To tim.ward@dtlr.gsi.gov.uk

The web address referring to this document was published in Energy and Environmental Management, March/April 2002, so I have seen the draft only recently.

Response to Draft of "Powering Future Vehicles" Gordon Taylor 5 April 2002

I am an automobile engineer, and spent 15 years with Ford. I have since written on energy technology and policy, and now practice as an independent consultant. (See http://www.thermal.demon.co.uk) Since Christmas 2000, I have owned a Toyota Prius petrol-electric hybrid car, having benefited from the £ 1000 rebate under the PowerShift programme. With a rated CO2 emission of 120 g/km, it already equals the tentative ACEA target for 2012. Also it already meets the 2005 Euro 4 standard for regulated emissions. My Prius has done some 10,000 miles, and all fuel has been logged. It is returning just over 50 mpg/under 5.2 l/km, whereas my previous car, a Cavalier, also with 5 seats, returned about 35 mpg/about 8 l/100 km.

1) Technology Snapshots

To address the subject of the draft, the first requirement is a current quantitative analysis of the fuel and vehicle options, or "technology snapshot". In this field, they are often known as "well to wheels" studies. These examine the energy and greenhouse gas implications of various combinations of fuels and vehicles, including both fuel production and distribution ("well to tank") and vehicle fuel use ("tank to wheels"). Some parameters may be improved over time with R & D, but many have "hard" limits determined by the laws of physics and chemistry.

Several such "well to wheels" studies have been published recently. One is from MIT. [Ref. 1] A second is from General Motors and Argonne National Laboratory. [Ref. 2] A third is by Ecotraffic of Sweden. [Ref. 3] For such studies, often only a single basic vehicle is considered. For example, the GM/ANL study considers a large pickup truck, such as is popular in the US "car" market, but is quite unrepresentative of the European car market. However, the Ecotraffic study has a European perspective, and also considers options for both the short and long term (i.e. sustainability). Moreover, it is independent of any fuel or vehicle manufacturer, and - being the most recent - compares its own findings with those of both the MIT and GM/ANL studies. Most notably, both the Ecotraffic and MIT studies find a gasoline (petrol) hybrid vehicle to have a higher overall efficiency than a compressed hydrogen fuel cell hybrid vehicle, while the GM/ANL study finds the opposite. Nevertheless, close study of the input data allows such "well to wheels" studies to be used to reduce the many fuel and vehicle options to a short list. However, such new vehicle propulsion options are still evolving rapidly, so it is necessary to study the specialised literature.

ICE-electric hybrids

Most internal combustion engine-electric hybrid vehicles are fuelled entirely by petrol or diesel oil, and the electric battery acts simply as a store of energy. In principle, a flywheel or a compressed air reservoir could be used instead. Its energy capacity is typically only a few percent of that of the fuel tank. However, it has a profound effect on the vehicle, by enabling the engine to run less of the time, but much closer to its maximum thermal efficiency. It does this by stopping the engine whenever the vehicle is stationary or going downhill. Moreover, at low speeds the vehicle is propelled by an electric motor, drawing from the battery. This in turn is re-charged by a generator driven by the engine, running briefly at full throttle, or when the vehicle is slowing down - known as regenerative braking. In low-speed, stop and go conditions, this last can improve the fuel efficiency by 20 or 25 %.

The best published work on the merits of hybrid vehicles has been done at Argonne National Laboratory, USA. One recent paper [Ref. 4] has also been presented in extended form. [Ref. 5] This is based on nine distinct hybrid vehicles - all from major vehicle manufacturers. Four are commercial gasoline cars (all Japanese), two are prototype gasoline sports utility vehicles (American), and three are prototype diesel cars (American). It concludes that "commercial gasoline HEVs (hybrid electric vehicles) achieve about 57 %

gain in mpg (on a performance equivalent basis)". Since it is based on Japanese production cars, which are on sale (two in Japan, and two in America and Europe), this should also be valid for European cars.

One of the commercial gasoline hybrids is the 2001 Toyota Prius. Compared with a Toyota Corolla 1.8 automatic, ANL found that it offers a 53.6 % gain in mpg. However, the Prius has some load reduction features, so the gain due to hybridization is put at 41 %. On the other hand, the Prius has slightly lower performance (assessed as the time to accelerate from 0 to 60 mph). Since it would need a larger engine for equal performance, the gain due to hybridization would be greater - at about 57 %.

This conclusion is based on measurements and calculations using the US city and highway driving cycles. The results of these are averaged, weighted by distance in the ratio of 55 % city and 45 % highway, giving the so-called Corporate Average Fuel Economy. However, this weighting was established in the 1970's, but driving in the US had changed to 65 % city and 35 % highway by 1997. [Ref. 6] Since gasoline-hybrids give a greater gain in mpg in city driving (e.g. 60 % or more), and a lesser gain in highway driving (e.g. 20 - 30 %), the overall gain may in practice now be more than 57 %. Moreover, ICE-hybrids are still very new, and are evolving fast. [Ref. 7]. Hence further improvement is likely.

Fuel Cell Vehicles

These are far less mature, and only exist as individual prototypes. Cars have been built by DaimlerChrysler, Ford, General Motors, Toyota and Honda, and buses converted by Ballard and others. The buses and many of the cars are fuelled by hydrogen (stored as compressed gas, cryogenic liquid, or metal hydrides). Some of the later cars are fuelled by methanol, which is "reformed" on board, to produce hydrogen for the fuel cells.

At this early stage in the evolution of fuel cells for vehicles, the rate of change is still very fast, and much of the work is confidential. This is entirely understandable, because it is so expensive, and any important patents that result could earn a good return in future. However, Toyota has published the following "well to wheels" comparison [Ref. 8].

Fuel and Engine	Well to Tank efficiency	Tank to Wheels efficiency	Well to Wheels efficiency
	%	%	%
Gasoline conv.	88	16	14
Gasoline hybrid	88	30	26.4
Compr. H2 FCHV	58	48	28

This shows that - at least at this stage - the overall energy efficiency of a Gasoline Hybrid vehicle is nearly as high as that of a Compressed Hydrogen Fuel Cell Hybrid Vehicle. Since at present no renewable energy or feedstock is (widely) used to produce gasoline or hydrogen, these energy efficiencies are a good indication of the relative carbon emissions. However, since gasoline is made from oil, while hydrogen is usually made from natural gas, the compressed hydrogen FCV may incur slightly lower carbon emissions.

Even so, the present prototype fuel cell vehicles are extremely complex. Also, there remain major issues such as start-up time, responsiveness to changing speed, cooling, noise from pumps and compressors, safety, operation in hot and freezing climates, range between refuelling, and of course cost. Each of these could result in significant compromising of even the present energy efficiency and carbon emissions.

The infrastructure for the production and distribution of hydrogen equivalent to 1 million barrels of oil per day (10 % of the US road transport requirement) might cost $ 100 billion. [Ref. 9] Assuming that the UK road transport requirement was 1 million barrels of oil a day, and the infrastructure cost of $ 100 billion was to be recovered from say 10 million UK households with cars, this would amount to $ 10,000 each.

Well to wheel data (originated by others) for conventional gasoline ICE vehicles and for methanol and gasoline FCVs has been published [Ref. 10].

Fuel and Engine	Well to Tank efficiency	Tank to Wheels efficiency	Well to Wheels efficiency
	%	%	%
Gasoline ICE	84	14	12
	85	20	17
	90	19-20	17-18
Methanol FCV	62	34	21
	67-71	25-34	17-24
	72	33	24
Gasoline FCV	84	28	23
	90	21-30	19-27

Taken with the previous table, this implies that - at least at this stage - methanol- and gasoline-fuelled FCVs are only comparable to gasoline hybrid vehicles in their overall "well to wheels" efficiency.

It is worth noting that Toyota is already manufacturing hybrid vehicles, while working on fuel cell vehicles. Their market capitalisation exceeds that of General Motors, Ford, and DaimlerChrysler, and they have been working on electric and hybrid drives for decades, and obtained some 300 patents [Ref. 11] - so gaining the "first-mover advantage". Other makers may use Toyota technology under licence. Thus the Honda Insight 2-seater uses a battery just half the size of the Prius, supplied by the Toyota-Panasonic battery joint venture. Moreover, the forthcoming option of a hybrid power train on the Ford "Escape" Sports Utility Vehicle will use hybrid components supplied by Aisin AW, a member of the Toyota family of suppliers - and therefore almost certainly using Toyota patents under licence.

Although the transport sector must eventually change to hydrogen - or possibly methanol - from sustainable sources, fuel cell vehicles are not essential. Either fuel could be used in ICE-hybrid vehicles (or even ICE-only vehicles) - albeit with suitable modifications. As noted in the present draft, using hydrogen in ICE-only vehicles has long been demonstrated - by BMW, among others. It could equally well be used in ICE-hybrids, with hybridization being justified by the saving in fuel cost, or (since hydrogen has a much lower energy density than petrol), perhaps by the greater range between refuelling. Likewise, methanol and ethanol could be used in blends up to 85 %.

2) Transition Scenarios

To address the subject of the draft, the second requirement is a quantitative study of possible transition scenarios. Taken together, the Technology Snapshots above imply that the most likely changes are first to ICE-hybrid vehicles, and then to hydrogen - or possibly methanol - with fuel cell vehicles.

An excellent scenario study has been published in Sweden. [Ref. 12] This considers the world-wide energy scene and within this the transport sector, and the change from petrol and diesel, with conventional vehicles, to methanol or hydrogen, with fuel cell vehicles, over the period from 1990 to 2100. (However, it did not consider ICE-hybrid vehicles). Crucially, this is studied in the context of a target for atmospheric carbon dioxide of 400 ppm. (This is somewhat less than that of 550 ppm CO2, requiring a 60 % reduction in U.K. carbon emissions, proposed in Report No. 22 of the U.K. Royal Commission on Environmental Pollution). To meet the target of 400 ppm CO2 requires that no more than 500 Gton (billion tons) of carbon be emitted world-wide over the period 1990 to 2100. The main finding (Figure 6.6) is that the transition from petroleum fuelled ICE vehicles does not start until 2040. Moreover, the change to hydrogen fuelled FCVs takes until 2080 for trucks, and 2090 for cars. This is because petroleum is especially suitable for transport, and its use persists until the carbon constraint applies. Moreover, the production and distribution infrastructure for hydrogen fuel would be expensive, while FCVs would probably also be more expensive. However, it finds that greater carbon reductions for less cost come from displacing coal, oil, and gas from the generation of heat and electricity.

The above findings imply that there is no need to do anything precipitate. Instead before choosing future transport fuels, it would be wise to wait for more data - especially on the efficiencies and costs of hydrogen production and of fuel cell vehicles.

A second scenario study considered how the characteristics of the existing vehicle fleet affect the uptake of vehicles that are more fuel-efficient and more expensive. [Ref. 13] The main finding is that the change takes 15-20 years, and - for the given assumptions - the new vehicles eventually form only 60 % of the fleet. (However, this study did not consider a carbon constraint). It also showed that if there was a lesser vehicle option (saving 50 %) available eight years sooner, then it could make significant savings by a given date, rather than waiting for a better vehicle option (saving 66 %).

Although the second study did not consider this case, these findings argue in favour of taking the savings from hybrid vehicles (which are already in volume production, with more in prospect), rather than waiting for fuel cell vehicles (which may not arrive in volume for ten years or more, if then).

Sustainability

Hydrogen is often proposed as the ideal sustainable fuel. However, its production by the electrolysis of water is at present far less efficient than the theoretical maximum. Hence the production (from sustainable sources), distribution, and use in vehicles must become much more efficient before this solution can be adopted.

As an alternative or supplement to hydrogen, sustainability could be helped by the use of liquid bio-fuels - e.g. methanol and ethanol. This would have a faster impact on transport carbon reduction, since they can be used in the existing vehicle fleet (where the average vehicle life is 10-15 years). Most ICE vehicles should be able to use up to 10-15 % of methanol or ethanol without modification, and thus constitute the initial market. Later, existing and new vehicles could be modified to run on a mixture of 15 % petrol, 85 % alcohol, as was done in Brazil under the "Plan Alcool". However, this required subsidies for the production of ethanol. Nowadays in Brazil, petrol is blended with 22-24 % (anhydrous) ethanol, and the production of ethanol (from sugar cane) is greater than ever. [Ref. 14]. It should also be possible for new vehicles to be fuelled flexibly, using petrol with 0 to 85 % alcohol. [Ref. 15]. Diesel vehicles can also use alcohol blends.

3) Comments on the present draft

P4. The draft says that "There is only a finite amount of oil available, and road transport is a major cause of environmental degradation, including climate change and air pollution". However much oil there is, as noted above, we must still not use more than a limited additional amount, since it increases the concentration of carbon dioxide (and methane) in the atmosphere, which causes global warming. Government must therefore communicate this to the coal, oil, and gas companies, who must turn themselves into energy service companies, supplying heat, power, and transport fuels - increasingly from sustainable sources.

P5. The draft says that "many experts believe that fuel cell will provide the long-term solution". However, few of them work for vehicle companies and perhaps even fewer have considered the infrastructure implications. Among the many practical problems noted above, the range of the hydrogen fuelled fuel cell vehicles demonstrated to date is far less than that of conventional petrol or diesel vehicles. Moreover, thus far the hydrogen would be made from natural gas, with unavoidable carbon emissions, and there are further losses in compressing the hydrogen, in order to extend the range. Even if hydrogen fuelled fuel cell vehicles were shown to give a worthwhile saving in carbon emissions, then - as noted above - building a hydrogen fuel production and distribution infrastructure would cost many billions, and take decades to deploy widely.

P5. The draft claims that "fuel cell electric vehicles are around 50 % more fuel efficient". However, the Toyota Prius ICE-hybrid car is already about 50 % more fuel efficient than a conventional car of similar carrying capacity. Moreover, such hybrid cars use the present fuel infrastructure. If fuelled directly by hydrogen, fuel cell vehicles may be around 50 % more fuel efficient on a "tank to wheels" basis. However, the "well to tank" efficiency of the infrastructure to produce and distribute the hydrogen will be lower than at present. Moreover, even if fuelled by methanol or clean petrol, any gain in the "well to tank" efficiency will be offset by a lower "tank to wheels" efficiency. Hence the overall "well to wheels" efficiency of FCVs (including FCV-hybrids) may be no higher than for ICE-hybrids, and could well be less.

P5. The draft refers to "fuel cells only becoming sustainable when the hydrogen is produced sustainably, for example (by) the electrolysis of water using wind power". As noted above, the future of fuel cell vehicles is uncertain, and at present, electrolysis is very wasteful, and requires far more energy than the theoretical minimum. So other fuel and vehicle solutions may have to be used for sustainability. Also, wind power may be better employed elsewhere.

4) Implications for Policy

Reducing carbon use in transport

According to the above Transition Scenario studies, there is no great urgency to reduce the use of the present fuels in transport on the grounds of sustainability. However, the UK will soon cease to be self-sufficient in oil, and such reduction would increase security, and cut the cost of imported fuels.

With Present Vehicles and Fuels

Even in the context of present vehicles and fuels the UK Government should seek to:

- Reduce the demand for travel by better town planning, with homes closer to places of work, and by encouraging remote working (tele-commuting) via the Internet. For this last, as a major employer, the Government could give a lead.

- Reduce car usage by encouraging modal switching to train, tram, bus, bicycle, and walking. However, this can only come about after delivery of an integrated transport policy that makes these alternative transport modes more attractive. Average car usage is 10,557 miles a year in the UK, but only 7776 in Germany, and very similar in other European countries [Ref. 16], most of which are both larger and more prosperous. Not only are homes often closer to places of work, but there are effective integrated systems of public transport.

- Reduce fuel consumption by weighting vehicle taxation much more strongly against large cars - as is or was done in France, Italy, and Denmark. Objectively, very few families need anything larger than a Ford Focus, VW Golf, or Toyota Corolla. These can all carry 4-5 people and their luggage at all legal speeds and more. Anything larger inevitably weighs more, and uses more fuel - assuming the same type of propulsion.

- Set an example by requiring essentially all new car purchases by Central, Regional, and Local Government, and by public services, such as the NHS, Post Office, Armed Services (excepting fighting vehicles), and many support vehicles for the Fire, Police, and Ambulance Services, to be no larger than a Ford Focus etc.

- Offset any loss of motor fuel tax by raising the taxes on fossil fuels used for heating and electricity generation. The most rational form would be a carbon tax for end users, such as has prevailed in Sweden since 1990. It is currently set at about $ 180 per tonne of carbon. As has happened in Sweden, this would strongly encourage the adoption of higher efficiency boilers and combined heat and power (CHP) generation and district heating - so reducing the (much greater) carbon emissions in these sectors. [Ref. 17].

With New Vehicles

The UK Government should also encourage the adoption of new low-consumption and hybrid vehicles:

- Encourage faster scrapping of vehicles with higher carbon emissions, with incentives for replacing them with vehicles with much lower carbon emissions. Logically, the incentives should be proportional to the prospective reduction in carbon emissions - e.g. smaller if replacing with a small conventional car, and larger if replacing with a hybrid car. This would be stronger than the existing PowerShift programme.

- Encourage Government and Agencies above to purchase significant numbers of hybrid vehicles. This has already been done in New York, with a fleet purchase of 300 Prius. This is no hardship, since they offer easy access, generous seating for 4-5, automatic transmission, and automatic air conditioning as standard, and satellite navigation as an option. They would be perfectly viable even as ministerial cars (save perhaps for those that must be armoured). Such high profile purchases and use would make a direct contribution to transport carbon reduction and send the right signals to other purchasers.

- Encourage Toyota to build the Prius and other hybrid vehicles in the UK.

- Encourage MG Rover and others to build hybrid vehicles - if necessary purchasing hybrid components from Toyota, Aisin AW, and the Toyota-Panasonic battery joint venture.

With New Fuels

The UK Government should encourage new fuels for sustainability by:

- Limiting concessions for fossil fuel extraction to only the total corresponding to the appropriate share of the carbon constraint (at either the UK or the EU level). This would help the coal, oil, and gas companies to plan their transition to energy services, using sustainable sources.

- Encouraging the production and use of biomass - from forestry and municipal wastes, and from energy crops. This should be used primarily to displace coal, oil, and gas, in the generation of heat and electricity. Although the boiler plant may require some adaptation, the biomass requires little processing, and thus effects the maximum reduction in carbon emissions. Growing e.g. woody biomass on short rotation, using "setaside" and other unused land, could give farmers another income stream. While there are already Government schemes for this, they could be scaled up considerably, and so make a greater impact.

- Encouraging the production of renewable electricity, from hydro and wind (on- and off-shore). However, it is not sensible to pre-empt renewable electricity for use in hydrogen production. Fuel cell vehicles may be unavailable, too expensive, or inefficient, while the electricity may displace more carbon if used in buildings or industry (or in electric trains and trams).

R & D

The UK Government should not support R & D in areas of technology where there is no industrial client in UK ownership - and no prospect of one. The automotive industry is in the "end game", with increasing consolidation, and no new company is likely to enter it as a major force. Only MG Rover remains in UK ownership and control, and should benefit from R & D funded by the UK Government. However, even with the Chinese collaboration, they are too small to fund their own R & D in hybrids and fuel cells. Significant R & D efforts in these areas cost billions, and can only be afforded by very large corporations or partnerships. Moreover, the UK is at least 10 years behind - so others hold many key patents. Hence, the UK Government should only support R & D on hybrid technology or fuel cells for transport if there is a real prospect of a UK-owned company becoming a world-class supplier.

The UK science and engineering R & D resource is much reduced, and now small compared to its international competitors. Hence the choice of R & D projects must be technically and economically sound - as they are in Holland, Sweden, and Denmark, which are all much nearer to sustainability (in all sectors).

To address the subject of this draft, the UK Government should direct any available R & D support to:

- Reducing the carbon emissions of vehicles - by reducing weight, rolling resistance, and aerodynamic drag - and by the integration of hybrid components. (These are the main recommendations of a recent US study, [Ref. 18]). This could benefit MG Rover (and the bus and taxi makers) - even though the hybrid components would almost certainly have to be bought or licenced from overseas companies.

- Increasing the (fossil) energy efficiency of production, distribution, and use of liquid bio-fuels -especially methanol and ethanol. Since they can be used in the existing vehicle fleet (where the average lifetime is 10-15 years), they would help speed the transition to sustainability. As noted above, most petrol-engined vehicles should be able to use up to 10-15 % of methanol or ethanol without modification, or up to 85 % alcohol with modification, while new vehicles could be fuelled flexibly, with petrol with 0 to 85 % alcohol. Diesel-engined vehicles can also use alcohol blends.

- Increasing the (fossil) energy efficiency of production, distribution, and use of hydrogen from both fossil and sustainable sources. While production from natural gas is already quite efficient, it produces carbon emissions. Also, production by the electrolysis of water (which may be required for sustainability) is far less efficient than the theoretical maximum. Production from biomass would also be worthy of study.

- Reducing the carbon emissions in heat and electricity generation. These are far larger than those in the transport sector, and any reduction would directly benefit the UK economy and help it to meet its "Kyoto" and subsequent obligations.

I would be pleased to contribute further to the paper on "Powering Future Vehicles" on a consultant basis. Among other things, I could then supply the references for the points indicated.

Gordon Taylor

19 The Vale,
Stock, Ingatestone,
Essex, CM4 9PW

Tel: 01277-840569
Email: gordon@thermal.demon.co.uk