Chapter Eight

Conclusions and Recommendations

8.1 General Conclusions

The work presented in this thesis may be used by many different organisations to compare conventional and alternative fuels on a life cycle basis, without the need for expensive field trials, for fuels and vehicles currently in operation throughout the UK.

An enhanced LCA of HGVs and buses within the general grouping of public service vehicles, which have not received much attention by other authors eg GREET, Hackney, ETSU, GM has been produced. The main focus of these other studies tends to be on passenger cars.

The fuel (F1-F6) and vehicle (V1-V4) cycles are based upon the current UK situation rather than the European and US. The vehicle cycle has picked the major elements of a vehicle to confirm that the V1, V2 and V4 stages are indeed contributing less to the total releases of the gaseous compounds in comparison to the total life cycle use of a vehicle.

The model compares conventional and alternative fuels (including landfill gas) on a life cycle basis and the holistic approach enables a user to modify the spreadsheets to incorporate any number of fuel and vehicle combinations.

The model is able to simulate change and provide some measure of uncertainty for any fuel and vehicle combination.

The need for information of this type will be critical over the coming years, as the amount of traffic and levels of pollution increase in our town and cities. One must be in a position to assess any alternative fuels with some degree of rigour. The current world economy is built around the recovery of hydrocarbons and models of this type could be used to estimate the environmental impact of the introduction of advanced fuels and vehicles as the hydrogen economy approaches.

In order to achieve sustainability one must use materials and processes that have no negative impact on future generations. This may become possible with the introduction of so-called greener power sources such as wind, wave and solar power. The production and purchase of green electricity is a step in the right direction but a lot more work is still required. Many nations are increasingly concerned about the environmental impacts of vehicles. They can no longer avoid the scientific evidence that links increased air pollution to increase in vehicle use. Local authorities and the Government must take decisive measures in pollution reduction in order to encourage the public to become more sustainable in their modes of transport.

By using this LCA model, the impact each person has on the environment can be assessed, for conventional and alternative fuels.

8.2 LCA Conclusions

The majority of alternative fuels LCA studies only consider the fuel cycle e.g. GREET, Hackney, ETSU, GM and NREL; this limits their use and confuses the audience. These studies, described in Chapter Three, could be expanded to include a phase of normalisation and weighting together with some uncertainty analysis. This would provide more robust models upon which some real world results could be produced. The original GREET model v.1.5 has been upgraded to version 1.6. The newer version uses the older data, however a GUI was introduced together with measures of uncertainty to enhance an existing model, so that it may be used by industry and academia. People with little knowledge of the complex calculations and LCA principles could generate results for their vehicles using a quick and easy model.

Data availability becomes a problem with all LCA studies and some common measures are required to provide a platform upon which some universally accepted models can be built. Practically, boundaries always exist and no LCA will ever be 100% complete.

8.2.1 Fuel Cycle Conclusions

The fuel cycle results highlight the significance of the F6 end-use stage in comparison to the F1-F5 stages. In general, the combustion of the fuel releases more pollutants into the atmosphere than the generation and delivery of the fuel itself to the vehicle. This is why there is a large focus upon engine efficiency and the development of exhaust after treatments. However, there is a limit to how much a fuel can be 'cleaned' within an ICE. The results of this study show that even with reduced sulphur content and particulate traps, the fuel and life cycle emissions of the liquid and gaseous fuels will never be able to compete with the electric vehicles. A hydrogen economy is predicted and on wide-scale implementation the demise of conventional petrol, diesel and gas power will occur.

8.2.2 Vehicle Cycle Conclusions

The significance of the vehicle cycles becomes apparent during the analysis of the life cycle results. These cycles play a small role in comparison to the use of the fuel itself and are of little concern. However, as the fuel cycle emissions are reduced, as with the electric vehicles, the vehicle cycle emissions have a larger impact. In the future, with the possibility of hydrogen vehicles, the vehicle cycle emissions may have a larger impact than they do for the conventional and alternative fuels evaluated in the present study.

8.2.3 Life Cycle Conclusions

Life cycle results provide the backbone for this study. The results Figures 5.19 – 5.21 show the absolute and relative impacts of each fuel and vehicle cycle under investigation. The combination of the fuel and vehicle cycles has shown that the contributions to CO_2 are much larger than the other compounds and the end-use stage F6 has the largest impact to the total results. The electric vehicles are clearly less damaging than their liquid and gaseous equivalents and the use of a HGV and bus contributes to higher releases of all compounds. Landfill gas (LFG) vehicles compare favourably to the other fuel types with the exception of the peaks in CO and CH_4. The analysis of the HGV has shown that a diesel HGV releases similar amounts of emissions in comparison to a NG-CNG and LFG-CNG HGV, with the LFG vehicle releasing less CO_2 and CO, offset by the large increase in CH_4.

The life cycle of the bus shows the largest releases of emissions for the majority of compounds. This is due to the operation of the vehicle, not the vehicle size. During start/stop conditions and at low speeds, buses release more pollution, per km travelled, in comparison to vans and HGVs, which tend to operate at a more constant speed with fewer stops. Should a van, HGV and bus operate under exactly the same conditions the results would be very different. For the operational cycles chosen, the LFG-CNG bus compares favourably to the diesel bus and poorly in comparison to the LPG bus. This is reflected in Figures 7.1 – 7.4 in Chapter 7.

8.2.4 LCEM Conclusions

The LCEM is a tool for combining the fuel and vehicle cycle results and applying the EDIP methodology. The model can be used for any fuel and vehicle combination. With simple adaptations of the existing worksheets it is possible to model any given vehicle. The only obstacle is the availability of data. A user will find difficulties in obtaining the relevant information, however any user is capable of using the existing data with adaptation to suite. The EDIP methodology had been developed to be used on the Worldwide and Danish scale, however there is no reason why the results could not be adapted for specific use in the UK. Given the time and resources, a model could be built to reflect the current UK situation. More information would be required and amendments to the existing model would be required. However, the results and conclusions made in the present study would not differ as the fuels and vehicles are compared relative to one another and at this point the EDIP methodology has little influence on the relative impacts. The absolute values however would change, due to the differences in the amount of emissions released in the UK and Denmark, subsequently the impact to GWP and HT would differ for the UK situation. In this situation the EDIP results would play a more significant role as comparisons between the UK and Denmark emissions profiles could be made. With a more extensive database of results the EDIP methodology could be used much more effectively. The case studies investigated in EDIP **1** are of little use for comparison with much larger industrial processes or transport operations. More comprehensive studies with expanded use would enable the methodology to be used more effectively in industry, after all this is the purpose of the EDIP method.

Once the model results are understood, the processes of normalisation and weighting can be performed with ease. Comparisons can be made with the industrial products analysed within the EDIP books, to provide a user with an understanding of the relative impacts and contributions to the environmental impact categories. GWP and HT were chosen in the present study, however other impacts such as ecotoxicity, acidification, nutrient enrichment and others exist. Other EIA can be made based upon these impacts.

Within the LCEM worksheet are a series of iterative calculations and some knowledge of advanced Microsoft Excel procedure may be required.

8.2.5 Uncertainty Analysis Conclusions

The uncertainty analysis has provided some idea of order of variation in the results. The extent to which this variation is used is at the discretion of the user. The limits of the present study are justified, however other fuel and vehicle combinations may require extended variations to describe different operational characteristics. The probability distributions and percentage variations chosen in this study reflect the operation of vehicle in the inner city and the suburbs. The LCEM model could be used to analyse motorway or rural drive cycles. The limiting factor becomes the use of the TRL UK Road Emissions Database, see equation 4.2, which sets a range of speeds upon which a vehicle can be tested.

The uncertainty analysis produces interesting results, in that it is possible for a bus to release similar amounts of compound to a large van has per-person. The results also serve to highlight the significance of each vehicle has and the possible range of impacts. The larger impacts, such as the diesel bus, have a larger variation. There is also some evidence of slight skewness, however the majority of fuels and vehicles could release more or less compounds with equal probability.

The sensitivity analysis has shown that the most significant stage in each of the life cycles, with the exception of the electric vehicles, is derived from the F6 stage. Furthermore the operational lifetime use, average speed, distance travelled per day and total operational days are the largest contributors to GWP and HT for all fuels and vehicles under investigation, again with the exception of the electric vehicles. To reduce the emissions of the compounds investigated, these four variables need careful consideration and future studies should focus upon them

8.2.6 Conclusions on the Future Developments

Major investment in conventional vehicle fuels is currently underway throughout the world, see 3.4.1, and it seem unlikely that any major switch towards hydrogen, or any other alternative, will occur this decade. The investment in petroleum fuels is large and the implication of a major switch away from crude oil production has political and social overtones as well as the technical and economic problems. However, the future is unpredictable and some changes are underway, with developments in fuel cell technology, hybrid vehicles and reformation of various fuels. These changes may or may not prove to be cost effective or operationally viable, however all countries agree that something has to be done and that conventional hydrocarbon based fuels do not provide the long-term solution. This is why the US and UK, see 3.4.2, have invested time and resources into the development of fuel cell vehicles and hydrogen fuel.

In the future, the decisions to introduce new or alternative fuels will have to be made based upon scientific, economic and logistical factors. LCA models of this type could be used as a decision making tool and could be linked into economic and logistical decisions, in order for a transport operator to make the correct choice. In the future, the work could also be linked into the Local Transport Plans (LTPs) for each City Council in the UK, providing a tool for assessment of alternatives. The results from the vehicles could then be linked into the review and assessment of air quality within a city and comparison could be made with natural releases, industrial processes, and other transport modes.

8.3 Recommendations for Further Study

The results presented in this thesis could be used in a much wider context. They could become part of a much larger Environmental Impact Assessment (EIA), a complete LCA for liquid solid and gaseous emissions or any other assessment. Other fuel and vehicle cycles could be introduced and compared to the conventional and alternative fuels. This has wider applications with the strong possibility of the introduction of fuel cell vehicles.

The following list details the main recommendations:

- A full LCA, inclusive of cost, emissions and energy consumption for all material and energy flows would be useful.

- A user friendly GUI should be built into the existing LCEM model, for use by industry and/or academia.

- The LCEM could be upgraded with more accurate information, eliminating the need for assumptions, from the present year and/or forecasted years to provide some measure of future emissions from each of the fuels and vehicles under examination

- The system boundaries of the model should be extended to include the emissions associated with the construction of the infrastructure required to extract, transport, refine and distribute the fuel and build the vehicles.

- Additional fuel and vehicle cycles should be included, with the introduction of different battery driven vehicles, fuel cell vehicles and liquid or gas hybrids.

- The GWP and HT calculations should be updated to include all processes and materials that impact of global and local pollution.

- Further transport related LCA studies are required that use the EDIP methodology in the final assessment phase. Any cross comparison could then be made.

- On a purely environmental impact basis, simulations could be performed for specific vehicle fleet operators, realising that cost is the primary driver. With accurate data on vehicle operation and life time use, the LCEM model could be used by the operators as a tool in decision making, without the need for expensive field trials.

- Further studies could be undertaken on the specific variables that influence GWP and HT. A user may be able to reduce the life cycle emission from their vehicle fleets by simply reducing the impacts made by the most critical variables that result from the simulation.