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EXPLORING SCENARIOS TO 2050 FOR HYDROGEN USE IN TRANSPORT IN THE UK

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1. INTRODUCTION

The work reported in this paper was carried out as part of a project funded by the Tyndall Centre for Climate Change Research. The project - “The Hydrogen Energy Economy: its long term role in greenhouse gas reduction” (Dutton et al., 2004) – was a collaboration between the Energy Research Unit at the CCLRC Rutherford Appleton Laboratory, the Science and Technology Policy Research Unit (SPRU) at the University of Sussex and the Institute for Transport Studies (ITS) at the University of Leeds. The project studied the potential contribution and viability of the hydrogen energy economy towards reducing UK carbon dioxide emissions in the time horizon to 2050.

This paper reports on the development and application of a quantitative model of the UK transport sector as part of this work. This model was developed to explore the degree to which hydrogen powered vehicles could play a major role in the UK transport sector and the potential impact on energy consumption under a range of future scenarios to 2050. The model incorporated the four main motorised modes and estimates the amounts of different types of fuel consumed by the UK transport industry up to 2050. Scenarios were used to inform the development of inputs to the model and therefore the model was able to shed light on the practicality of the scenarios, and the potential impact of hydrogen in each.

2. BACKGROUND

The recent UK Energy White Paper (DTI, 2003) commits the UK to a target of reducing carbon dioxide emissions to 60% of their 2003 level by 2050 in order to mitigate the effects of climate change. Transport accounted for 27% of end user emissions of carbon dioxide in 2001 (DfT, 2003). It is therefore important to study the ways in which the transport sector could reduce its emissions of greenhouse gases.

The development of a hydrogen energy economy has been proposed as a way of reducing greenhouse gas emissions. This would involve the development and widespread adoption of hydrogen as an *energy vector*. It would be used to store and transfer energy from source (preferably a low or non carbon generating one) to where it would be used (on board a vehicle for example). The advantage of using hydrogen is that it allows the generator increased flexibility because it can be produced by an energy source which varies due to daily or seasonal fluctuations. Using hydrogen as a fuel also produces negligible local pollution.

Hydrogen is a versatile fuel with a higher energy content per unit mass than any other. It can easily be substituted for existing fuels in stationary or mobile applications, for instance in internal combustion engines. Hydrogen can also be used as a fuel for a fuel cell, an electrochemical device that combines fuel and an oxidant to produce electricity. Using hydrogen (with oxygen as the oxidant) in a fuel cell produces water and heat as the only by products – it therefore can create electrical energy which is “pollution free” at the point of use.

Hydrogen can be produced, stored and distributed in a number of different ways, but current methods for achieving this are complex and expensive. The most commonly suggested ways of producing hydrogen (usually by electrolysis) are expensive by comparison with fossil fuels and the cheapest way of producing hydrogen currently is from natural gas by steam methane reforming (a process which produces carbon dioxide) (Dutton, 2002). Hydrogen storage and distribution present significant challenges and some authors consider these to be so constraining that they feel that a hydrogen energy economy would be inferior to a “Synthetic Liquid Hydrocarbon Economy” which would use liquid hydrocarbons (e.g. methanol and ethanol) as fuels instead of hydrogen (Bossel et al., 2003).

This paper explores the degree to which hydrogen powered vehicles could play a major role in the UK transport sector and the potential impact on carbon dioxide emissions under a range of future scenarios to 2050. This work was carried out by developing a model of the UK transport sector and using it to explore the feasibility of different scenarios for the introduction and widespread take-up of hydrogen powered vehicles.

The model was combined with a wider model of the UK energy system (THESIS) in the Hydrogen Energy Economy project to predict overall primary fuel demand and carbon dioxide emissions.

This paper describes the development of the transport model, the four scenarios that were used and how they were developed to provide the inputs to the model. Finally, it discusses the results achieved and draws some conclusions from the research.

3. DEVELOPMENT OF THE TRANSPORT MODEL

The transport model was designed to be quick and easy to use so as to allow the use of an iterative procedure to develop pathways for testing the different scenarios. It is based around the four main energy consuming transport modes: road, rail, air and water. The model uses readily accessible and relatively aggregate data sources so as to speed construction and use and is conceptually relatively simple, though maintaining enough functionality to allow the differentiating features of the scenarios to be represented.

For the rail, air and water sectors, the required inputs are the levels of different types of activity (by different vehicle types) for all years up to 2050.

These are combined with fuel consumption factors to predict total fuel consumed (by fuel type) for every year up to 2050. As the road sector is the major source of emissions, a more sophisticated approach is used, involving basic modelling of the vehicle fleet (stock turnover for a wide variety of different vehicle types) and the use of fuel consumption equations (NAEI, 2004) that take into account vehicle speeds on three different road types (urban, rural, and motorway).

The model consists of a series of Excel workbooks, one each for Water and Air, and two for Road and Rail, which distinguish between Great Britain and Northern Ireland. This is because much of the data on road and rail transport is reported in this way, whereas the overall THESIS model operates for the whole of the UK. All the sub-models have a similar conceptual structure, the two road transport workbooks are the most complex, but are identical in structure.

For all the sub-models the basic assumption used is that:

Level of activity x fuel consumption factor = total fuel consumed

Known levels of activity and fuel consumption factors are built into the sub-models for 2000, 2001 and 2002. The inputs to the sub-models are therefore the changes in the levels of activity and the changes in the fuel consumption factors expected over the forecasting period (2003 – 2050).

3.1 Road transport sub-model

Road transport is at present the dominant source of carbon dioxide emissions within the transport sector accounting for 91% of total UK transport emissions of carbon dioxide (DfT, 2003). The road transport sub model is the most complex for this reason and also because data is available to facilitate a fairly detailed approach. The road transport sub-model has the structure:

no. of vehicles (stock) x kilometrage per vehicle x fuel consumption (speed) = total fuel used

3.1.1 Stock

The vehicle stock is disaggregated by vehicle type and vintage. The vehicle classes used in the model are shown in Table 1. All vehicle types (except motorcycle which has very low energy consumption) have at least one hydrogen fuelled future vehicle type, a Hydrogen Fuel cell (HFC) vehicle. For cars a Hydrogen Internal Combustion Engine (HICE) and a diesel Hybrid have also been included.

The vehicle stock is divided into 15 different age categories, from vehicles which are less than 1 year old to vehicles which are between 13 and 14 years old and those which are over 14 years old. This allows the dissemination of new vehicle types to be modelled. Survival factors for each vintage of vehicle, that is, the proportion of that vehicle type and age surviving to the next year, were calculated from those implied by the stock figures calculated for 2000, 2001 and 2002. The survival rates for alternatively fuelled vehicles were assumed to be the same as those for diesel cars. Survival rates are assumed to remain constant over the period modelled.

Table 1: Road vehicle classes

Car	Petrol	small (< 1.4 l)	Heavy goods	Diesel	Rigid
		medium (1.4 - 2.0 l)			Artic
		large (> 2.0 l)		HFC	Rigid
	Diesel	small (< 2.0 l)			Artic
		large (> 2.0 l)	Light goods	Petrol	
	Hybrid	small		Diesel	
		large		HFC	
	HFC	small	Bus or coach	Diesel	
		large		HFC	
	HICE	small	Motorcycle		small (<=50cc)
		large			medium (50 - 499cc)
					large (>=500cc)

Stock for forecast years is calculated from the new buy for the forecast year and the survival factors. The inputs for the stock part of the sub-model are therefore the changes in the new buy from the previous year.

Data for the base years were taken from the Vehicle Licensing Statistics (VLS) series published by Transport Statistics: DfT (DETR, 2001, DTLR, 2001, DfT, 2003a).

3.1.2 Kilometrage

Vehicle kilometrage data was taken initially from the relevant editions of Transport Statistics Great Britain (DfT, 2003). These figures for total vehicle kilometres by vehicle type were modified by using the NAEI dataset of vehicle kilometres by vehicle type and propulsion type (NAEI, 2004). This allows the total kilometres figures for car and light goods vehicles to be split by propulsion type.

Kilometrage per vehicle was obtained by dividing through by total stock for that vehicle type. It was not possible to differentiate between different car sizes, so these were given the same kilometrage per vehicle. It was assumed that alternatively powered vehicles would have the same kilometrage per vehicle as diesel vehicles.

3.1.3 Speeds

Speeds are used as an input to the fuel consumption factors, they are broken down into the different vehicle types, but also three different road types; motorway, rural and urban. The speed data was taken from DfT (2003) using the average speed for each road type and vehicle. It is likely that this approach leads to an under-estimation of the total fuel used due to:

(i) the non-linear relationship between speed and fuel consumption,
(ii) increased fuel use during start-up and acceleration (particularly in urban areas),
(iii) the mean speeds clearly having been measured on open, free-moving roads.

Further research is required on how best to model or allow for these effects.

3.1.4 Fuel consumption factors

For conventional vehicle types fuel consumption factors are taken from the NAEI (2004) dataset and are calculated using the equation:

fuel used (g/km) $= (a + b.v + c.v^2 + d.v^e + f.\ln(v) + g.v^3 + h/v + i/v^2 + j/v^3).x$

where v is speed in km/h and a to j and x are supplied parameters specific to vehicle classes and vintages.

For non-conventional vehicles (Hybrid, HFC and HICE) the treatment of fuel consumption was cruder, with a simple non-speed-related factor being used. Information for cars was calculated from information in Owen and Gordon (2002), on estimated “well to wheels” emissions of carbon dioxide and hydrogen consumption for various important future car vehicle types. These were converted to “tank to wheels” fuel consumption figures using the conversion factor supplied in the paper and the well known relationship between mass of fuel used and carbon dioxide produced. For hydrogen powered car types amount of hydrogen consumed is given directly by Owen and Gordon (2002).

As far as non car HFC vehicles were concerned, fuel consumption figures for PSV and LGV were taken from Hart et al. (2000); rigid HFC HGV fuel consumption was assumed to equal that of PSV; while that for articulated HFC HGV was assumed to be in the same ratio to rigid HFC HGV fuel consumption as for conventional HGV.

The final figures used for non conventional road vehicle types are given in Table 2.

Table 2: Fuel consumption figures for non-conventional road vehicles

Vehicle Type	Fuel	Fuel consumed (g/km)
Car – diesel hybrid	diesel	29.7
Car – hydrogen ICE	hydrogen	22.7
Car – hydrogen fuel cell	hydrogen	11.6
LGV – hydrogen fuel cell	hydrogen	18.8
PSV – hydrogen fuel cell	hydrogen	84
Rigid HGV – hydrogen fuel cell	hydrogen	84
Articulated HGV – hydrogen fuel cell	hydrogen	149

There must be considerable uncertainty over these figures given the novel nature of the technology and the lack of experience with these vehicle types. They should only be regarded as very approximate.

3.2 Rail transport sub-model

Rail is a relatively minor mode as far as fuel consumption is concerned. It currently accounts for only 3% of carbon dioxide emissions in the transport sector (DfT, 2003). Available data on fuel consumption for rail is very basic resulting in fairly crude modelling of this sector. It was not possible to find fuel consumption factors for hydrogen powered trains and therefore, in view also of the comparatively low contribution of rail to overall transport provision, hydrogen was not introduced into the rail sub-model. The units used are thousands of kilometres for passenger trains and millions of tonne kilometres for freight trains. Rail vehicle/activity classes were Intercity, Regional, London and the South East and Freight. These were further subdivided into diesel and electric powered classes. These classes broadly reflect variations in vehicle type. The kilometrage data was taken from SRA (2003) which provides annual kilometrage by train operating company. The final data was determined by splitting the company kilometrage data by the proportions of each train type and then summing the totals by the region that the train company is located.

Because of the simple structure of the model it would be relatively simple to introduce a hydrogen fuel cell train type if data on fuel consumption became available.

Rail fuel consumption factors were taken from the NAEI (2004) inventory and are for a typical service pattern.

3.3 Air transport sub-model

The air transport model is sub-divided into domestic and international flights and passenger and freight. It was assumed that all flight emissions from domestic flights and half of the emissions from international flights should be included. In the case of international flights this means one Landing and Take Off sequence (LTO) and one leg of a return journey. The model split air activity into LTO cycles and cruise distances for both domestic and international traffic. The units were thousands of aircraft movements and thousands of kilometres.

For domestic flights, a representative modern aircraft type (B737-400) was used for passenger and cargo as well as a prospective hydrogen powered “cryoplane” (CRYOPLANE, 2003). For international flights, the typical aircraft type chosen was a B767 300 R and a similar long distance cryoplane type.

The LTO figures were taken from DfT (2003), as was the average cruise distance for domestic flights (total kilometrage divided by LTO). The cruise distance for international flights was taken from CAA (2003)

Fuel consumption factors were taken from EMEP (2002), which provide kilogrammes of fuel consumed by the LTO phase and cruise distance phase (based on distance) for the aircraft types chosen. The figures for the cryoplane were calculated on the assumption that the aircraft would use a similar technology to conventional aircraft and that therefore the hydrogen consumed can be calculated from the energy density of the hydrogen fuel relative to conventional fuel.

3.4 Water transport sub-model

Very little data exists for the Water transport mode; however, shipping only accounts for 3% of carbon dioxide emissions in the UK (DfT, 2003).

Activity was broken down into millions of tonne kilometres by inland and sea going water transport. Data was taken from (DfT 2003). It was assumed that the fuel consumed by water transport would stay the same over the forecasting period.

3.5 Results

For each sub model results are available in terms of total fuel consumed disaggregated by vehicle or activity type and year. For the road model results are also available for vehicle vintages and road types. For simplicity, various macros were used to extract more aggregate information such as total vehicle kilometres and stock levels for further analysis. Further calculations allowed total energy used to be calculated using known factors for energy content of different fuels (Dutton, 2004, DTI, 2004)

4. DEVELOPMENT OF SCENARIOS

The scenarios used were adapted for use in this study by SPRU (Watson et al., 2004) from a framework developed for the Intergovernmental Panel on Climate Change and widely used for characterising different possible futures. These scenarios represent four possible directions of development up to 2050. They are defined around two different dimensions for possible future development, values (which can tend towards either consumerism or community) and governance (regionalisation or globalisation). Divergent development in these two dimensions produces four qualitatively different future scenarios. The 4 scenarios are referred to as: world markets, global sustainability, provincial enterprise and local stewardship (Figure 1).

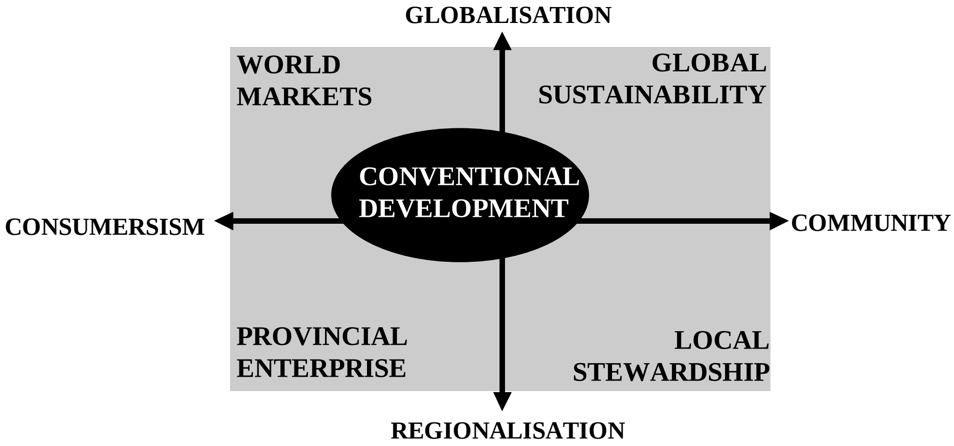

Figure 1: The four scenarios (Foresight, 1999)

These four scenarios can be characterised in qualitative terms (Foresight, 2003):

World Markets - People aspire to personal independence, material wealth and mobility to the exclusion of wider social goals. Integrated global markets are presumed to be the best way to deliver this. Internationally co-ordinated policy sets framework conditions for the efficient functioning of markets. The provision of goods and services is privatised wherever possible under a principle of 'minimal government'. Rights of individuals to personal freedoms are enshrined in law.

Provincial Enterprise - People aspire to personal independence and material wealth within a nationally-rooted cultural identity. Liberalised markets together with a commitment to build capabilities and resources to secure a high degree of national self-reliance and security are believed to best deliver these goals. Political and cultural institutions are strengthened to buttress national autonomy in a more fragmented world.

Global Sustainability - People aspire to high levels of welfare within communities with shared values, more equally distributed opportunities and a sound environment. In the UK, there is a belief that these objectives are best achieved through active public policy and international co-operation within the European Union and at a global level. Social objectives are met through public provision, increasingly at an international level. Markets are regulated to encourage competition amongst national players. Personal and social behaviour is shaped by commonly held beliefs and customs.

Local Stewardship - People aspire to sustainable levels of welfare in federal and networked communities. Markets are subject to social regulation to ensure more equally distributed opportunities and a high quality local environment. Active public policy aims to promote economic activities that are small scale and regional in scope, and acts to constrain large-scale markets and technologies. Local communities are strengthened to ensure participative and transparent governance in a complex world.

In order to use these scenarios in the transport model they had to be converted from qualitative descriptions into the inputs needs for the models – numerical changes in new vehicle buying, activity and fuel economy.

More information was available on the implications for transport of the four scenarios (DTI, 1999 and ERAG, 2001) and transport use of hydrogen in 2050 was also estimated by the project team (Watson et al., 2004). This information is summarised in Table 3. In the case of World Markets, for example, increasing car ownership and low energy prices are expected to lead to increases in vehicle use and hence congestion, in which case speeds are likely to fall in the absence of further investment in road infrastructure. Low energy prices and little investment in alternatively fuelled vehicles will also ensure that petrol and diesel fuelled vehicles remain the norm under this scenario. Under all scenarios except Local Stewardship Transport energy demand is expected to increase by 2050 and in the case of World Markets will more than double. The scenarios represent a wide range of possible levels of hydrogen use in the transport industry over the next 50 years. For example, in Global Sustainability high investment in low energy and low emission vehicles driven by high energy prices and an emphasis on environmental gains results in 80% to 100 % of the energy used by Transport coming from hydrogen in 2050.

Table 3: Scenario details

	World Markets	**Global Sustainability**	**Provincial Enterprise**	**Local Stewardship**
Technology change	Low investment	High Investment	Low Investment	High investment at local level.
New technologies	ICT in cars	Low energy, Low emission vehicles	Little innovation	Alternatively fuelled vehicles
Energy Prices	Low	High	High	High
Car Ownership	High growth	Moderate growth	Low growth	Falls
Congestion	Increases (all modes)	Investment reduces congestion	Increases (due to lack of investment)	Congestion reduced
Bus Use	Falls	Increases	Falls	Increases
Transport energy demand in 2050 (TWh) ***638 TWh (2000)***	1359	646	1101	403
% Hydrogen use in Transport in 2050	5 %	80-100% 10-20% (2030)	15-25% 5% (2030)	20% Including 20-50% for buses

adapted from DTI (1999), ERAG (2001) and Watson et al. (2004)

These descriptions were then quantified into the necessary inputs for the transport model. The start dates for the introduction of hydrogen vehicles were determined using both the DTI (1999) report to determine the rate of technological change, demand for energy and the demand for transport for each of the scenarios and Owen and Gordon (2002) paper which suggests two potential routes for the introduction of hydrogen powered cars in the UK. These two routes ("low carbon" and "hydrogen priority") closely match the assumptions used in the Local Stewardship and Global Sustainability scenarios respectively. For each of the scenarios assumptions were made as to which modes of transport would be most likely to convert to using hydrogen first and in the case of scenarios with low hydrogen targets for 2050 (e.g. World Markets) which would be the most unlikely modes of transport to be fuelled by hydrogen in 2050. The introduction dates and final levels of hydrogen vehicle use for each scenario are given in Table 4 for road vehicles. Assumptions also had to be made about the speed of take up of hydrogen powered vehicles and also the degree to which these will replace conventionally fuelled vehicles.

Table 4: Introduction dates and take up of hydrogen powered road vehicles

		World Markets	**Global Sustainability**	**Provincial Enterprise**	**Local Stewardship**
Cars	**Introduced in**	not introduced	2016	2036	2030
	%age of vehicles (2050)	0	80	10	25
HGVs	**Introduced in**	not introduced	2019	not introduced	not introduced
	%age of vehicles (2050)	0	60	0	0
LGVs	**Introduced in**	2030	2004	2031	2021
	%age of vehicles (2050)	30	85	54	50
PSVs	**Introduced in**	2011	2003	2015	2016
	%age of vehicles (2050)	50	85	50	50

An alternative approach could have been to work back from the end points (the "target" levels of total energy and proportion of hydrogen energy shown in Table 3). However, the approach taken was to attempt to explore the feasibility of the scenarios by trying different feasible inputs in terms of penetration rates of new vehicles iteratively. In integrating the results of the transport model with the rest of the THESIS model the approach taken was to additionally constrain the model by ensuring a one for one replacement of conventional vehicles by hydrogen powered ones and by a much more even penetration rate of the new technology through the new vehicle buy (Dutton et al., 2004).

5. SCENARIO RESULTS

The transport model requires, as inputs, the year by year changes in levels of activity and fuel consumption and additionally, for the road sub-model, year by year changes in new vehicle buying behaviour and vehicle speeds. The model was used iteratively, to try different levels of change and then assess whether these led to the estimated outcomes required. This process meant that it was difficult to achieve an exact match between the “target” levels of energy demand (Table 3) and the results of the model. The results achieved for energy consumed by transport are shown in Figure 2 and these also show only broad agreement with the “target” proportions of hydrogen use in the transport sector in Table 3.

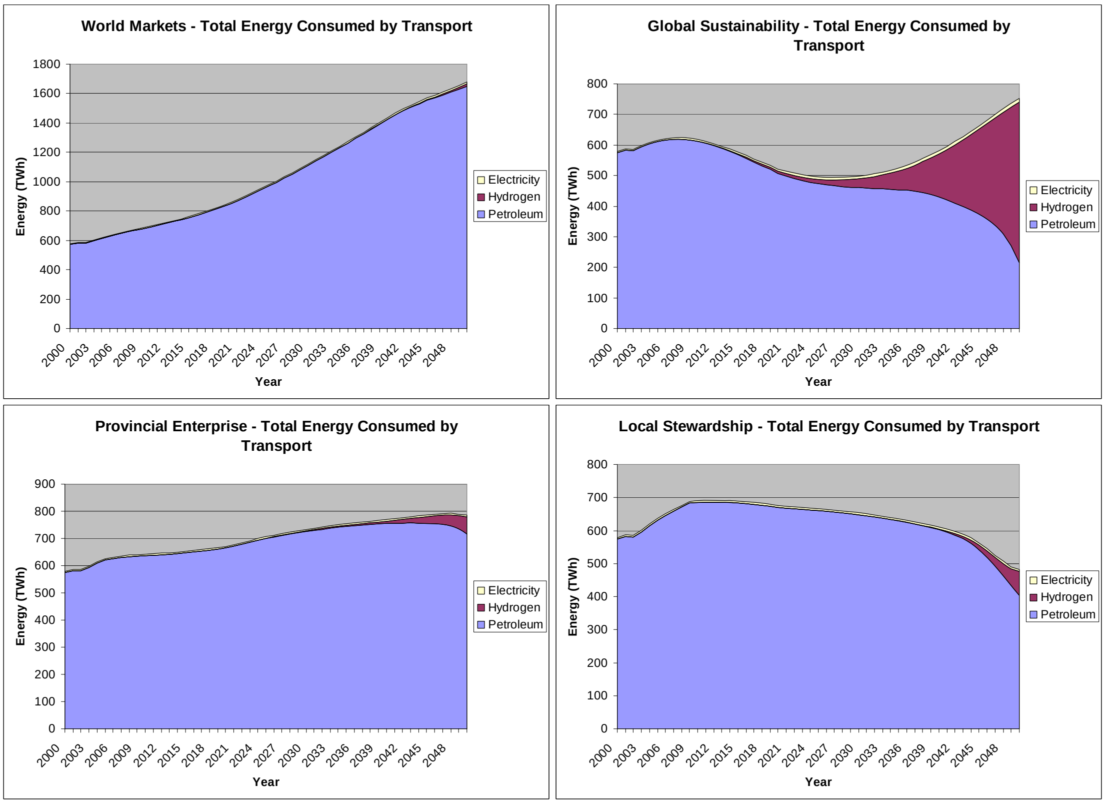

Figure 2: Total Energy consumed by the transport sector by scenario (TWh)

In the World Markets scenario energy demand has more than doubled. This is largely due to an increase in car and air travel. This scenario has the largest increases in energy demand and the lowest use of hydrogen. Hydrogen has only broken through in the bus industry and a small share of the LGV market, as can be seen in Figure 3. Total energy consumed is above the “target” energy demand for the transport sector of 1359 TWh (Table 3).

In the Global Sustainability scenario energy use has grown slowly. This is due to increasing the energy efficiency of vehicles and the move to more sustainable modes of transport for longer distance trips. One of the major contributors to energy demand is international air trips which have increased in number due to the need to be connected globally. Hydrogen vehicles have been introduced in all modes with the exception of rail and water. Figure 3 shows that the percentage hydrogen target rates described in Table 4 have been met, with over 80% of the energy demand for cars being met by hydrogen in 2050. However, while hydrogen was introduced in 2023 to the air sector, it did not achieve the level of penetration necessary to push the hydrogen energy consumed by the transport sector beyond 70% overall. Again, total energy consumed is above the “target” energy demand for the transport sector for this scenario of 646TWh. One of the challenges of this scenario was to represent correctly the substitution of large numbers of petrol and diesel fuelled road and air vehicles for hydrogen vehicles which have different energy consumption characteristics. This substitution process is a factor causing the dip in the energy use graph shown in Figure 2. Further work is required to study the substitution process and how to model it, particularly the likely responses of people to the widespread availability of hydrogen powered road vehicles.

In the Provincial Enterprise scenario energy demand has increased slightly. This is due to an increased dominance of the private car as a means of transport (balanced by the use of more economical conventional car types) and reliance on road freight as a means of transporting goods. By 2050 hydrogen has been introduced into the bus, LGV and car market (at varying levels) as can be seen in Figure 3. In this scenario total energy consumed is below the “target” energy demand for the transport sector for this scenario of 1101 TWh (Table 3). The percentage use of hydrogen in 2050 is also below the “target” at only just over 8%, showing how difficult it was to increase hydrogen use in a situation where the hydrogen car vehicle type in particular was introduced relatively late.

In the Local Stewardship scenario energy use declines over the model period. This is due to a fall in demand for personal motorised travel and emphasis on local solutions to transport problems. Hydrogen is dominant in the bus industry which has seen an upturn in use. In this scenario total energy consumed is above the “target” energy demand for the transport sector for this scenario of 403 TWh (Table 3) and again, it was not possible to push hydrogen energy consumed up to the “target” level of 20% despite the fact that in 2050 over 50% of bus kilometres were hydrogen powered.

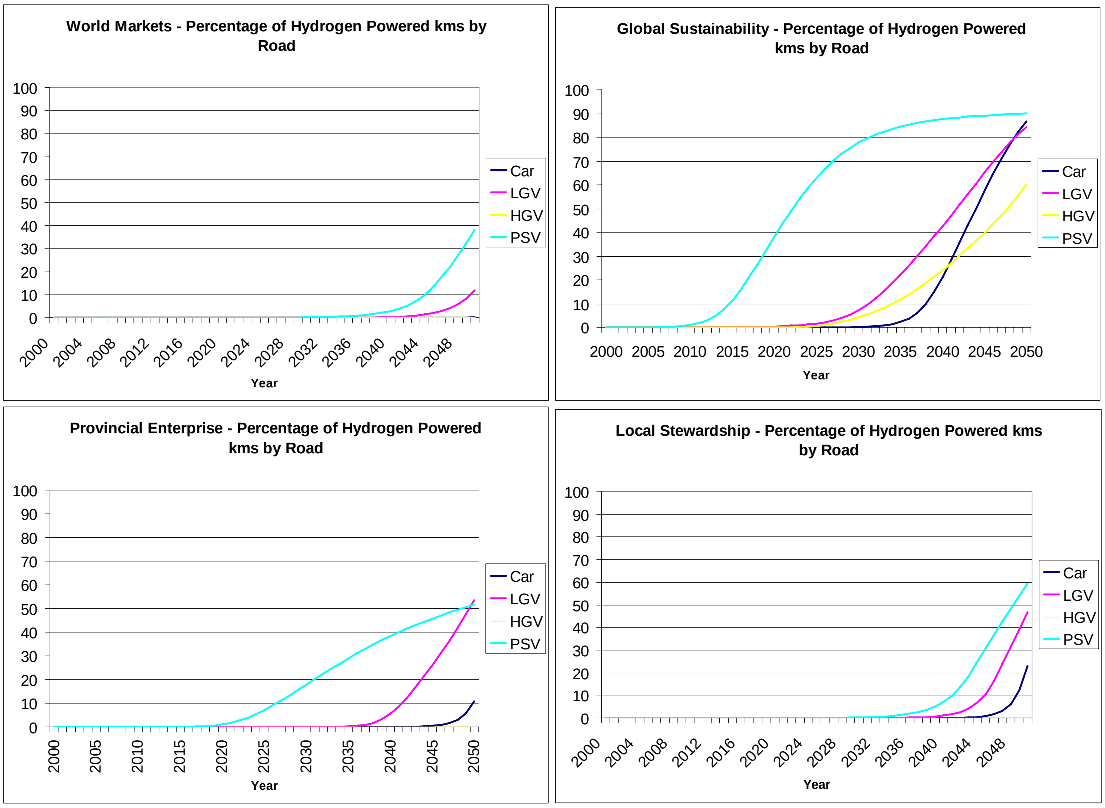

Figure 3: Percentage of hydrogen powered kilometres by road by scenario

6. DISCUSSION AND CONCLUSIONS

The transport sector model was designed to forecast fuel consumption and energy use for the four main modes to 2050. Its inputs were the year by year changes in levels of vehicle activity and fuel consumption and additionally, for the road sub-model, year by year changes in new vehicle buying behaviour and vehicle speeds. The purpose of developing the model was to feed the fuel consumed into the wider THESIS model in order to study the overall energy demand and hydrogen production requirements for the hydrogen energy economy. It has proved difficult to use the model to achieve “targets” for energy use or proportion of hydrogen energy used. However, attempting this has raised some interesting issues.

There are significant difficulties in modelling the transition to hydrogen powered vehicles, especially the unknowns of whether conventionally powered private vehicles will simply be exchanged one to one for hydrogen powered vehicles. This will depend on the actual vehicles produced and their performance and range. It is possible to imagine that in some circumstances hydrogen powered vehicles might be bought as additional vehicles for short urban journeys. In this case they will not replace the ownership of conventional vehicles and might not even replace their use, instead replacing journeys by bus, cycle or on foot.

There are significant uncertainties in when new vehicle technology will become available and how quickly it will penetrate the new vehicle buy. Rapid development of new technology (specifically hydrogen fuel cells) is required for the introduction dates and high levels of take up would be required to meet the more optimistic scenarios for hydrogen use. The model is a convenient way of studying the effect of changes in new vehicle buying behaviour.

There are even greater uncertainties over the development of the infrastructure necessary to support hydrogen in the transport sector. The sector is characterised by a large number of small consuming units which are privately owned and widely spread. Any infrastructure will need to include efficient storage and distribution of a fuel which is difficult to handle (Bossel et al., 2003) as well as providing attractive and widespread refuelling points. It seems likely that substantial prior investment will be needed in a situation where conventional fuels are still widely available.

There must also be significant uncertainties over whether the electricity generation system can cope with the extra demand for high levels of hydrogen production if hydrogen is to be produced from this source (rather than from fossil fuels by steam methane reforming for example). If this extra electrical demand is not to contribute to emissions of carbon dioxide, it would have to be from nuclear or renewable generation.

The scenario with the greatest level of hydrogen use in transport (Global Sustainability) would require 526 TWh per year of hydrogen energy in 2050 and this is below the original “target” suggested. Assuming this is produced by electrolysis, which has been estimated would have an efficiency of between 0.75 and 0.81 by 2050 (Dutton et al. 2004) this would require between 649 and 701 TWh of electrical generation. This ignores electrical distribution and hydrogen storage and distribution inefficiencies, which could be significant (Bossel et al., 2003). Dutton (2004) assumes that for the Global Sustainability scenario half the demand for electrical generation would be met by renewables (and most of the rest by nuclear) by 2050. This would be between 325 and 351 TWh of renewable electrical generation for the transport hydrogen demand alone. This is not far short of the *total* 2003 electricity demand for UK (400 TWh (DTI, 2004)). Of this 2003 figure, renewables of all kinds generated about 10.6 TWh (wind contributed 1.3 TWh of this figure) so this would imply an approximately 30 fold increase in renewable electricity generation to satisfy the transport sector alone. This would have to be at the same time as a very significant expansion of the nuclear sector.

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The views expressed in the paper are those of the authors alone.

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