Chapter One

Alternative Fuels – The Present Study

1.1 Introduction

The first practical internal-combustion engine (ICE) was developed in 1860 and construction of the steam car soon followed. As early as 1900 there were 1681 steam, 1575 electric, and only 936 petrol cars made, Motavalli (2000). As technology advanced the market demand for steam engines dried up and by 1911 a complete switch to petrol power had occurred. Today, the market demand for petrol and diesel is increasing, as the number of vehicles on the road increases; fuels must be of a specific composition in order to be used within any modern vehicle and are subject to a high degree of processing and filtration. All petrol and diesel produced for UK consumption today has been refined and modified in accordance with the British Standards Institute (BSI) and the European Commission (Directive 2001/27/EC). At present the US and UK vehicle markets are dominated by petrol and diesel and so-called alternative fuels such as Liquefied Petroleum Gas (LPG), Compressed and Liquefied Natural Gas (CNG, LNG) Electric, Biofuels and Landfill Gas (LFG) are available but account for only about 2% of total fuel consumption, in all US vehicle types, Chang (1999). A similar situation holds in the UK.

The term “alternative fuel” has been used to describe any fuel suggested for use in a vehicle other than petrol or diesel. In many ways, the current position regarding fuels for transportation vehicles resembles the time in the early 1900s when vehicle buyers could choose among ICEs, steam, or electric vehicles. During this period, there were great debates about which fuels were best. Henry Ford envisaged many of today’s concerns about fuel availability and the environment by investigating the use of ethanol as a renewable, home-grown fuel whose production would benefit agriculture, Becktold (1997). The wide availability of inexpensive gasoline as a by-product of kerosene refining was a large factor in the subsequent success of the ICE in vehicles.

Predictions by the world's leading motor manufacturers suggest that another vehicle revolution is imminent; some are as bold as to suggest that the ICE will become redundant. As in 1911, the market will dictate the future of the various vehicle fuels. However, it is not a completely free market, Motavalli (2000). Government policies will impact on the market. The drivers for change will include taxation and legislation primarily arising from global and local air quality issues.

Evidence of these drivers already exists in the European Union (EU) where petrol and diesel fuels are subject to high taxes. Within the EU, some 68% of the final price is tax, with 16% going to refiners and markets and the other 16% to oil exporters, OPEC (2000). The UK now has the most highly taxed petrol in Europe.

Significant improvements in the quality of vehicle exhaust systems have reduced emission levels by approximately 95% that of new cars in the 1960s. For example, a Ford Fiesta built in 1998 emits one-twentieth of the pollution emitted from an earlier (1970) model, Chang (1999). . Three-way catalytic converters, direct-injection engines and other advanced technologies have greatly reduced individual emissions which, however, has been offset by increased ownership and use each year.

Approximately 600 million vehicles were on the road in 1995, almost 80% of them passenger cars, the remainder consists of HGVs and buses, Colls, J (1997). This number will probably reach one billion before 2010, IEA (1999). In 1950, in the UK, there were only just under 2 million cars registered. By 1998 this number had risen to over 21.6 million. The car has replaced the bus as the predominant form of transport, 82% of journeys by mileage are car. Its flexibility and convenience has led to traffic growth across all areas, with a displacement of rail as the dominant form of freight transport to

HGVs, which has led to a three-fold increase in HGV use, from 11 billion vehicle kilometres in 1950 to 32 billion vehicle kilometres in 1998. Approximately four-fifths of domestic inland freight transport (in terms of goods carried) now travels by road, CVTF (1999). Vehicle use is rising faster than vehicle stock and more than 99% of today's energy supply for road transport in developed countries is from crude oil (69% petrol, 30% diesel), IEA (1999).

Crude oil is refined to produce, petrol, diesel and other commodities in oil refineries. The result of the combustion of these hydrocarbon (HC) fuels in an ICE produces gaseous emissions which include, Carbon Dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Hydrocarbons (HC) and Particulate Matter (PM). These emissions can have a harmful impact on local and global air quality and human health.

Air pollution is a problem in major cities throughout the world. International comparisons of urban air quality suggest that the concentrations found in cities across the UK are similar to those found in similar sized cities elsewhere in Northern Europe. At a national level, road transport is the single most important source of most pollution, with the exception of Sulphur Dioxide (SO_2) and Volatile Organic Compounds (VOCs). Cars are the most dominant source of road transport emissions, contributing between 50 to 90% of the share of CO_2, CO and NOx and are a less important source of PM, of which the largest source is HGVs, Holman (1996)

Many Life Cycle Assessment (LCA) studies, see Chapter 2, have focused upon cars due to their larger impact on local and global air quality, however the present study focuses upon the use of conventional and alternative fuels in Public Service Vehicles (PSV) such as large vans, HGVs and Buses. This is because there is little information available to the public for the large vehicles and conversely perhaps, too much information on smaller vehicles. Moreover any future switch to alternative fuels will require proven technology with a relatively large fleet of vehicles. The use of Landfill Gas (LFG) plus other alternative fuels can be demonstrated in these larger vehicles, as some local authorities and businesses are willing to try alternatives, although the majority are sceptical and need financial inducements to pilot schemes.

1.2 The Problem

Vehicle and vehicle fuel suppliers are faced with a rapidly changing technological, sociological and economic environment. Legislative pressure, emission regulations and other constraints have led to a highly competitive automotive industry, which invests a huge amount in research and development. One of the aims of this investment is to reduce energy consumption and emissions throughout production and end-use. Recent years have seen many pressures on road vehicles and fuel performance to meet increasingly stringent emissions regulations and improve fuel consumption, while maintaining and improving the acceptability and performance of vehicles, CONCAWE (1995). The same pressures apply to the vehicle fuel suppliers (e.g. oil companies), who now produce and supply the fuels dictated by the hybrid market demand. Pollution abatement requirements impact upon the type of fuel supplied.

Fuel type changes are today evident with the switch from conventional petrol and diesel to so-called 'greener petrol/diesel'. These are varied and wide-ranging including: Ultra-low Sulphur Petrol (ULSP); Ultra-low Sulphur Diesel (ULSD); Lead Replacement Petrol (LRP); Premium Unleaded, Super-plus Unleaded, Auto-diesel and BP Lead free 4 Star, ESSO (2001).

In addition to the petroleum-based fuels, one must consider the Natural Gas (NG) fuels which, in today's economy, can provide vehicle owners with an alternative fuel source at a reduced price. The alternative fuels vehicle market in 2001 is dominated by ‘greener’ petrol and diesel, natural gas and to a lesser extent electric power. Appendix A provides details pertaining to the common alternative fuels available today, Finnegan (1999, 2000).

1.3 The Solution

In theory the solution is simple, it is to identify the most cost effective, energy efficient and environmentally friendly vehicle and fuel combination. In practice the solution is riddled with complexity. Cost effectiveness can be found with combination of the costs (fixed or variable) involved and the societal impacts of each stage within the LCA.

To maximise energy efficiency is to strive towards being 100% efficient. To study the efficiency of energy use, one must start with an examination of methods of energy conversion from one form to another, Eastop and Croft (1995). The conservation of energy principles limit the overall efficiency of any process. For example, the overall efficiency of a conventional, coal-burning power station is approximately 30% and the efficiency of the human body is approximately 70%, Norman *et al* (2001).

The most environmentally friendly fuel and vehicle combination depends upon many factors and is not a simple calculation. Pollution can occur on many different levels, micro to macro and the user must specify the area under investigation i.e. a particular fuel and vehicle may contribute to the lowest levels of regional pollution and to the highest levels of global pollution.

1.3.1 The European Approach

The European Commission (EC) identified the problem and subsequently set up the Directorate General for Energy and Transport (TREN), which is sub-divided into seven Directorates. One such Directorate is the EC Directorate General 17 (DG17). This Directorate administered THERMIE 2001, a programme that supports and funds seven alternative fuel demonstration projects across Europe. With a large initial capital investment, these demonstrations will, it is hoped, encourage other fleet operators and local authorities to use alternative fuels. The projects are as follows:

ANTARES (2001)

A New Traffic Approach Regarding Energy Saving (ANTARES) project aims to demonstrate the reduction in the global energy consumption due to the mobility needs. "Achieved through both reducing and rechanneling traffic flows; this will also mean a reduction in current level of fossil fuel consumption and as a consequence a lesser dependence on external energy supply", further details are available on the website, see http://europa.eu.int/comm/energy/en/thermie/antares.htm

CENTAUR (2001)

The objective of the Clean and Efficient New Transport Approach for Urban Rationalisation (CENTAUR) project is to "contribute to the rationalisation of the use of urban transport with the final aim of diminishing the negative impact on environmental conditions produced by the use of motorized transport means", see http://europa.eu.int/comm/energy/en/thermie/centaur.htm

ENTIRE (2001)

The European City Network on Transport Innovation for the Rational Use of Energy (ENTIRE) project. The project will "examine the synergistic effects of European networks and integrated approaches in transport management for improving the energy and emission balance of European cities. The results of these demonstrations will provide strong support to raise the market profile of energy saving technologies on the basis of practical achievements, and to promote their further implementation in other European sites through active technology transfer", see http://europa.eu.int/comm/energy/en/thermie/entire.htm

JUPITER-2 (2001)

Joint Urban Project in Transport Energy Reduction (JUPITER–2) focuses upon the promotion of the concept of an energy efficient city from the perspective of the transport sector. One of the aims is to evaluate the impacts of the demonstration projects using common methods and tools, and to advance the state of the art in this field, see http://europa.eu.int/comm/energy/en/thermie/jupiter2.htm

SAGITTAIRE (2001)

The name of the project refers to the mythical creature of the Sagittarius, a hybrid creature who is symbol for the complementarily between horse and man. The aims of the project are "to demonstrate the use of advanced hybrid-electric buses fitted with innovative batteries to improve the overall efficiency and attractiveness of public transport and to allow guidelines for future developments in urban transport organisation and technology to be drawn", see
http://europa.eu.int/comm/energy/en/thermie/sagitair.htm

ZEUS (2001)

ZEUS is an acronym of Zero and low Emission vehicles in Urban Society. The project consists of introducing at least 1200 vehicles in the eight cities participating in the project, the total population of which exceeds 20 million citizens. The consortium' s commitment is to "demonstrate the relevance of a series of technical measures to reduce CO_2 emissions in a significant way, as well as to improve energy efficiency in urban transport". Also it is expected to increase the interest to use a sustainable public transport, see
http://europa.eu.int/comm/energy/en/thermie/zeus.htm

CATCH (2003)

CATCH is an acronym of Clean Accessible Transport in Community Health. The project is a demonstration project in the European Commission's Life-Environment Programme. It supports the EC's Sixth Environmental Action Programme by promoting sustainable mobility in order to improve air quality, see
http://www.cleanaccessibletransport.com

Each project focuses upon reducing emissions and saving costs with alternatively fuelled vehicles. Some are specific to gas powered vehicles, some to electric vehicles and others compare and contrast a range of vehicles, with an overall aim off producing zero and low emission vehicles.

Within Merseyside, the JUPITER-2 programme focuses upon LPG, Biofuels, Electric (Battery), CNG, Diesel-Electric Hybrids, Innovative Diesel, Weight-Reduction Techniques (i.e. Lightweight Vehicles) and Fuel Cell Systems. As indicated previously, other vehicle fuels are under examination within each of the other EU THERMIE Targeted Transport Programmes (TTP), see
http://europa.eu.int/comm/energy/en/thermie/ttp-home.htm

1.4 Present Study

1.4.1 Study Aims

The study aims have been to investigate the state-of-art of LCA, with reference to fuel-vehicle combinations with a focus on Public Service Vehicles (PSV), i.e. vans, HGVs and buses, so that guidance might be available to decision makers and fleet operators involved in the use of alternative fuels in these types of vehicles. The present study does not attempt to address every single impact and aspect of an LCA in this field but aims to establish a framework for this, highlighting where further work is required and where gaps in data exist.

1.4.2 Methodologies

By the nature of the study and the resource base available, no dedicated experimental work has been undertaken. The thesis is based on a very wide review, validation and use of data from published and unpublished sources to calibrate the elements of the models. This has required contacts with other academic research bodies, commercial organisations and UK local and Central Government Authorities and Agencies. Some matters have been regarded as commercially confidential, such as specific emissions factors, and have not been made available. In other cases the data had been presented to different reference time basis or the definitions of the various classifications of data have been obscure. This has made validation difficult but simple concepts of mass transfer and energy conservation, together with quantitative and qualitative comparisons with other LCA studies, have been used to test results of the present study.

1.4.3 Thesis Organisation

The thesis contains eight chapters. The first chapter has given a broad overview of the problem and solution to the question of alternative fuels for public service vehicles. It also details the most common alternative fuels available together with a very brief history of the automotive industry. In the second chapter, the concept of a life cycle assessment is introduced as well as a breakdown of each stage, as defined by the International Standardisation Organisation (ISO14040): 1997 Environmental Management – Life Cycle Assessment – Principles and framework. The end of this chapter displays the vehicle and fuel cycle diagram, which is the building block upon which the LCA is built. This analysis has been developed from other LCA transport studies within the US, UK, Australia and Switzerland. The third chapter provides an extensive review of the UK oil and gas industry relating to vehicle fuels, from the initial extraction of oil and gas through refinement, transportation and storage to its end use in a vehicle. It is from these fossil fuels that the majority of alternative fuels originate. Within each stage of the life cycle of any given fuel and vehicle, consideration is given to the emissions profile. This chapter also contains details of the excel spreadsheet model and it's use within a LCA. Chapter four details the building of the LCA model and considers the life cycles of each fuel and vehicle under examination. The fuel cycles consist of 6 stages (F1-F6) and the vehicle cycles consist of 4 stages (V1-V4). The F6 and V3 stages are linked to combine both cycles, see Figure 2.2. The model itself was named in this chapter as, LCEM, the Life Cycle Emissions Model and forms the basis upon which the impact assessment, simulation and sensitivity was performed. The fifth chapter comments upon the results from the LCEM, focusing upon the comparisons between each individual fuel and vehicle cycle and other studies. Detailed discussions of the results from each fuel and vehicle cycle are made together with the combination of cycles to form the actual life cycles. These life cycle results are the basis upon which the normalisation and weighting occurs as per the Environmental Design of Industrial Products (EDIP) methodology. Chapter six follows with the application of the EDIP method to the life cycle results. This method enables a user to compare the life cycle results on a common basis and weight the relative impacts. The impacts considered are those of global warming potential (GWP) and human toxicity (HT). The chapter ends with the calculation of GWP and HT for each fuel and vehicle under consideration. These results then form the basis of the uncertainty and sensitivity analysis that follows in the penultimate chapter seven. The simulation software @RISK is used in chapter seven in order to measure uncertainty within the life cycle results. The outputs from a series of simulations are used to measure correlation and identify the sensitivity of each output variable. Chapter eight comments upon the development and use of the LCEM and concludes with an explanation of the future for conventional and alternative fuels. Recommendations for further research are then made.

1.4.4 Multi Model Research

The information and results within this thesis have been used by Liverpool City Council and have attracted a great deal of interest from Merseytravel. As a result of the work, a number of presentations have been given and a poster presentation was made to MPs at the House of Commons at the 2002 UK Medal and Prize for Excellence in Engineering by a Younger Engineer in December 2002 see Finnegan (2002). In 2003, a paper was presented at the Logistics 2003 online conference, see www.logistics-2003.com and Appendix B. Papers have recently been presented at the International Conference on Transportation Systems Planning and Operation TRANSPO2004, Indian Institute of Technology, Madras, India and the Tenth International Conference on Urban Transport and the Environment in the 21st Century, Urban Transport 2004. Dresden, Germany, see Finnegan, S and Tickell, G (2003) and Finnegan, S *et al* (2004).

The work has attracted a great deal of interest from many environmental groups, transport operators and planners. Further details can be found at the end of the reference section.