Minutes of Seminar on Global Growth in CO2 Emissions from Transport and Prospects for New Technologies to Deliver Emission Cuts

12th January 2005, room 8A Ashdown House, 123 Victoria Street, London.

Attendees

Nick Stern, head of Stern Review of the Economics of Climate Change
Chris Taylor, Stern Review
Vicki Bakhshi, Stern Review – chair
Sophie Cruickshank, Stern Review
Gideon Hoffman, Stern Review
David Thompson, Chief Economist, DfT
Nigel Campbell, DfT
Frank Kelly, Chief Scientist, DfT
Sarah Love, DfT
Laura Fellowes, DfT
Aaron Berry, DfT
Grant Allan, CfIT
Chris Nicholls, Defra
Laura Cozzi, IEA
Ausilio Bauen, Imperial College
Adam Chase, E4Tech
Ian McCrae, TRL
Nobuhiko Koga, Toyota
Kazunori Kojima, Toyota
Chris O'Keefe, Toyota
Jamila Fattah, BP
Stephen Hennigan, Energy Review
Andrew Jackson, DTI
Joanne Marsden, DTI
Alistair Wray, DfID
Jeremy Doyle, DfID
David Welsh, Rolls Royce
Greg Archer, Low Carbon Vehicles Partnership

1. Nick Stern welcomed everyone to the seminar. The Stern Review of the Economics of Climate Change began work in Autumn 2005 and will report to the Prime Minister and the Chancellor in Autumn 2006. The Review is looking at the impact of climate change, especially on developing countries, into the future; how society will adapt to climate change; the effect of climate change on economic growth; and the appropriate incentive structures for use in facilitating carbon abatement. Transport is a crucial work area of work for the review because it is a large and fastest growing source of emissions. The purpose of this seminar is to improve our understanding of the drivers behind growth in emissions from transport and the prospects for new technology to deliver emission cuts.

2. David Thompson expressed how pleased he was that this seminar had been organised. Balancing the need to travel and the impact of transport on the environment (carbon emissions, local air quality, and landscape) was necessary for sustainable development.

3. Vicki Bakhshi welcomed everyone to the seminar. It was agreed the seminar would operate using Chatham House Rules.

Emission trends in transport sector – presentation by Laura Cozzi, IEA

4. The first presentation was by Laura Cozzi, senior energy economist from the International Energy Agency (IEA). The IEA has a global model of energy and emissions up to 2030.

5. Reference scenario

6. Laura outlined the IEA reference scenario, which assumes no major policy changes relative to what we have now, a rising oil price, and stable GDP growth. The key results from the reference scenario for all energy demand and emissions are:-

7. Energy-related CO2 emissions increase by more than 50% between now and 2030. China accounts for a larger share of this increase than OECD countries combined, but OECD emissions per capita are still two times higher than China's by 2030.

8. Fossil fuels provide a broadly constant share (c. 80%) of energy supply to 2030. The share of gas increases; this is driven by growth in power sector consumption. The growth in the absolute level of energy provided by renewables is mainly driven by Government policies in OECD countries. Nuclear may play an increasingly important role in power generation, given the revived interest of many countries.

9. Developing countries (especially Asia) accounts for two thirds of the increase in world energy demand between 2003 and 2030. Developing countries' energy-related CO2 emissions overtake the OECD's in the 2020s.

10. Global daily oil production increases by 40% between 2004 and 2030. The OECD share of production falls from 25% to 12%; the share from Middle East and North African countries rises from 35% to 44%. One of the most significant sources from the MENA region is the Ghawar field (the largest oilfield in the world) indicating the importance of how Saudia Arabia choose to manage this resource.

11. The power sector is overwhelmingly important as it accounts for by far the largest share of CO2 emissions every year to 2030. However there are more alternatives in the power sector compared to transport.

The key results from the reference scenario regarding transport are:-

12. Transport is the fastest growing end-use sector (2.1% pa CO2 emission growth) so worthy of particular attention. It accounts for over one quarter of incremental emissions between 2002 and 2030.

13. Regarding the oil, transport relationship there are two important points to note:

- Growth in oil demand is largely explained by growth in transport. Oil consumption grows by 40m b/d between 2004 and 2030. This is

overwhelmingly explained by growth in transport (approximately 27m b/d, of which 20m b/d is from non-OECD).
- There is a concern about energy security of supply for transport because of increasing oil import dependence.

14. Income growth is a key driver behind growth in transport. Some studies suggest that in developed countries vehicle ownership rises roughly at the same rate as income.

15. Among the modes of transport facing rapid growth in emissions are road, aviation and, in non-OECD countries, motorbikes (because they are often poorly maintained).

16. The key driver behind growth in road transport is car ownership. In 2004 global car sales were 3% pa, but China's growth wasit reached 10% pa. Over the next 25 years car stocks in non-OECD countries will triple. However estimates of the extent of car ownership growth in non-OECD countries is uncertain. Countries such as OECD North America have a high car ownership rate (currently around 700 per 1000 people) because the country is rich and spread out. Car ownership in China is around 20 per 1000 people.

17. Another important driver behind road transport emissions is vehicle fuel efficiency. In 2002, OECD North America had the worst average new vehicle fuel efficiency and OECD Europe had the best (approximately 50% better than OECD North America). The main reason for this is vehicle and fuel choice: as Americans get richer they choose to buy bigger cars, and their fuel choice is gasoline (less efficient than diesel). Fuel efficiency in China is only marginally better than in OECD North America, but this is explained by the poor state of vehicle maintenance. As the developing countries become richer, we would expect vehicle maintenance to improve, thus improving fuel efficiency; but there is uncertainty about the extent to which efficiency improvements will be eroded by a switch to larger cars.

18. Emissions from aviation are also forecast to rise. These projections reflect annual incremental improvements in fuel efficiency, but these carbon savings are more than outweighed by an increase in demand for flights. Rolls Royce suggested that aircraft fuel efficiency would improve 50% over the next few decades.

<u>Alternative policy scenario</u>

19. Laura Cozzi also presented some model results for the world alternative policy scenario. This assumes the introduction of new environment and energy security policies that are already under consideration. For example, strengthening of US CAFÉ standards, prolongation of Chinese standards, increased sales of biofuels, mode switching (e.g. increased use of high speed rail in Japan). The key findings are:-

20. In 2030, energy related CO_2 emissions are 16% lower than in the reference scenario, of which 4-5 percentage points are attributable to reduced emissions from oil.

21. Transport accounts for two thirds of the oil savings in the alternative scenario and 20% of the CO_2 emission reduction. Slightly more of this cut comes from OECD countries.

22. IEA estimated that the alternative scenario is highly cost effective. The alternative scenario additional demand side cost (i.e. buy more efficient car) is estimated at $1.1 trillion greater than the reference scenario, but the associated fuel saving is six times greater.

23. The IEA World Energy Outlook in 2006 will include work on:

- Enhanced and expanded World Alternative Policy Scenario, including analysis of developing countries emission reduction potential, and a in-depth analysis of transport and power sector.
- What role can nuclear play in the energy system
- Impact of high oil price on demand. Analysis in the World Energy Outlook (2005) found that if we relax the investment assumption in the reference scenario (the assumption that the Saudi's make sufficient investment in their oil production infrastructure) then the price of oil could be 30% higher, oil production could be 10 mb/d lower, and GDP could be 0.2% lower.
- Country focus on Brazil: including improving our understanding of their biofuels potential and oil deepwater offshore potential.

Prospects for hybrid technology – presentation by Nobuhiko Koga, Toyota

24. The second presentation was from Nobuhiko Koga, Group Manager of Powertrain Management Division, Toyota Motor Company. The key points coming out the presentation and subsequent discussion are summarised below.

<u>Background</u>

25. High underlying growth in global demand for car transport: 1.2bn vehicle stock estimated in 2020, an increase of 50% on current levels (Handbook of Automotive Industry, 2001).

26. Oil production is forecast to peak in the 2020s to 2040s and decline thereafter. This poses serious security of supply challenges for transport, which is heavily reliant on oil.

<u>What is hybrid technology?</u>

27. More than 2 power sources to enhance fuel economy by energy recovery and reuse. The Toyota Prius has a petrol internal combustion

engine (ICE) and a batter and electronic motor. To start the car, the electric motor is used (which has the advantage of lower emissions relative to petrol ICE, when most emissions are produced). When driving, the ICE and/or electric motor is used. When braking, the lost energy is used to charge up the battery. The Prius automatically regenerates its battery: it does not have to be plugged in to charge up.

28. The Prius produces 50% of the well to wheel (WTW) CO2 emissions of a petrol ICE. Diesel hybrids produce even less CO2 but they are not feasible at present because the technology is not developed enough to be cost effective. Biofuels have the lowest WTW CO2 emissions. Hydrogen fuel cells have negligible tank to wheel (TTW) emissions but potentially well to tank (WTT) CO2 emissions (depending on how the hydrogen is produced).

Advantages of hybrid technology

29. Fuel efficiency is greater especially in cities where lots of stop and start (and could be further improved using gear shift indicators, see below). Hybrids are around 30% more fuel efficient than conventional cars.

30. Quieter vehicle performance – the Prius gives users the opportunity to use the electric motor only, which is quieter.

31. Mobile power source – useful for emergencies, etc.

Challenges for hybrid technology

32. Driving performance. The Prius does not have as much acceleration power as conventional vehicles. Plug in hybrids have the further disadvantage of requiring regular recharging. The “Jeremy Clarkson” factor – would he recommend buying this vehicle? Research by the Low Carbon Vehicle Partnership[1] found that vehicle price, features, performance and brand were the most important factors in determining motorist choice of car; environment ranked as among the least important considerations. Motorists reported fuel efficiency as an important factor, but poor knowledge and understanding of fuel efficiency suggests it was not as important as they claimed.

33. Cost. Hybrid vehicles are more expensive than conventional vehicles. LCVP research highlighted the importance of price as a factor influencing choice. The payback period varies by country (depending on fuel price, motorist driving style, etc). There are some financial incentives to buy the Prius, for example in the UK it is congestion charge exempt.

[1] Low Carbon Vehicle Partnership (2005): “Car Buyer Research Report: Consumer Attitudes to Low Carbon and Fuel-Efficient Passenger Cars”, see http://www.lowcvp.org.uk/uploaded/documents/Consumer_research_-_final_5.05.pdf

34. Fuel efficiency. When driving on highways, the Prius has higher fuel consumption than a diesel vehicle. It does have lower CO2 emissions on highways; but from the perspective of the motorist, the higher fuel consumption would discourage take up.

35. Infrastructure in developing countries. It would be difficult to disseminate hybrid vehicles in developing countries because there is not much infrastructure for maintenance of new technology.

How can hybrid technology be improved?

36. Fuel efficiency can be improved further using gear shift indicators (GSI). These encourage drivers to shift gear at the appropriate engine speed for each gear. This raises awareness of efficient driving and is a permanent education tool. GSI is estimated to achieve fuel consumption benefits of over 5% (Toyota study, 2005); a large scale study will be undertaken by the FIA from Spring 2006. However, GSI is not necessarily good for local air quality – further studies will reveal more. GSI has not yet been introduced, but is under consideration.

37. Infrastructure such as road pricing and ITS can help reduce congestion, which in turn improves fuel economy.

38. It is feasible to design a vehicle that is a hybrid of hydrogen fuel cell and battery.

39. Developments in battery technology could drive costs down, but there is great uncertainty this will happen. This is reflected in the fact that more motor manufacturers have hydrogen than hybrid R&D programmes.

40. Annual sales of Toyota hybrids forecast to rise to 1m in 2010 (an increase of 230% on 2006). However this will only represent about 1% of new vehicles sold in 2010.

Prospects for biofuels – presentation by Ausilio Bauen, Imperial College

41. Ausilio Bauen from Imperial College London and E4Tech gave an overview of biofuels in transport.

What are biofuels?

42. Biomass (for example, sugar and starch crops) is converted (for example, though a process of fermentation) into biofuels which can be used for road, rail, marine and air transport. Biodiesel and bioethanol from sugar, starch and oil crops are produced commercially today. Bioethanol, synthetic diesel and other synthetic fuels from

lignocellulosic biomass are at the demonstration or pre-commerial stage.

43. Biofuels may be most easily introduced in road transport. Biofuels, mainly biodiesel, could also be used in rail and marine transport. Synthetic kerosene from biomass could be used for aviation.

Emissions relative to other fuels

44. The emissions from biofuels and the cost of producing them varies greatly depending on what type of biomass it is produced from and the process used to convert it. Biofuels are often beneficial in relation to air quality, and result in lower emissions of GHGs in transport. GHG emissions result from production of the biomass and the biofuels, but the actual combustion of the biofuel can be considered GHG neutral.

45. GHG emissions reductions from biofuels relative to petrol or diesel base case vary. They can range from 7 to 77% in the case of wheat to ethanol, and between 40 and 60% in the case of biodiesel. The production of biofuels from lignocellulosic biomass can achieve very high emissions reductions >70%.

Cost

46. Analysis suggests that biofuels are generally not commercially competitive at an oil price of $50/barrel. At this oil price, diesel/petrol costs approximately $10 per GJ. The cheapest biofuel is produced from sugar cane in Brazil and costs $13.5 per GJ (although costs of bioethanol from sugarcane can be as low as $6 per GJ, depending on specific production costs and exchange rate). Ethanol produced from UK grain costs $18-$30 per GJ (the costs are at the low end of the range if revenue from co-products is considered). At low blends ethanol and gasoline may be compared on a volume basis because of octane enhancement benefits of ethanol, which would make ethanol more competitive.

47. Biofuels start to become competitive when oil price is over $65/barrel. At $65/barrel, biofuel from sugar cane in Brazil is a comparable price to petrol. However as these biofuel costs exclude blending and infrastructure costs, in reality the oil price would have to rise above $65/barrel to make it competitive. The cost of biofuels in the future is uncertain: production process techniques may improve and push down costs, but on the other hand if the demand for feedstocks increases then underlying prices would rise The oil tipping price could be affected by the treatment of tax on gasoline and biofuel: these figures exclude tax, so any favourable tax policy for biofuels could reduce the oil tipping price further.

48. The monetised costs and benefits suggest that biofuels are currently not a cost effective way of reducing carbon emissions; however non

monetised benefits make the fuel more attractive. The monetised GHG benefits are very much dependent on the cost of oil. The cheapest biofuel is ethanol produced from sugarcane in Brazil and this costs $40/tCO2, which is $147/tC or £83/tC (for an oil price of $50 per barrel). Compared to a social cost of carbon of £70/tC biofuels do not appear cost effective, especially as the blending and infrastructure costs are not included in this estimate. However there are non monetised benefits from biofuels such as increased energy security of supply and possibly reduced air pollution. Innovation in producing 2nd generation biofuels could also have positive effects on an eventual future use of biomass for hydrogen production.

49. Biofuels can be used to reduce GHG emissions more cheaply from other sectors, such as heating. The advantage of using biofuels in transport is that they bring some energy security of supply to a sector that is heavily dependant on oil; and also, they may be a stepping stone to producing hydrogen more cheaply, via lessons learned in the production process. Sectors such as heating and energy generation already have other clean technologies available to reduce emissions.

<u>How much could they supply to transport, by when?</u>

50. The estimates of how much biofuels could contribute to transport fuel demand vary. Ausilio Bauen indicated that biofuels could make a material contribution. For example, biofuels could technically contribute up to 20% to 30% of road transport fuel by 2030 in Europe, based on domestic resources. The contribution could be higher if hydrogen were produced for use in fuel cell vehicles.

51. Biofuels could displace up to one third of road transport fuel in the UK if we used all agricultural and forestry residues, the organic fraction of MSW and up to 4 million hectare of agricultural land for energy crops. The actual potential is going to well be below this, but could still be material.

52. IEA study[2] suggested 5% of motor fuel use could be displaced by biofuel worldwide by 2010. Countries such as Brazil and India will produce relatively low cost biofuel and should have more than enough for domestic needs. Biofuel produced by OECD countries is likely to be higher cost.

53. The UK is considering introducing a Renewable Transport Fuels Obligation[3] setting a target for 5% of all transport fuel to be from renewable sources by 2010; this would save an estimated 1 MtC pa. Department of Transport analysis suggests the UK currently has the

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[2] IEA (2004): "Biofuels for Transport: an International Perspective". See: http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=127

[3] See Department for Transport reference: http://www.dft.gov.uk/stellent/groups/dft_roads/documents/divisionhomepage/610328.hcsp

capacity to produce enough biofuels to satisfy at least 5% of UK transport fuel demand.

54. Constraints on the production of biofuel include:
    - Water: biofuel production uses lots of water and this may be an increasingly scarce resource in the future.
    - Production and blending capacity is limited and not sufficient if biofuel production is to be scaled up significantly.
    - Land area available to cost-effectively produce significant amounts of biofuels is limited because it must compete for land used for other agricultural purposes.

Emissions from transport in developing countries – presentation by Ian McCrae, TRL

55. Ian McCrae gave a presentation on the prospects for reducing emissions from developing countries.

Trends in emissions from developing countries

56. As developing countries become richer, they tend to switch from cheaper modes of transport (such as rickshaws in India and bicycles in China) to two-wheelers and private cars. For example, China has seen a 45% growth in privately owned vehicles and one third increase in passenger rail kilometres from the mid-1980s to mid-1990s.

57. Car fuel efficiency in developing countries tends to be poor because they have poor vehicle maintenance. Developing countries often buy second hand vehicles from developed countries and use these vehicles until they no longer work. However as these countries become richer, we might expect fuel efficiency to improve if people buy younger vehicles and maintain them better.

58. Data inadequacies mean that it is difficult to accurately estimate the baseline emissions from developing countries. The best way seems to be the use of oil consumption figures to derive carbon emissions. However, emission estimates worked out this way will not be perfectly accurate because of fuel quality, consistency and intentional fuel adulteration issues. To improve our estimates of emissions, it would be useful to have better data on fuel sales.

59. Better data on number of vehicles over time would give us an insight into mode switch in developing countries. Specifically, it would be useful to have data on total vehicle kilometres over the last twenty years for different modes (private car, motorbike, HGV, etc) in India, China and other developing countries.

How can we reduce emissions from developing countries?

60. Traffic management and driver training. To encourage overall improvements in driving standards, enforcement of vehicle loading restrictions and improvements in road signage and lane discipline.

61. Improve vehicle maintenance. For example, by providing information and funding for enhanced inspection and maintenance, including the support of local car repair garages.

62. Clean technology transfer. The technology should be compatible with the infrastructure in the country. For example, developing countries may not have the technical expertise to maintain technologies such as hybrids. In addition the transport infrastructure and condition is often poor, and thus mechanical damage to technologies, such as exhaust after-treatment systems, is high in developing countries.

63. Promote public transport. Encouragement of fair pricing policies. Public transport is often priced beyond the means of the poorest parts of society.

64. Sustainable transport policies. For example, town planning that reduces the need to travel and builds greater public transport infrastructure. This is an especially useful intervention to make at this time, when countries such as China and India are experiencing urbanisation and a migration to the cities. Seminar attendees were not aware of any sustainable transport programmes currently underway.

65. Introduce regulation on vehicle fuel efficiency. China has introduced policy to improve fuel efficiency but this was driven by concerns about energy security of supply and local air quality rather than climate change.

66. Policy measures to encourage uptake of biofuels. For example, two thirds of vehicles sold in Brazil are "fuel flex"; South African has also developed an indigenous bioethanol programme. Such policies tend to be driven by energy security of supply concerns and high oil prices rather than climate change worries.

67. Carbon sequestration. Developed countries can pay developing countries to maintain forests on their land in order to carbon off set emissions produced elsewhere. However this can reduce the biodiversity in the local areas and use up water resource and may prevent the land being used for more pressing uses such as growing food. Carbon sequestration is not likely to be feasible when we consider planting additional forestry in the UK: for example, the Scottish Executive found that to offset the 1MtC from road transport on the Scottish trunk road network would require them to plant a forest 1.3 times the size of Glasgow, every year.

68. Other lessons learnt on how to implement carbon saving policies in developing countries include establishing roles of local governance

organisations and building capacity for participation within residential and business communities.

Presentation on prospects for hydrogen, by Adam Chase, E4tech

69. Adam Chase, Director of E4tech, gave a presentation on the prospects for hydrogen technology.

How does hydrogen technology work and what's the status of its development?

70. Hydrogen can be produced either by electrolysis of water, or by reforming hydrocarbons. Other means, such as direct production from sunlight or through biological processes, are at a much less developed level. Once produced, hydrogen can be stored as a liquid, a compressed gas, or chemically (bonded within the chemical structure of advanced materials). Each storage method has problems in terms of cost, bulkiness, or safety.

71. Hydrogen can release its energy content either in combustion (e.g. internal combustion engines or gas turbines, thus generating heat and mechanical power) or in fuel cells which are based on electrochemical reactions. Hydrogen fuel cells convert hydrogen and oxygen into water in a process that generates electricity. They are almost silent in operation, have high efficiency, produce only water as a by-product and are available in a range of sizes. Major R&D efforts are underway to bring hydrogen fuel cells to market, particularly in vehicle applications.

72. Hydrogen fuel cells should not be confused with high temperature fuel cells which can use hydrocarbons such as natural gas. These fuel cells are also the focus of major R&D efforts, chiefly for stationary power applications. Very small fuel cells are also under development as battery replacements for portable electronic devices. These are mostly fuelled by methanol rather than hydrogen.

73. Hydrogen is already widely used in some industrial processes such as oil refining, steel and glassmaking.

74. Safety continues to be a key issue in the storage and use of hydrogen.

How might hydrogen be used in transport?

75. Of all the modes of transport, hydrogen is best suited to use in road vehicles via combustion in ICEs or use in fuel cells. Urban fleet vehicle applications such as buses are a good opportunity for deploying fuel cells because there are economies of scale (for example, buses can fuel up at depots), the low pollution and noise benefit is maximised and they familiarise the public with these technologies.

76. Use of hydrogen in road vehicles, would probably begin by hydrogen being delivered to refuelling points in road tankers (in compressed or liquid form) as this is currently used. There are also options for reforming or electrolysis to produce hydrogen at small scale at the refuelling point. In the longer term, it would be better to pipe it; some of the existing pipe network could be used. For a hydrogen ICE, a compressed hydrogen tank on the car would have to be 3-4 times larger than a petrol ICE to achieve a similar driving range; for a fuel cell, the tank would have to be about 2 times larger.

77. Hydrogen ICEs are ready for market penetration but fuel cells require more development. BMW have a hydrogen ICE ready to bring to market very soon; it is estimated to cost up to £5000 more than the comparable petrol/diesel ICE. Hydrogen fuel cells are a more desirable technology than hydrogen ICE because the former are about twice as fuel efficient. Fuel cell vehicles using hydrogen from natural gas can deliver well to wheels CO2 savings compared to conventional vehicles. However, for fuel cells and hydrogen to deliver substantial CO2 savings and energy diversification benefits, lower CO2 forms of hydrogen production will be needed. These are available to varying extents today, but significant efforts are continuing in, for example, linking renewable energy to electrolysis. Large-scale production of hydrogen from low CO2 sources will be important for the longer term, though hydrogen from fossil sources is expected to play an important role in the transition.

78. Fuel cells in road vehicles are at the prototype stage. Forecasts by the vehicle and fuel industries and other commentators vary over the date and definition of the start of commercial sales. 2015-20 is the period that is currently regarded as being realistic for the start of volume sales of vehicles with marketable performance and cost. The early stages of hybrid vehicle sales offers a useful lesson, in that uptake has been limited to those prepared to pay a higher price for a different customer proposition from an equivalent conventionally-fuelled vehicle.

79. Hydrogen fuel cell technology is the most significant risk area of hydrogen development. The hydrogen infrastructure is technically simpler (though not trivial) and demonstrations in the UK and worldwide are determining options for how this could be implemented. There is no set date at which we will know whether fuel cell technology will be commercially viable; rather the indications will come gradually.

80. Aviation presents a very difficult technical challenge due to the weight of fuel that needs to be carried. Most marine applications would require very large volumes of fuel to be carried. Rail locomotives could employ fuel cells, but if CO2 reduction and fuel source diversification are the goals then electrification of rail routes in combination with low carbon electricity supply is probably more economically effective.

81. Hydrogen brings energy security of supply advantages to transport as it can be produced from a diverse range of primary resources which are geographically dispersed (including several that are indigenous).

How do the emissions and cost of hydrogen compare to other transport technologies and fuels?

82. In terms of £/tonne of carbon saving compared with gasoline vehicles, hydrogen compares favourably to other carbon cutting technologies and fuels in 2030. Hydrogen produced by biomass, wind, nuclear, natural gas and CCS, and coal and CCS cost between -£50 (net benefit) and £20 per tonne CO2, assuming a doubling of untaxed fuel costs from those associated with £25/barrel. This compares to battery cost of £75/tonne CO2 and gasoline hybrid cost of £25/tonne CO2. All of these carbon saving technologies become relatively less cost effective when we assume lower oil prices, but hydrogen still appears favourable relative to the others. These figures suggest that in a high oil price scenario, some forms of hydrogen are cost effective relative to the social cost of carbon (£19/tonne of CO2).

83. As an indication, to provide hydrogen to fuel 20% of the 2030 UK vehicle stock as fuel cell vehicles would require 5.2-7 GW of power, or 6-7 medium sized nuclear power stations.