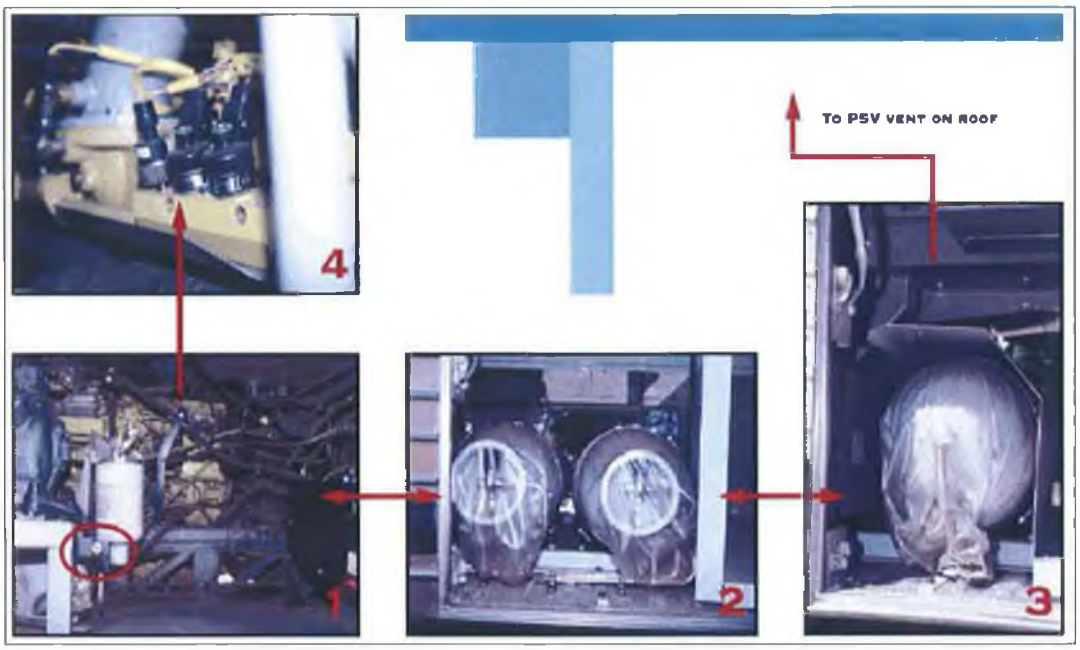


Fig 2.13 Fuel system diagram [8]

2.4.4 CNG on Dual Fuel Bus

CNG components on dual fuel buses were investigated by McKinley and Bining [34], The three buses were each fitted with four CNG cylinders for a total CNG capacity of 48 Diesel Equivalent Gallons (DEGs) at 3,000 psi (58 DEGs at 3,600 psi). (A diesel equivalent gallon is defined as the quantity of CNG at a specified pressure with the same energy content as one gallon of diesel.) Three cylinders were installed in the lower rear baggage compartment; one cylinder was installed in the lower forward baggage compartment. The cylinders were hooded to vent CNG leaks to the atmosphere, instead of into the baggage compartment. Pressure relief valves and associated plumbing were installed to vent over-pressurization events to the rear roof area of the bus. Bus range was approximately 460 miles in dual fuel mode (based on the average 56% CNG substitution rate and 5.3 miles/DEG obtained over the demonstration period). Figure 2.14 illustrates CNG components on the bus.



1) Passenger side engine compartment housing the CNG fill nozzle, pressure gauge, regulator and shut-off valve. 2) CNG storage tanks located in the luggage compartment. 3) Storage tanks incorporate pressure relief valve located on the driver side of the bus. 4) CNG injectors located on the air intake manifold of the dual fuel engine. The arrows show direction of CNG flow.

Fig 2.14 CNG components on a dual fuel bus [34]

2.5 Alternative Fuel Vehicles (AFVs) Industry

CNG is one of the most important alternative fuel systems for vehicles. The position of the automotive industry is that research and development of alternative fuels for automotive use will continue only if it is required by the government and society. In part, this is because sales of AFV's have been minimal to date. Automobile manufacturers, like all businesses, are subject to the demands of the market and will not continue to produce low-demand products unless they perceive a change in these demands or are forced to do so by the government. It is important to recognize, however, that if the market favoured AFV sales, auto makers would likely increase production and thereby reduce the overall cost of AFV's. Currently, the imposition of government fuel economy standards, and subsequent provisions for AFV's in those standards, has prompted auto makers to develop lines of AFV's. There are two types of AFV's, those

manufactured by the auto maker called Original Equipment Manufactured (OEM) and those converted by after-market conversion companies [34].

2.6 Government Incentives

A number of governments (at the national and local levels) have been approached to create policies that are favourable to NGV's and/or alternative fuels. Some have responded favourably. Others still have yet to put NGV's and clean fuels on their political agendas. The NGV industry struggles internationally to win government incentives to bring the economics closer to that of gasoline and diesel vehicles [35].
Government actions which would support the further development and use of NGV's would be:

1. Incentive policies such as competitive gas price, tariff reduction for NGV's and related equipment, investment incentives for NGV-related businesses, attractive loan packages for CNG bus operators/users;
2. Mandates including gas infrastructure, clean air act implementation, franchising/registration;
3. Financial support for research and development;
4. Development of standards;
5. Public education [36].

Incentives encouraging the use of NGV's differ by country. In the Philippines for example, emissions from motor vehicles have been identified as the major cause of air pollution in the Metro Manila area. Almost 4.2 million motor vehicles that the various roads and thoroughfares in the Philippines are diesel and gasoline fed. The Government of the Philippines, through the Department of Energy (DOE), has focused on developing an ambitious program on the use of clean fuels that is facilitated through the intensive promotion and utilization of alternative fuels and technologies [37]. In Germany, Sweden, and the UK there are special tax provisions that reduce fuel taxation. In Belgium, Ireland, and Italy there is no fuel tax on natural gas as a vehicle fuel, making it very economical, compared to other competitive fuels. In Germany, the ministry of the environment ran a competition worth approximately 5 million Euros, which it awarded

to the city of Augsburg as a promotion for NGV's. Other incentive programmers are developing slowly in Europe [35].

During this case of this work, has been highlighted the role of the Irish government to ensure the success of CNG vehicles. It is suggested that the government should meet the following criteria:

1. Financial incentives for those who either supply, purchase or convert to Natural Gas Vehicles. Reducing the tax on natural gas in comparison with that of gasoline to encourage people to convert or buy NGV's.
2. Mandates to ensure that quotas of NGV use are reached within given timeframes.
3. Set an example by using NGV's for public transport, government cars etc.
4. Invest in Research & Development in Institutes and Universities around the country who will seek to improve performance characteristics of the CNG vehicles
5. Launch a nationwide campaign to educate the population on the benefits of NGV's from both an economical and environmental point of view.
6. Ultimately develop an Alternative Fuels Policy for the country modelling on other countries where NGV's are more common [38].

McFadden, [49] pointed out that the two major advantages of using AFV's are reducing automotive emissions and limiting dependence on foreign sources of oil. It was found that the federal government has shown that it recognizes the potential benefits of AFVs in both of these categories. It is clear that the government is trying to maximize the benefits of AFVs while maintaining a balance between government mandates and consumer demand. Williander [40], has suggested that eco-benign products are developed in a domain wherein various interests, initiations, organizations and policies are intersecting. Such products require strategic treatment by top management. He recommended the managers at Volvo Cars Company should support and even initiate governmental initiatives that make environmental product attributes competitively rational, and also he recommended Government should design legislation to bring competition into use for eco-environmental improvements.

2.7 Survey Research

Surveys are an important means of learning about people's attitudes, behaviour, and characteristics and to assess any activities in any field. Every day, policy-makers, the media, and market researchers use surveys to describe the population, to make critical decisions, to analyse how various groups feel about a range of topics. According to Whitman [41], a survey is a systematic method used to collect data from more than one source to answer one or more questions typically arranged on a form called a questionnaire. There are several methods that can be considered in order to collect data in survey research. Each has advantages and disadvantages. Bachmann and Elfrink [42] and Diem [43] have classified methods of collecting data in survey research these methods are: postal survey, telephone survey, personal interview (face-to-face), and web-based survey. This research involved both postal and web-based surveys.

2.8 Web-Based Surveys

Over the last decade, electronic surveys have evolved from disk-by-mail surveys, to e-mails with embedded or attached surveys and finally to web-based surveys posted on the Internet [45]. With web-based surveys, participants are usually notified by e-mail to participate in the survey. The e-mail generally includes a link to the URL (uniform resource locator) web address of the survey [46]. Internet based technology such as the World Wide Web (web) is fast becoming accessible to large segments of society. Usage is doubling every year with a current estimate of 1 in 6 people using the Internet in North America and Europe [47]. However, two web-based surveys were produced for the purposes of this study. One aimed at CNG car and OEM companies, the other at CNG vehicle customers.

In this research in the field of survey of the development of alternative fuel system for vehicles, both paper questionnaire and web-based surveys were used as a method to collect data. As part of this study, a comparison between the two methods (paper questionnaire and web-based surveys) will be conducted.

2.8.1 Historical Development of the Web-Based Survey

Beginning in the late 1980s and early 1990s, prior to the widespread use of the Web, e-mail was explored as a survey mode. As with the Web today, e-mail offered the possibility of nearly instantaneous transmission of surveys at little or no cost. Unlike the Web, however, early e-mail was essentially static, consisting of a basic ASCII (text-only) message that was delivered via the Internet. E-mail surveys tended to resemble the linear structure of a paper survey and were generally limited in length. Furthermore, because e-mail surveys were primarily text-based, document formatting was rudimentary at best. The only significant advantage they offered over paper surveys was a potential decrease in delivery and response time and cost, although some observers also hypothesized that the novelty of the new medium might actually have enhanced response rates [48, 49]. The Web started to become widely available in the early- to mid-1990s and quickly supplanted e-mail as the Internet survey medium of choice. Whereas early e-mail was all ASCII-based, the Web offered the possibility of multimedia surveys containing audio and video, as well as an enhanced user interface and more interactive features [50].

2.8.2 Methods of Online Survey

MacElroy [51], has classified current methods/ technologies for conducting on-line research projects into seven methods. These range from the most basic, least costly methods (e.g., text e-mail) through highly sophisticated and relatively expensive forms:

- E-mail (text);
- Bulletin boards;
- Web HTML;
- Web fixed-form interactive;
- Web customized interactive;
- Downloadable surveys;
- Web-moderated interviewing: chat interviewing and other discussion formats (qualitative).

1. E-mail (text)

One of the earliest methods for conducting surveys over the Internet or over a company's internal system (intranet) is the simple text-based e-mail survey. These surveys can be generally thought of as on-line paper-and-pencil surveys [51].

2. Bulletin Boards

Specific web sites were used in inviting discussion topics or where discussion topics are posted. This online research is relatively easy and fast. It is also considered as inexpensive category of bulletin board research where responses are collected over time. The user responds to the original topic and to whatever the other users have written in response to the topic. This way the information is fed back and forth between users. The task of forming a bulletin board is not difficult but it would be required to have more skill than forming an e-mail survey.

3. Web HTML

The most common form of on-line surveying is the flat HTML survey form. Characteristically, these surveys take the shape of a long, single page on which the respondent clicks buttons and boxes, fills in text boxes, and eventually submits the information all at once.

4. Web Fixed-Form Interactive

Another new form of on-line research is being driven by survey authoring tools. Many of these tools have been developed from previous generations of softwares used to conduct computer-assisted telephone interviews (CATI) or disk-by-mail (DBM) studies. They have been adapted to "play" questions on the Web the same way they would play for an interviewer at a tele-polling station.

The big innovation is the option of allowing the individual researcher to construct highly sophisticated studies for the on-line environment. These software packages put many of the sophisticated controls, which have been available for phone studies since the late '70s, directly into the researchers' hands. Most of these tools exist as packaged software programs that the researcher uses on his or her own PC. As an alternative, several

interesting new Web sites have emerged which allow the author to design the research on-line without the need for loading the design software.

5. Web Customized Interactive

The most powerful and flexible of all on-line surveying options are those that involve the custom programming skills of highly skilled technical people. They also tend to be the most expensive. Like the fixed-form tools, custom programming provides all of the modern technical controls (screening, skip-patterns, logic, error-checking, etc.), but also offers many other tricks and options that allow the researcher the highest level of flexibility currently available for design and functionality.

6. Downloadable Surveys

Another on-line survey method attracting attention is surveys that are downloaded from the Web and run on previously installed software provided by the researcher. This shifts the computing tasks from the on-line server to the respondent's PC. Once pre-loaded, the survey software can then read much smaller files that the respondent downloads from the Internet. The result is surveys that run in a very similar manner to the fixed-form interactive surveys. Once the survey has "played" on the respondent's PC, a data file is created which can then be uploaded the next time the Internet is accessed [51].

7. Web-moderated Interviewing: Chat Interviewing and Other Discussion Formats (qualitative)

In these interview sessions, the logic and control mechanisms are supplied by a highly skilled human moderator. People enter the interviewing chat session and then type the answers to questions posed by the moderator. While the results from traditional focus groups can be highly influenced by the skill of the moderator, these on-line chat sessions are doubly tricky. Just as the traditional moderator must control the overly enthusiastic participant, the on-line moderator must control the "tyranny of the fastest typist." [51].

2.9 Structure of the Web-based Survey through the HTML

Most Internet surveying is now being done using HTML forms with potential respondents often contacted via email cover letters. While some developers still directly code these forms in HTML, there are dozens of HTML editors available, and they are becoming increasingly sophisticated and easy to use. There are two general methods of capturing the data entered into a HTML form. The form can be programmed to email the data back to a specified email address or captured by a program on the server called a common gateway interface (CGI) script. Using CGI scripts is more robust, offers more flexibility and is the far more commonly used method of capturing data. There are several HTML development packages that both provide HTML editing capabilities and automate the process of developing the CGI scripts necessary to capture data from HTML forms developed with the package. Two widely used examples of these packages are Microsoft's FrontPage and Macromedia's Cold Fusion.

While these packages are general purpose Web development tools, there is also a growing number of software development systems designed specifically for Web-based surveying. These packages tend to offer additional features specific to survey research. Examples include the managing of the distribution of email cover letters, built-in statistical analysis and reporting capabilities, and automatic tracking of people who have responded, coupled with the ability of sending out follow-up email reminders to those who have yet to respond. Their HTML editors are also geared for survey form development, allowing them to simplify and streamline the process of developing and formatting the question response fields [52].

2.10 Response Errors and Rates

This is very important topic in any survey based research which relates to reliability and validity. According to Sudman and Bradburn [54], the different types of errors fall into four factors:

- Memory: material may be forgotten or may be remembered clearly.
- Motivation: respondents may want to present their companies in a better light.
- Communication: inability to understand the questions asked.
- Knowledge: respondents may not know the answer.

Apart from the problem of response errors that have a bearing on the reliability and validity of the survey and consequently the research study, the problem of low response rate has always been a major cause of concern to any researcher.

According to Moser and Kalton [55], it is not the loss in sample numbers that is serious, but the likelihood that the non-respondents differ significantly from the respondents.

There are various types of non-response such as:

- Companies outside the population
- Companies refusing to co-operate.
- Change of addresses or wrong addresses.

2.11 Summary of the Literature Review

The literature survey revealed very important major aspects based on previous studies in relation with CNG scenario. These studies showed the weakness of implementation of CNG market around all Europe, the weakness of level of CNG development and the increase of emissions which originate from transport sources.

Based on these facts, it was essential to investigate and develop a suitable strategy which will assess the level of development of CNG systems, by conducting two comprehensive surveys which were addressed to CNG car and OEM companies, and CNG vehicle ownerships in order to ensure the success in development of CNG program all around Europe. Sections 2.8 to 2.11 were used to gather the data in this work. These are discussed in great details in chapter 3.

Chapter 3
Designing the Survey

3.1 Introduction

Given the relevant literatures, the purpose of this chapter is to describe the topics concerning the various research methodologies used in this study. Subsection 3.2 explains the objective of the research methodology. Subsection 3.3 identifies the sample covered by the methods used in this study. The methods used in this study are described in subsections 3.4 and 3.5. Four types of scales are identified in subsection 3.6. Moreover, the overall questionnaire organisation is discussed in subsection 3.7. In section 3.8 a pre-test and a pilot survey are performed. Finally, 3.9 includes the analysis of the CNG car manufacturers' survey and the CNG customers' survey.

3.2 Objectives of Surveys

The survey aims to evaluate the development and implementation of CNG vehicles by the car industry. The survey objectives can be summarised as the follows:-

1. To determine the obstacles facing the adoption of CNG systems in the car industry.
2. To determine the level of current development in CNG car manufacturing.
3. To determine the desire to adopt the technology over the coming years.
4. To study the effects and incentives influencing CNG vehicle manufacturing and CNG vehicle customers.
5. To evaluate customer satisfaction with CNG vehicles.

3.3 Coverage of Surveys

Two methods have been employed in this survey;

1) Postal survey

2) Web-based survey.

Both techniques were used to survey CNG manufacturing companies. Whereas only the web-based survey was used to question CNG vehicle customers.

A total of 250 manufacturing companies were identified and contacted. Since DCU is a member in European Natural Gas Vehicle Association (ENGVA), this organisation was contacted to provide us with information associated with CNG car manufacturing companies. As a response, details of 180 companies were obtained. From information received from the Engineers present during a conference held in Dublin City University in 2004, titled VAFSEP [44], a further 70 manufacturing companies and their relevant activities and addresses were identified.

The questionnaire surveys were sent to these 250 manufacturing companies by post and via the Internet. The number of responses received by post was 32 and the e-mail responses were 24.

For CNG vehicle customers, a list of customers was obtained from car dealerships around Europe. A total of 92 customers of CNG vehicles were selected for the on-line survey (Only contacted by email).

3.4 The Postal Survey

The postal survey materials were printed in booklet form, on A4 paper. The questionnaire was 5 pages long. A cover letter was printed on the official letterhead of the Mechanical and Manufacturing Engineering School, and signed by the investigator, and a reply-paid envelope was included in the packet. Reminder questionnaires were distributed after a month of the first questionnaire.

3.5 Web-based Survey Research

In the web-based survey used in this research, four tools were used to develop the interface of the Web-based survey of CNG vehicle manufacturers to restrict respondents' choices: radio buttons, check boxes, text boxes, and submit button. Radio buttons are used in multiple-choice questions to which the respondent is allowed to choose only one answer. Radio buttons are useful when the number of choices is relatively small because the other choices are automatically deselected when one choice is made. Radio buttons reinforce the rule that no more than one answer may be given to a question. This method is used in both questionnaires. Check boxes are used in

multiple-choice questions to which the respondent is allowed to choose one or more than one answer. This used in the CNG vehicle manufacturer survey. Text boxes are also used when it is necessary to get some details from the respondent. These are also used in the CNG vehicle manufacturers' survey. The submit button allows respondents to return the completed form. Figure (3.1) and (3.2) shows a snap shot of the online questionnaires

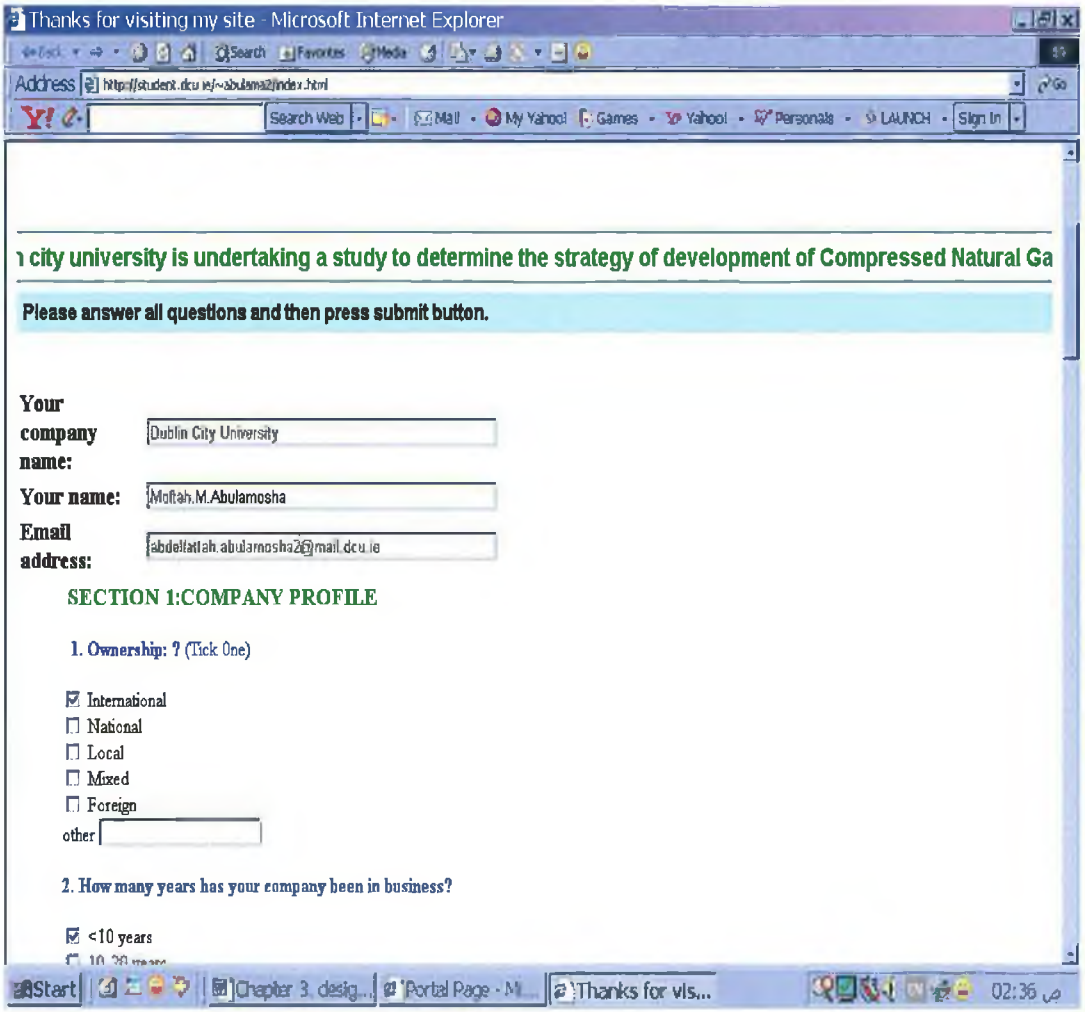


Fig 3.1 Snap shot of the online CNG vehicle manufacturing questionnaire

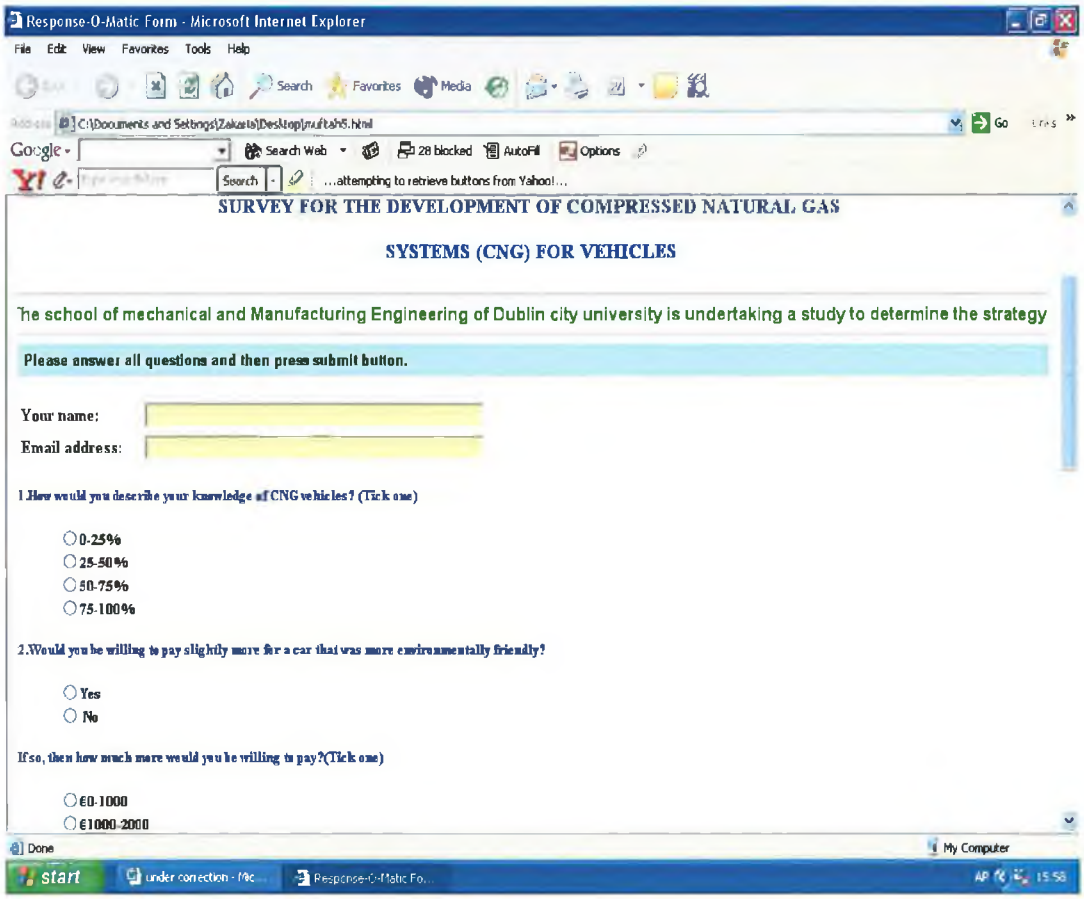


Fig 3.2 Snap shot of the online vehicle customer questionnaire

Response-O-Matic [53], was used in this analysis, which is a free form processor for html authors who want to add forms to their web pages.

In this work email messages were sent including a hyperlink to the web sites: http://student.dcu.ie/~abulama2/index.html for CNG vehicle manufacturing companies and http://www.mecheng.dcu.ie/abulama/muftah4.html for vehicle customers, inviting them to visit the website and complete the questionnaires on-line. When the respondent clicks on the Submit button, the contents of the form are sent to Response-O-Matic for processing. First, it returns the information the respondent has entered in the form. Second, it displays a "Thank You" page for the respondent. The "Thank You" page contains the contents of the completed form, so the respondent can review what was entered. Figure (3.3) and (3.4) shows a snap shot of the thank you pages.

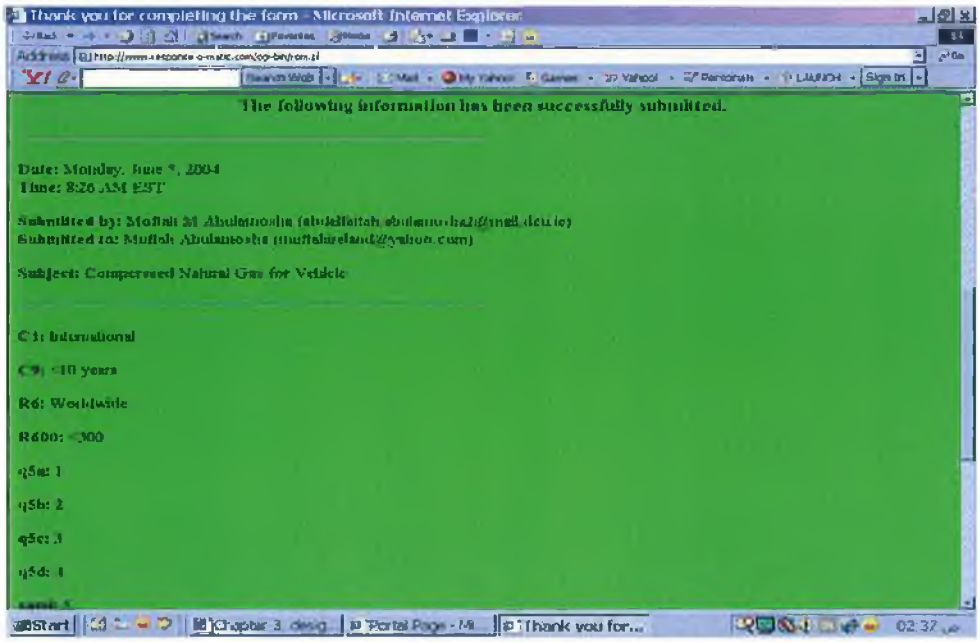


Fig 3.3 Snap shot of tank you page of CNG vehicle manufacturing survey

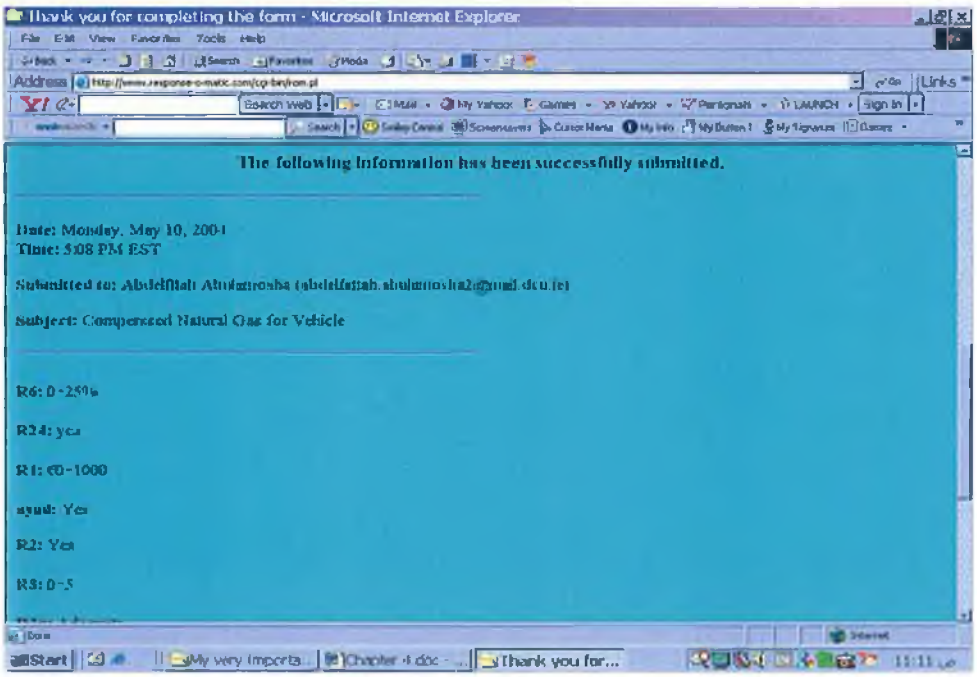


Fig 3.4 Snap shot of thank you page of vehicle customer's survey

3.6 Scaling of Responses

Scales are ways of ordering possible responses to a question. There are four types of scales that may involve numbers, each with different characteristics that determine the suitability of applying statistical tests, the types of scales are [41, 55]:

- Nominal scales,
- Ordinal scales,
- Interval scales, and
- Ratio scales.

- *A nominal scale* is simply a set of categories, which may or may not be numerically coded. There are many questions in this survey, which take this type of scale. Example: Section no 1, Question no 3: Focus markets? And the possible responses offered are: Worldwide, All of Europe, America, Africa and others. It is possible to code these responses using letters or numbers. There is no relationship between the types or codes used except to represent the names of the possible respondents.
- *Ordinal scale* use numbers, but only to represent an order or sequence to the responses, not to imply that there is an evenly spaced interval between sequential numbers. Example: Section 4, Question no. 2, 3 (refer Appendix B).
- *An interval scale has* equal units of measurement that makes it possible to interpret not only the order of the scales but also the magnitude of the distance between them.
- *Ratio scales* use numbers that start with a zero as a base, so that all the numbers are defined in an identical way relative to zero and the first number. Therefore, the number 2 means exactly twice the value between zero and one; the questions number 1, 2 of section 2.

3.7 Overall Questionnaire Organisation

Whitman [41], and Czaja and Blair [56] have identified several important factors and procedures for any questionnaire design. The questionnaire design should take into careful consideration the following points:

1) Clear and unambiguous questions,

2) Wording of questions,

3) Formatting the questionnaire, and length of the questionnaire.

Certain guidelines were also proposed by Sudman and Bradburn [54] and Frink [57]. In designing both questionnaires all the above guidelines have been taken into consideration. When designing the questionnaire for CNG vehicle manufacturers ideas have been taken from a similar survey carried out on 1999, namely the Survey of Advanced Technology in Canadian Manufacturing [58]. In this work, the questionnaire was divided into four sections:

***Section 1*:** Company profile

This section contains four questions (Questions 1 to 4). It covers the information concerning the Ownership, the number of years in business, implementation of such new technology, focus markets, and the number of employees.

***Section 2*:** Level of development of CNG system.

This section contains four questions (Questions 1 to 4). It covers the information concerning the level of CNG System in present and future plan, the obstacles as well as the CNG System for implementing advanced new technology in the factory.

***Section 3*:** Engine system after development CNG system

This section contains three questions (Questions 1 to 3). It covers the information concerning the current CNG engine after developed CNG system.

Section 4: Government Subsidy.

This section contains three questions (1 to 3). It covers the information concerning the government fund and benefit of these subsidies to the CNG car manufacturing.

All questions are in multiple choices format and a number of them have some space to make comments. This will save time for respondents and make questions more understandable.

In order to least interrupt the respondent's train of thought influencing his or her response, the questions have been ordered in logical sequence, for example question 2 section 2 sought information about the current level of the obstacles as well as the CNG System for implementing advanced new technology in the factory, next question sought information about the level of development of CNG system at the moment, and question 4 sought information about the level of development within next years.

3.8 Pre-test and Pilot Survey

Within the framework of the general principles and guidelines for administrating a sound survey, and in order to be sure that the questionnaire is understandable, to get any suggestions for improvements, to avoid any difficulty and to observe that the instructions and questions work as expected, pre-testing and pilot survey are necessary. In this study, pre-testing of the survey questionnaire was carried out on a number of occasions. Sample questionnaires were given to peers, academic staff of the School of Mechanical and Manufacturing Engineering and technical staff who are familiar and have experience in the industry field, and then revised by the project supervisor.

The pilot-testing phase showed that the average completion time of the on-line survey was about 20 -25 minutes.

By taking the results of the pilot test into consideration, reviewing and eliminating problem questions, the final questionnaire was refined to a form that can be characterised as: all questions are clear, understandable, in logical sequence, the length of the questionnaire is reasonable with an answering time of about 20 minutes.

3.9 Analysis of the questions' targets

In this section, the questions are analysed, one by one, to make sure that the meaning of each question is clear. It is also intended to clarify the aim of each question.

3.9.1 CNG Vehicle Manufacturing Companies

SECTION 1: COMPANY PROFILE

1-Ownership:

- ❑ National
- ❑ Local
- ❑ Mixed
- ❑ Foreign

This question seeks to identify the ownership of the companies. The objective of the question is to understand the investor nationality.

2-How many years has your company been in business?

- ❑ <10 years
- ❑ 10-20 years
- ❑ 20-30 years
- ❑ >30 years

The answer of this question with correlation with answers to questions 3 and 4 in section 2, should help to understand if young companies would like to adopt the new technology and whether older companies with more experience, could adopt or improve their current technology.

3- Focus Markets:

- ❑ Worldwide
- ❑ All of Europe
- ❑ America
- ❑ Africa

Parts of Europe _____

This question should help to understand if the company has established a network of distributors and relationships with automotive research Institutes, OEM and equipment distributors worldwide. Particularly in nations with active alternative fuels market.

4- Number of Employees

- ❑ <300.
- ❑ 301-1000
- ❑ >1000

This question would help to determine the company capacity and its strength of influencing the national and international market.

SECTION 2: LEVEL OF DEVELOPMENT of CNG SYSTEM

1- Based on your experience, please indicate the level of development, at your plant, with the following CNG vehicle categories:

*[Scale: **1**-non **2**-dissatisfied; **3**- very dissatisfied; **4**-satisfied; **5**-very satisfied]*

	1	2	3	4	5
Trunk space/cargo carrying capacity	❑	❑	❑	❑	❑
Driving range	❑	❑	❑	❑	❑
Refuelling component	❑	❑	❑	❑	❑
Vehicle safety	❑	❑	❑	❑	❑

This question will stress to the appropriate bodies whether or not their product is meeting the service level needed to continue and expand and will also highlight any problems arising.

2- Please rank the obstacles to Compressed Natural Gas Systems implementation in your plant?

*[Scale: **0**-Non **1**- very low **2**-low **3**-average **4**-high **5**-very high]*

	0	1	2	3	4	5
Time from development to implementation.	❑	❑	❑	❑	❑	❑
Cost.	❑	❑	❑	❑	❑	❑
Technical skills of staff.	❑	❑	❑	❑	❑	❑
Management commitment	❑	❑	❑	❑	❑	❑
Business nature unsuitable for development.	❑	❑	❑	❑	❑	❑

* *For any unlisted obstacles above, please specify: -*

F_____	**0□**	**1□**	**2□**	**3□**	**4□**	**5□**
G_____	**0□**	**1□**	**2□**	**3□**	**4□**	**5□**

This question seeks information on the obstacles of implementing CNG control system in the vehicle industry. Five general obstacles are identified, which usually face manufacturers when implementing new technology.

3- What is the level of development of CNG systems at your plant (check one)?

- ❑ No development
- ❑ Sparsely developed
- ❑ Somewhat developed
- ❑ Mostly developed
- ❑ Fully developed

In general the level of the development in industry plays an important role in the productivity process. Development has a direct effect on efficiency, quality and productivity. High levels of development in CNG vehicle industry or in general industry should increase quality and productivity- at the same time decreasing costs and cycle time. This question enquires about the level of development or the lack of it in relation to the amount of products and number of employees of the organization. Five objective answers are provided expressing five level of the development, as above. The respondent should tick the appropriate one.

4- What level of development do you envisage at your plant within the next coming years (check one)?

- ❑ No development
- ❑ Sparsely developed
- ❑ Somewhat developed
- ❑ Mostly developed
- ❑ Fully developed

Normally the implementation of new CNG system will increase gradually in line with the growth and development of the organization. This question seeks information on the future level of CNG development within the next years. Again five objective answers are provided expressing five levels of development as above. The respondent should tick the appropriate one.

SECTION 3: ENGINE SYSTEM

1- Are you satisfied with the latest improvements of the CNG feeding and injection components used in your company?

- ❑ Yes
- ❑ No

Through the knowledge of improvements in CNG feeding and injection component we will know the extent of satisfaction with their CNG advances that will maintain the high fuel economy of CNG vehicle and meet future emission standards.

2- Does the new engine design provide better performances after the addition of the new CNG components?

- ❑ Yes
- ❑ No

The aim of this question to see to what extent the recent CNG engine provides the best performance by eliminating the technical and cost barriers associated with displacing important petroleum fuel.

3- Is your company developing or implementing any CNG components for heavy-duty applications?

- ❑ Yes
- ❑ No

If Yes, for which emission standard level?

- ❑ Euro 3

- Euro 4
- Euro 5

This question seeks further information about which level the development of CNG has been implemented in these companies to meet Euro standards.

SECTION 4: GOVERNMENT SUBSIDY

1- Do you get governmental incentives for the investment in CNG components development?

- Yes
- No

This question seeks information as to whether the company gets funding from the government for the investment in CNG vehicle which would result in numerous economic and social benefits.

2- Do you think that the government should be offering incentives to encourage the development of CNG components?

- Yes
- No

If so, then what percentage of the total cost would be required to make you consider supplying this type of vehicle?

- 0-5%
- 5-10%
- 10-15%
- 15-20%

In the consumer questionnaire a similar type of question was asked. The purpose of this question is to determine whether or not there is a consensus between industry and consumers as to whether or not incentives like they have in Italy should be introduced in all Europe. Again in the development of this industry the government must be a large pushing force. The result from this question could prove to be a lobbying tool.

3- Would you be willing to contribute to the production of fuelling stations in your country to encourage the spreading of CNG vehicles?

- Yes
- No

If so, then how much would you be willing to contribute?

- €0-5000,
- €5000-10,000,
- Greater than €10,000.

The ranges of money contributions in the multiple selections were decided in a way that accounts for small as well as big companies. Even though chances are slim that manufacturers are actually willing to give money, but it could be possible for companies to support the suggestion in the question to create a more competitive market.

3.9.2 CNG Vehicle Customer

1- How would you describe, in terms of percentage, your knowledge of CNG vehicles?

- 0-25 %
- 25-50%
- 50-75%
- 75-100%

This question will firstly ascertain whether or not people in Ireland and Europe are currently even aware of CNG powered vehicles. If not then this information should be used to illustrate the fact that there is a poor understanding of environmentally powered vehicles in Europe, considering the fact that by 2020 a 20% of all vehicles should be powered by CNG, then this is a cause for alarm.

2- Would you be willing to pay more for a car that was more environmentally friendly?

- Yes

- No

If so, then how much more would you be willing to pay?

- €0-1000
- €1000-2000
- €2000-3000
- €3000-4000

The ranges of extra cost presented in this question are based on indications, from the previous survey's analysis, that the cost of conversion from traditional fuel to CNG system has decreased by 40%.

Question two will ascertain whether or not the public would be willing to pay that bit extra for a more environmentally sound automotive vehicle. The subsequent value of this difference will highlight what people are willing to accept.

3- Would you be willing to wait for extra five minutes to refuel your vehicle and also refuel it slightly more often if it was beneficial to the environment?

- Yes
- No

Current vehicles available on the market are proven to take that little bit more time to fuel. It is important to understand whether or not this would be a major limiting factor in the development of the said fuel and if so make recommendations to focus efforts on alleviating this problem as a primary issue.

4- With the same consideration, would you be willing to travel further distances to refuel your vehicle?

- Yes
- No

If so, then how much further before you would reconsider?

- 0-5 miles
- 5-10 miles

- 10-15 miles

It will take time to bring CNG fuelling stations to anywhere near the number of Gasoline stations around the country. Gauging public opinion on whether or not they would be willing to travel that extra distance and by the subsequent question how much further would be an acceptable distance would demonstrate whether they will accept it and how many fuelling stations will be required to meet an acceptable level for all users.

5- How would you describe the public fuelling infrastructure for the number of stations?

- Inadequate
- Adequate
- More than Adequate

This question will stress to the appropriate bodies on whether or not their product is meeting the service level needed to continue and expand, also it will highlight any problems arising.

6- If you are an owner of a CNG vehicle. Do you feel safe driving your vehicle?

- Safe
- Moderately Safe
- Fully Safe

Safety questions can be used as promotional tools if the results indicate a satisfaction of the customers with the safety of new vehicle technologies.

7- In your opinion, should the government be offering financial incentives for those who use more energy efficient and environmentally friendly alternative powered vehicles?

- Yes
- No

If so, would these incentives encourage you to purchase such a vehicle?

- Definitely

- Maybe
- Probably

A 'yes' answer is expected of most people. It is the duty of the government to provide a certain number of these vehicles on the roads within a relatively short timeframe. By presenting them with salient evidence that the public would use such a scheme will hopefully induce them to act politically on the subject.

Chapter 4 Results and Discussion

4.1 Introduction

This chapter covers the analysis of the results obtained from the survey; together with the comparison between traditional postal surveys and web-based surveys. The main software used in this task is **S**tatistical **P**ackage for the **S**ocial **S**ciences (SPSS) which is a data management and analysis product produced by SPSS, Inc [59]. Some descriptive statistics such as, frequencies, and charts have been used in the analysis of these results; also correlation and t-test techniques have been used to find out the relationship between some variables.

4.2 Statistical Package for the Social Sciences (SPSS)

The collected information will be best represented by a strong analytical package capable of predictive analysis for the future. SPSS offers these functions and can provide much greater detail and analysis. The way in which SPSS works is that you define the variables e.g. Question 2 of the CNG car manufacturing survey. The question states '*How many years has your company been in business?*', The answers could be <10 years (Input 1), 10-20 years (Input 2), 20-30 years (Input 3) and >30 years (Input 4). These answers are converted to numerical values of the (years) variable as can be seen in the second column in the spreadsheet in figure 4.1.

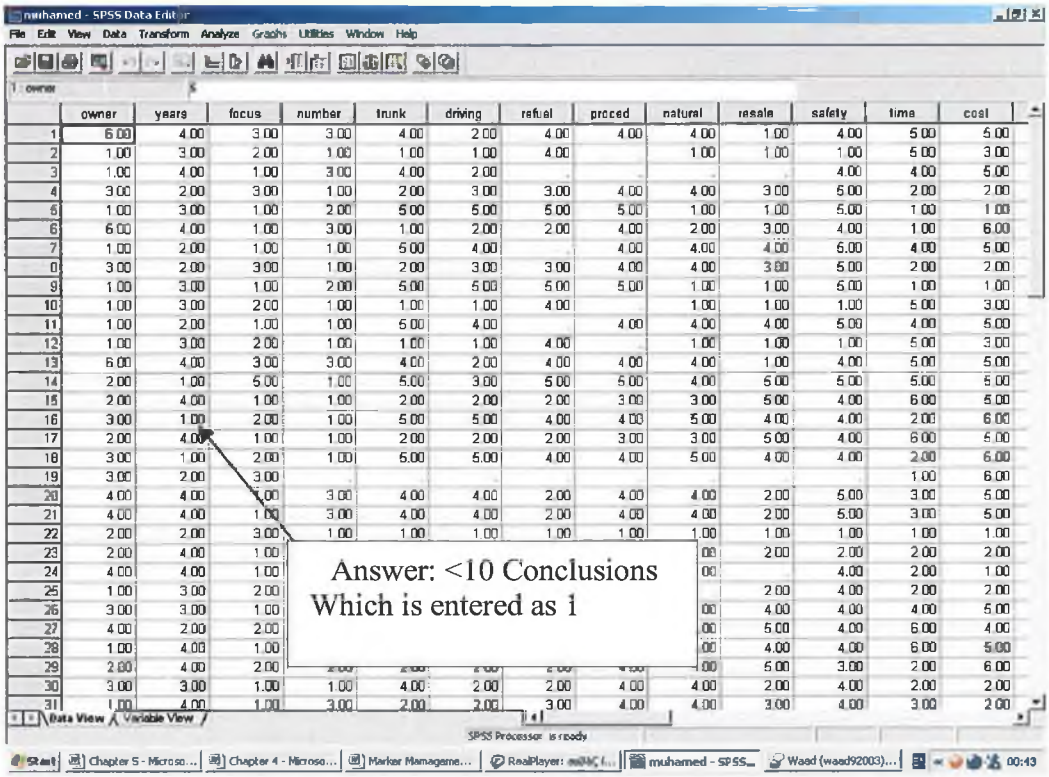


Fig 4.1Extract from data editor for CNG car companies survey

4.3 Comparison between Tradition Postal Survey and Online Surveys

1. Response rate: The apparent disadvantage of on-line survey is the comparatively low response rate. Comley [60], summarizes the response rates of all virtual surveys in 1999, most of them being in the range 15% - 29%.

- ***CNG vehicles and OEM companies – postal and online survey***

As far as the traditional postal survey is concerned, in this survey the questionnaire was sent twice (first questionnaire and reminder questionnaire) to the sample population. Table 4.1 reveals that the response rate of both questionnaires from the CNG car manufacturers was 5.2% and 8.4% respectively, giving a total of 13.6%. The OEM companies response rate was 2.8% of the total response rate.

In the online survey a total of 6.0% response rate was obtained from CNG car manufacturers, as can be seen in table 4.1. While the total response rate of the online and post survey of CNG vehicle and OEM manufacturers which is 22.4 %.

- ***CNG car customers – online survey only***

The response rate of the first and reminder questionnaire (both web-based) from CNG car customers was 13% for the first questionnaire and 5.4% for the reminder questionnaire as illustrated in table 4.1.

Finally, the total response rate of the online survey of CNG car customers with a value of 18.4%.

Table 4.1 Response rate of CNG car, OEM companies and CNG vehicle customers

CNG vehicles companies and OEM companies – postal and online survey			
	Total	Frequency	Rate
First questionnaire of CNG car	200	13	5.2%
Reminder questionnaire of CNG car		21	8.4%
Online survey of CNG car		15	6.0%
OEM companies	50	7	2.8%
Response rate	250	56	22.4%
CNG car customers – online survey only			
	Total	Frequency	Rate
First questionnaire	500	65	13%
Reminder questionnaire		27	5.4%
Response rate	500	92	18.4%

From table 4.1 it is clear that the response rate to the first questionnaire sent online to CNG car customers was much higher than the response rate to the reminder questionnaire. On the other hand the rate of the CNG car and OEM companies to the postal survey was a higher response rate to the reminder survey. It is interesting to compare the response rate to the postal and online surveys. The response rate of the CNG Car and OEM companies was 15.6 % total response rate to the postal survey and

6.8% to the online survey. This finding is in line with Dommeyer and Elanore [61], argument that online data collection methods do not result in a higher response level. This also supports the work of McDonald and Adam [62] who found that the response level of online data collection method is less than half that of the postal data collection method.

2. Response time. Short response time certainly is one of the greatest advantages of on-line surveys. Online surveys allow messages to be instantly delivered to their recipients, irrespective of their geographic location. Ray, et al [63] in their survey of on-line surveys, found that 34% of the on-line surveys took less than two weeks, 33% between two weeks and one month and 33% longer than one month.

In this study the first message concerning the survey that was sent to CNG vehicle customers including a hyperlink to the web page was sent on the 28th of April 2004. The questionnaire was sent to 13% of the CNG vehicle customers on the same day. A reminder message including a hyperlink to the web page was sent on the 2nd of July 2004. The process of checking the email account for the remaining responses continued till the end of the two months. The period of time for the on-line survey of the customers was about 66 days.

On the 15th of May 2004 an e-mail was sent to the CNG car manufacturing companies asking them to participate in the on-line survey. On the same day, a message received e-mail was received back from 6.8% of those surveyed. The reminder message including a hyperlink to the web page was sent on the 2nd June 2004. None of the subsequent responses received arrived within a day of the message being sent. The process of checking the email account for the remaining responses continued till the end of the three months. Therefore the period of time for on-line survey of companies was about 90 days.

3. Data quality. Schonlau et al [50], have demonstrated that data quality is usually measured by the number of respondents who have, intentionally or unintentionally,

missed at least one survey item or by the percentage of missed items on the respondents' questionnaires. In the online survey of CNG car manufacture, about 16 variables were found that have no information in the survey's database (respondents did not give any answer) were 5.22% answers missing in the on-line survey.

On the other hand, online survey of CNG vehicle customer survey about 7 variables were found that have no information in the survey's database (respondents did not give any answer), answers were missing in the on-line survey 5.11%. This findings support the observation of Basi [64], who suggested that those who complete online questionnaires complete more questions than those completing postal survey.

4. Cost. Most of the facilities involved for online survey like software for designing the web page, server hosting the web, and Response-O-Matic were available in the university, so it is possible to say that there was only marginal cost involved for online survey due to the of internet access etc.

For the traditional postal survey the costs involved have been computed as the ersatz paper, envelopes and four-way postage costs, the total of cost for each questionnaire is about €2.20.

This finding supports findings reported by McDonald and Adam [62] and Mehta and Sivadas [65] who concluded that the cost of postal data collection is higher than online methods.

4.4 Data Analysis

In the survey results analysis below, the pie charts include the frequency and the percentage of the respondents to the total number of the surveyed. These details will read as (frequency / percentage %). For example, in the CNG and OEM companies survey, the number of companies with international ownership in figure 4.10 is 13, this represents the frequency. The percentage of these companies to the total is calculated by dividing the frequency by the total number of respondents, 13 / 56 = 23.2%. Both the frequency and the percentage are shown in figure 4.10 as (13 / 23.2%). This scheme is followed throughout the analysis. However, the results are referred to as percentages in the text that precedes the figures.

4.4.1 CNG Car Manufacturing and OEM companies

The profile surveyed companies consist of 'Ownership', 'Age of companies', 'focus market' and 'number of employees'. In other words, frequency tables and figures (pie charts) are presented for each single item that is associated with the profile of the companies. The interesting finding from the following tables and figures is that 22.4% out of 250 companies have responded to the CNG car manufacturing and OEM survey. This fact enhances the value of the data, because the majority of the respondents were knowledgeable in their development of CNG program and were able to provide us with valuable information.

Section One: - General Information

1. Ownership

Questions on ownership of the companies around Europe, showed that 32.1% of were of national ownership and this corresponded to a frequency of 18. International ownerships were 23.2% of the respondents with a frequency of 13. Local ownerships were 19.6% with a frequency of 11. Mixed ownerships were 14.3% of the respondents, corresponding to a frequency of 8. There was 1 company with foreign ownership that counted as 1.8% of the respondents. These results are illustrated by the pie chart in figure 4.2.

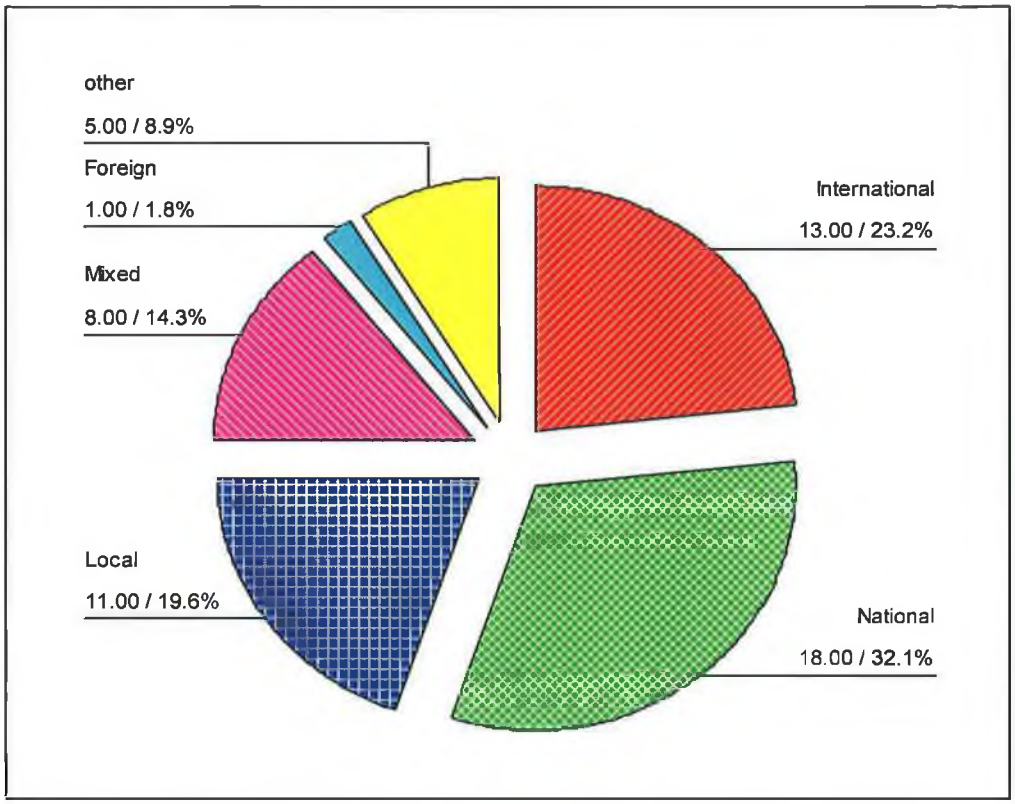


Fig 4.2 Ownership of the CNG vehicle and OEM companies

2. Age of companies

The results in figure 4.3 show that 39.3% of the companies surveyed have been in business more than 30 years. Moreover, 28.6% of the companies have been in business for a period between 20-30 years. Furthermore, 17.9 % of the companies have been in business between 10-20 years. However, 14.3% of the companies have been operational for less than 10 years.

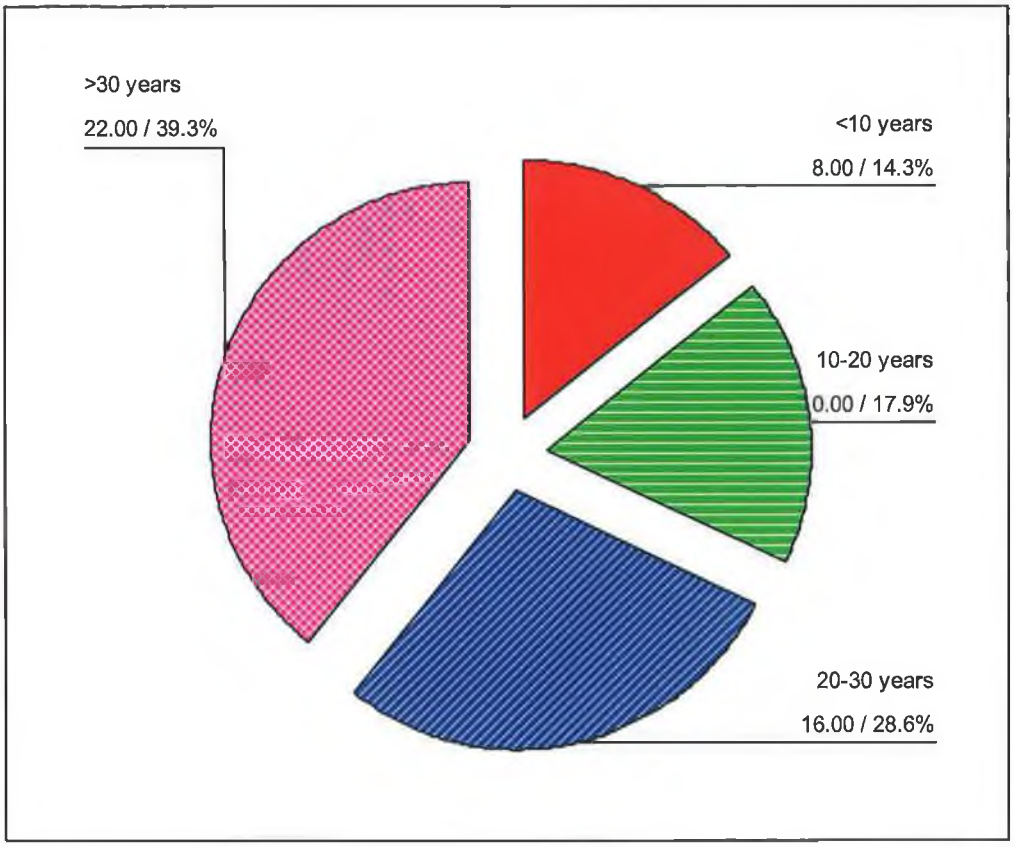


Fig 4.3 Age of CNG vehicle and OEM companies

3. Focus markets

Most of the companies stated that their concentration is on worldwide markets, those companies counted as 46.4% of the surveyed companies. A percentage of 28.6% of the companies have their concentration on all European markets. Furthermore, 23.2 % of the companies indicated that their concentration is on American markets. However, 1.8% of the companies concentrate on other markets, specifically on Germany and Italy. This market concentration distribution is illustrated in figure 4.4

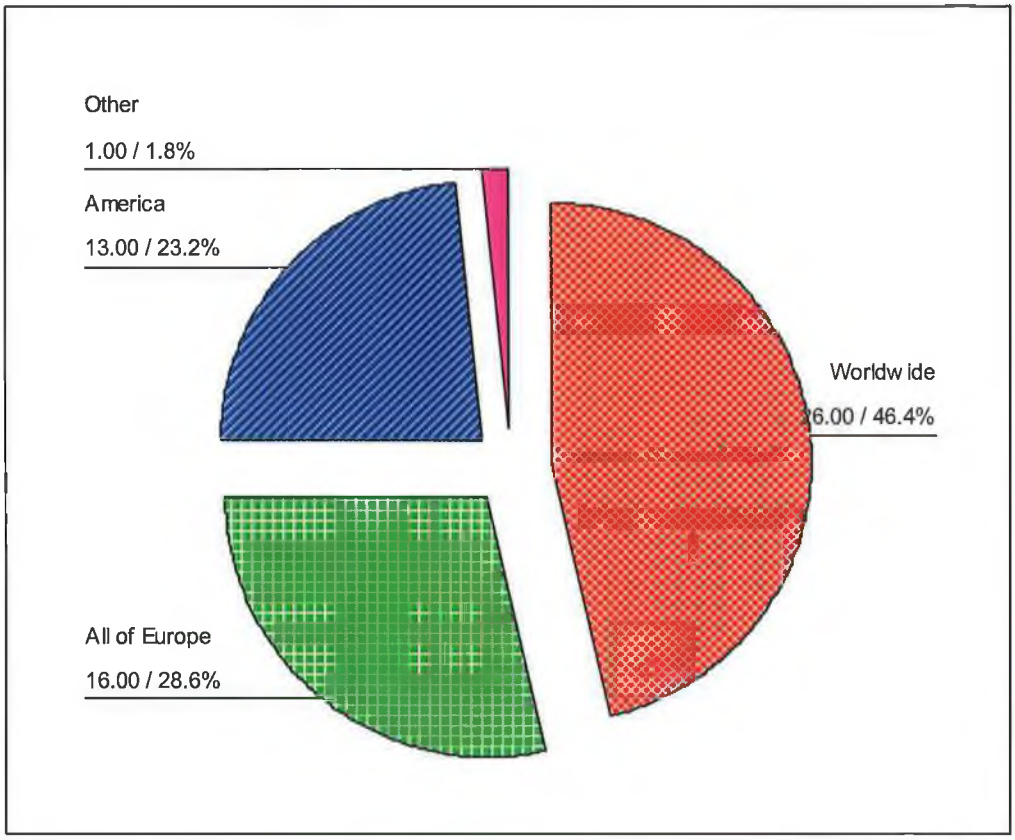


Fig 4.4 Concentration markets of CNG vehicle and OEM companies

4. Number of employees

Often the size of the company depends on its number of employees. In other words, the range of employee numbers less than 300 is considered to represent small companies, the range from 301-1000 of employee number is considered to represent medium companies and range greater than 1000 of employee numbers is regarded to represent huge companies.

Based on the results in figure 4.5, majority of the respondents have a number of employees ranging from less than 300 and 301-1000, representing small and medium size companies, their percentage distribution was 35.7 % and 33.9% respectively. Companies with more than 1000 employees had a percentage of 28.6%. Only 1.8% of the surveyed companies did not give an answer or deemed the question not applicable.

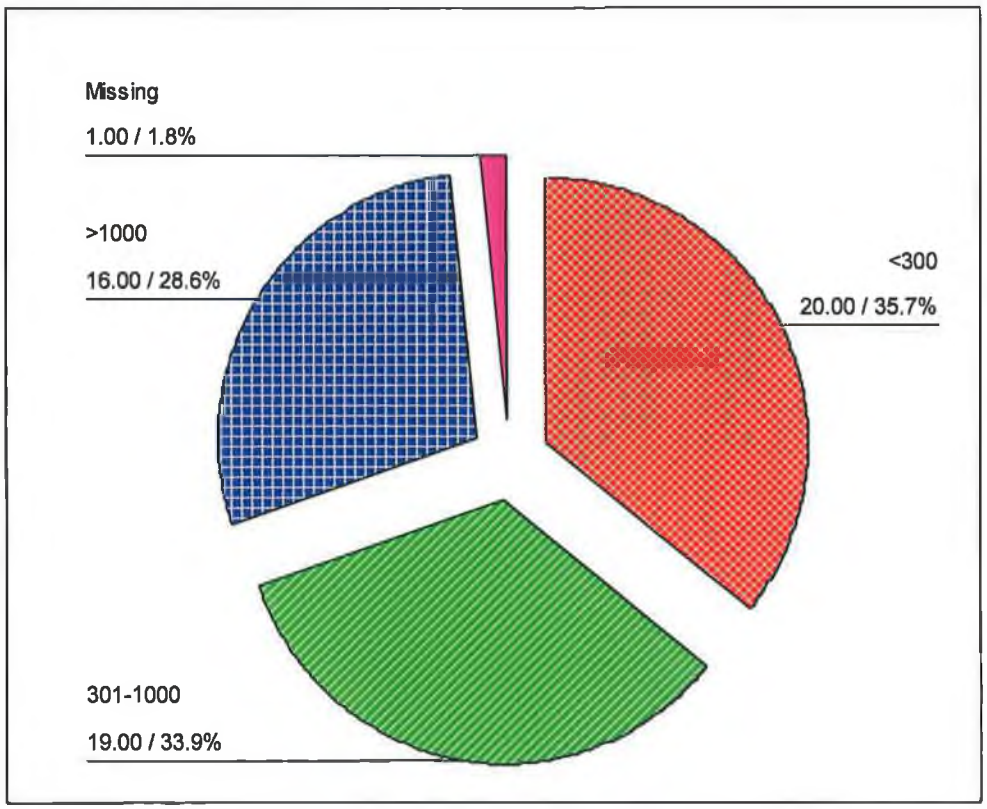


Fig 4.5 Distribution of percentage of employees in vehicle and OEM companies

Section Two: - Level of Development of CNG Systems

1. Satisfaction with CNG technology

1. Trunk space (boot space, as called in Ireland)

Figure 4.6 shows the satisfaction level among the CNG manufacturers with the space occupied by the gas cylinder in the vehicle's trunk. It was found that 33.9% of the respondents were dissatisfied with volume of trunk space occupied by the CNG fuel cylinder. A percentage of 25.0% were satisfied with the trunk space volume. The very satisfied respondents were 19.6%, while 10.7% had no preference on the trunk size, answering (none) to the question. The very dissatisfied CNG manufacturers were only 8.9%.

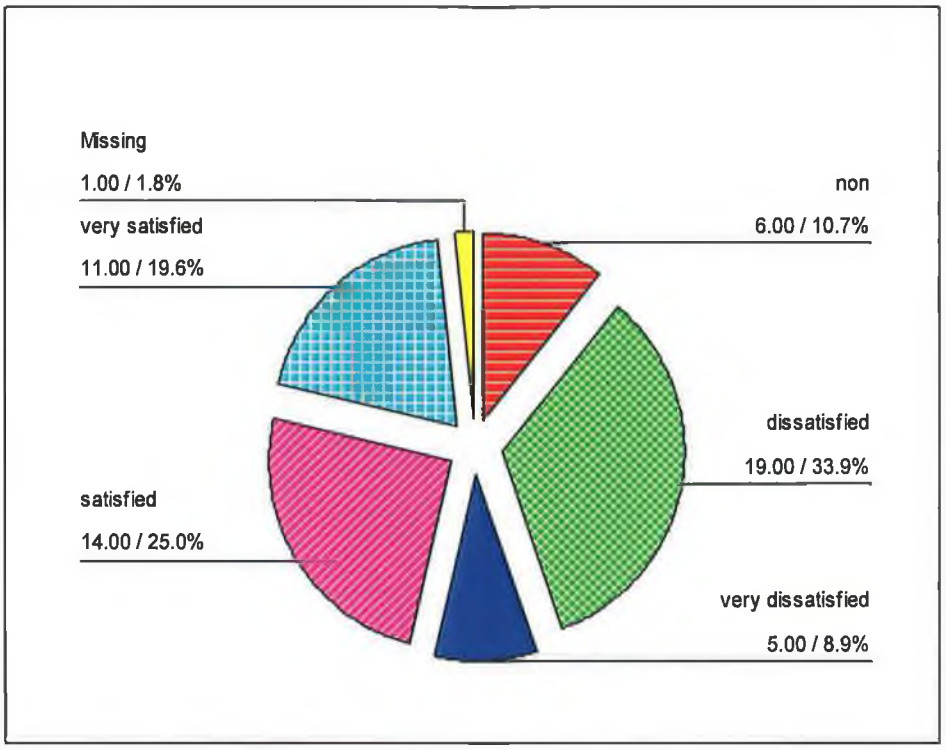


Fig 4.6 Level of satisfaction with CNG vehicle and OEM of Trunk space capacity

2. Driving range

The driving range is the range within which CNG vehicle owners can drive with certainty about refuelling and maintenance facilities. Figure 4.7 shows that 41.1% of the respondents were dissatisfied with driving range. On the other hand, 23.2% of respondents were satisfied with the driving range. Of the surveyed manufacturers, 16.1% were very dissatisfied with driving range. While 7.1% were very satisfied, similarly 7.1% did not consider the driving range as an obstacle. Only 5.4% did not give answer to the question.

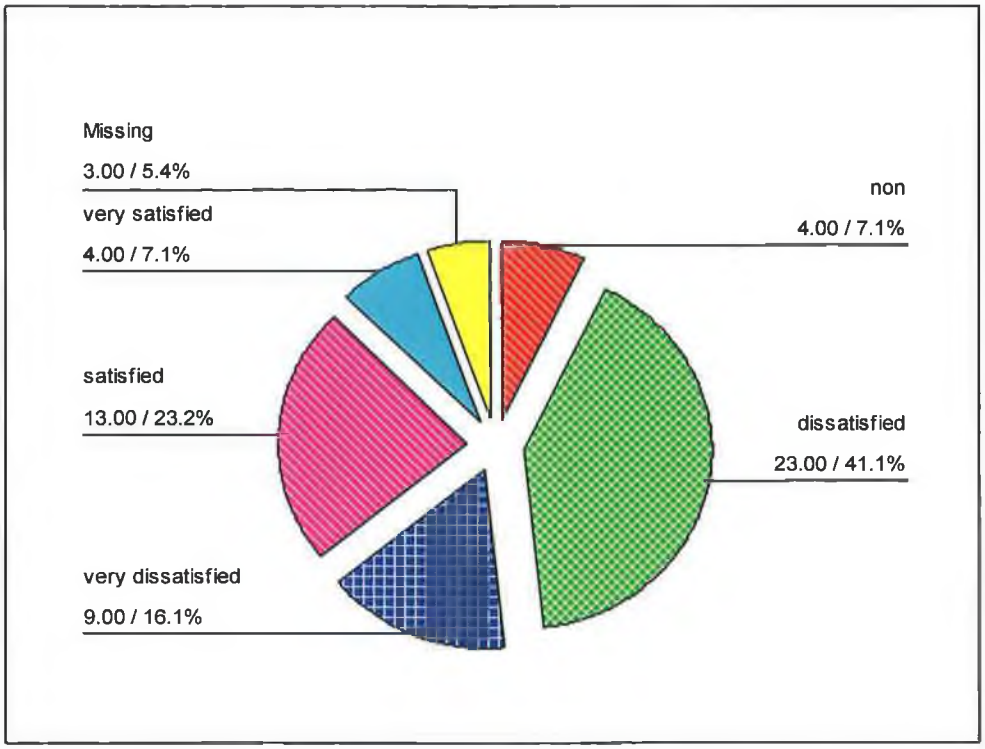


Fig 4.7 Level of satisfaction with CNG vehicle and OEM of driving range

3. Refuelling component

The refueling component is the fuel system in the vehicle that is mainly composed on a cylinder of compressed gas and controlling valves. Figure 4.8 shows that 32.1% of the surveyed companies were dissatisfied with the refuelling component. The very dissatisfied were 26.8%, similarly 26.8% of respondents were satisfied with the refuelling component. Only 5.4% of respondents were very satisfied with the refuelling component. Finally, a minimum of 1.8% were not satisfied with the refuelling component.

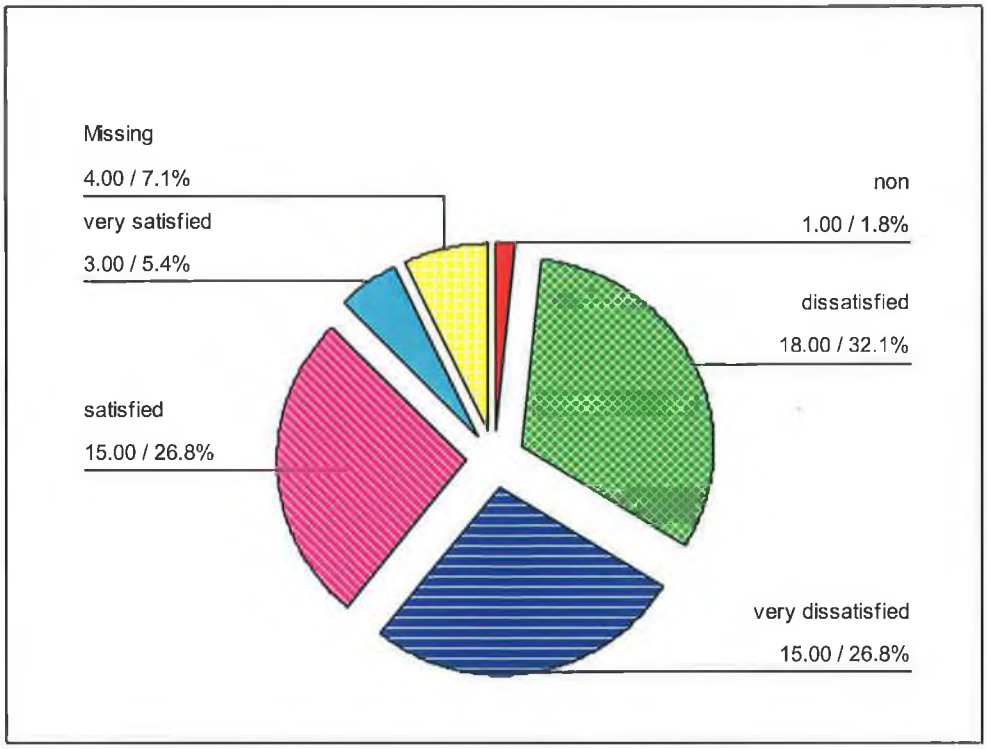


Fig.4.8 Level of satisfaction with CNG vehicle and OEM of refuelling component

4. Safety of CNG vehicles

The results of this question are shown in figure 4.9. It was found that 50% of the respondents are satisfied with the CNG vehicle safety. Furthermore, 30.4% of respondents were very satisfied. A percentage of 7.1% were very dissatisfied and 3.6% were dissatisfied.

This issue was included in the CNG vehicle customer's survey. The customers' response to this point is discussed in question 6 of section 4.4.2.

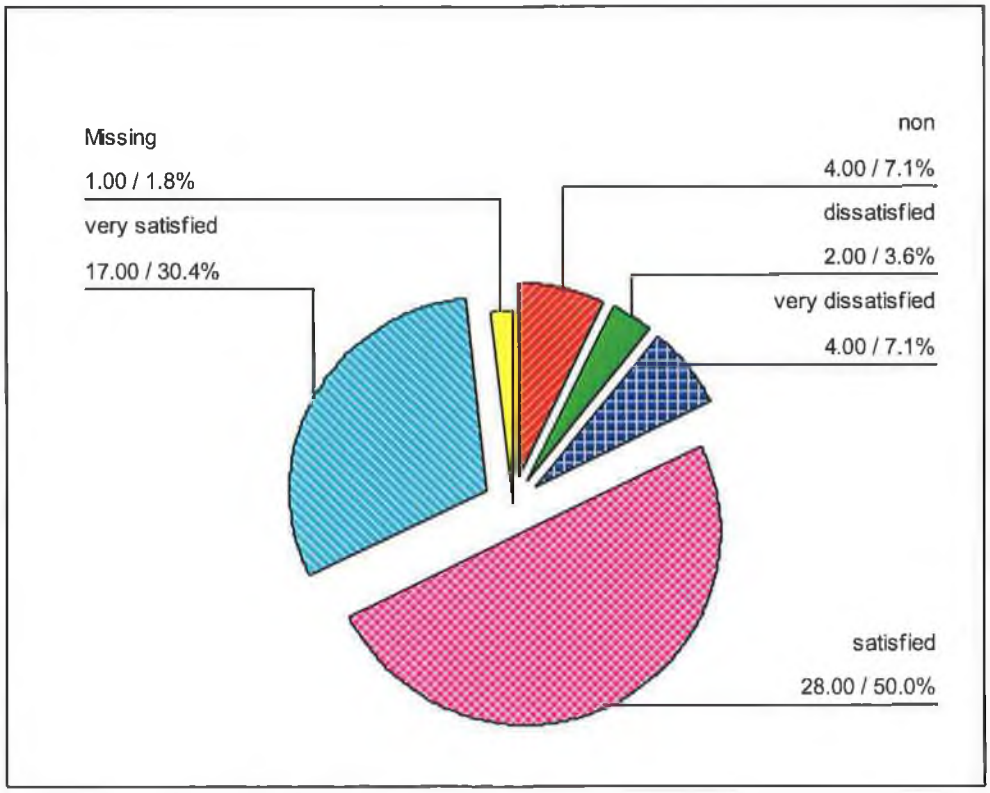


Fig.4.9 Level of satisfaction with CNG vehicle and OEM of CNG vehicle safety

2. The implementation obstacles of compressed natural gas system in car manufacturing companies

In this question, the important common obstacles for implementation of Compressed Natural Gas System were identified and analysed. The respondents were requested to identify the severity of the obstacles from scale 0 to 5 as follows:

{0-None 1- very low 2-low 3-average 4-high 5-very high}

1. Time from development to implementation

Time was put to question as an obstacle to the implementation of Compressed Natural Gas Systems in car manufacturing companies. As shown in figure 4.10, 30.4% of the surveyed companies indicated that time was a very low obstacle. Furthermore, 21.4% of the companies indicated that time was a low obstacle. While 17.9% of the companies considered it as an average obstacle, 12.5% did

not consider time as an obstacle. Time was a high obstacle for only 10.7% of the companies. Only 7.1% of the companies surveyed indicated that time was a very high (major) obstacle.

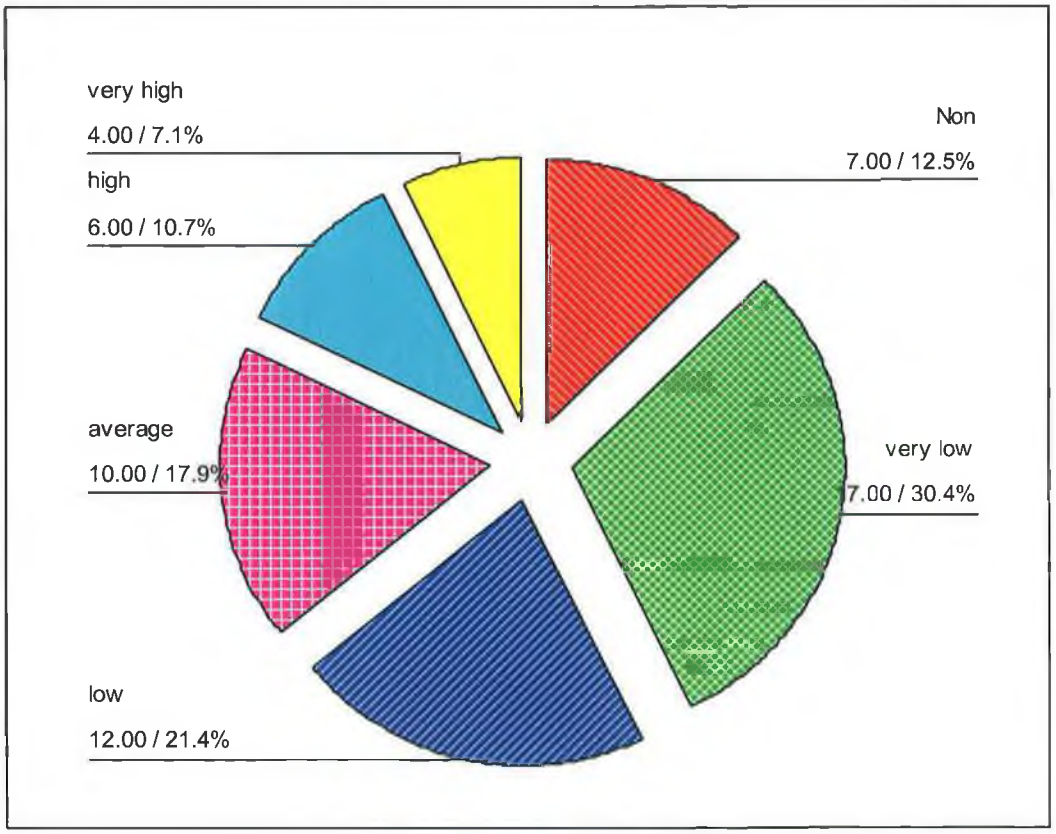


Fig 4.10 Time as an obstacle to implementation of CNG system

2. Cost

Cost was investigated as an obstacle to the implementation of Compressed Natural Gas Systems in car manufacturing companies. As shown in figure 4.11, 33.9% of the surveyed companies indicated that cost was a high obstacle. On the contrary, 26.8% of the companies indicated that cost was a low obstacle. Furthermore 14.3% of the companies considered it as a very low obstacle. Cost was considered as an average obstacle by 8.9% of the companies. Similarly,

8.9% of the companies considered cost as a very high obstacle. Only 7.1% of the companies surveyed indicated that cost was not an obstacle.

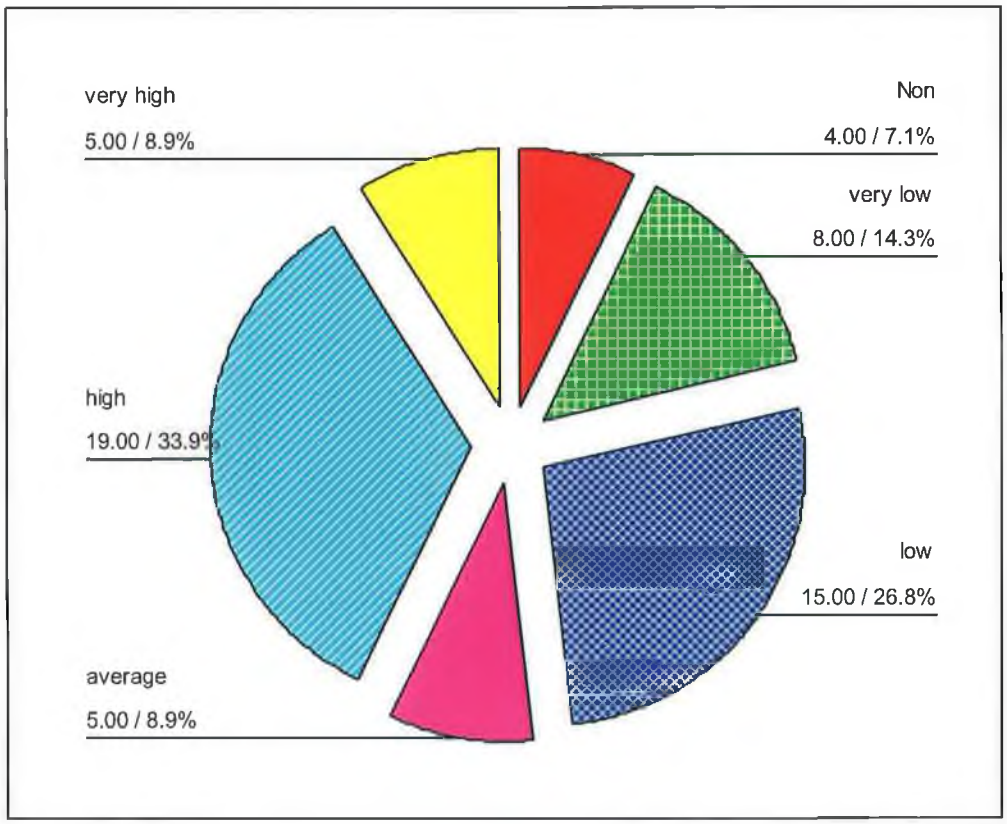


Fig 4.11 Cost as an obstacle to implementation of CNG systems

3. Technical skills of staff

As it is the common case with new technologies, training of the technical staff of interested companies is always necessary. The issue of the technical skills was inspected as an obstacle in this question. Figure 4.12 shows that 41.1% of the companies surveyed indicated that the technical skills were an average (appreciable) obstacle. However, 19.6% of the companies considered it as a very low obstacle. Moreover, 17.9% of companies said that it was a low obstacle. While 10.7% of the companies indicated that the technical skills were a high obstacle, only 5.4% considered it as a very high (major). Only 5.4% of the companies did not consider the technical skills as an obstacle.

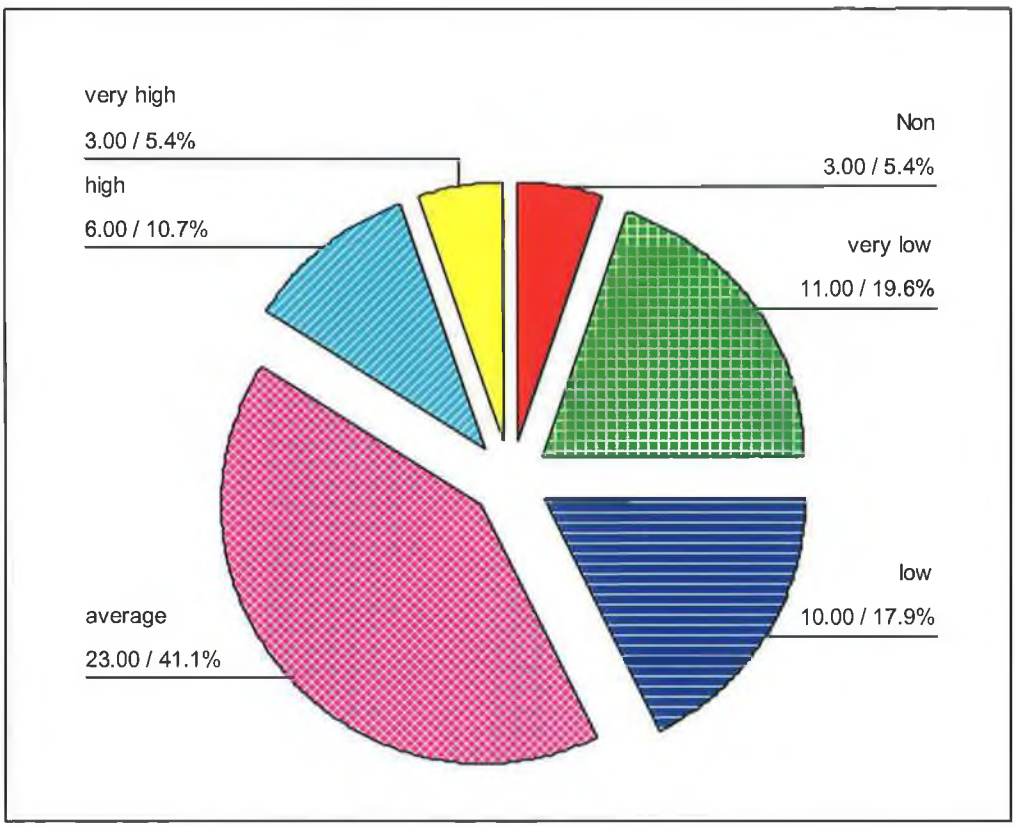


Fig 4.12 Technical skills as an obstacle to implementation of CNG systems

4. Management commitment

The analysis of the management commitment to the implementation of CNG system as an obstacle is shown in figure 4.13. About 23.2 % of the companies surveyed indicated that the management commitment was a very low obstacle. Similarly, 23.2% of the companies referred to it as an average obstacle. Furthermore, 21.4% of the companies indicated that the management commitment is a low obstacle. While 17.9% of the companies considered it as a high obstacle, a percentage of 10.7% of the companies treated it as a very high obstacle. Finally, 3.6% of the companies indicated that the management commitment was not an obstacle.

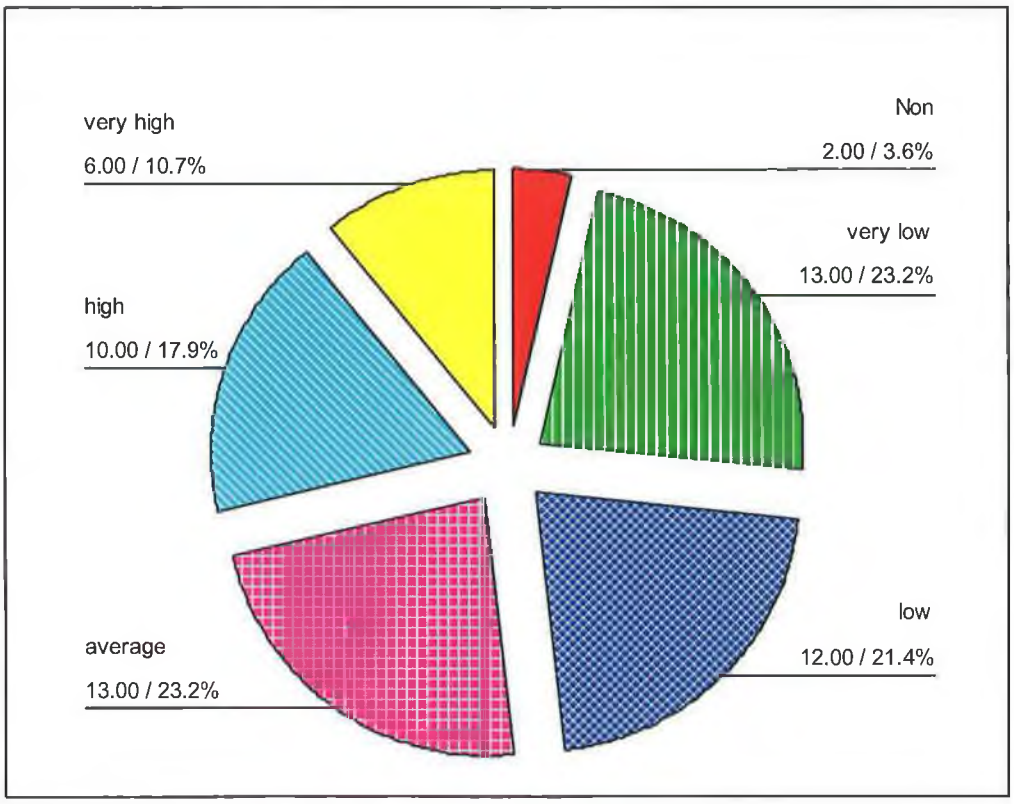


Fig 4.13 Management commitments as an obstacle to the implementation of CNG systems

5. Nature of business

The analysis of the nature of business as an obstacle to the implementation of CNG system is shown in figure 4.14. About 37.5 % of the companies surveyed indicated that the nature of business was a very low obstacle. On the other hand, 17.9% of the companies referred to it as a high obstacle. While 16.1% of the companies indicated that the nature of business is a low obstacle, 14.3% of the companies did not consider it as an obstacle. A percentage of 10.7% of the companies treated it as an average obstacle. Finally, 3.6% of the companies indicated that the nature of business was a very high obstacle.

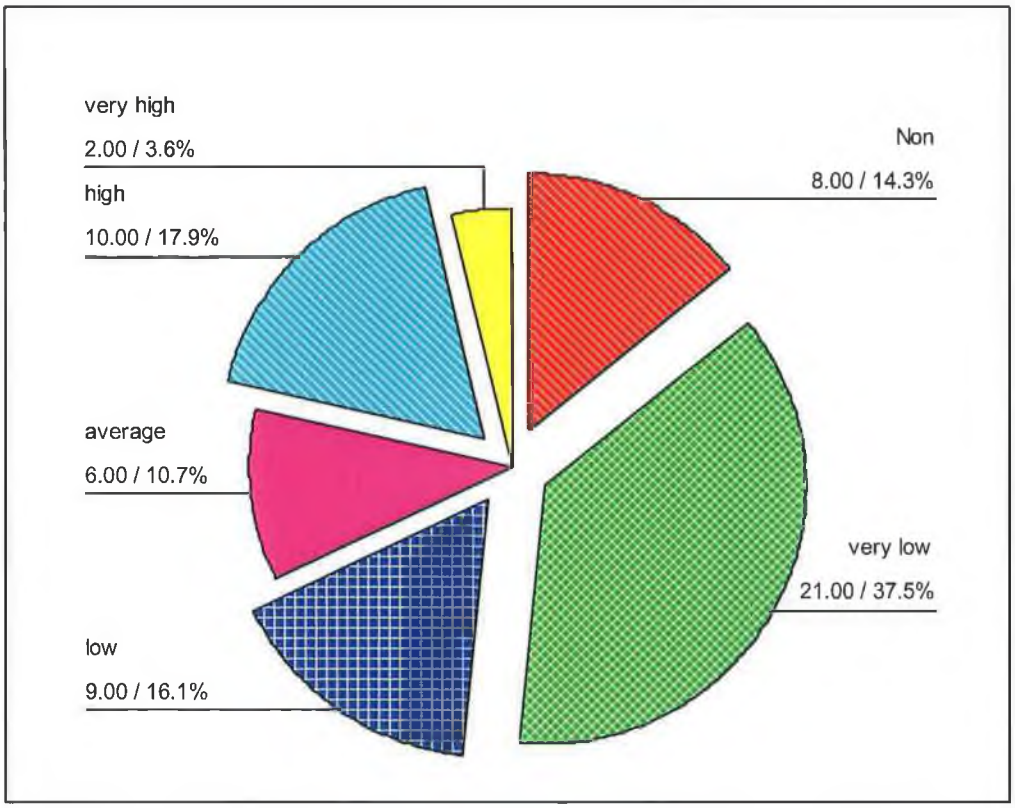


Fig 4.14 Nature of business as an obstacle to the implementation of CNG systems

3. Level of development of CNG vehicles system at plants

In this question, the level of development of CNG system at the surveyed plants was identified and analysed. The respondents were requested to identify the level of development from scale 0 to 5 as follows:

{No development, Sparsely developed, Somewhat developed, Mostly developed and Fully developed}

1. Current level of development

Figure 4.15 shows that 30.4% of the companies surveyed were mostly developed. Moreover, 28.6% of the companies were somewhat developed, while only 19.6% of the companies were fully developed. No developed companies accounted for 12.5% of the companies surveyed. Finally, 8.9% of the companies were sparsely developed.

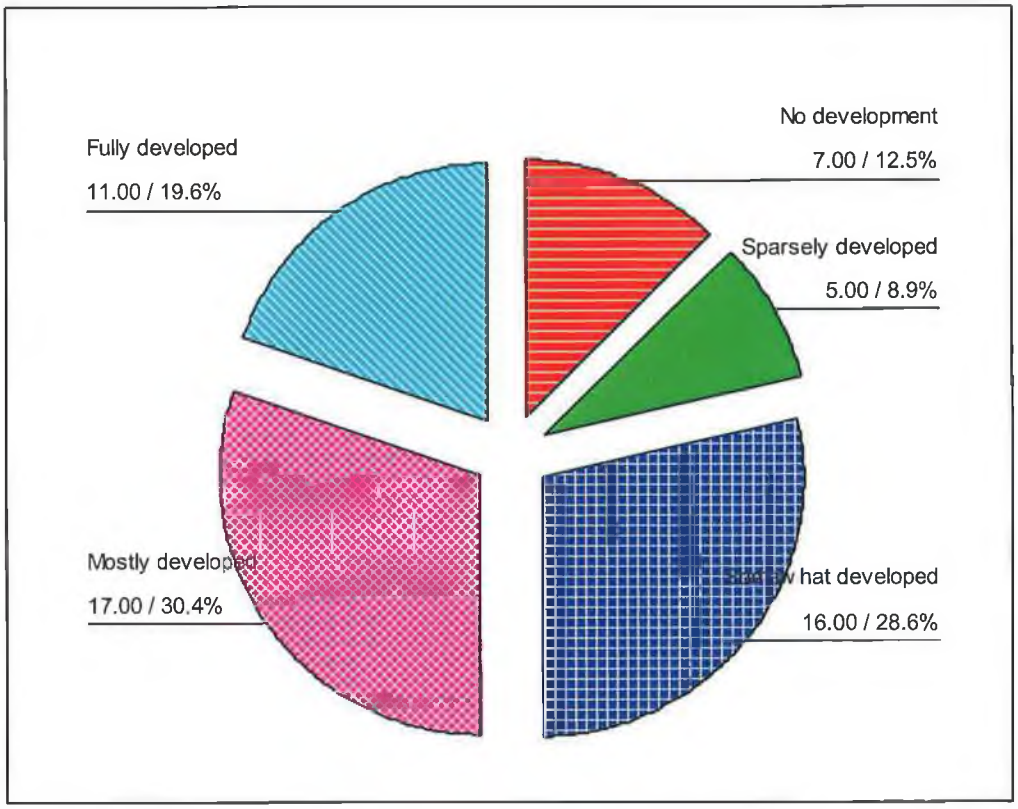


Fig 4.15 Current level of development of CNG vehicle and OEM companies

2. Level of development envisaged within the coming years

Figure 4.16 shows the level of development envisaged within the coming years at CNG car manufacturing. Only 35.7% of the companies expect to be somewhat developed. Furthermore, the companies that indicated that they will be mostly and fully develop accounted for 28.6% each. The sparsely developed companies accounted for only 5.4%, while only 1.8% will have no development in the coming years.

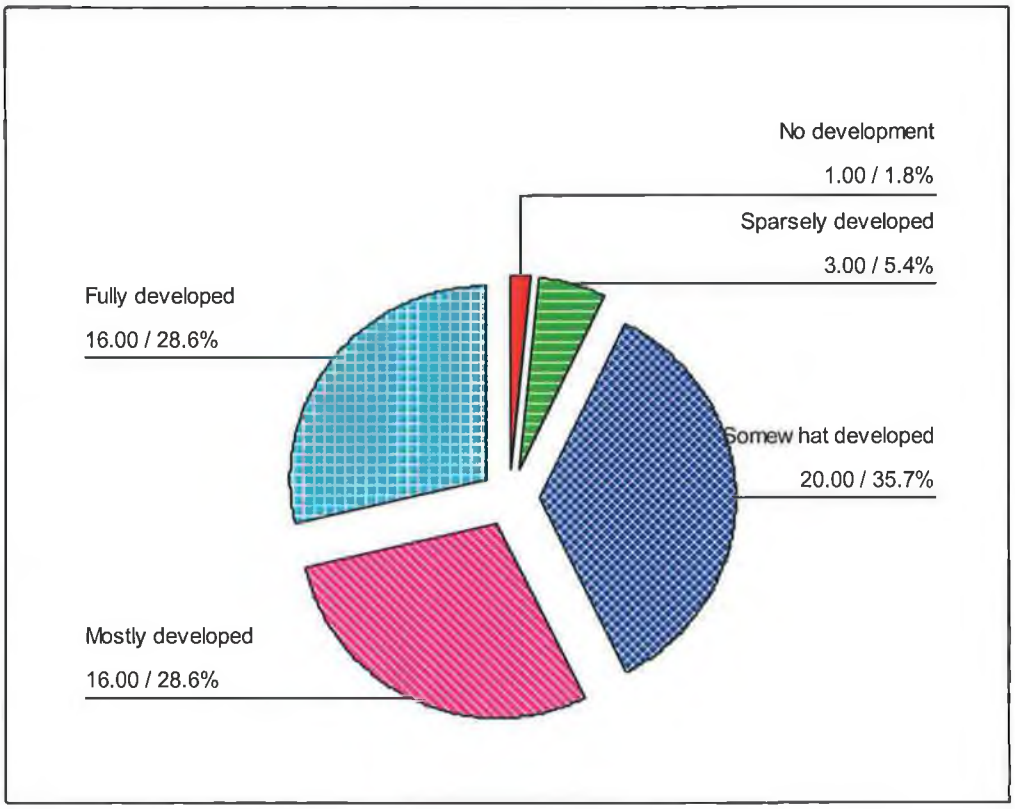


Fig 4.16 Level of development envisaged within the coming years in CNG vehicle and OEM companies

Section Three: - Engine System

1. Satisfaction with latest improvements in CNG feeding and injection component

This section was intended to check the level of satisfaction of the latest improvement in different CNG car system operations. Figure 4.17 shows that 60.7% of the companies answered 'yes' to the satisfaction with latest improvements in CNG feeding component. On the other hand, 35.7% of the respondents answered 'No' to the satisfaction with latest improvements in CNG feeding component. Only 3.6% of companies did not answer the question.

Moreover the level of development envisaged within the coming years was predicted, from the previous section, to be fully and mostly developed by, 28.6% each, in the surveyed companies. Based on that it seems there is going to be improvements in the CNG engine in the near future.

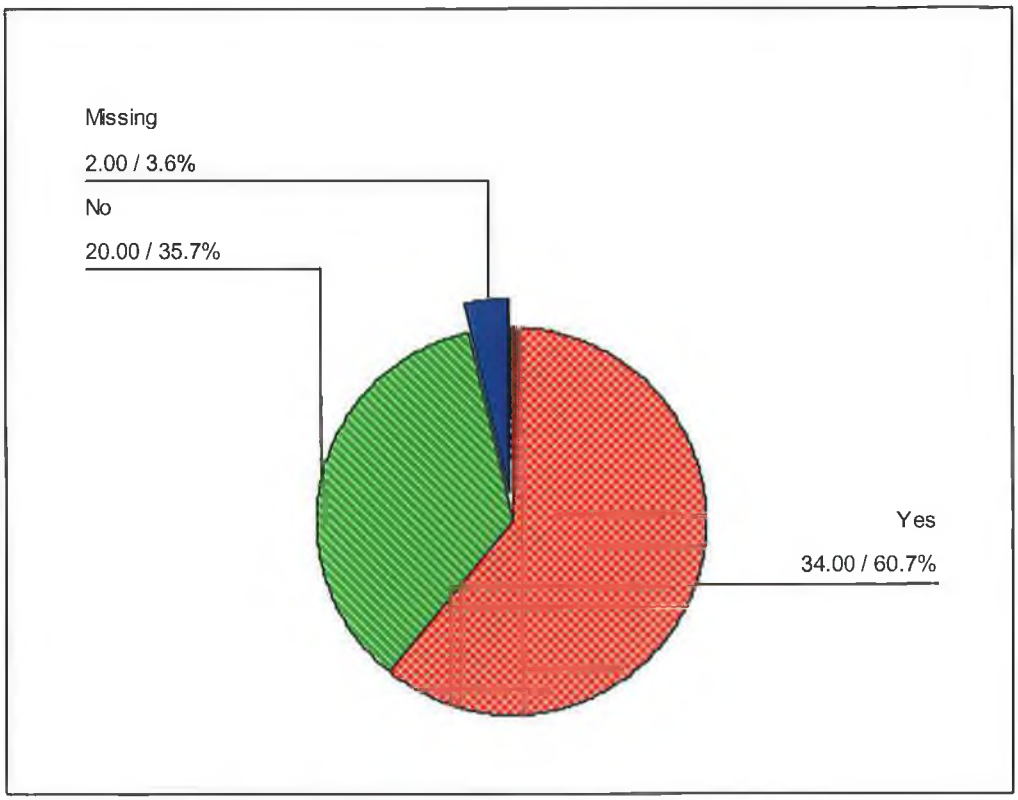


Fig 4.17 Level of satisfaction with the latest improvements in the CNG feeding and injection component

2. Best performances during implementation of new CNG component

This question investigates the satisfaction of the manufacturers with the recent CNG engines. Figure 4.18 shows that 58.9% of the companies answered 'yes', the recent engines provided best performance during implementing CNG component. However, 33.9% of the respondents answered 'No' the recent engines do not provide best performance during implementing CNG component. Only 7.1% of companies either did not answer or said not applicable.

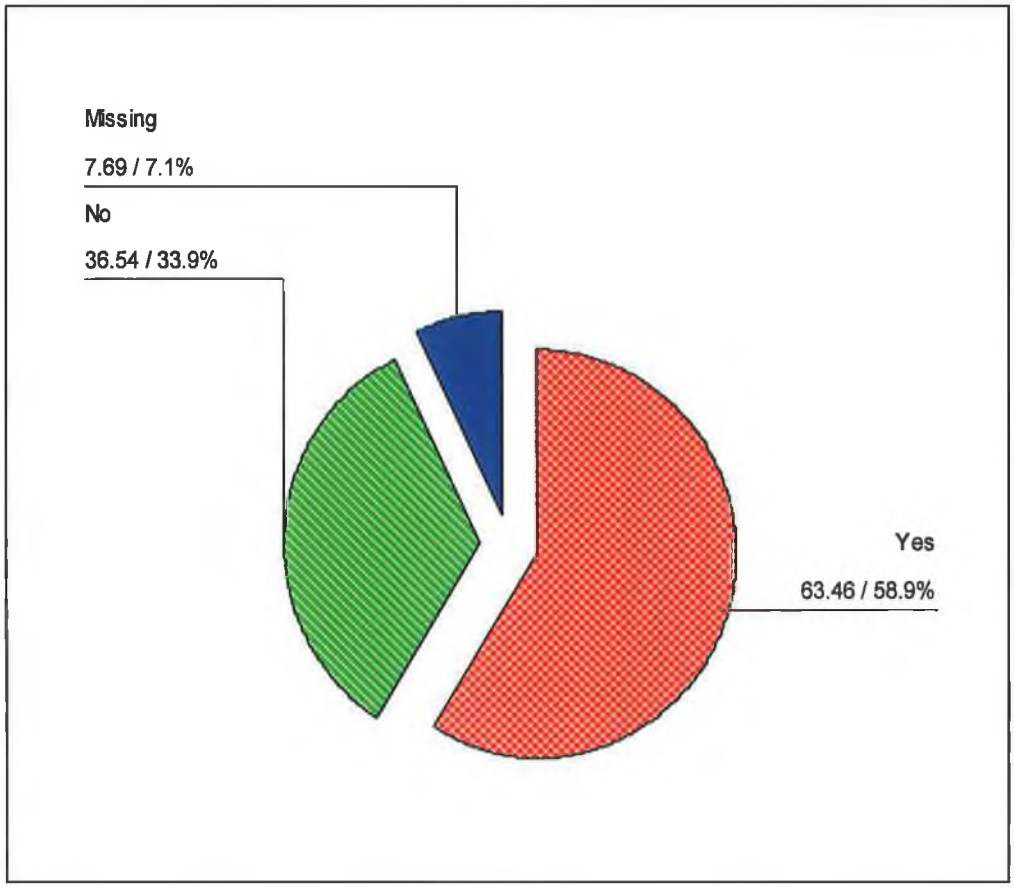


Fig 4.18 Best performances during implementation of new CNG component

3. Developing or implementing CNG component for heavy-duty application

This question investigates if the manufacturers have used CNG components in heavy-duty vehicles. Figure 4.19 indicates that the 53.6% of companies surveyed are developing or implementing CNG component for heavy-duty vehicles. On the other hand, 37.7% of the companies have not utilised CNG components in heavy-duty vehicles.

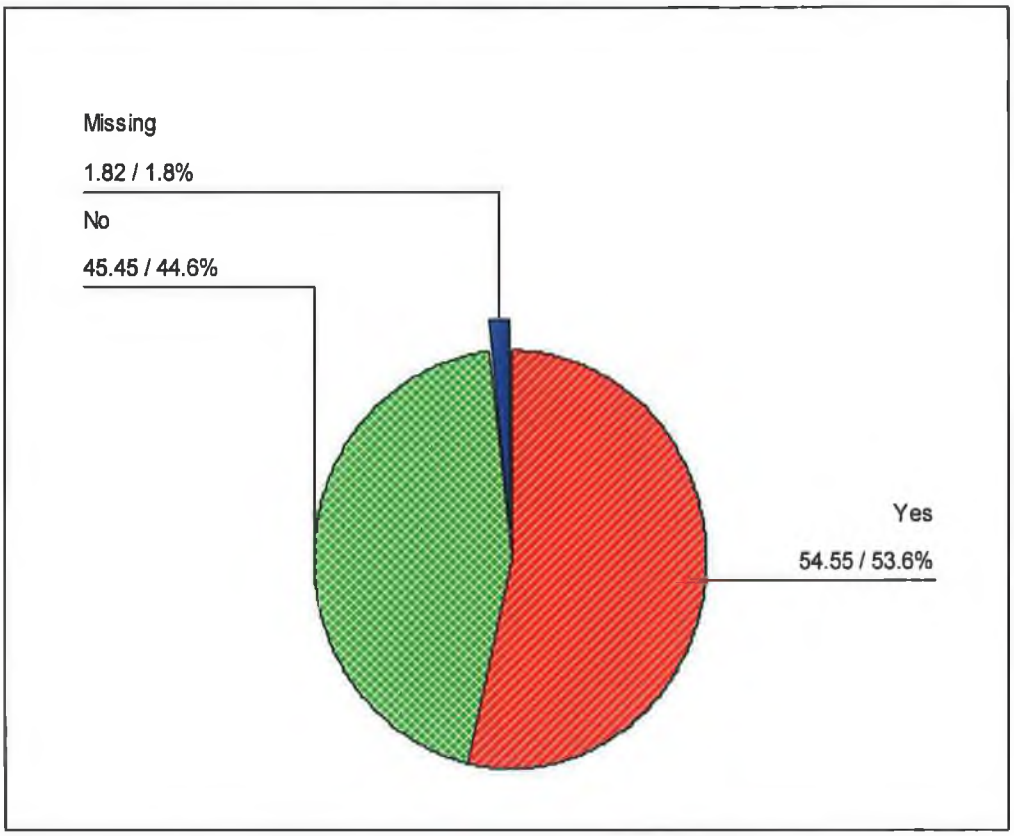


Fig 4.19 Developing or implementing CNG component for heavy-duty application

4. Emission standards

This question investigates the emission standard at which the heavy-duty vehicles are built to operate on. Figure 4.20 shows that only 21.4% of the companies build heavy-duty vehicles that operate on 'Euro 5' standard. While 19.6% of the companies surveyed 'Euro 4' standard, only 7.1% have their vehicle operating on 'Euro3' standard. A majority of 51.8% did not give answer or deemed the answer not applicable.

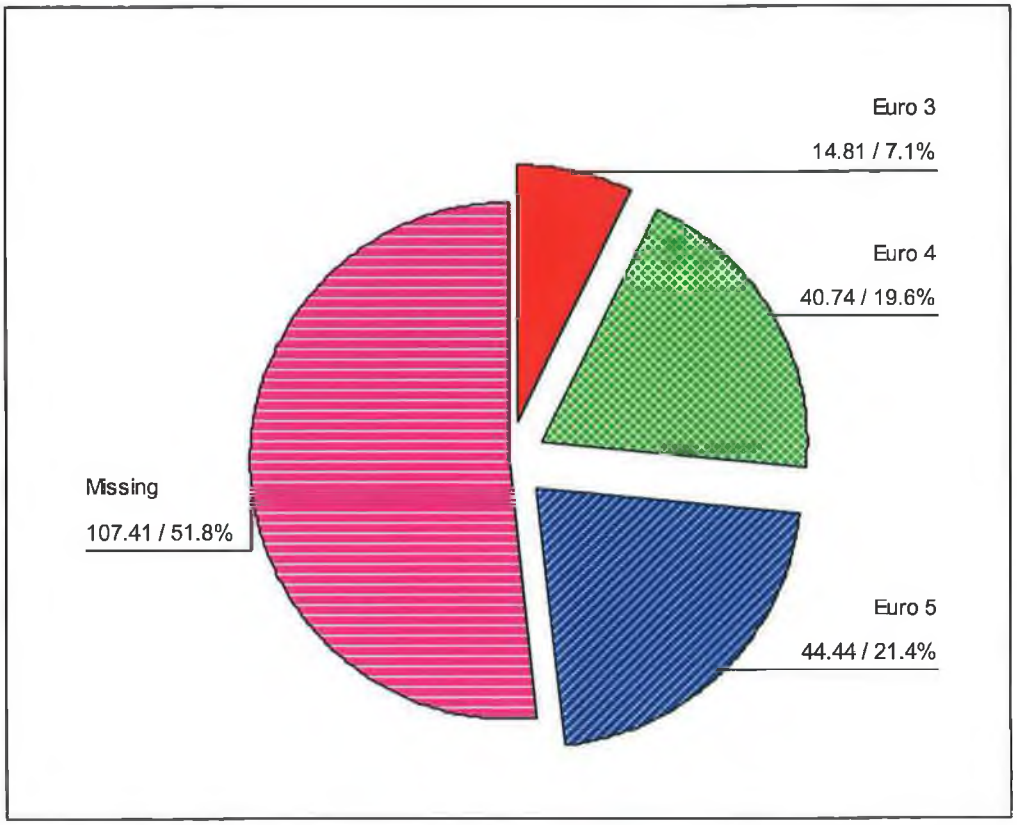


Fig 4.20 Level of emission standards on heavy-duty vehicles

Section Four: - Government Encouragements

1. Government fund for the investment in CNG development

The results in figure 4.21 indicate that 53.6% of the companies questioned received funding from the governments for investment. On the other hand, 46.4% of the companies surveyed that did not get government funding.

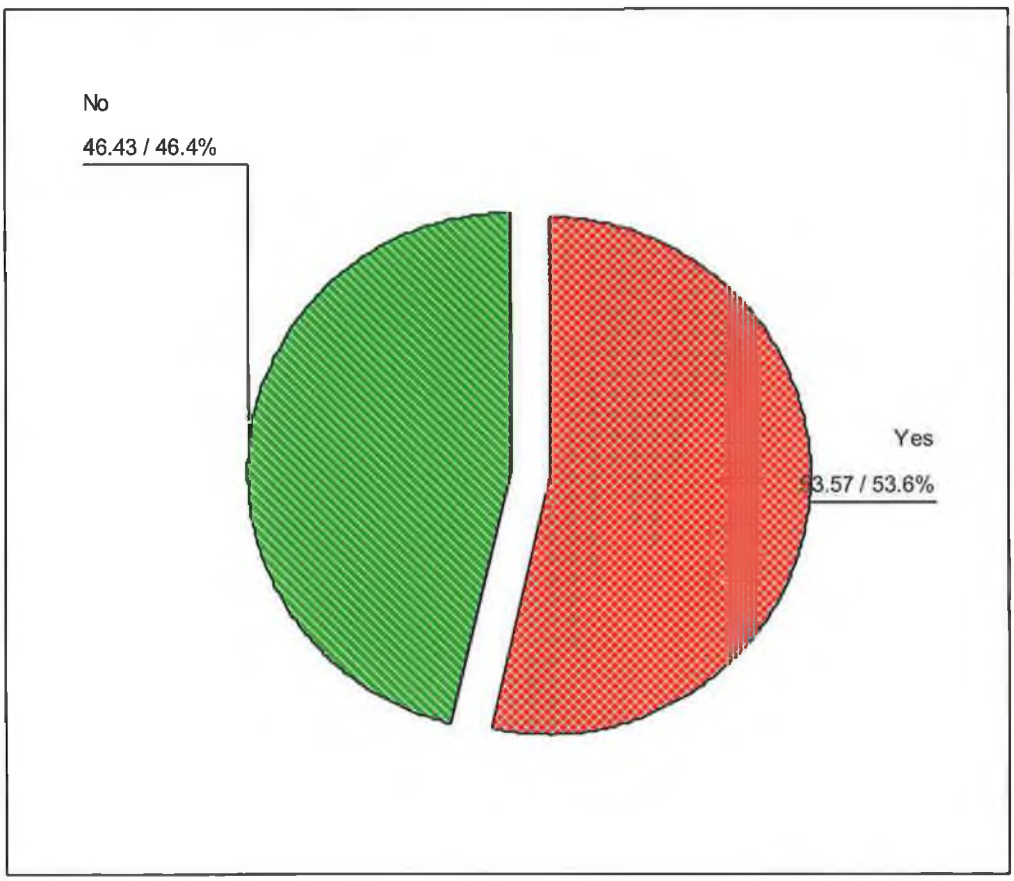


Fig.4.21 Government fund for the investment in CNG development

2. Government incentives

This question was concerned with the views of the respondents regarding the role of government incentives to encourage producing and marketing CNG vehicles. Figure 4.22 shows that a majority of 98.2% of the companies stated that governmental incentives are necessary.

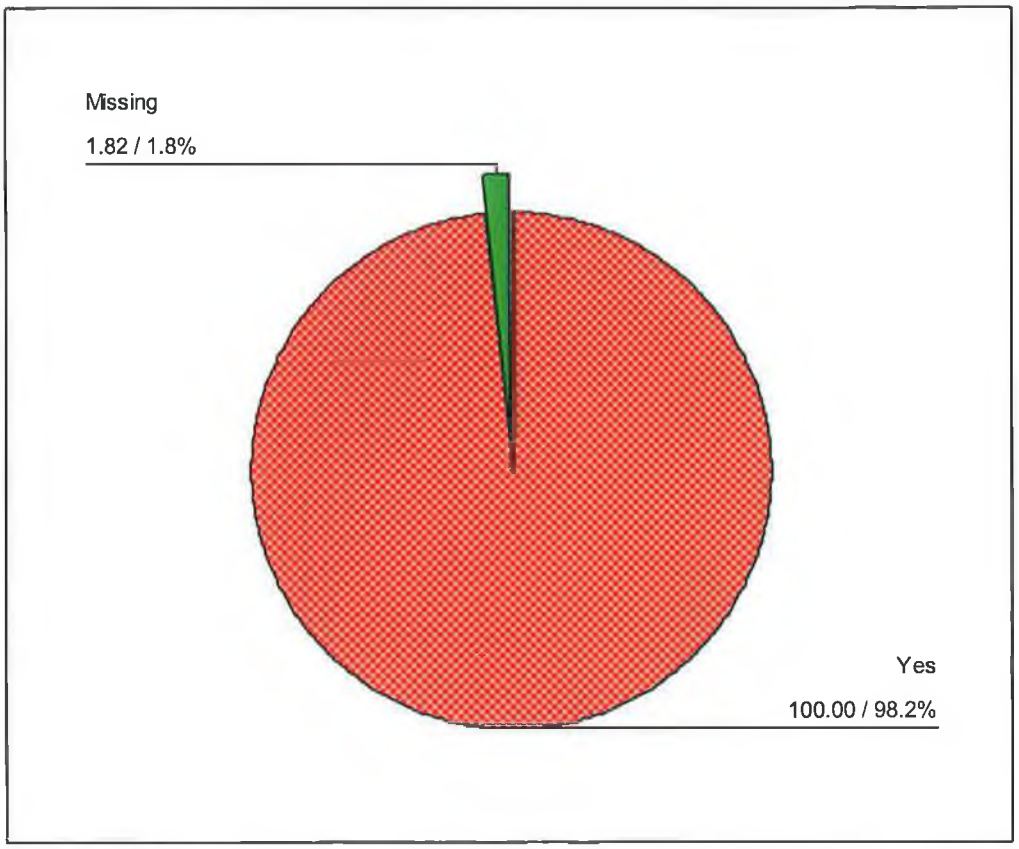


Fig 4.22 Government incentives

3. The percentage of the total cost required from governments to encourage car manufactures to supplying CNG vehicles

To ascertain the level of financial incentive that would be required to make car manufacturers plan for producing CNG vehicles, the previous question had a follow up remunerative option. There was little consensus among the respondents with regards to the level of financial incentive required. Figure 4.23 shows that 53.6% of the respondents stated that they would require between 15-20 % of the total cost. Furthermore, 19.6% of the respondents reported that they would require between 5-10%. While, 17.9% of the respondents opted for 10-15%, only 1.8% chose 0-5% of the total cost. Finally, 7.1% of companies did not give answer or considered it not applicable.

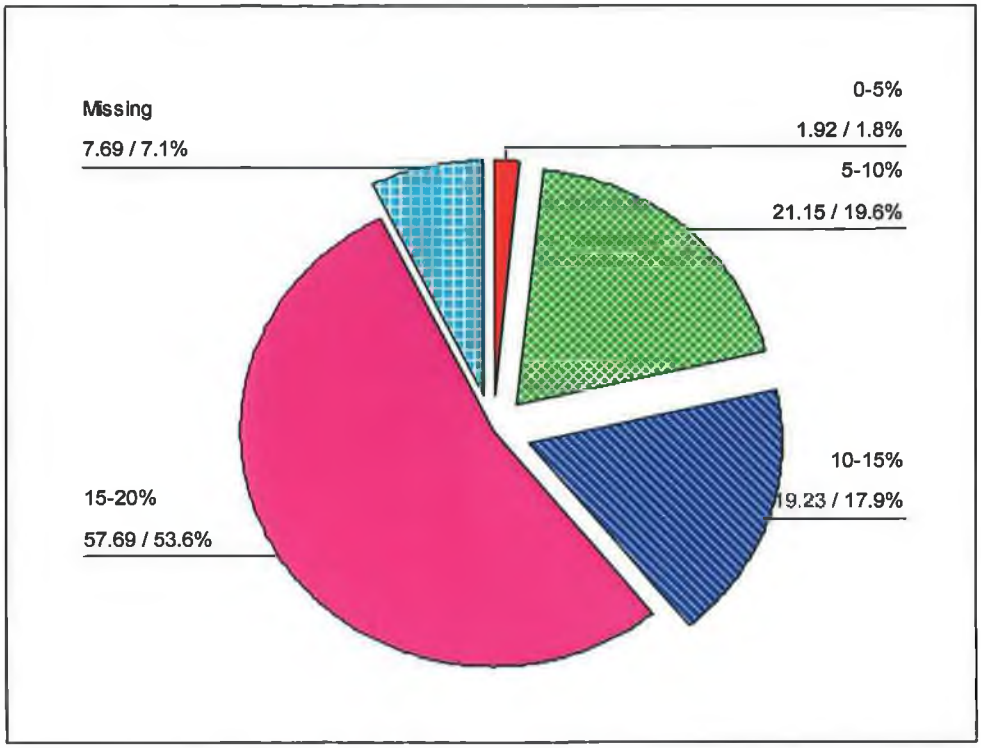


Fig.4.23 The total cost would required to make car manufactures consider supplying CNG vehicles

4. Willingness to contribute to production

The responses were less ambiguous when investigated the willingness of car manufacturers of contributing to the creation of fuel supply chains or industrial facilities to help promoting CNG vehicles in the markets. Figure 4.24 shows that 50.0% of the car manufacturers would not be prepared to contribute. On the other hand, 46.4% of the respondents reported a willingness to contribute.

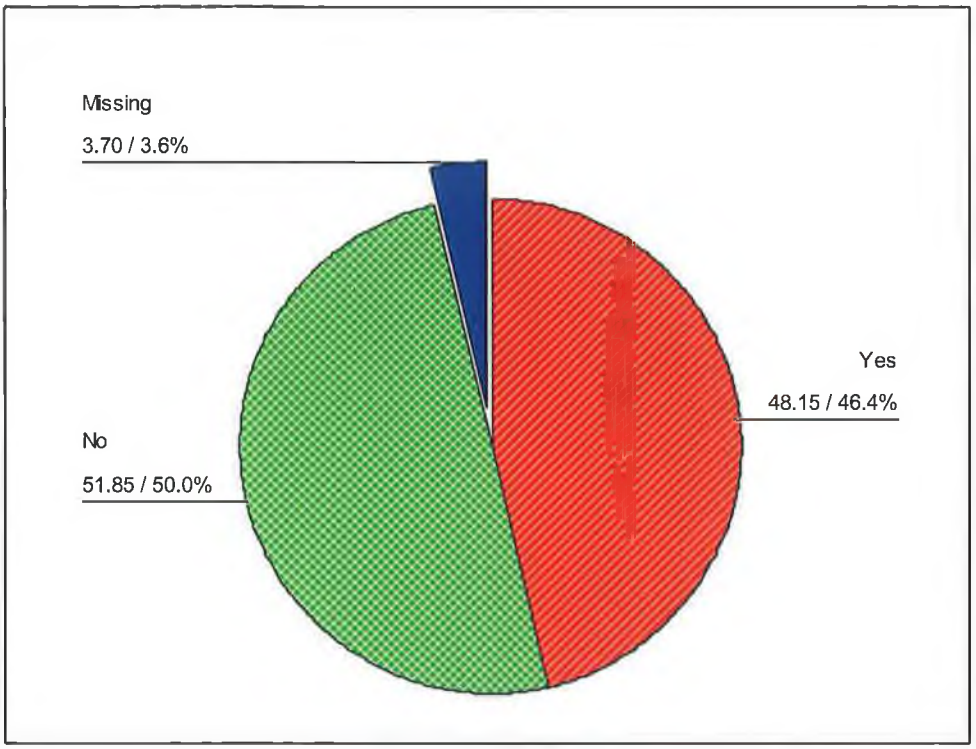


Fig 4.24 Vehicle manufacturing remunerative contribution

When asked about how much they would be contributing, the responses were as shown in figure 4.25, clearly the contribution and support from car manufacturers and suppliers cannot be relied upon. The encouragement and development of new facilities and markets depend greatly on the governmental incentives. While these responses were expected, it was still important to ascertain just how much the company would be willing to contribute to the creation of new facilities and markets.

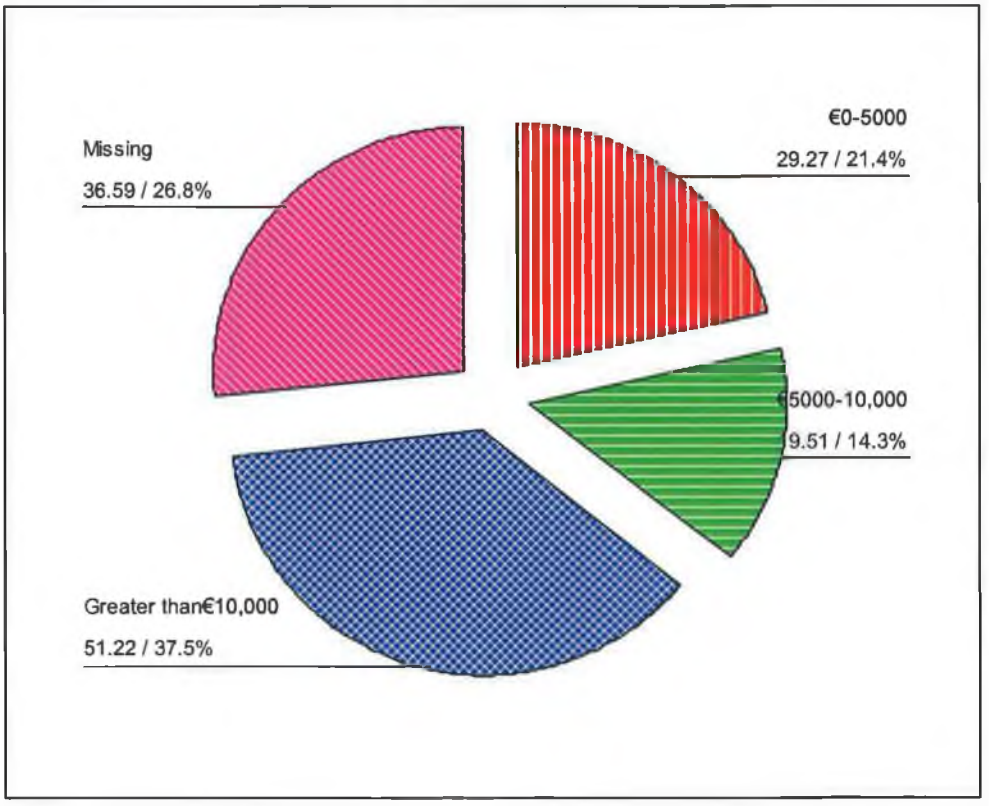


Fig 4.25 Vehicle manufacturing companies value contribution

Car Manufactures Comparison to OEMs

1. Trunk space/ boot space

Figure 4.26 shows the satisfaction level among the OEM companies with the space occupied by the gas cylinder in the vehicle's trunk. It was found that 42.9% of the respondents were dissatisfied with volume of trunk space occupied by the CNG fuel cylinder. A percentage of 28.6% were very dissatisfied with the trunk space volume. The very satisfied respondents were 14.3%, The very dissatisfied OEM companies were only 14.3%. While 10.7% had no preference on the trunk size.

Comparing the results from the car manufacturer and OEMs (see figure 4.6) to those of just the OEM (see figure 4.26) it can be seen that the OEM companies see the reduced trunk space as more of a problem than the car manufactures.

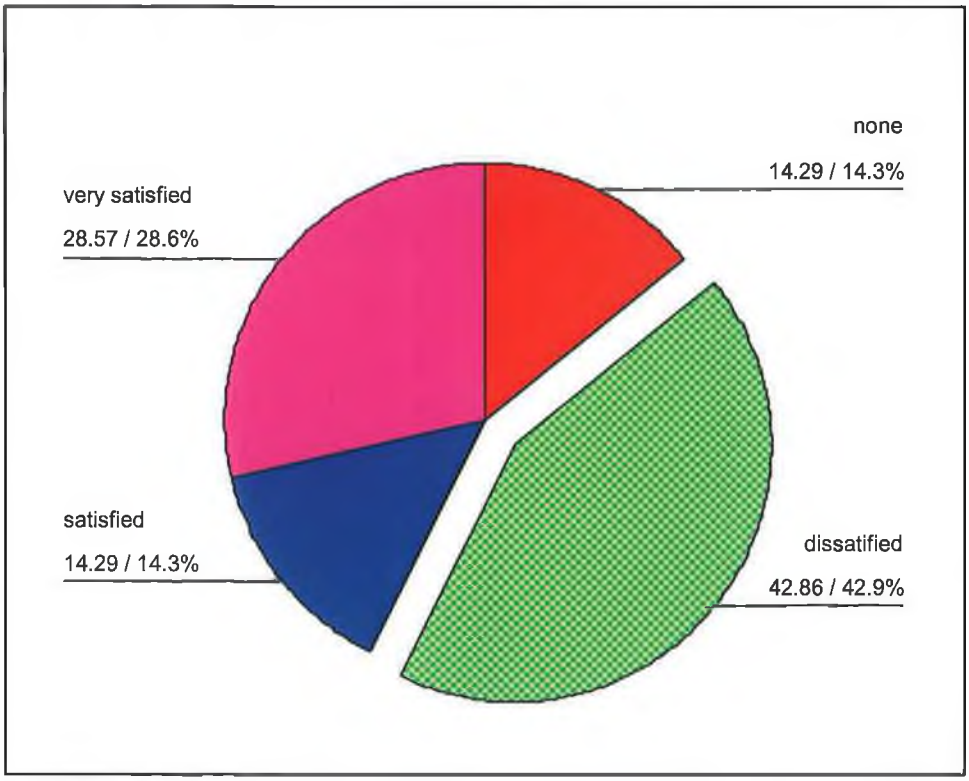


Fig 4.26 Level of satisfaction of the OEM's of trunk space capacity

2. Technical skills of staff with OEMs

As it is the common case with new technologies, training of the technical staff of interested companies is always necessary. The issue of the technical skills was inspected as an obstacle in this question. Figure 4.27 shows that 14.29 % of the OEM companies surveyed indicated that the technical skills were an average (appreciable) obstacle. However, 28.6% of the companies considered it as a very low obstacle. Moreover, 14.29% of companies said that it was a low obstacle.

From those results, the car manufactures (see figure 4.12) see the requirement for the technical skills as being more important than the OEMs (see figure 4.27).

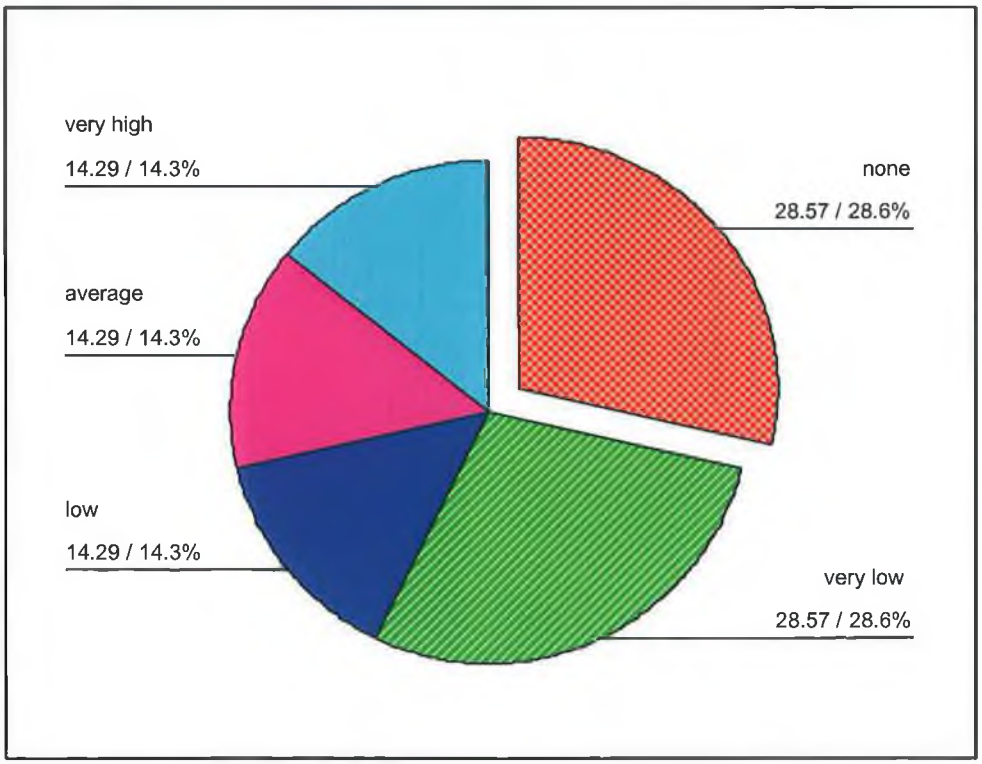


Fig 4.27 Technical skill as an obstacle to implementation of CNG systems with OEMs

3. Satisfaction with latest improvements in CNG feeding and injection component with OEMs

This section was intended to check the level of satisfaction of the latest improvement in different CNG car system operations. Figure 4.28 shows that 42.9% of the OEM companies answered 'yes' to the satisfaction with latest improvements in CNG feeding component. On the other hand, 40% of the respondents answered 'No' to the satisfaction with latest improvements in CNG feeding component. It can be interesting inferred from this that the

car manufactures see the improvement in car performance as being more important for their industry (see figure 4.17) than the OEMs see it (see figure 4.28)

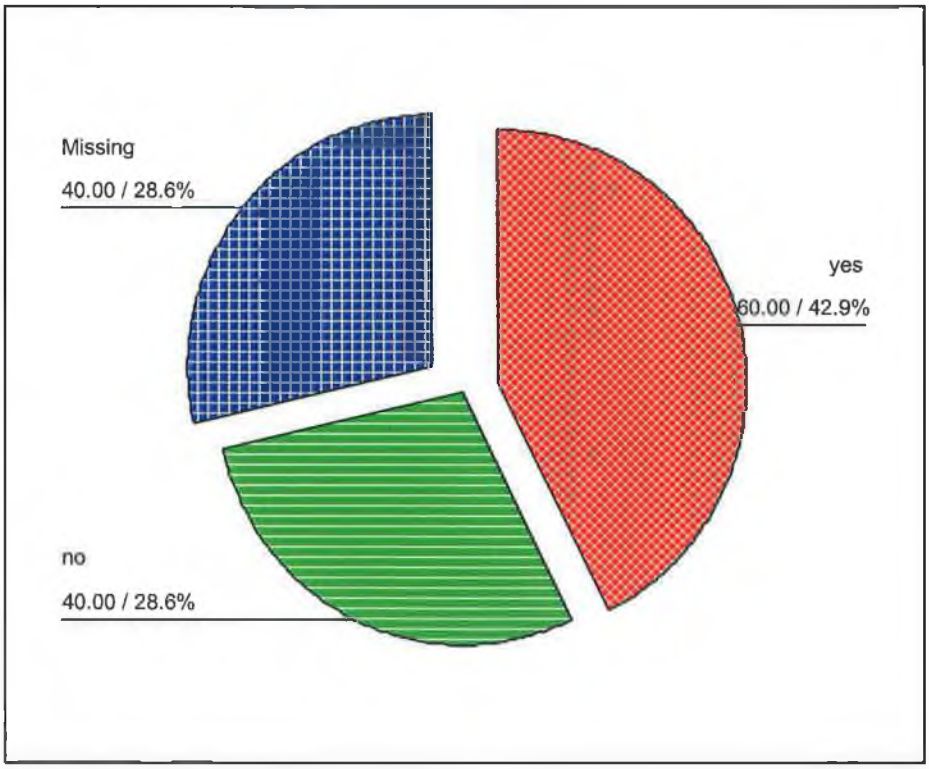


Fig 4.28 Level of satisfaction with latest improvements in the CNG feeding injection component with OEMs

4.4.2 Vehicle Customer Survey

1. Knowledge of CNG vehicles

The purpose of the first question was to explore the customers' knowledge of CNG vehicles. It can be seen in figure 4.29 that there is considerable lack of knowledge about CNG around Europe. Currently, 55.4% of respondents replied that they had nearly no knowledge of the topic, and a further 17.4% reported that they were only slightly

familiar. Moreover, 14.1% of the respondents reported that they had some knowledge of CNG Vehicles, but only 13.0% of these reported that they were highly aware of the CNG vehicles.

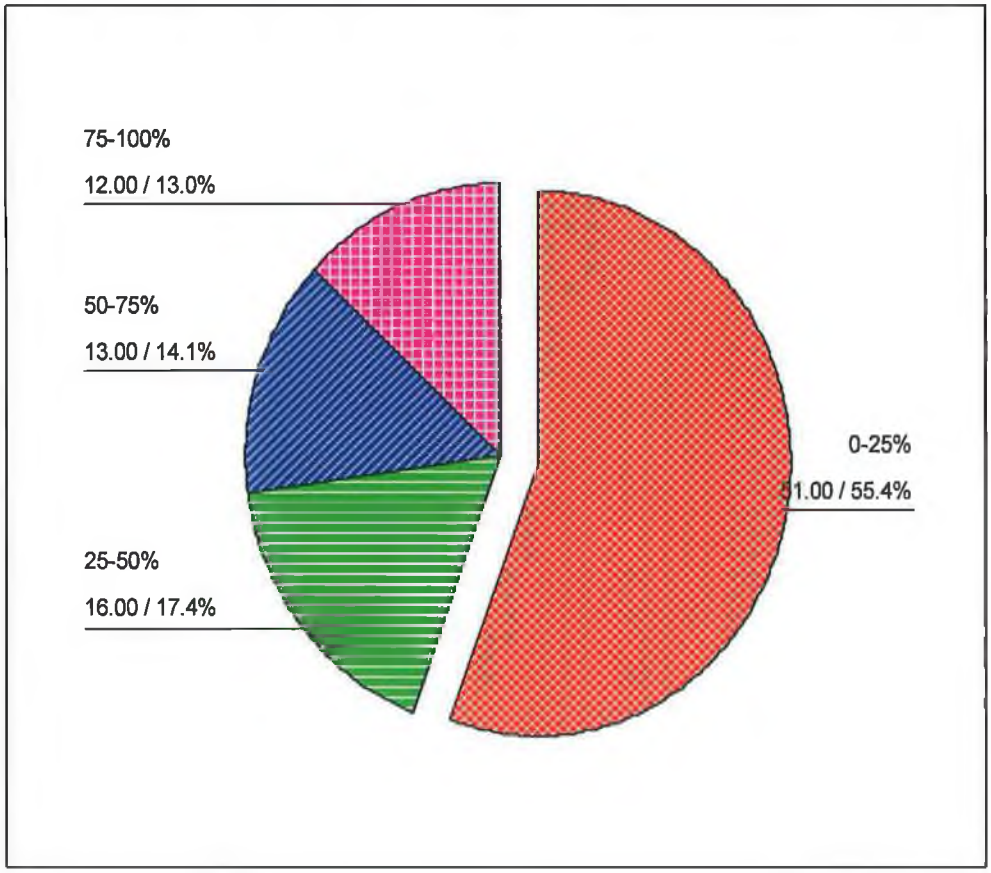


Fig 4.29 Description of the customers' knowledge of CNG vehicles

2. Customer contribution to better environment

Despite very few customers reported that they were knowledgeable about CNG Vehicles, there was a surprisingly high level of endorsement for the idea of a paying price premium for more environmentally friendly vehicles. This was evident from the 91.3% of the respondents that stated they would be willing to pay more for an environmentally friendly car. Only 7.6% stated they would not do this. It may be

inferred from this result that the majority of customers would be willing to pay the cost of conversion also (approx €2000). For the development of the industry it is promising that so many respondents were in favour of environmentally friendly mean of transportation and are willing to pay a price premium. Only 1.1% of costumers either didn't answer or considered it not applicable. These results are presented figure 4.30.

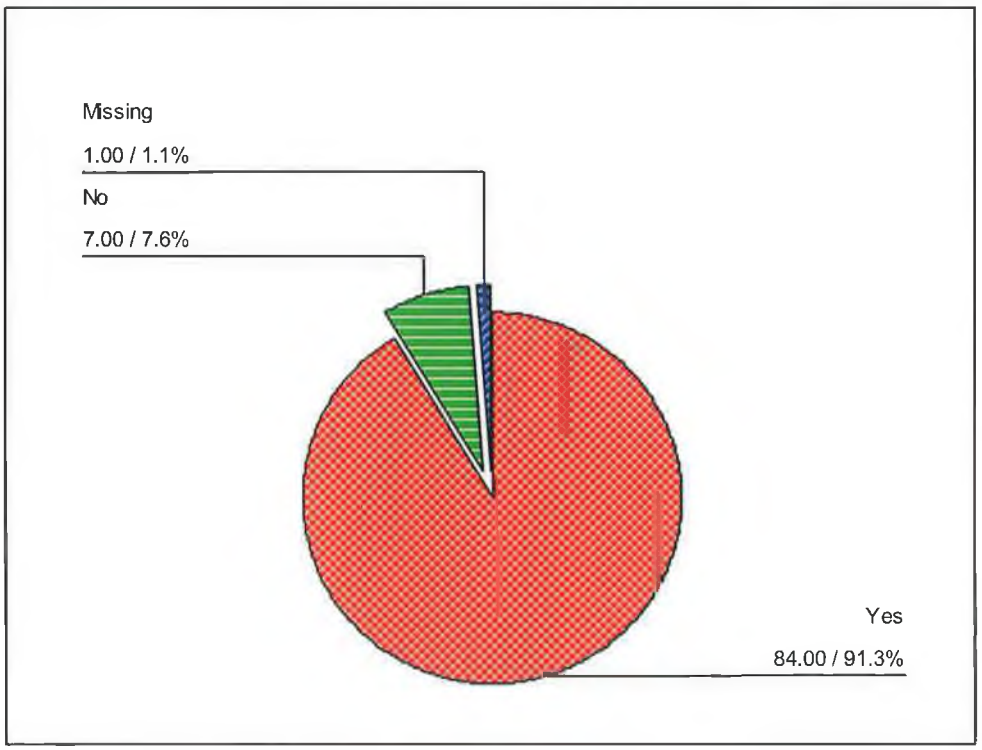


Fig 4.30 Willingness to contribution for environmentally friendly CNG vehicle

As a follow-up, question 2 also attempted to gauge the level of price premium that customers would be willing to pay. Figure 4.31 shows that over half (53.3%) of respondents reported that they would be willing to pay up to €1000. however, 34.8% reported that they would pay between €1000 – 2000. While 5.4% could be paying between €2000 – 3000, only 2.2% would pay between €3000 – 4000. Finally, 4.3% of costumers either did not answer or consider it not applicable.

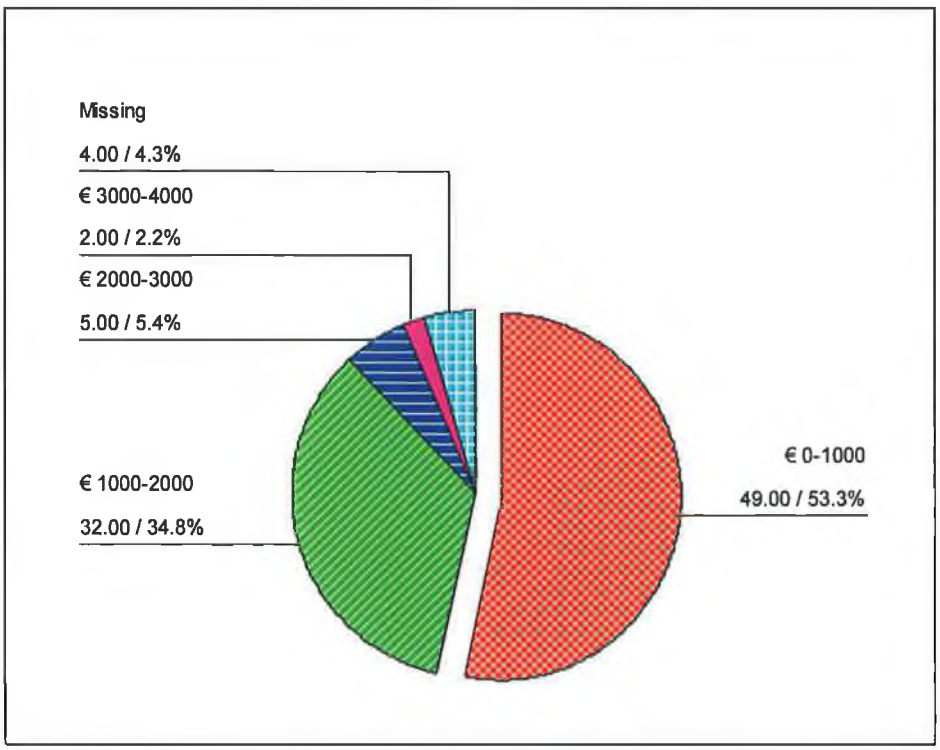


Fig 4.31 Current level of contributions

3. Waiting duration for refuelling CNG vehicles

The questionnaire next explored the customers' reactions to some factors involved in owning a CNG car. One of these factors is the inconveniences encountered with the refuelling time and distances. This question asked the respondents whether they would be willing to wait for additional five minutes to refuel their car, if it was beneficial to the environment. Figure 4.32 shows a majority 85.9% of the customers reported that they would be willing to wait for an extra few minutes.

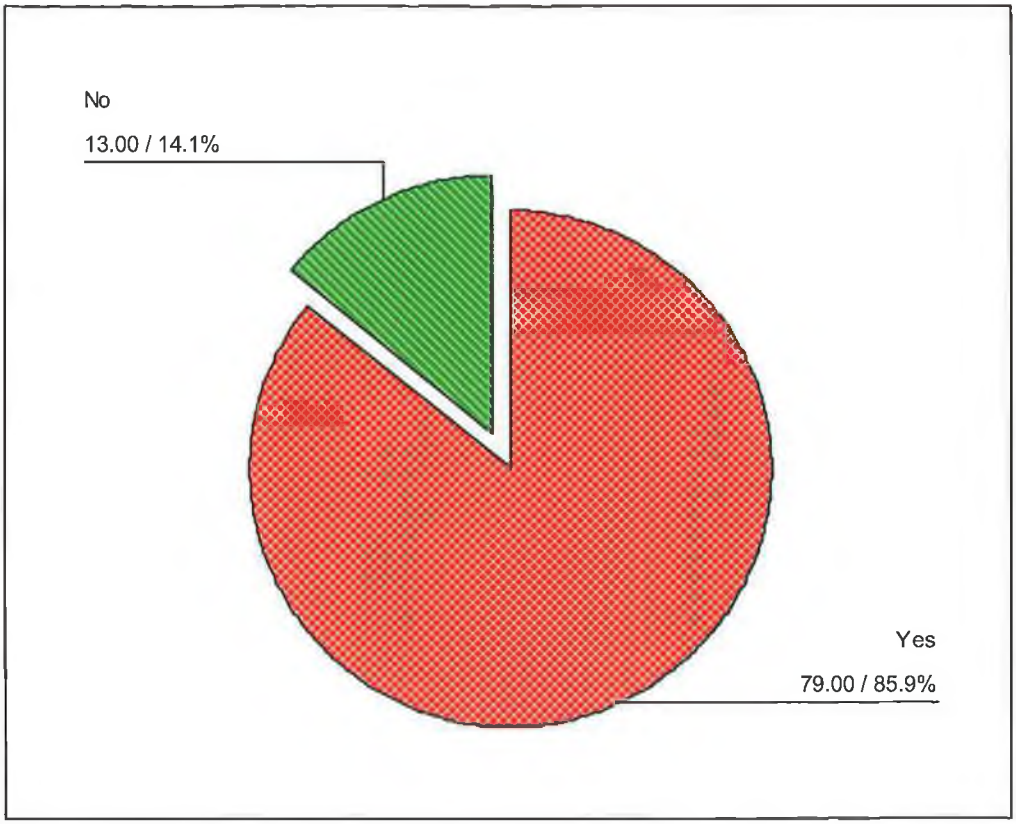


Fig 4.32 Tendency to wait more for refuelling CNG vehicles

4. Travelling further distances to refuel CNG vehicles

The customers' opinions were more divided on this issue. Although the respondents did not, on average, seem to have a major problem with waiting longer to refuel CNG vehicles, to go out of their route or to travel further for refuelling a CNG vehicle was a considerable problem. Figure 4.33 shows that 79.3% of the customers accepted to travel further to refuel if it was better for the environment, while 19.6% said the opposite. Only 1.1% of the costumers did not answer.

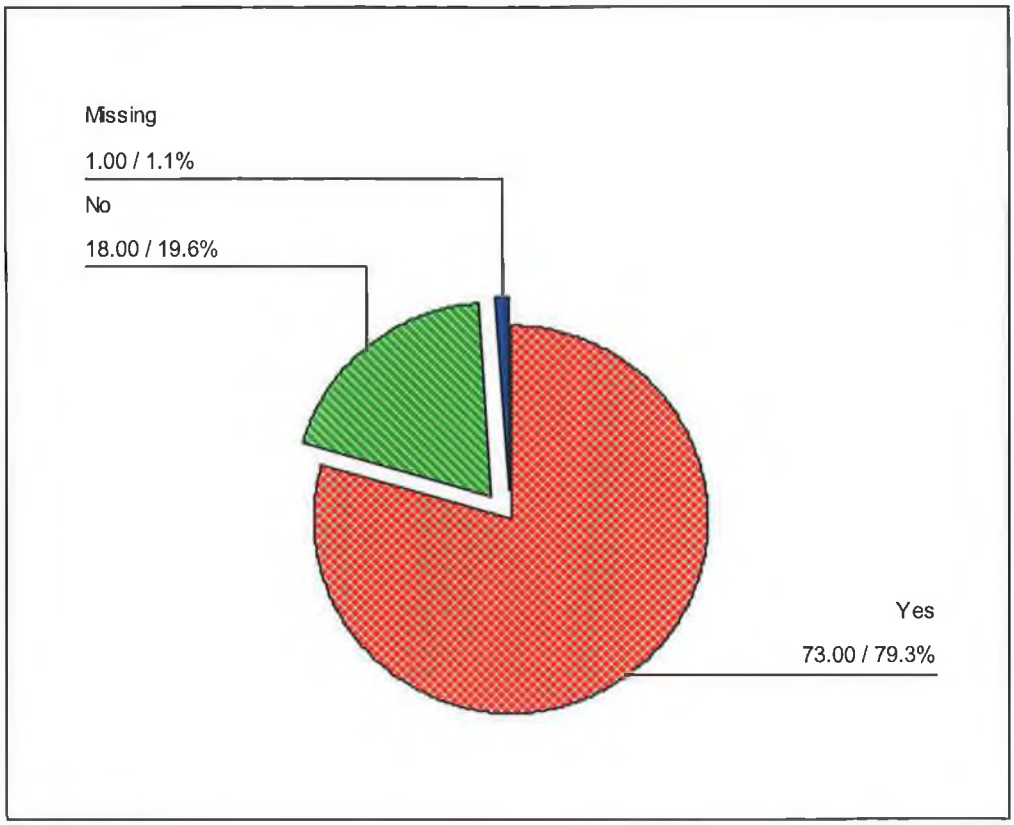


Fig 4.33 Willingness to travel further distances to refuel CNG vehicles

Furthermore, when asked how much further the customers would be travelling to refuel a CNG vehicle, the results drew a clearer view of the issue. Figure 4.34 shows that 43.5% of the customers would travel between 0-5 miles and 26.1% of the customers would travel between 5-10 miles. Moreover, 20.7 % of the customers indicated between 10-15 miles. Finally, 9.8 % did not give answer or considered it not applicable.

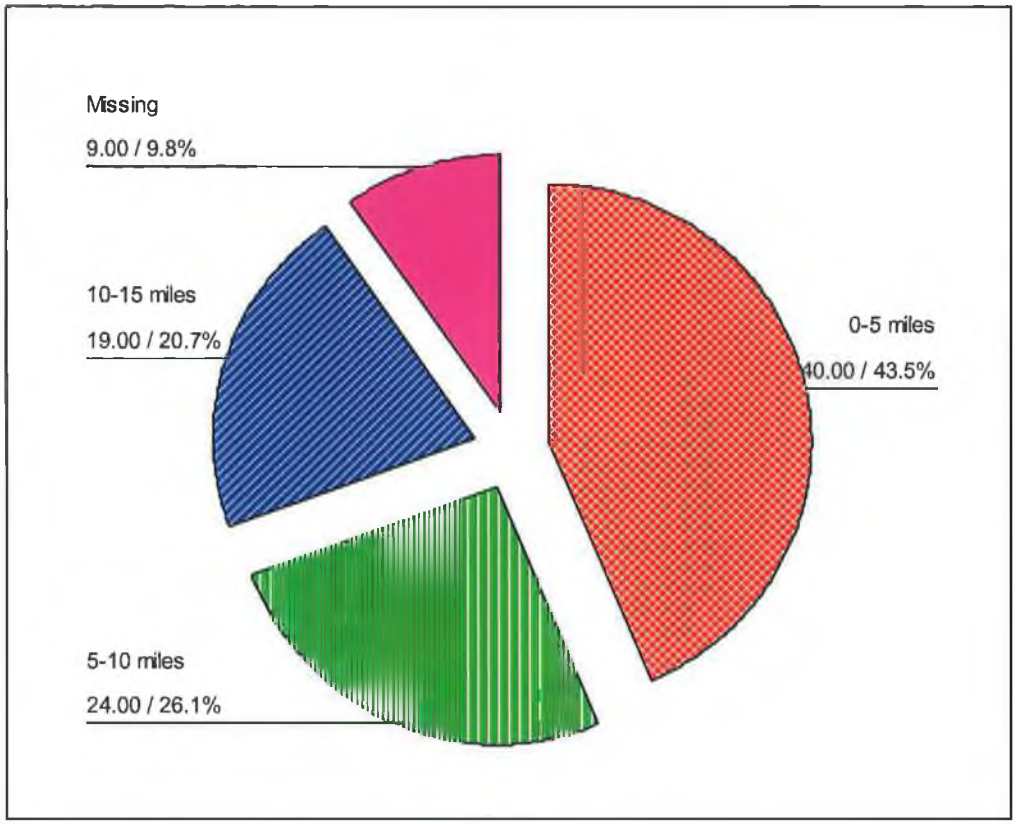


Fig 4.34 Further distances to be travelled for refuelling a CNG vehicle.

5. The current level of satisfaction with the public fuelling infrastructure for CNG vehicles

Figure 4.35 indicates that the 63% of CNG vehicle owners were dissatisfied with the number of CNG refuelling stations. The limited refuelling infrastructure had a major impact on how they use their vehicle. When they were asked if the lack of refuelling infrastructure prevented them from driving to places they, would otherwise, like to drive, nearly all the owners answered affirmatively. When the respondents wanted to take their CNG vehicle somewhere they were uncertain about CNG fuel availability, they would usually take their gasoline vehicle instead. Since finding a gasoline station is comparatively easier, they eliminate the risk of not finding fuel for the CNG vehicle in an area which they are unfamiliar with. CNG vehicle owners would sometimes

experiment with new stations, which allow them to increase the geographic area they would feel assuring for driving their CNG vehicles. This usually involves a "trial" trip, a trip they would only do if they have enough fuel to return to a more familiar station. Only 2.2% of customers either did not answer or considered it not applicable.

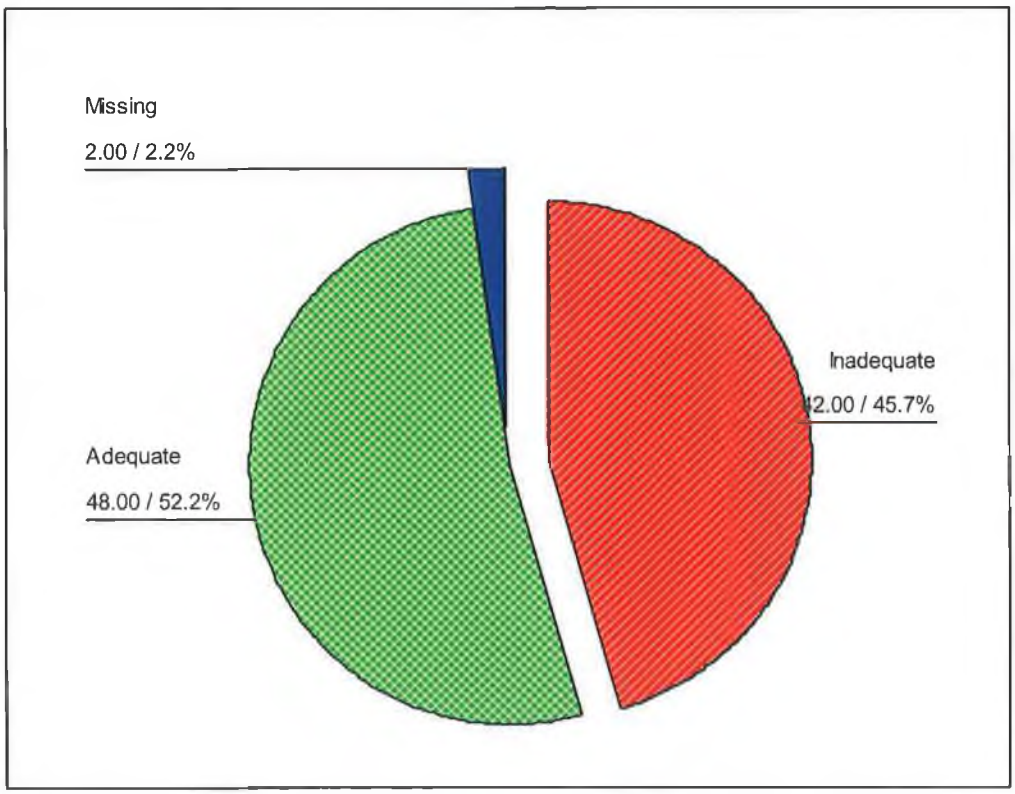


Fig 4.35 Current level of satisfaction with the public fuelling infrastructure

6. Safe driving with CNG vehicles

The results indicated that, CNG vehicle owners, questioned in this study, are confident about the safety of their vehicles as evident from their responses to this question. While the overall safety of the vehicle was considered rather than just the fuel system, figure 4.36 shows that 42.4% of the customers confirmed that the vehicle was moderately safe. They might have researched the issue of vehicle safety on various internet sites and believed that the vehicle is as safe as a gasoline-equivalent vehicle. It is hypothesized that some owners may have compared the safety of their CNG vehicle (in most cases a subcompact vehicle) to others on the road resulting a 23.9% of the customers who

indicated that their vehicles are fully safe. While 28.3% of the customers either did not answer or considered it not applicable, only 5.4% indicated that CNG vehicles are not safe.

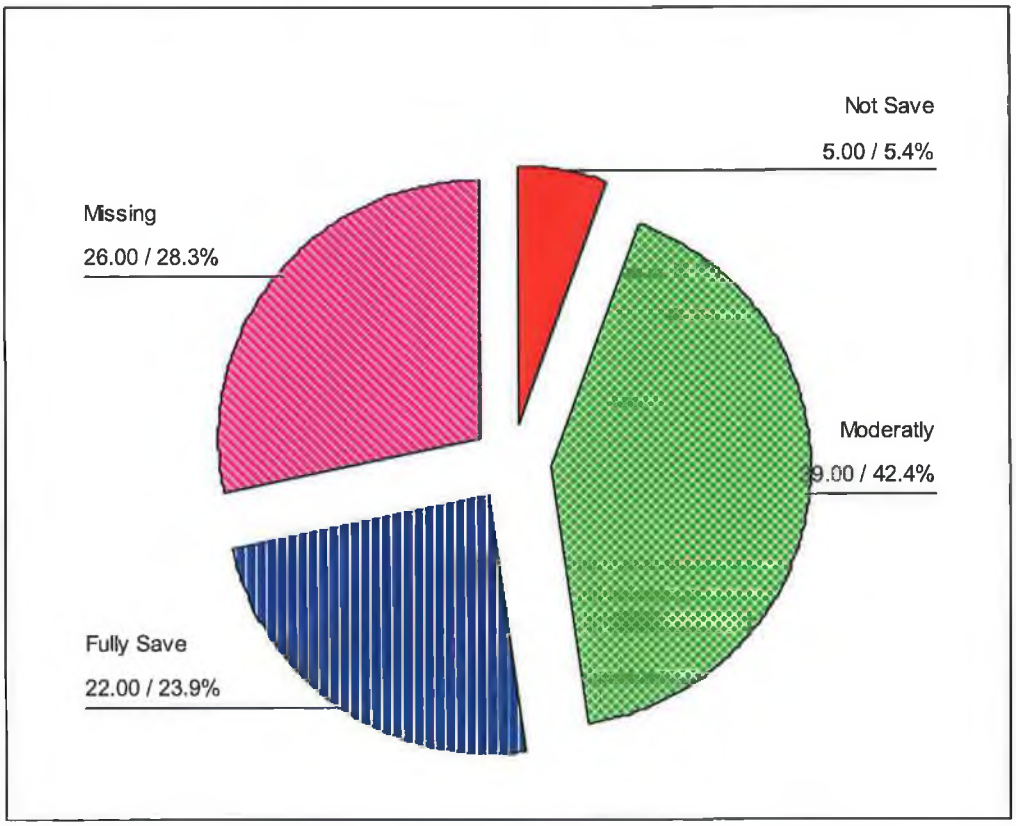


Fig 4.36 Level of safety of CNG vehicles

7. Government encouragement

Finally, the questionnaire asked customers about their views on whether the government should offer financial incentives for those people who use more energy efficient and environmentally friendly alternatively powered vehicles. Figure 4.37 shows that 88.0% of the customers stated that there should be governmental incentives for CNG vehicles. Only 12.0% of the customers disagreed with the introduction of such incentives. It is worth noting that this endorsement of governmental incentives helps promoting environmentally friendly vehicles among customers more than it does in the case of the car manufacturers.

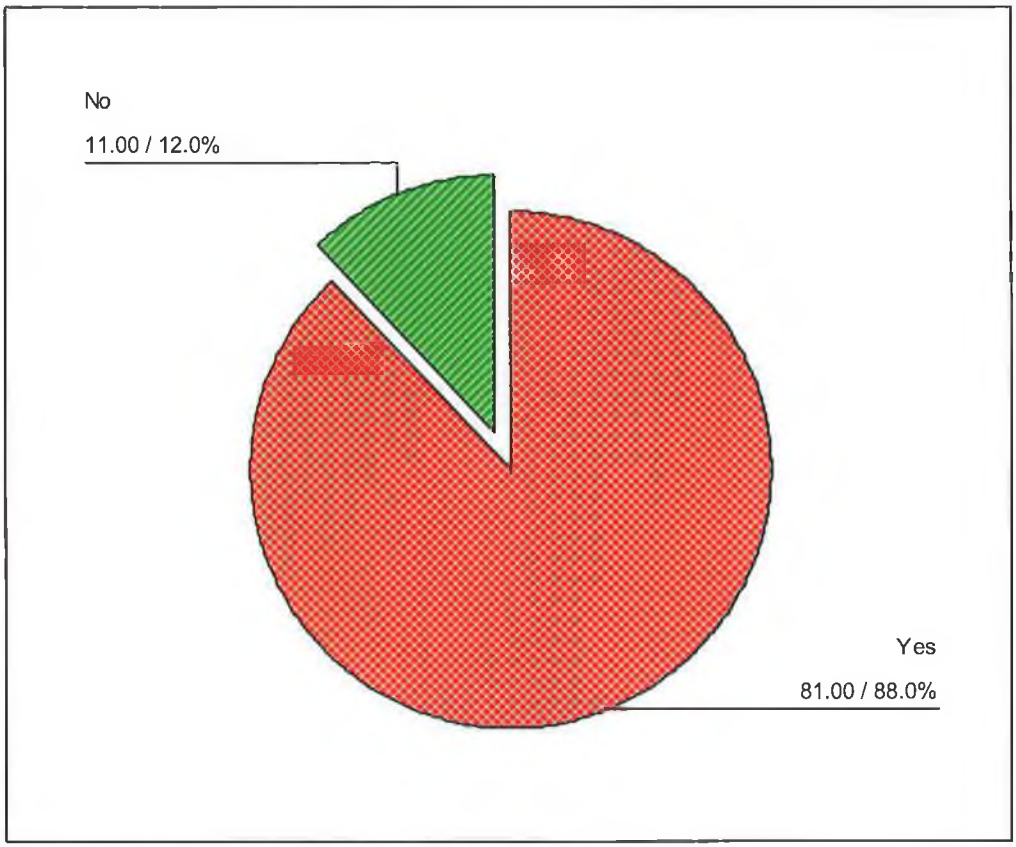


Fig 4.37 CNG car customer's opinions on the need for Government incentives

Another question posed in the questionnaire was whether the respondents believed that governmental incentives would encourage more people to purchase CNG vehicles. Figure 4.38 shows that some customers answered in a manner, which reflected their personal opinions whether they should receive more incentives, 39.1% answered "Definitely". The customers who answered "maybe", and counted as 37.0%, tended to believe if governments were serious about increasing the market growth of CNG vehicles, it might be necessary to offer greater incentives. However, some believed that the financial incentives did not influence their decision; their answer was "Probably Not" and counted as 19.6%, indicating that, in their opinion, the current incentive package was reasonable or sufficient. Finally, 4.3% did not give answer or not consider it applicable.

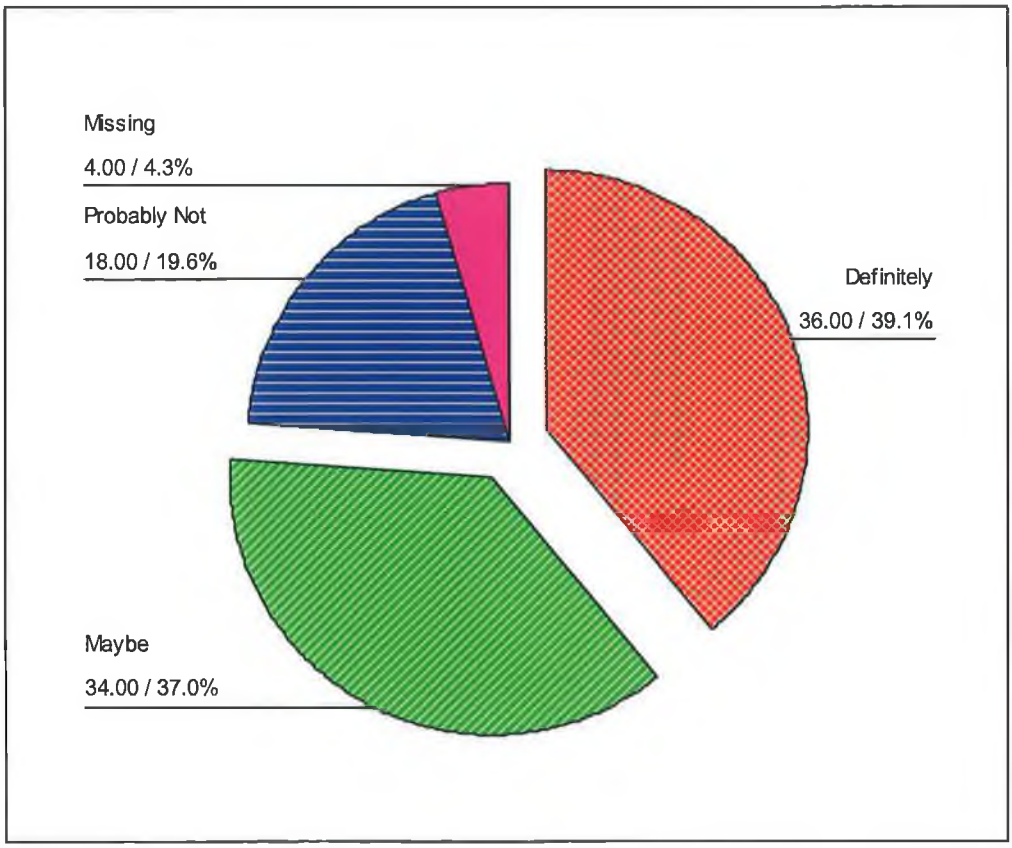


Fig 4.38 Customers' view on the importance of governmental incentives

4.5 Discussion

4.5.1 CNG Vehicle Manufacturing Survey

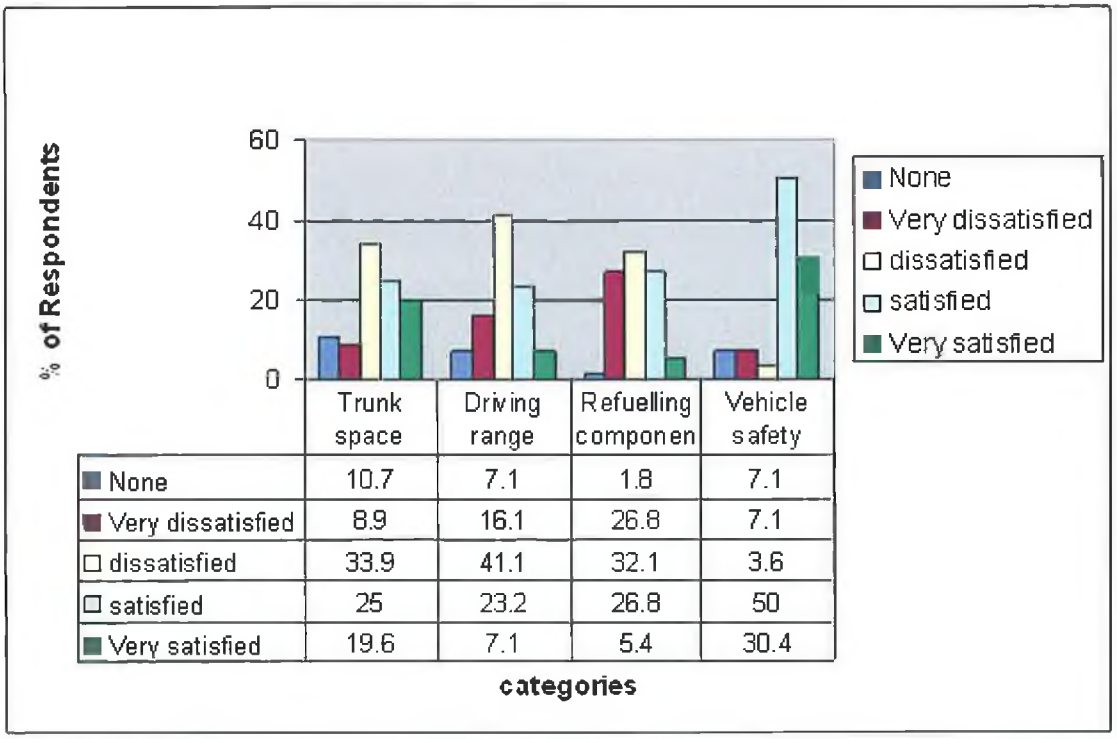
4.5.1.1 Ownership

The analysis of the "Ownership" variable showed that the CNG car manufacturing companies are classified into five groups: International car manufacturing companies, National car manufacturing companies, Local car manufacturing companies, Mixed car manufacturing companies and foreign car manufacturing companies.

Satisfaction with CNG technology

With regards to the satisfaction of implementing CNG technologies in the car manufacturing industry, it appeared that, in general, the three biggest obstacles are

trunk space/ boot space, driving range and CNG components. Figure 4.39 illustrates the obstacles that are facing manufacturers wishing to implement CNG technology. The values in the bar chart are obtained by summing the values of the appreciable obstacles and the major obstacles discussed in the CNG car manufacturing analysis, section 2, question 1, under the section (satisfaction with CNG technology). These results are very comparable to the study made in [66] at the Applied Physics Laboratatory (APL) of the Johns Hopkins University. The authors have developed a mid-sized CNG sedan that had ultra low emissions along with an acceptable driving range, performance, trunk space. The developed vehicle met the federal safety standards that are comparable to gasoline-powered cars.



	Trunk space	Driving range	Refuelling componen	Vehicle safety
None	10.7	7.1	1.8	7.1
Very dissatisfied	8.9	16.1	26.8	7.1
dissatisfied	33.9	41.1	32.1	3.6
satisfied	25	23.2	26.8	50
Very satisfied	19.6	7.1	5.4	30.4

Fig 4.39 Level of satisfaction with some categories after development in CNG car manufacturing

1. Trunk space/ boot space

Figure 4.39 shows the manufacturers satisfaction with the trunk space/ boot space. It was found that 53.5 % of the respondents were between non satisfied,

dissatisfied and very dissatisfied with the volume of trunk space occupied by the CNG fuel cylinder. On the other hand, it was found the 44.6% of respondents were between satisfied and very satisfied. This result coincides with the customers' opinion which indicated that the reduced trunk space prevented them from taking trips by the vehicle. This study reveals that the trunk space is a very important issue. The vehicle manufactures should solve this obstacle by optimizing the trunk geometry and space.

2. Driving range

Figure 4.39 shows the responses to the satisfaction with the vehicles driving range. It was found that the majority of 64.3 % of the respondents were not satisfied and dissatisfied very dissatisfied with driving range of CNG vehicle. About 30.3 % of the respondents were satisfied and very satisfied with the driving range of CNG vehicles.

Current CNG vehicle companies share the opinion that the driving range is one of their main concerns. This is closely related to the limited refuelling infrastructure as depicted from the results of the CNG vehicle customers found in question 6 sections 4.4.2. Since none of the CNG companies had much experience with the low driving range imposed by the vehicle, it has caused more inconvenience than they had expected.

It was also noticed that the surveyed CNG vehicle owners would be affected by the low driving range, they must refuel every two or three days. The reduced driving range and limited refuelling infrastructure also prevents the drivers from taking the vehicle on trips outside their normal "activity space".

3. Refueling component

Figure 4.39 shows the level of satisfaction with the CNG refuelling component. It was found that majority of the respondents were between not satisfied, dissatisfied and very dissatisfied with the refuelling component by 60.7 %.

On the other hand, 32.2 % of the respondents were between satisfied and very satisfied with the refuelling component. It is obvious that improving the CNG

refuelling component will have a positive effect on the customers by saving their time in the refuelling stations.

4. Vehicle safety

Figure 4.39 shows the responses to the question about the satisfaction with the vehicle safety. It was found that majority of the respondents were between satisfied very satisfied with the CNG vehicle safety by 80.40 %. However, 17.8 % of the respondents were not satisfied, dissatisfied and very dissatisfied with the CNG vehicle safety.

CNG vehicle companies' comments revealed that they are confident in the safety of their CNG vehicle as it was evident from their responses to this question.

But according to the customers, they are concerned about the vehicles' safety, they have the feeling that they are riding on "bombs" due to the high-pressure cylinder tank, this feeling is despite the commendable safety record in all the vehicle applications.

Level of CNG development

The analysis, of the current level of development, showed that the plants with ≤ 1000 employees, are generally less developed than those with >1000 employees. Figure 4.40 shows that 23.10% of the small and medium plants are mostly developed. Whereas, 50% of the large plants are mostly developed.

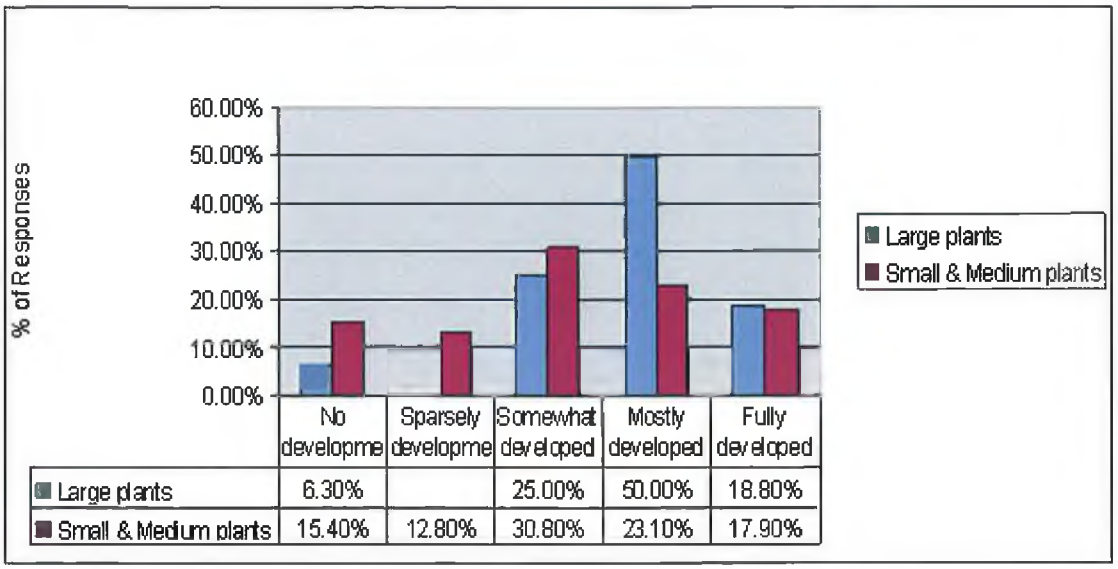


Fig 4.40 Current level of development in the small, medium and larger plants

This trend also applies to the level of development that is expected within the coming years. The analysis of question 4 of section 2 shows the level of development expected within the coming years for small, medium and large companies can be ssn in figure 4.41. For small and medium plants, 38.5% indicated that the plant would be somewhat developed, and 20.5% indicated that the plant would be fully developed. For large plants, 31.3% indicated that the plant would be somewhat developed, while 43.8% would be fully developed.

The study reveals that small, medium and large companies are planning to increase their capabilities of developing and implementing the CNG components. These findings show that there is a good scope for development around Europe.

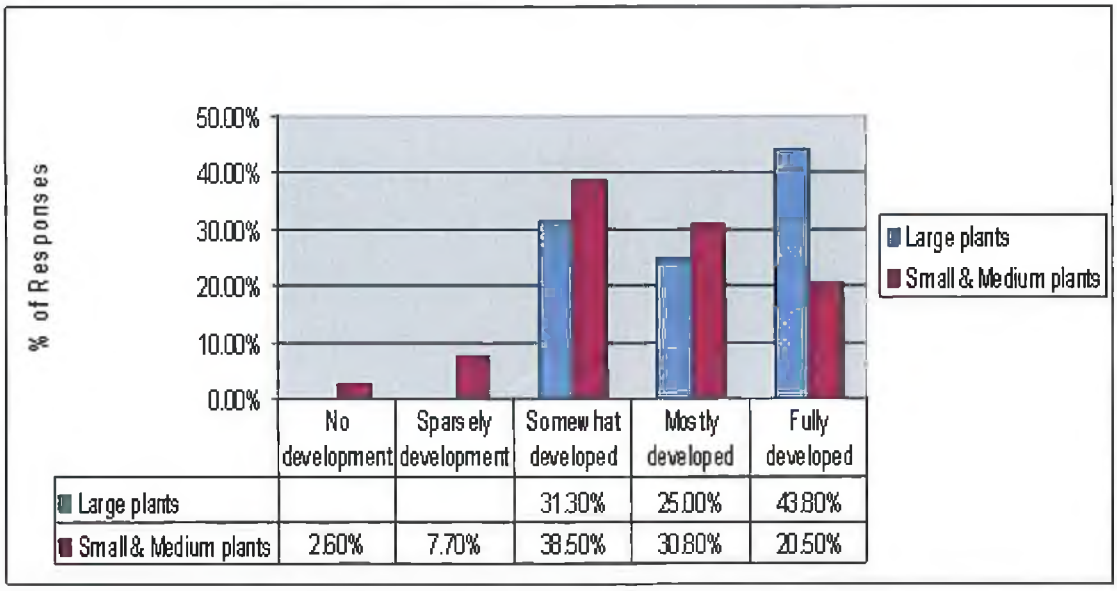
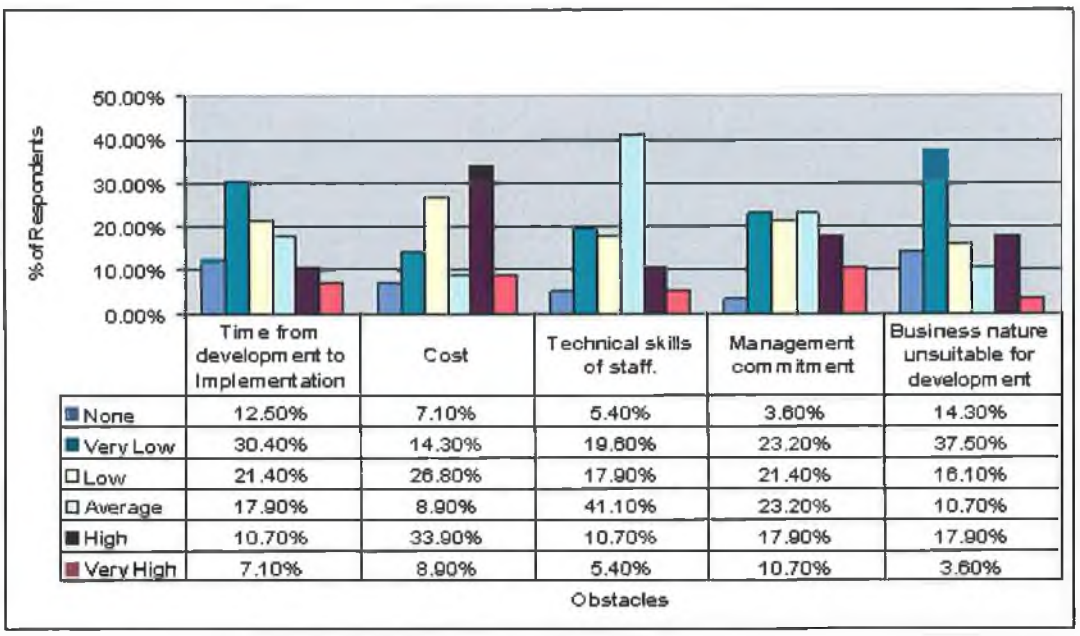


Fig 4.41 Level of development expected within the nest years in small, medium and large plants

With regards to the obstacles facing the implementation of CNG technologies in the car manufacturing industry, it appears that the two biggest obstacles are cost and technical skills. The analysis of question 2 in section 2 illustrates the obstacles that are facing manufacturers wishing to implement the CNG components in the car industry, those results can be seen figure 4.42. The values in the bar chart are obtained by summing the values of appreciable and major obstacles discussed in the CNG car manufacturing questionnaire.



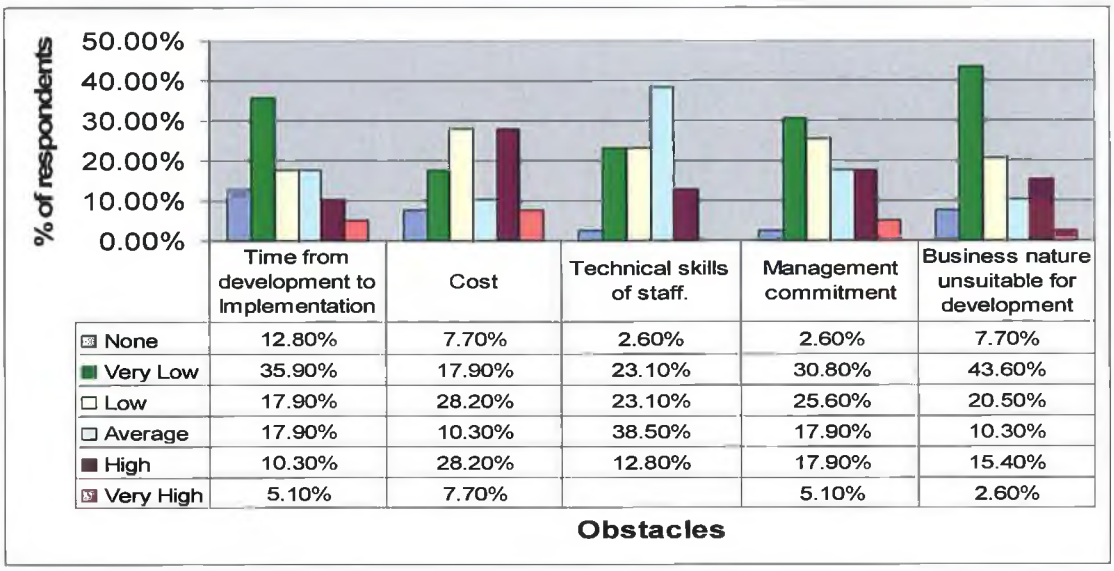
	Time from development to Implementation	Cost	Technical skills of staff.	Management commitment	Business nature unsuitable for development
None	12.50%	7.10%	5.40%	3.60%	14.30%
Very Low	30.40%	14.30%	19.60%	23.20%	37.50%
Low	21.40%	26.80%	17.90%	21.40%	16.10%
Average	17.90%	8.90%	41.10%	23.20%	10.70%
High	10.70%	33.90%	10.70%	17.90%	17.90%
Very High	7.10%	8.90%	5.40%	10.70%	3.60%

Fig 4.42 Survey results on obstacles to the implementation of CNG component in the vehicle industry

It is obvious from these results that to improve the companies' capabilities, it is necessary to improve their staff's technical skills. At the same time, the cost should be tackled to improve the competitiveness with the conventional fuel system.

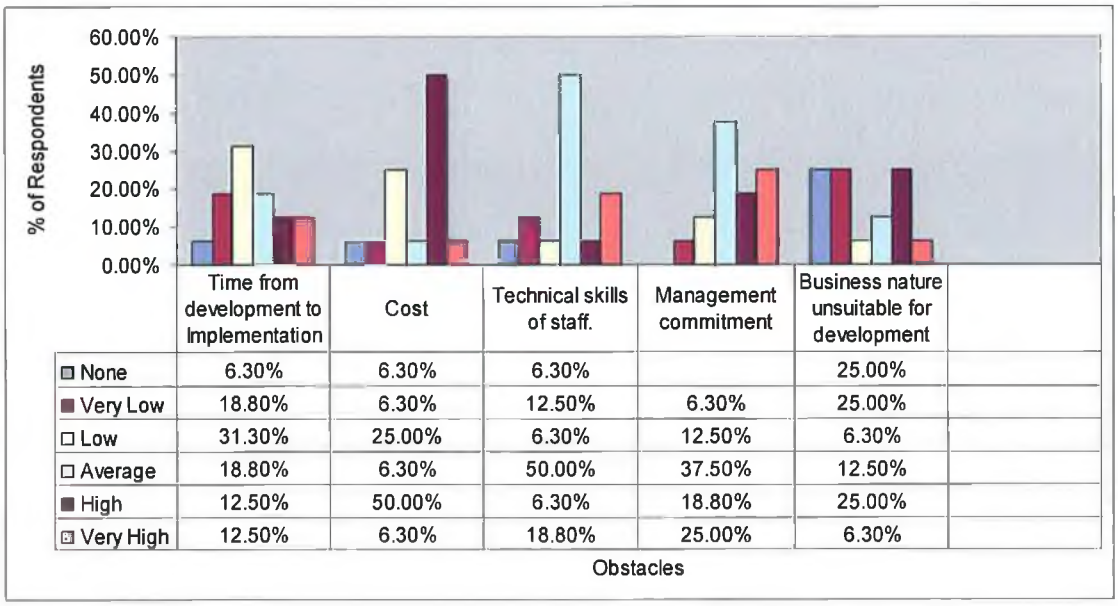
Also, the government should offer better financed machinery to help the small and medium companies play a bigger role in developing and manufacturing a competitive CNG fuel system.

Also it seems that in small and medium companies, there is less management commitment to supporting CNG implementation. Again their policies could be tackled by providing better financed machinery for those companies to motivate their management towards the development and implementation of CNG components. Figure 4.43 shows the obstacles to implementing CNG components in small and medium companies and figure 4.44 shows the obstacles to implementing CNG components in large companies.



	Time from development to Implementation	Cost	Technical skills of staff.	Management commitment	Business nature unsuitable for development
None	12.80%	7.70%	2.60%	2.60%	7.70%
Very Low	35.90%	17.90%	23.10%	30.80%	43.60%
Low	17.90%	28.20%	23.10%	25.60%	20.50%
Average	17.90%	10.30%	38.50%	17.90%	10.30%
High	10.30%	28.20%	12.80%	17.90%	15.40%
Very High	5.10%	7.70%		5.10%	2.60%

Fig 4.43 Survey results on obstacles to implementing CNG components in the small and medium plants group



	Time from development to Implementation	Cost	Technical skills of staff.	Management commitment	Business nature unsuitable for development	
None	6.30%	6.30%	6.30%		25.00%	
Very Low	18.80%	6.30%	12.50%	6.30%	25.00%	
Low	31.30%	25.00%	6.30%	12.50%	6.30%	
Average	18.80%	6.30%	50.00%	37.50%	12.50%	
High	12.50%	50.00%	6.30%	18.80%	25.00%	
Very High	12.50%	6.30%	18.80%	25.00%	6.30%	

Fig 4.44 Survey results on obstacles to implementing CNG components in the large plants group

4.5.1.4 Correlations and inference analysis

Correlation analysis and regression analysis deal with the relationship between variables. Correlation addresses the question of whether there is a relationship between two particular variables [67].

In this section some correlations between a number of variables will be assessed and their effect on the implementation of CNG components and the level of CNG development in the car industry will be discussed. Also, some inference analysis of the results will be presented.

A correlation between the age of the plants and the number of employees in the companies was expected. Table 4.2 shows that the correlation coefficient between these variables is 0.642, which indicates that there is a positive relationship between these variables. P-value indicates that the correlation is statistically significant.

It means that the more years the company is in business the more employees they are likely to have.

Table 4.2 Correlation table between age of plants and number of employees

Correlations

			How many years has your company been in business	Number of Employees
Spearman's rho	How many years has your company been in business	Correlation Coefficient	1.000	.642**
		Sig. (2-tailed)	.	.000
		N	56	55
	Number of Employees	Correlation Coefficient	.642**	1.000
		Sig. (2-tailed)	.000	.
		N	55	55

**. Correlation is significant at the .01 level (2-tailed).

Furthermore, a negative relationship between the number of employee and the level of development would have been expected; however the analysis indicates that there is no significant relationship between these variables as indicated in table 4.3 it can be said that the level of development is not affected by this aspect of the process

(decrease in the number of employees) and may effect the time saving, or product quality.

Table 4.3 Correlation table between level of development and number of employees

Correlations

			Number of Employees	What is the level of development of CNG system at your plant
Spearman's rho	Number of Employees	Correlation Coefficient	1.000	.068
		Sig. (2-tailed)	.	.624
		N	55	55
	What is the level of development of CNG system at your plant	Correlation Coefficient	.068	1.000
		Sig. (2-tailed)	.624	.
		N	55	56

A positive relationship was expected between the age of the companies and the level of development. The correlation coefficient (-.154) indicates that the relation is not significant as shown in table 4.4

Table 4.4 Correlation between, age of company and level of development

Correlations

			How many years has your company been in business	What is the level of development of CNG system at your plant
Spearman's rho	How many years has your company been in business	Correlation Coefficier	1.000	-.154
		Sig. (2-tailed)	.	.257
		N	56	56
	What is the level of development of CNG system at your plant	Correlation Coefficier	-.154	1.000
		Sig. (2-tailed)	.257	.
		N	56	56

4.5.1.5 Improvements achieved with high development

This section presents the improvement achieved through applying high development in all plant categories (*large, small and medium)* in the car manufacturing companies around Europe. Three standard levels of emissions were measured, which are: *EURO 3, EURO 4 and EURO 5.*

- Large plants with employees volume >1000
- Small and medium plants with employees volume <300 & 301-1000

1. Large plants (employees volume >1000)

Companies who invested substantially in CNG vehicle component reported they were more than 68 percent satisfied with the latest improvements of CNG feeding and injection components, especially those companies who develop or implement CNG vehicle components, see figure 4.45.

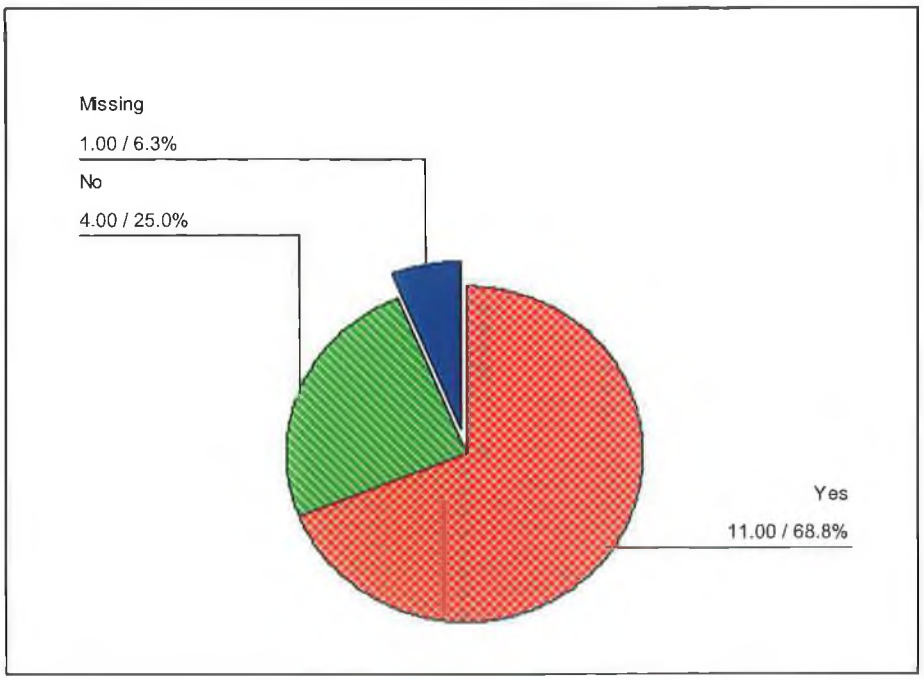


Fig 4.45 Satisfaction with latest improvements in CNG in large plants

Figure 4.46 indicates that 37.5% of the large companies are developing or implementing CNG component. Then survey asked to which level of emission standard they are developing or implementing

It was found that large companies are developing and implementing CNG component to comply with EURO 5 by 31.3%, while 6.3% comply with EURO 3 and 62.5% of the companies did not give any answer, these results can be seen in figure 4.47.

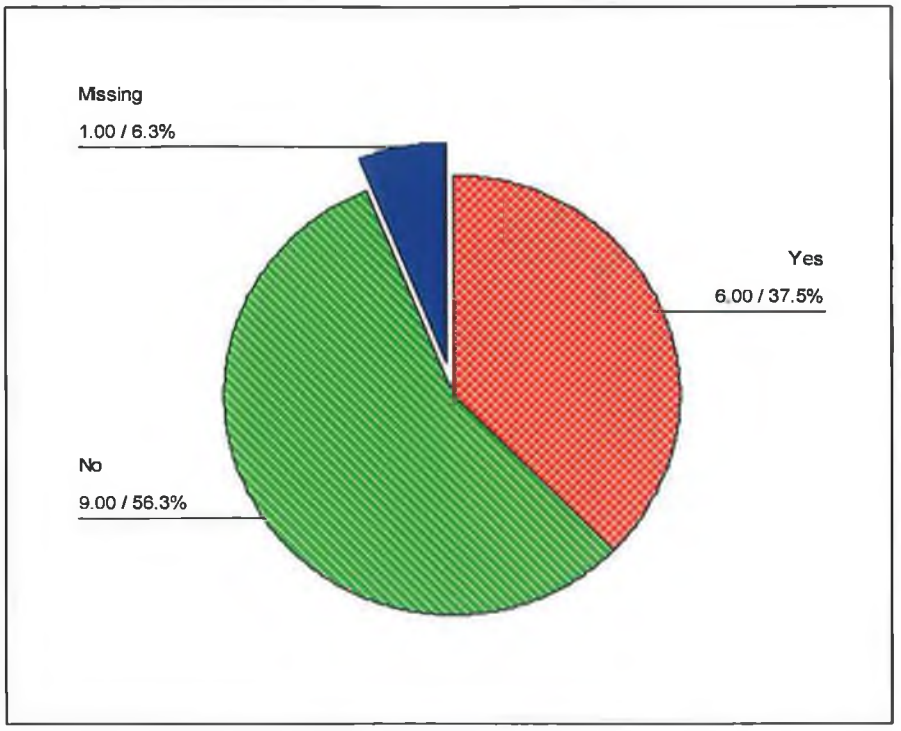


Fig 4.46 Number of companies developing or implementing CNG component in large plants

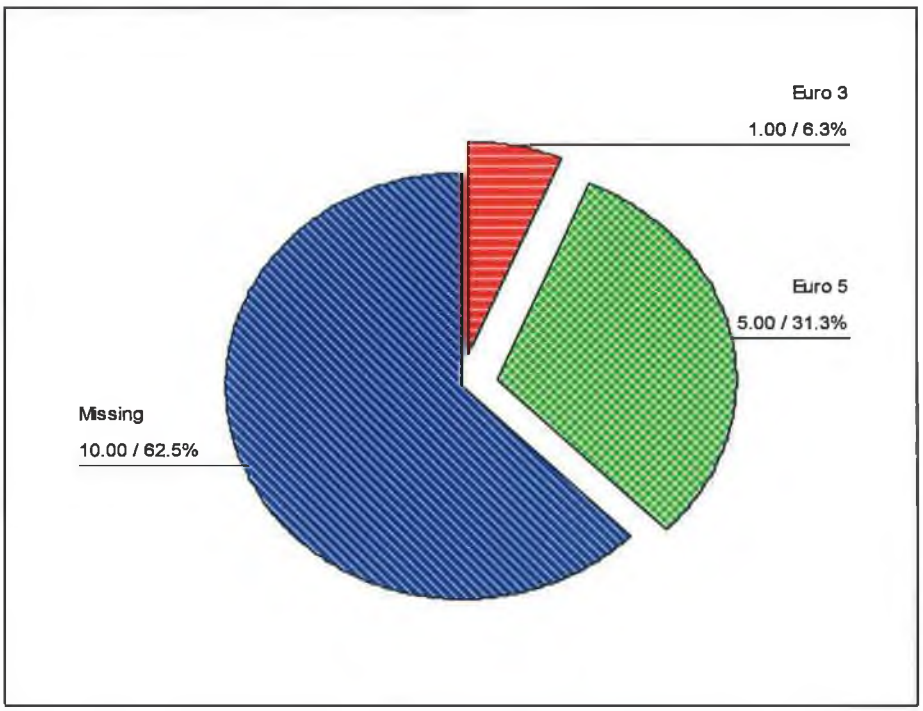


Fig 4.47 Latest improvement of emission standard in large plants

2. Small and medium plants (employees volume <300 & 301-1000)

Companies who invested substantially in CNG vehicle component reported more than 56.4% of companies are satisfied with the latest improvements of CNG feeding and Injection component, especially those companies who develop or implement CNG vehicle component, as indicated in figure 4.48.

Figure 4.49 indicates that 59.0% of the small and medium companies are developing or implementing CNG component.

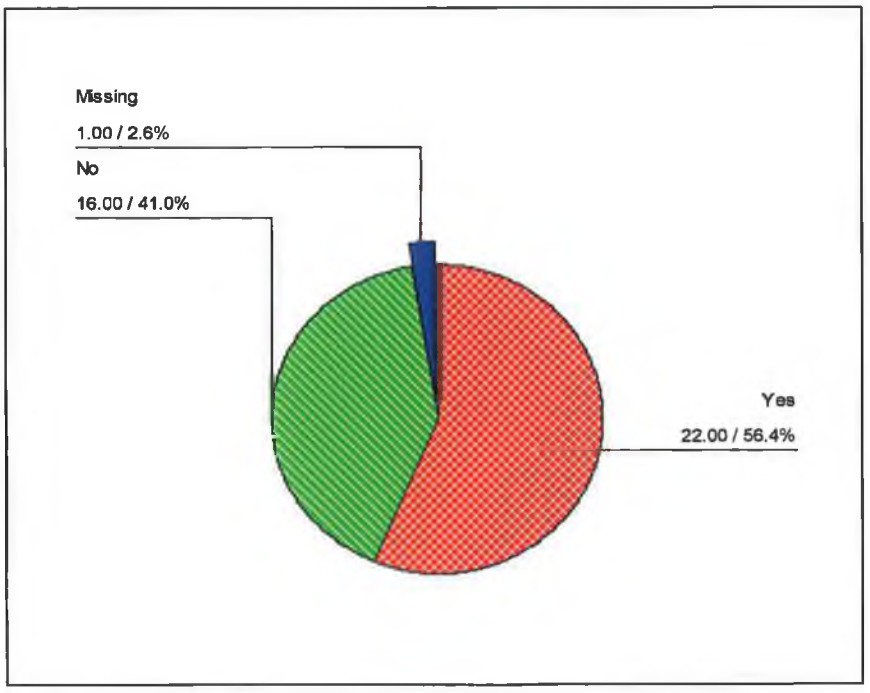


Fig 4.48 Satisfaction with latest improvements in CNG in small and medium plants

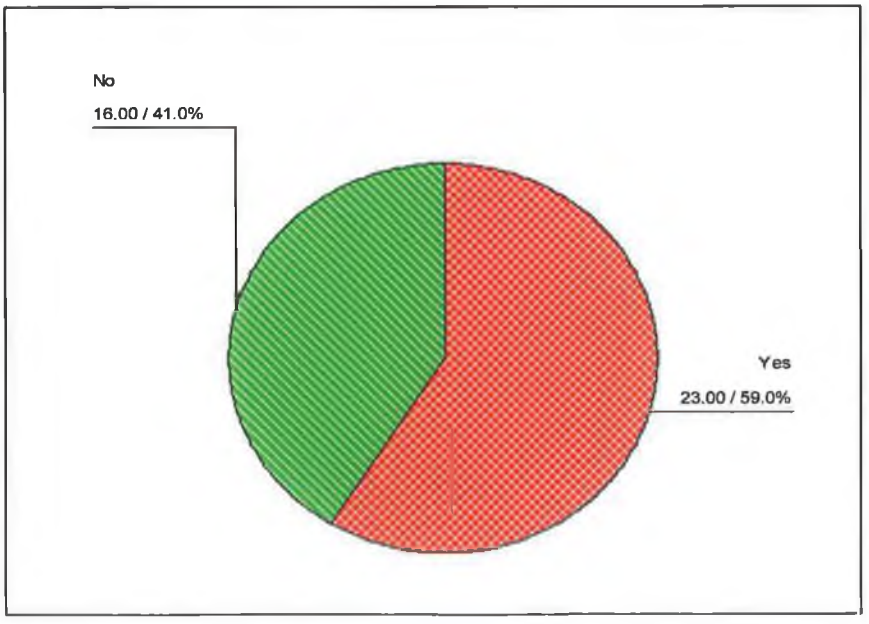


Fig 4.49 Number of companies developing or implementing CNG component in small and medium plant

Concerning the emission standard level, it was found that the majority of the small and medium companies who are developing and implementing CNG components are complying with EURO 4 and 5. Small percentages are complying with EURO 3. Figure 4.50 shows the last improvement of emission standard in small and medium companies, it can be noticed that 46.2% did not give any answer.

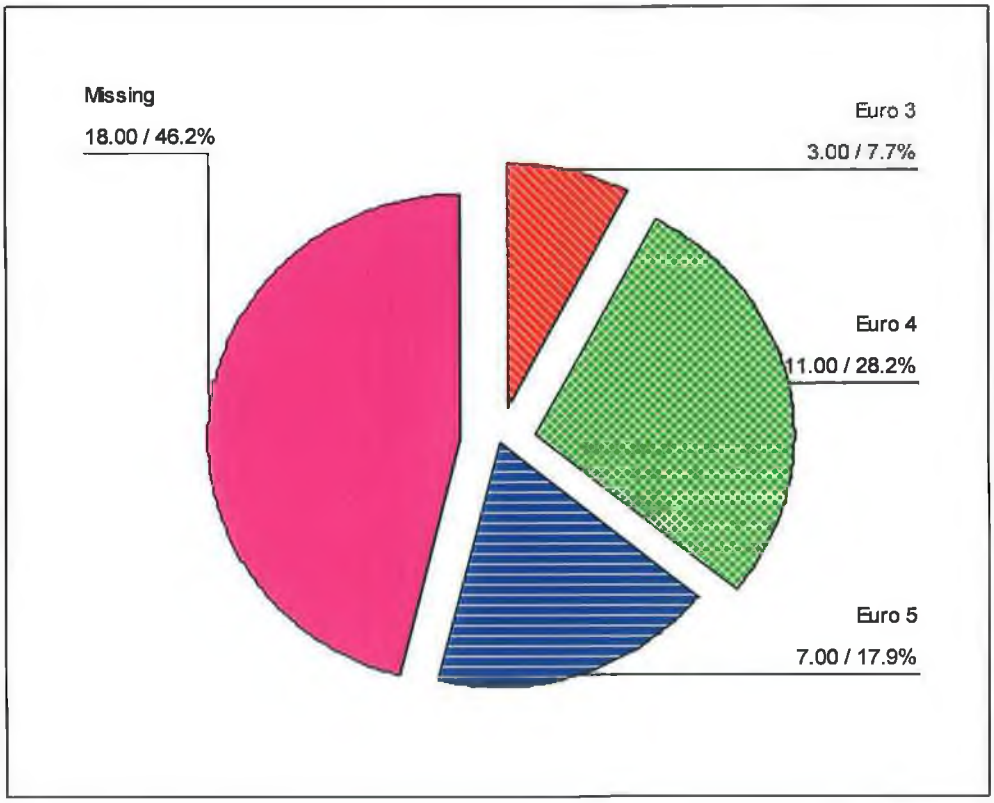


Fig 4.50 Latest improvement in emission standards in small and medium plant

4.5.1.6 Obstacles to CNG component implementation

- As mentioned before, small/medium plants developing or implementing CNG component are facing two main obstacles regarding the CNG development level; these are the cost and the technical skills of staff.

- The analysis shows that large companies developing or implementing CNG component are facing these same two obstacles.
- With regard to the manufacturers' satisfaction at implementing CNG vehicle technologies, it appears that the three biggest obstacles that could face demand are Trunk Space, Driving range and CNG refuelling component. These results are illustrated in figure 4.36.

4.5.1.7 Remarks on the survey of manufacturers

Based on the survey results, the outcome can be summarised as follows:

The CNG car manufacturing can be classified into five categories:

- International car manufacturing.
- National car manufacturing.
- Local car manufacturing.
- Mixed car manufacturing.
- Foreign car manufacturing.

1. It was found that the main manufacturing obstacles are: time from development to implementation, cost, technical skills of staff, management commitment and business nature for development. It is advised that these companies should reconsider their policy to tackle the above mentioned obstacles.

2. The survey reflects that most CNG manufacturers are willing to increase the implementation of CNG vehicle components in the near future.

3. It is evident that most of the small and medium and large companies are implementing Euro 4 and 5 as an emission standard for CNG components. These results show that CNG manufacturers are complying with the European emission standards.

4. The large, small and medium CNG car industry plants have a low development level, mainly to avoid the cost involved in the implementation.

5. With regards to the implementation of CNG technologies in the car manufacturing industry, it appears that the biggest three obstacles are the trunk space, the driving range and the refuelling component. It is obvious that more research and development should be carried out in these areas.

4.5.2 Vehicle Customer Survey

- It was evident that the majority of vehicle customers have no or little knowledge about CNG vehicles. This lack of consumer awareness and knowledge is an important issue for the development of a CNG vehicle industry around Europe. Clearly, steps must be taken to ensure that there is a higher level of public awareness on the topic.

- Despite very few consumers reporting that they were knowledgeable about CNG Vehicles, there was a surprisingly high level of endorsement for the idea of paying price premium for more environmentally friendly vehicles. The pie chart in Figure 4.30 shows 91.3% of respondents stated that they would be willing to pay more for an environmentally friendly car.

- Regarding the refuelling time and distance. The majority of the respondents reported that they would be willing to wait the extra time it took to re-fuel a CNG vehicle (quick fill). Prior to the circulation of this questionnaire, the refuelling time issue was perceived as a major obstacle as consumer attitudes to waiting are often unfavourable. It may be, however, that consumers feel more strongly about environmental issues than has been previously believed, and that marketers of CNG should strongly promote the environmental benefits of CNG.

- The consumers' opinion was more divided on whether they would be prepared to travel an additional distance in order to refuel their car. The pie chart in figure

4.32 shows that three-quarters of the consumers were prepared to wait a few minutes longer to re-fuel their vehicle. Less than half were prepared to drive further distance to re-fuel their vehicle. As in figure 4.33 it is indicated that a total of 79.3% of the consumers would travel further to re-fuel if it meant that it were better for the environment. Clearly, the success of CNG vehicles depends on the availability of fuelling stations. Indeed, consumers' proximity to CNG fuel stations needs to be as high as for traditional gasoline stations and this is a major challenge for the CNG industry.

- It was noticed that the majority of CNG vehicle owners were dissatisfied with the number of CNG refuelling stations. The limited refuelling infrastructure has had a major impact on how they use their vehicles. When they were asked if the lack of refuelling infrastructure prevented them from driving places they would otherwise like to drive, nearly all owners answered affirmatively. When respondents want to take their CNG vehicle somewhere they are uncertain about CNG fuel availability, they will usually take their gasoline vehicle instead since finding a gasoline station is comparatively easy.

- The study shows that the safety issue would have a great concern from the customers due to the high-pressure cylinder tank, despite a commendable safety record in all vehicle applications. This concern could be diminished by improving customer knowledge about CNG vehicles.

- CNG vehicle owners clearly indicate government financial incentives may have had an insignificant impact on the decision to purchase a CNG vehicle at this point in time. This may be especially true in Europe where no incentives were offered. The questionable impact of government incentives to influence a purchase decision suggests, in the absence of a public information campaign advocating CNG vehicles, that perhaps incentives were not a cost-effective use of government funding. However, future populations may be more influenced by financial incentives. In contrast, CNG vehicle access to the high occupancy

vehicle lane was the single most motivating factor in the decision to purchase a CNG vehicle for nearly all respondents. Current owners clearly value the reduced travel time and improved travel time reliability. According to respondents, this benefit exceeds the refuelling inconvenience and incremental cost of ownership compared with a gasoline-equivalent vehicle. This policy has been more effective at stimulating a consumer response to CNG and suggests future policies/incentives for CNG vehicles should perhaps focus on this incentive for CNG vehicle owners rather than simply reducing the cost to that of a gasoline-equivalent vehicle.

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

This study has demonstrated the current situation with regard to development and implementation of CNG system in the car manufacturing companies and the current situation among the customers of CNG vehicles. This research has used two methods:

- Postal traditional survey for the car manufacturing companies.
- Two web-based surveys have been built; one is related to car manufacturing companies and the other related to the customers of CNG vehicles.

The response from the industry was more positive in the postal survey than in the web-based survey. However the web-based survey was less time-consuming and costly. However, the web-based survey aimed at customers was more positive.

5.1.1 The CNG Car Manufacturing Survey

Based on the results from the CNG vehicle manufacturing survey, the following can be concluded from this study:

1. The level of development within the car industry is extremely varied. Manufacturing plants with higher number of employees are generally highly developed and are motivated for future development, while, manufacturing plants with small numbers of employee have less potential towards development.
2. The current level of implementation of CNG components in the car industry is still low; the expectations indicate that the use of CNG technologies will increase demand on this type of alternative fuel vehicles.
3. In regard to the satisfaction of implementing CNG vehicle technologies in the car manufacturing industry, it appears that the three biggest obstacles that are going to face customer demand are Trunk Space, Driving Range and the Refuelling Component.
4. The technical skills and the cost are considered to be the main obstacles to implementing new technologies.

5.1.2 The Vehicle Customer Survey

Based on the results from the CNG vehicle customer survey, a few conclusions can be drawn from the effects of government incentives, vehicle refuelling, ownership experience, and the demographics of CNG vehicle owners:

1. There is a lack of knowledge about CNG in Europe presently.
2. The limited refuelling infrastructure has a major impact on motivating customers to buy CNG vehicles.
3. Government incentives would have a very positive effect on causing customers to buy a CNG vehicle.

5.2 Recommendations for Future Research Work:

Based on the research results, some recommendations for further work are listed below:

1. To conduct real case studies to assess how CNG components have been used in selected car industries.
2. To develop guidelines that allow companies to choose the most appropriate development plan and to justify the plan's cost.
3. To compare the use of CNG components in advanced manufacturing countries and developing countries to determine the most appropriate approach to successfully implementing CNG systems in car industries.
4. If the European Union is interested in reducing the rate of petroleum consumption and improving energy security it will be necessary to stimulate the customer market for alternative fuel vehicles. CNG vehicles are the only currently commercially available options and are capable to be produce in large production volumes with minimal resistance from automotive manufacturers. Moreover there is a large enough refuelling network to accommodate greater volumes than currently in use.

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APPENDIX (A)

PUBLICATION ARISING FROM THIS WORK

1. A. M. Abulamosha, S. Scally, A. G. Olabi, and M. S. J. Hashmi, "Strategy for CNG Application in Ireland", The International Conference on Vehicle Alternative Fuel Systems & Environmental Protection, 6th to 9th July 2004, Dublin City University of Ireland.

2. A. M. Abulamosha, A. G. Olabi and M. S. J. Hashmi, "Development of Compressed Natural Gas (CNG) System for vehicles", Minia International Conference " Towards a Safe and Clean Environment", 15th to 18th April 2005, Minia University, Egypt.

APPENDIX (B)

Survey for the development of Compressed Natural Gas (CNG) systems for vehicles at car manufacturers and OEM companies

The school of mechanical and manufacturing engineering of Dublin City University is undertaking a study to determine the survey for the development of Compressed Natural Gas Systems **(CNG)** for vehicles. As part of this study, your assistance in completing this questionnaire would be highly appreciated. ***Please tick or fill in the blanks provided. Thank you***

SECTION 1: COMPANY PROFILE

1-Ownership:

- ❑ National
- ❑ Local
- ❑ Mixed
- ❑ Foreign

2-How many years has your company been in business?

- ❑ <10 years
- ❑ 10-20 years
- ❑ 20-30 years
- ❑ >30 years

3-Focus Markets:

- ❑ Worldwide

- ❑ All of Europe
- ❑ America
- ❑ Africa

Parts of Europe_____

4-Number of Employees

- ❑ <300.
- ❑ 301-1000
- ❑ >1000

SECTION 2: LEVEL OF DEVELOPMENT CNG SYSTEMS IN YOUR PLANT

1-Based on your experience, please indicate the level of development, at your plant, with the following CNG vehicle categories:

*[Scale: **1**-none **2**-dissatisfied; **3**- very dissatisfied; **4**-satisfied; **5**-very satisfied]*

	1	2	3	4	5
Trunk space/cargo carrying capacity	❑	❑	❑	❑	❑
Driving range	❑	❑	❑	❑	❑
Refueling component	❑	❑	❑	❑	❑
Vehicle safety	❑	❑	❑	❑	❑

2-Please rank the obstacles to Compressed Natural Gas Systems implementation in your plant?

*[Scale: **0**-None; 1- very low; **2**-low; **3**-averag;e **4**-high; **5**-very high]*

	0	1	2	3	4	5
Time from development to implementation.	❑	❑	❑	❑	❑	❑
Cost.	❑	❑	❑	❑	❑	❑
Technical skills of staff.	❑	❑	❑	❑	❑	❑
Management commitment	❑	❑	❑	❑	❑	❑
Business nature unsuitable for development.	❑	❑	❑	❑	❑	❑

3- What is the level of development of CNG systems at your plant (check one)?

- ❑ No development
- ❑ Sparsely developed
- ❑ Somewhat developed
- ❑ Mostly developed
- ❑ Fully developed

4- What level of development do you envisage at your plant within the coming years (check one)?

- ❑ No development
- ❑ Sparsely developed
- ❑ Somewhat developed
- ❑ Mostly developed
- ❑ Fully developed

SECTION 3: ENGINE SYSTEM

1-Are you satisfied with the latest improvements of the CNG feeding and injection components used in your company?

- ❑ Yes
- ❑ No

2- Does the new engine design provide better performances after the addition of the new CNG components?

- ❑ Yes
- ❑ No

3-Is your company developing or implementing any CNG components for heavy-duty applications?

- ❑ Yes
- ❑ No

If Yes, for which level of emission standard?

- ❑ Euro 3

- ❑ Euro 4
- ❑ Euro 5

SECTION 4: GOVERENMENT SUBSIDY

1-Do you get governmental incentives for the investment in CNG components development?

- ❑ Yes
- ❑ No

2- Do you think that the government should be offering incentives to encourage the development of CNG components?

- ❑ Yes
- ❑ No

If so, then what percentage of the total cost would be required to make you consider supplying this type of vehicle?

- ❑ 0-5%
- ❑ 5-10%
- ❑ 10-15%
- ❑ 15-20%

3-Would you be willing to contribute to the production of fuelling stations in your country to encourage the spreading of CNG vehicles?

- ❑ Yes
- ❑ No

If so, then how much would you be willing to contribute?

- ❑ €0-5000,
- ❑ €5000-10,000
- ❑ Greater than €10,000

APPENDIX (C)

Survey for the development of Compressed Natural Gas (CNG) systems with CNG vehicle customer

The school of mechanical and manufacturing engineering of Dublin City University is undertaking a study to determine the survey for the development of Compressed Natural Gas Systems **(CNG)** for vehicles. As part of this study, your assistance in completing this questionnaire would be highly appreciated. ***Please tick or fill in the blanks provided. Thank you***

1- How would you describe your knowledge of CNG vehicles?

- ❑ 0-25 %
- ❑ 25-50%
- ❑ 50-75%
- ❑ 75-100%

2- Would you be willing to pay more for a car that was more environmentally friendly?

- ❑ Yes
- ❑ No

If so, then how much more would you be willing to pay?

- ❑ €0-1000
- ❑ €1000-2000
- ❑ €2000-3000
- ❑ €3000-4000

3- Would you be willing to wait for extra five minutes to refuel your vehicle and also refuel it slightly more often if it was beneficial to the environment?

- ❑ Yes
- ❑ No

4. With the same consideration, would you be willing to travel further distances to refuel your vehicle?

- ❑ Yes
- ❑ No

If so then how much further before you would reconsider?

- ❑ 0-5 miles
- ❑ 5-10 miles
- ❑ 10-15 miles

5. How would you describe the public fuelling infrastructure for the number of stations?

- ❑ Inadequate
- ❑ Adequate
- ❑ More than Adequate

6. If you are an owner of a CNG vehicle. Do you feel safe driving your vehicle?

- ❑ Safe
- ❑ Moderately Safe
- ❑ Fully Safe

7. In your opinion, should the government be offering financial incentives for those who use more energy efficient and environmentally friendly alternative powered vehicles?

- ❑ Yes
- ❑ No

If so, would these incentives encourage you to purchase such a vehicle?

- ❑ Definitely
- ❑ Maybe
- ❑ Probably

APPENDIX (D)

Source Code of CNG Vehicle & OEM on-line survey

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OS COMPRESSED NATURAL GAS SYSTEMS FORVEHICLES</b></center></font>
 <p> </p>

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 and Manufacturing Engineering of Dublin City University is undertaking a study
 to determine the strategy of development of  Compressed Natural Gas Systems (CNG)
  for Vehicles. As a part of this study i would be highly appreciated,if
 you could complete this questionnaire and send it back to me.  </b></center></font>
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name:</b></font></td><td><input size="50" name="visitor_name"></td></tr>

 <tr>
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<dd><input type="checkbox" value="Local  " name="C3"> Local
<dd><input type="checkbox" value="Mixed  " name="C4"> Mixed
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 <dd><input type="checkbox" value=">30 years" name="C11">30 years</font>

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<dd><input type="radio" value="301-1000" name="R600"> 301-1000
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<dd>

<dd>SECTION 2:LEVEL OF DEVELOPMRNT CNG SYSTEM IN YOUR PLANT</dd></dl>

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<p>[Scale: 1- non; 2- dissatisfied; 3- very dissatisfied; 4- satisfied; 5- very satisfied]</td>

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 </tr>

 <tr>
 <td width="332"><font face="arial, helvetica" size="-1"><b>h.</b>Vehicle
safety</font></td>
 <td align="center" width="63"><input type="radio" value="1" name="sami3"></td>
 <td align="center" width="44"><input type="radio" value="2" name="sami3"></td>
<td align="center" width="44"><input type="radio" value="3" name="sami3"></td>
 <td align="center" width="54"><input type="radio" value="4" name="sami3"></td>
 <td align="center" width="58"><input type="radio" value="5" name="sami3"></td>
  </tr>

 </tbody>
 </table>
```

<p>
<table width="671" border="0" height="75">
<tbody>
<tr>
<td vAlign="top" align="left" width="2" height="71"></td>
<td align="left" height="71" width="655">2. Please rank the obstacles of Compressed Natural Gas System implementation in your plant?

<p> [Scale: 0-Non 1- very low; 2- low; 3- average; 4- high; 5- very high]</td>
</tr>

</tbody>
</table>
<dd>
<table width="638" border="1">
<tbody>
<tr>
<td width="333"> </td>

<td align="center" width="43">0</td>
<td align="center" width="43">1</td>
<td align="center" width="43">2</td>
<td align="center" width="43">3</td>
<td align="center" width="43">4</td>

```
<td align="center" width="43"><font face="arial, helvetica" size="-
1"><b>5</b></font></td>
</tr>

<tr>
<td width="333"><font face="arial, helvetica" size="-1"><b>a.</b>Time from
development to Implantation</font></td>
<td align="center" width="43"><input type="radio" value="0" name="q8a"></td>
<td align="center" width="43"><input type="radio" value="1" name="q8a"></td>
<td align="center" width="43"><input type="radio" value="2" name="q8a"></td>
<td align="center" width="43"><input type="radio" value="3" name="q8a"></td>
<td align="center" width="43"><input type="radio" value="4" name="q8a"></td>
<td align="center" width="43"><input type="radio" value="5" name="q8a"></td>
</tr>

<tr>
<td width="333"><font face="arial, helvetica" size="-1"><b>b.</b> cost.</font></td>
<td align="center" width="43"><input type="radio" value="0" name="q8b"></td>
<td align="center" width="48"><input type="radio" value="1" name="q8b"></td>
<td align="center" width="43"><input type="radio" value="2" name="q8b"></td>
<td align="center" width="42"><input type="radio" value="3" name="q8b"></td>
<td align="center" width="39"><input type="radio" value="4" name="q8b"></td>
<td align="center" width="44"><input type="radio" value="5" name="q8b"></td>
</tr>

<tr>
<td width="333"><font face="arial, helvetica" size="-1"><b>c.</b>Technical skills of
staff.</font></td>
<td align="center" width="43"><input type="radio" value="0" name="q8c"></td>
<td align="center" width="48"><input type="radio" value="1" name="q8c"></td>
<td align="center" width="43"><input type="radio" value="2" name="q8c"></td>
```

<td align="center" width="42"><input type="radio" value="3" name="q8c"></td>
<td align="center" width="39"><input type="radio" value="4" name="q8c"></td>
<td align="center" width="44"><input type="radio" value="5" name="q8c"></td>
</tr>

<tr>
<td width="333">d.Management commitment</td>
<td align="center" width="43"><input type="radio" value="0" name="q8d"></td>
<td align="center" width="48"><input type="radio" value="1" name="q8d"></td>
<td align="center" width="43"><input type="radio" value="2" name="q8d"></td>
<td align="center" width="42"><input type="radio" value="3" name="q8d"></td>
<td align="center" width="39"><input type="radio" value="4" name="q8d"></td>
<td align="center" width="44"><input type="radio" value="5" name="q8d"></td>
</tr>

<tr>
<td width="333">e. business nature unsuitable for development.</td>
<td align="center" width="43"><input type="radio" value="0" name="ayad"></td>
<td align="center" width="48"><input type="radio" value="1" name="ayad"></td>
<td align="center" width="43"><input type="radio" value="2" name="ayad"></td>
<td align="center" width="42"><input type="radio" value="3" name="ayad"></td>
<td align="center" width="39"><input type="radio" value="4" name="ayad"></td>
<td align="center" width="44"><input type="radio" value="5" name="ayad"></td>
</tr>

</tbody>
</table>
   3. What is the level of development of CNG system at your plant?(Tick one)

<dd>   <input type="radio" value="No development" name="R4">
No development
<dd>   <input type="radio" value="Sparsely developed" name="R4">
Sparsely developed
<dd>   <input type="radio" value="Somewhat developed " name="R4">
Somewhat developed
<dd>   <input type="radio" value="Mostly developed" name="R4">
Mostly developed
<dd>   <input type="radio" value="Fully developed" name="R4">
Fully developed
   4. What level of
development do you envisage at your plant within the next 5 years?(Tick
one)

<dd>   <input type="radio" value="No development" name="R5">
No development
<dd>   <input type="radio" value="Sparsely developed" name="R5">
Sparsely developed
<dd>   <input type="radio" value="Somewhat" name="R5" developed>
Somewhat developed
<dd>   <input type="radio" value="Mostly developed" name="R5">
Mostly developed
<dd>   <input type="radio" value="Fully developed" name="R5">
Fully developed

 SECTION 3: ENGINE
SYSTEM

   1. Are you satisfied with the latest improvement of CNG feeding and injection produced by your company?(Tick one)

<dd> <input type="radio" value="yes" name="R3">Yes
<dd> <input type="radio" value="no" name="R3">No

   2. Is the new engine provide the best performances during implementation of new CNG component?(Tick one)

<dd> <input type="radio" value="yes" name="R11">Yes
<dd> <input type="radio" value="no" name="R11">No

   3. Is your company developing or implementing CNG component for heavy-duty application?(Tick one)
<dd> <input type="radio" value="yes" name="R12">Yes
<dd> <input type="radio" value="no" name="R12">No

 *if, Yes. For which emission standard level?(Tick one)

<dd> <input type="radio" value="Euro 3" name="R9">Euro 3
<dd> <input type="radio" value="Euro 4" name="R9">Euro 4
<dd> <input type="radio" value="Euro 5" name="R9">Euro 5

 SECTION 4:GOVERENMENT SUBSIDY

   1. Do you get Government fund for the investment in CNG development or component?(Tickone)

<dd> <input type="radio" value="Yes" name="R22"> Yes
<dd> <input type="radio" value="No" name="R22"> No

<dd>   2. Do you think that the government should be offering incentives to encourage the development of CNG component to be implemented on vehicles?</dd>
<dd>
  <input type="radio" value="Yes" name="R23"> Yes
  <input type="radio" value="No" name="R23">No

   *If so, then what percentage of the total cost would be required to make you consider supplying this type of vehicle?(Tick one)

<dd> <input type="radio" value="0-5%" name="ayad24">0-5%
<dd> <input type="radio" value="5-10%" name="ayad24">5-10%
<dd> <input type="radio" value="10-15%" name="ayad24">10-15%
<dd> <input type="radio" value="15-20%" name="ayad24">15-20%

   3-Would you be willing to contribute to the production of fuelling stations in your country to encourage the spreading of vehicles?(Tick one) <font size="-1">

```
<dd>  <input type="radio" value="yes" name="R24">Yes
<dd>  <input type="radio" value="no" name="R24">No
</font>

<p><font color="#0000bb" size="2"><b>   **If so, then how much would
you be willing to contribute?</b></font><font color="#0000bb" size="2">(Tick
one)</font></p><font size="-1">

<dd>  <input type="radio" value="€0-5000" name="ayad27"> €0-5000
<dd>  <input type="radio" value="€5000-10,000" name="ayad27">€5000-10,000
<dd>  <input type="radio" value=" Greater than €10,000" name="ayad27"
>Greater than €10,00</font>

<p><b>  *Thank you for your time and patience, the information you
      have provided is extremely valuable for this study.</b></p>

<br>
<center><input type="submit" value="Submit and get Results"><input type="reset"
value="Reset"><br><font face="arial, helvetica" color="red" size="-1">(wait for
results)</font></center></FORM>

      <p> 
      <p></FORM>
      </p>
      </dd>
      </dl>
      </form>
      </body>  </html>
```

APPENDIX (E)

Source Code of CNG costumer on-line survey

<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.0 Transitional//EN">
<HTML><HEAD><TITLE>Response-O-Matic Form</TITLE>
<META http-equiv=Content-Type content="text/html; charset=windows-1252">
<META content="MSHTML 6.00.2800.1226" name=GENERATOR></HEAD>
<BODY bgColor=#ffffff>
<FORM action=http://www.response-o-matic.com/cgi-bin/rom.pl method=post>
<H1>
<CENTER> </CENTER></H1>
<H1>
<CENTER><FONT color=#000000>Thanks for visiting my site!</FONT>
</CENTER></H1>
<H3>
<CENTER><INPUT type=hidden value=abdelfattah.abulamosha2@mail.dcu.ie
name=your_email_address> <INPUT type=hidden value="Abdelfttah Abulamosha"
name=your_name> <INPUT type=hidden value="Comperssed Natural Gas for Vehicle"
name=email_subject_line> <INPUT type=hidden value=your_email_address
name=required_fields> <INPUT type=hidden
value="Thank you for completing the form" name=thank_you_title> <INPUT
type=hidden value=http://www.dcu.ie name=return_link_url> <INPUT type=hidden
value="Back to the DCU page" name=return_link_name> <INPUT type=hidden
value=#00FFFF name=background_color> <INPUT type=hidden value=#000000
name=text_color> <INPUT type=hidden value=#0000FF name=link_color> <INPUT
type=hidden value=#8000FF name=visited_link_color> <INPUT type=hidden
value=#0000FF name=active_link_color> </CENTER></H3>
<META content="MSHTML 6.00.2800.1226" name=GENERATOR>
<META content=FrontPage.Editor.Document name=ProgId><FORM

```
action="--WEBBOT-SELF--" method="post"><!--webbot bot="SaveResults" S-Label-
Fields="TRUE"
 U-File="form_results.txt"
 S-Format="TEXT/CSV" -->
<P> </P><FONT color=#0000ff size=4>
<CENTER><B>STRATEGY OF DEVELOPMENT OF
ALTERNATIVE </B></CENTER></FONT>
<P></P><FONT color=#0000ff size=4>
<CENTER><B>FUEL SYSTEM FOR VEHICLES</B></CENTER></FONT>
<P></P>
<HR>

<MARQUEE><FONT face=arial color=green>
<CENTER><B>The school of mechanical and Manufacturing Engineering of Dublin city
university is undertaking a study to determine the strategy of development of
Compressed Natural Gas system (CNG) for vehicles.As a part of this study I would
be highly appreciated,if you could complete this questionnaire and send it back
to me.</B></CENTER></FONT></MARQUEE></FONT>
<HR>
<FORM METHOD="POST" ACTION=" /cgi-bin/uncgi/mailcensus">
<TABLE cellPadding=4 width="100%" bgColor=#ccffff border=0>
<TBODY>
 <TR>
<TD align=left><FONT face="arial, helvetica" size=-1><B>Please answer all
    questions and then press submit button.
</B></FONT></TD></TR></TBODY></TABLE></TBODY>
<P>
<TABLE border=0>
<TBODY>
 <TR>
```

```
<TD width=116><FONT size=+0><B>Your name:</B></FONT> </TD>
<TD><INPUT size=50 name=visitor_name> </TD></TR>

<TR>
 <TD width=116><FONT size=+0><B>Email address:</B></FONT> </TD>
<TD><INPUT size=50 name=visitor_email_address>
</TD></TR></TBODY></TABLE>

<P><FONT color=#0000bb size=2><B>1.How would you describe your knowledge of
CNG vehicles? </I>(Tick one)</FONT></P><FONT size=-1>
<DD><INPUT type=radio value="0-25%" name=R6>0-25%
<DD><INPUT type=radio value=25-50%  name=R6>25-50%
<DD><INPUT type=radio value=50-75%  name=R6>50-75%
<DD><INPUT type=radio value="75-100%" name=R6>75-100%
</FONT>

<P><FONT color=#0000bb size=2><B>2.Would you be willing to contribute more for a
car that was more environmentally friendly?</B></FONT></P><FONT size=-1>
<DD><INPUT type=radio value=yes name=R24>Yes     
<DD><INPUT type=radio value=no name=R24> No    </FONT>

<P><FONT color=#0000bb size=2><B>  If so, then how much more would you be
willing to contribute?</B>(Tick one)</FONT></P>
<P><FONT size=-1></P>
<DD><INPUT type=radio value=€0-1000 name=R1>€0-1000
<DD><INPUT type=radio value=€1000-2000 name=R1>€1000-2000
<DD><INPUT type=radio value=€2000-3000 name=R1>€2000-3000
<DD><INPUT type=radio value=€3000-4000 name=R1>€3000-4000</FONT>

<P></P>
```

<P><FONT color=#0000bb size=2><B> 3.Would you be willing to wait five minutes at a times to refuel your vehicle and also refuel it slightly more often if it was beneficial to the environment?</B>(Tick one)</FONT></P>
<P><FONT size=-1></P>
<DD><INPUT type=radio value="Yes"name=ayad -> Yes
<DD><INPUT type=radio value="No"name=ayad - >No</FONT>

<P></P>
<P><FONT color=#0000bb size=2><B>4.By the same consideration, would you be willing to travel further distances to refuel your vehicle?</B>(Tick one)</FONT></P><FONT size=-1>
<DD><INPUT type=radio value=Yes name=R2>Yes
<DD><INPUT type=radio value=No name=R2>No </FONT>

<P><FONT color=#0000bb size=2><B>If so then how much further before you would reconsider?</B>(Tick one)</FONT></P><FONT size=-1>
<DD><INPUT type=radio value=0-5 miles name=R3>0-5 miles
<DD><INPUT type=radio value=5-10 miles name=R3>5-10 miles
<DD><INPUT type=radio value=10-15 miles name=R3>10-15 miles</FONT>

<P><FONT color=#0000bb size=2><B>5.How would you describe the public fuelling infrastructure for the number of stations?</B><(Tick one)</FONT></P><FONT size=-1>
<DD><INPUT type=radio value=Inadequate name=R3a>Inadequate
<DD><INPUT type=radio value=Adequate name=R3a>Adequate
<DD><INPUT type=radio value=Adequate name=R3a>More than Adequate</FONT>

<P><FONT color=#0000bb size=2><B>6.If you are owner of CNG vehicle.Do you feel save driving with your vehicle?</B><(Tick one)</FONT> <FONT size=-1>
<DD><INPUT type=radio value="Not Save" name=R4>Not Save
<DD><INPUT type=radio value="Moderately Save" name=R4>Moderately Save

<DD><INPUT type=radio value="Fully Save" name=R4>Fully Save </FONT>

<P><FONT color=#0000bb size=2><B>7.In your opinion ,Should the government be offering financial incentives for those who use more energy efficient and environmentally friendly alternative powerd vehicles?</B>(Tick one)</FONT></P><FONT size=-1>
<DD><INPUT type=radio value="Yes" name=R5>Yes
<DD><INPUT type=radio value="No" name=R5>No </FONT>

<P><FONT color=#0000bb size=2><B>*If so, would these incentives encourage you to purchase such a vehicle?.</B></FONT></P><FONT size=-1>
<DD><INPUT type=radio value=Definitely name=ayad24>Definitely

<DD><INPUT type=radio value=Maybe name=ayad24> Maybe
<DD><INPUT type=radio value=Probably name=ayad24> Probably
<P></P></FONT>

<P> </P>
<P><B>*Thank you for your time and patience, the information you have provided is extremely valuable for this study.</B></P>
<CENTER><INPUT type=submit value="Submit and get Results"><INPUT type=reset value=Reset>
<FONT
face="arial, helvetica" color=red size=-1>(wait for
results)</FONT></CENTER></FORM>
<CENTER></CENTER>
<P>
<P>
<P></FORM></P></DD></BODY> </HTML>