

World car travel under environmental and resource constraints

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Abstract

World car numbers have already risen far more in the first decade of the twenty-first century than in any previous decade. This rise is largely fuelled by growth in the rapidly industrializing countries of Asia, particularly China. Both vehicle number forecasts and inferences from projected economic growth rates suggest that the world fleet could swell from the 800 million in 2007 to as high as two billion by 2030. These projections, however, ignore possible resource and environmental constraints on future car ownership, with the two most important being global oil depletion and global climate change.

This paper seeks to answer the question of whether or not cars have a future at anything like their present level of ownership and use, particularly in the presently high-mobility countries of the Organisation for Economic Cooperation and Development (OECD). The rapid growth in Asian car sales points to a globally more uniform distribution of car ownership, but the twin challenges of oil depletion and climate change suggest a large reduction, not a rise, in future global vehicle use. The paper explores possible technical solutions to these two challenges, but finds them either ineffective, or too late in delivering remedies in the limited time available. Accommodating these conflicting tendencies will probably require a dramatic drop in OECD car use, with deep consequences for urban travel.

Introduction

In 2006, the global vehicle fleet – vehicles with four or more wheels – numbered some 949 million, of which roughly 783 million – including sports utility vehicles (SUVs) in the US – were passenger vehicles. The car vehicle fleet was still heavily concentrated in the Organisation for Economic Cooperation and Development (OECD), as, to a lesser extent, was the commercial vehicle fleet (World Bank 2009, OPEC 2009). All this is undergoing change, mainly because of the extraordinary rise of car ownership in Asia. Car ownership in the US may well have peaked; in 2009, 10 million new vehicles were bought, but 14 million were junked (Brown 2010).

The growth in Asian car ownership started with Japan, which as Table 1 shows, had a negligible car fleet in 1960. After the establishment of a motor industry there – car production in 1960 was 165,000 units (Altschuler et al. 1984) –, car ownership rose very rapidly, and now is at the same level as Australia and other high-car ownership countries in

the OECD. Nearby East Asian countries South Korea and Taiwan were next to establish vehicle industries.

Now China has also recognized the value of a vehicle manufacturing industry as both a driver of economic growth and as a strategic industry which links together industries such as the steel, glass, rubber, plastics, and now, electronics. (In 1994 the Chinese government ‘designated the automobile industry as a pillar of economic development and official encouraged private ownership of vehicles’ (Leung 2010)). In 2009, sales of all vehicles exceeded 13 million units, surpassing US sales, the first time any country has bought more vehicles per year than the US in the entire post-war period. Of these, cars numbered 7.3 million, and car sales of nearly 9 million are expected for 2010 (Scotia Capital 2010).

Table 1 Cars per 1000 population in various countries and globally, 1950–2007

Country	1950	1960	1970	1980	1990	2000	2007
Australia	94	196	307	401	437	500	579
China	0	0	0	0	1	7	26
Japan	0.6	5.0	85	247	398	505	541
Korea (South)	0.1	0.5	1.9	6.5	49	171	330
Taiwan	0	1	3	41	114	213	249
United States	264	340	435	534	572	748	786
World	20	33	53	71	84	101	120
World cars total (million)	51.3	98.2	194	321	439	669	802

Sources: Altschuler et al. 1984, ABS 2007, Moriarty and Kennedy 2004, Biz/Tech (2007), OPEC 2009, Statistical Research and Training Institute 2008, US Census Bureau 2009, World Bank 2009.

Note: US figures include sports utility vehicles; Japan figures include light (*kei*) cars.

Figure 1 shows the very strong relationship between car ownership and per capita income for the world overall, over the period since 1950. The graph suggests that further growth in global GDP, as projected by various official bodies such as the International Energy Agency (IEA), the US Energy Information Administration (EIA), the Intergovernmental Panel on Climate Change (IPCC) and the Organization of the Petroleum Exporting Countries (OPEC) will inevitably be accompanied by a corresponding growth in car ownership. OPEC (2009) give a base case projection of 1372 million cars for 2030 – and 352 million commercial vehicles – assuming a 3 per cent real economic growth rate out to 2030.

The 2009 EIA report (IEA 2009) assumes a 3.5 per cent real economic growth rate out to 2030. Extrapolating the line in Figure 1 would give 216 cars per 1000 population in 2030, or a total of about 1800 million. These figures are both very large but, if in 2030 the world had 400 cars per 1000 population, well below the average ownership in the EU, total cars worldwide would be 3320 million, or about four times the 2007 level of 802 million. Freight vehicle numbers are anticipated to rise even faster than cars, and a 5 per cent annual growth in air travel is projected for the coming decade. The question arises: can the optimistic forecasts of official agencies, let alone a move to near-parity with OECD transport levels, be reconciled with either oil availability or the need for climate mitigation?

This paper seeks to answer the question just raised, and also whether or not cars have a future at anything like their present level of ownership and use in the high-mobility OECD countries. The rapid growth in Asian car sales points to a globally more uniform distribution of car ownership, but the twin challenges of oil depletion and climate change suggest a large reduction, not a rise, in future global vehicle use. The paper explores possible technical solutions to these two challenges, but finds them either ineffective, or too late in delivering remedies in the limited time available. Accommodating these conflicting tendencies will

probable require a dramatic drop in OECD car use, with major consequences for urban travel. Although not considered in this paper, public transport and active modes – walking/cycling – will need to largely replace the car in urban areas.

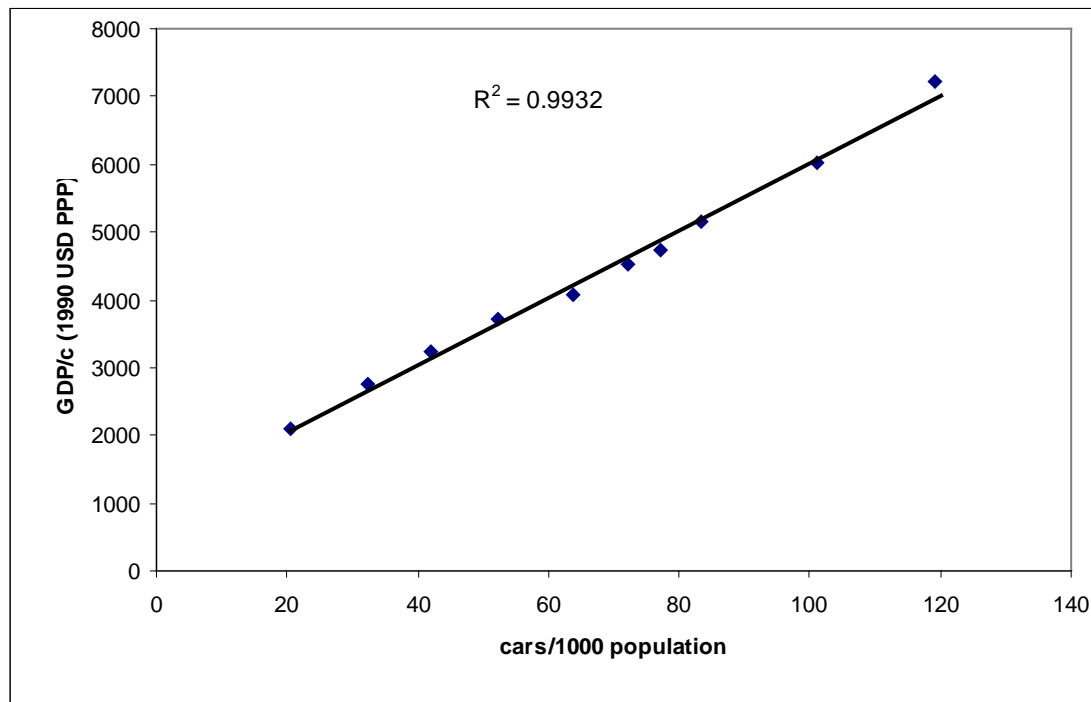


Figure 1 Global cars per 1000 population vs global GDP per capita (US\$ 1990 PPP)
Sources: As for Table 1.

World car transport’s twin challenges

Particularly in urban areas, car travel produces a number of adverse effects. Much urban air pollution results from hydrocarbon and nitrogen oxide emissions from vehicle exhausts. The movement and parking of vehicles require large amounts of urban land, and results in traffic disruption of neighbourhoods. Road transport overall in the world kills over one million people annually, and injures tens of millions more (Moriarty and Honnery 2008a). This paper, however, concentrates on two other challenges with global implications: oil depletion and global climate change.

Unlike urban air pollution, land take-up, or traffic fatalities, these two looming challenges to transport are very controversial, with many arguing that the problems don’t exist. Others acknowledge these challenges, but argue that timely and affordable solutions to both are readily available. The main purpose of this paper is to examine the reality and urgency of the two problems, and to assess the efficacy and timeliness of the proposed technical solutions. It limits itself to private car transport; this sector worldwide accounts for about 45 per cent of transport energy use and greenhouse gas emissions from all transport (Kahn Ribeiro et al. 2007).

Global oil depletion

Transport, both passenger and freight, surface and air, is still almost totally dependent on petroleum-based fuels. Despite the century-old use of electricity for many urban rail systems, and the recent popularity of transport biofuels made from grain, sugarcane or oil seeds, petroleum still provides about 97 per cent of all transport energy (IEA 2009).

Figure 2 shows the historical growth in per capita oil use for China, the US and the world overall. Historical data are shown up to 2008, with projections to 2030 from the base case

scenario of the US (EIA 2009). Global oil use per capita peaked in 1978, at the time of the second oil crisis, at 0.712 tonne/capita, declined gradually until the early 1980s, and has since been remarkably constant at a little under 0.60 tonne/capita. The EIA anticipate it rising slightly until 2030, although it will still be below the 1978 value.

The EIA also project that on a per capita basis, oil use in the US – and most other OECD countries – will in 2030 have fallen slightly below their 2008 levels. For China, and other industrializing countries like India, steady growth is anticipated, continuing the growth of the first decade of the twenty-first century. Even so, per capita use in China is still anticipated to be only 17.7 per cent of US levels in 2030, and much less for India. But will China, and other industrializing countries like India, permanently accept such inequality in access to global oil supplies? As Michael Klare (2008) documents in his book, China and India are already actively taking steps to ensure future supplies by investing in oil fields around the world.

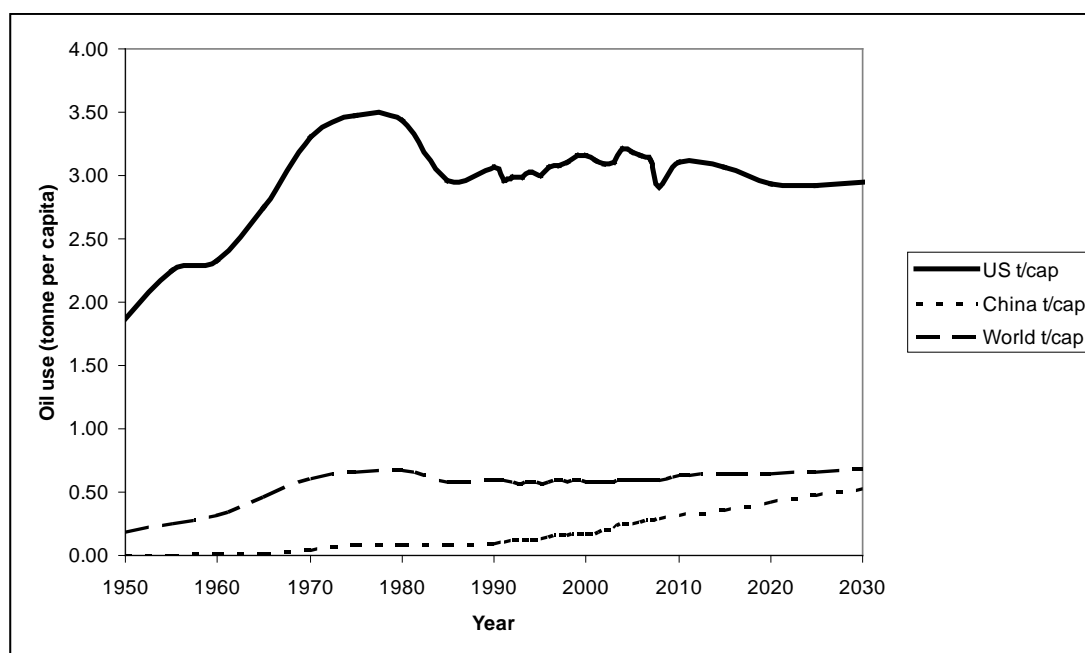


Figure 2 Oil consumption per capita for US, China, and the world overall, 1950–2008 with EIA projections to 2030

Sources: BP 2009, EIA 2009

The EIA 2030 projection for global oil consumption per capita seems modest enough, until it is compared with more pessimistic projections on oil availability. The Association for the Study of Peak Oil and Gas (ASPO) (2009) and Campbell (2009) have projected global oil availability out to 2050. Their figures include oil from all geological sources, whether conventional, or unconventional, such as oil from tar sands. Combining their data with the UN (2008) median population projections give per capita oil availability of 0.35 tonne/capita in 2030 and only 0.18 tonne/capita in 2050. Contrast this value with the EIA forecast of 0.68 tonne/capita for 2030. Since it is also possible that not only oil, but also natural gas and even coal will see absolute production peaking within a couple of decades, conversion of coal or gas to liquid fuels can only be a temporary option (Moriarty and Honnery 2009a).

With ASPO predicting that actual oil availability will be only half that projected by the EIA – and the IEA and OPEC forecasts for 2030 are nearly identical to the EIA – the optimistic projections for future transport either predicted or implied by official forecasts become problematic. Of course it is possible that the more mainstream projections of the EIA, IEA, and OPEC might prove more accurate than those of ASPO, but there are two strong reasons for doubt.

The first is that the official statistics for oil reserves and forecasts of future annual production capacity may be inaccurate. Colin Campbell has pointed out the sudden rise in official reserves in several OPEC countries in the 1980s, apparently because production quotas for each country were based on their reserves. These large additions to reserves were unsupported by any new discoveries. Further, it is possible that the IEA is aware that its figures for future oil production are overstated, but regards it as more important to avoid panicking financial markets, as suggested by an IEA 'whistleblower' in late 2009 (Campbell 2009). After all, both OPEC and the IEA were established primarily to serve the interests of their member states, not to establish the truth about oil reserves.

The second reason is that even the ASPO oil availability projections assume that the only constraints on future oil production will be geology, the economic costs of developing new fields, and prudent field development practices. The major oil importing nations like the US, the EU, China, Japan and India are increasingly involved in intense competition to secure oil from Africa, the Gulf and the Caspian region (Klare 2008). This activity is in sharp contrast to the upbeat official view of future global oil availability discussed above.

We have already witnessed politically inspired export reductions by Russia to other countries of the former USSR for natural gas, and by OPEC for oil (Klare 2008). Exporting countries with modest reserves might decide to limit production to save oil for their own future. Indonesia, a former OPEC member country, is now a net importer of oil. Other exporters may wish to avoid putting themselves in this position. Finally, even the IEA have warned that the uncertainty in future oil prices could hinder new oil field development, especially for high cost oil from deep sea waters or tar sands, reducing availability of oil in future years.

Global climate change

One of the very few good outcomes of the 2009 Copenhagen climate conference was the recognition that the average global temperature rise must be restricted to 2 °C above the preindustrial value to avoid serious anthropogenic climate change (UN 2009). If we were serious about observing this limit, what would it mean for future global emissions of CO₂ and other greenhouse gases (GHGs)? And in particular, what are its implications for private passenger travel in the high-mobility countries of the OECD?

Using global climate models, a number of research teams have investigated this vital question, including the IPCC in their 2007 report. It is increasingly recognized that CO₂ is a long-lived gas in the atmosphere. Although most will be absorbed naturally by the oceans over a two to 20 century time span, about 20–40 per cent will remain in the atmosphere for even longer periods (Archer et al. 2009). It follows that it is the cumulative amount that is emitted, rather than the annual emission trend, that is important for assessing climate change impacts.

One simple way of looking at cumulative emissions is to recognize that for every four billion tonnes (Gt) of carbon (14.7 Gt of CO₂) emitted to the atmosphere, the CO₂ atmospheric concentration rises by one part per million (ppm) above its present level of about 387 ppm (Moriarty and Honnery 2010). (Present global releases are about 10 Gt of carbon, implying an annual 2.5 ppm CO₂ rise.) So if we put a limit on atmospheric CO₂ ppm, it is very simple to calculate how much additional CO₂ the world can release. Not so simple is to find an acceptable way of allocating these emissions among the world's nations.

This cumulative emissions approach means that past emissions are of equal importance to present emissions over the short time frames of human interest – and most of the cumulative emissions since the Industrial Revolution have been from OECD countries. Further, most emissions, especially from fossil fuel combustion, have occurred over recent decades.

Brahic and Pearce (2009) writing in *New Scientist*, claim that for a 75 per cent chance of average surface temperature staying below the 2 °C limit mentioned above, the world can only afford to release an additional 250 Gt of carbon, compared with the 500 Gt already emitted since the mid-eighteenth century. (Notice the relaxed attitude shown toward global climate change. We might have, say, a 10 per cent chance of catastrophic climate change if we go beyond 2 °C. Would any of us fly with an airline that offered these odds for a catastrophic accident?)

Put simply, on a present population basis, the OECD countries have more than used up their quota, if the criterion used is equal per capita emissions for all. (It could be argued, of course, that the present generation is not responsible for emissions of past generations; the point is that most OECD emissions are from people still alive.) If we have used our share, then our future emissions should be zero – a 100 per cent reduction in emissions. (Of course, in an interconnected world, it is not necessarily in the interests of lower per capita emission countries that their OECD trading partners suddenly drop to zero emissions, as this would also cause global depression. Further, there are many high-emitting individuals in countries with low average per capita emissions. The possibilities for delay are endless...)

Solution: improve vehicular fuel efficiency

Two general approaches are possible for improving the efficiency of all road vehicles, both freight and passenger. The first is to reduce the ‘road load’, or the resistance of the vehicle to motion. The road load comprises tyre rolling resistance, air (or ‘wind’) resistance, which becomes more important as vehicle speed rises, and inertial resistance, important in urban stop-start driving conditions. Hence reducing road load involves tyre redesign to lower resistance (and using higher tyre pressures), aerodynamically efficient vehicles, and lighter vehicles. Regardless of the propulsion system used in future, reducing road load will deliver efficiency gains in terms of Megajoules (MJ) per vehicle-km.

A second approach is to improve the engine efficiency, in terms of the fuel required to power a vehicle of a given weight under given driving conditions. Some breakthrough in vehicle technology is clearly needed, and hopes have focused on hybrid electric vehicles (HEVs). Unlike hydrogen-powered vehicles, HEVs are actually selling in significant numbers, although the global financial crisis and the resultant drop in oil prices have both acted to lower their sales. Cumulative hybrid sales in the US from January 2004 to April 2009 were about 1.25 million, or some 0.9 per cent of the total personal vehicle fleet (Green Energy Efficient Homes 2009).

The big advantage of HEVs over conventional vehicles is their ability to use regenerative braking; because they have electric drive, it is possible to capture much of the energy normally dissipated as friction during braking for later use in propulsion. HEVs are more complex than conventional vehicles, needing both a conventional internal combustion (IC) engine and an electric propulsion motor. However, the IC engine can be smaller – and lighter – than in an ordinary car, and can be run at its maximum efficiency point, which further cuts fuel consumption. Also, fuel loss during engine idling can be eliminated.

If reductions in road load and HEV technology are both vigorously implemented, a review of the literature suggests it might be possible to improve the efficiency of light vehicle fleets by at most a factor of three or four by the year 2050. No change in vehicle occupancy rates is assumed. By 2030, perhaps a doubling of fleet efficiency might be possible (Moriarty and Honnery 2008b).

This doubling refers to ‘tank to wheels’ efficiency only. But as oil is depleted, and production from unconventional oil sources rises, the energy needed to produce and transport one litre of

fuel to the petrol tank will rise – the ‘well to tank’ efficiency will fall – partly offsetting any gains in ‘tank to wheels’ efficiency. Alternatively, we can say that the primary energy costs – and with it the GHG costs – of delivered fuel (eg petrol) will rise as we move to non-conventional oil sources, or to synthetic liquids from coal.

What are the chances for achieving such unprecedented gains in efficiency? Cars are very different from other devices households own, such as refrigerators, in that vehicles are occupied for several hours daily, and further, both car ownership and use confer psychological benefits to motorists. This helps explain why an obvious solution, the adoption of smaller and lighter cars, a solution that also matches the declining occupancy rates of cars, has not been popular. Cars are often purchased with an eye to maximum capacity needs (eg family holidays), rather than average needs. Vehicle fuel efficiency is only one of the qualities motorists look for in buying a vehicle.

Over the past century IC engines have become more efficient, but this has not resulted in much overall improvement in vehicle efficiency. The explanation is that these engine efficiency gains have been offset by higher performance in vehicles, increases in vehicle weight, and the rising energy demands of auxiliary systems, such as air-conditioning, power steering, and electronic information and entertainment systems (Moriarty and Honnery 2008b). In Australia, the result has been that overall vehicle efficiency, measured in vehicle-km travelled per litre of fuel, did not improve over the period 1985–2005 (Moriarty and Honnery 2007a).

For the US, Woodcock et al. (2007) claim that present-day Ford vehicles are no more efficient than the T-model Ford. The data of Sivak and Tsimhoni (2009) suggest a modest rise in overall US light vehicle fleet fuel efficiency from 1923 to 2006, including the generally more energy-efficient imported vehicles. In summary, we cannot expect the primary energy required per passenger-km of car travel to fall much – or to fall rapidly – in the future, given the offsetting effects of declining seat occupancy rates (Moriarty and Honnery 2008b), and the rising energy costs of energy extraction.

Solution: use alternative vehicular fuels

The use of alternative fuels for transport has the aim of solving both the global oil depletion and the global climate change challenges. They also promise to reduce, or even eliminate, vehicular air pollution emissions, a major problem in urban areas, especially in Asia’s large cities. Two main approaches are possible. The first, which is the most developed, looks at finding alternatives to petroleum-based fuels for use in both existing IC vehicles, and in hybrid electric vehicles, which are also ultimately fuelled by liquid fuels.

The second approach requires that the vehicular power source, is, either in whole or in part, derived from electricity. Two proposed future vehicles are of this type: plug-in HEVs, and hydrogen-powered vehicles, whether hydrogen fuel cell (HFC) or IC vehicles. Of course, electric traction public transport vehicles have been in operation for over a century, but they do not carry their energy on board. The advantage of electric power is that it expands the range of possible fuels – all forms of renewable energy, and nuclear power, are now possibilities.

Biomass-based transport fuels

Alternative fuels for internal combustion engines could include liquid fuels from other fossil fuels – coal or natural gas. While these would help alleviate the oil scarcity problem, they would raise emissions of CO₂ compared with oil-based fuels (Moriarty and Honnery 2008b). That leaves biomass-based liquid fuels. Ethanol from grain or sugarcane, and biodiesel from vegetable oil seeds in 2008 accounted for nearly 77 billion litres (GL) of fuel annually, compared with the liquid fuel use from global road transport alone in that year of about 5000 GL (Renewable Fuels Association (RFA) 2009, BP 2009). These fuels are all based on food

crops, and so their expansion much beyond present levels is limited. In 2008, ethanol already used 23 per cent of the US corn crop (RFA 2009).

An obvious requirement for an alternative fuel to be a solution for global warming is that it produces less CO₂-equivalent emissions than the oil-based fuels it is replacing. It is tacitly agreed by both sides of the debate that US corn ethanol has at best only marginally lower CO₂ emissions than the petrol it displaces (Patzek et al. 2005). But growing corn requires heavy inputs of nitrogenous fertiliser, and recently Nobel Laureate Paul Crutzen and colleagues (Crutzen et al. 2008) have argued that emissions of nitrous oxide derived from the nitrogenous fertiliser applied would negate any climate change benefits of corn ethanol.

We can conclude that for biomass-based liquid fuels to make a difference, they must be based on the much more abundant cellulosic feedstocks, such as agricultural crop and forestry wastes, and even purpose-grown bioenergy plantations of fast-growing grasses or trees (Moriarty and Honnery 2007b). Obtaining ethanol from cellulose is far more difficult than from the more readily available starches in grains or sugar cane. This difficulty explains why no commercial cellulosic ethanol plants are yet in operation, despite decades of research and pilot plant operation, although a number are reported to be now under construction (RFA 2009).

There are questions, though, about how much agricultural and forestry waste can be sustainably withdrawn without either lowering soil fertility or increasing soil erosion. Even including biomass energy plantations, the sustainable bioenergy potential, whether used as a power station fuel or for cellulosic ethanol, may be minor on a global scale, with a US study (Field et al. 2008) giving a global potential of only 27 EJ. This value needs to be compared with present global primary energy use of about 500 EJ (IEA 2009). Further, Felix and Tilley (2009) have questioned whether cellulosic ethanol will give a much better energy return on energy invested than grain ethanol does. It is very easy to produce optimistic values in the absence of any hard data from operating plants. The conclusion is that biomass energy potential is limited, and that it is probably better to use any biomass that is sustainably available as a power station fuel, a proven process, than as a feedstock for ethanol.

Transport vehicles powered by electricity

As shown above, electric propulsion is inherently more efficient than internal combustion engines, because it readily allows for regenerative braking. Electric propulsion is easy for public transport vehicles, which can draw power from overhead wires or from a third rail. But for private road vehicles, on-board storage of energy is needed. Petrol and diesel fuels are easy to transport and store, and have high energy density – energy stored per unit mass of fuel, or unit volume of fuel – which largely explains why they won out over battery electric vehicles early in the twentieth century. Higher energy density fuels have greater travel ranges before refuelling.

Batteries, however, have low energy densities compared with petroleum fuels. For example, widely used batteries like the lead-acid or cadmium-nickel ones store only about 0.2–0.4 MJ of energy per kg of battery weight, compared with 46.5 MJ/kg for petrol (Brooks 2009). Part of this large difference arises because electricity cannot be readily stored; instead, mains electricity is first converted into chemical energy which is then stored in the battery. This chemical energy is then reconverted into electricity when the battery circuit is closed. Both conversion processes involve energy losses.

At present the most widely used car batteries are the familiar lead-acid batteries, which although cheap and durable, are heavy. A vehicle running entirely on energy stored in a lead-acid battery pack would therefore consume a lot of the stored energy merely in moving the battery pack itself. A vast number of alternatives to the lead-acid battery have been proposed

and even developed, but the battery with the highest energy stored per unit mass is the lithium-ion battery (Brooks 2009). The reason is simple: lithium is the lightest metal, with only the gases hydrogen and helium of lower atomic number. These batteries are already widely used in electronic equipment, including laptop computers.

Their extension from electronic equipment with their small power needs to vehicles, with their high power needs and harsh operating environment – vibration, high temperatures – is problematic. There have been safety problems with lithium-ion batteries – they can catch fire. Vehicles powered solely by batteries may never be widespread. The favoured option, plug-in hybrids, would allow HEVs to do at least some of their travel from lithium batteries charged by mains electricity. In conventional HEVs, the battery nickel-metal hydride battery pack is charged from the petrol engine.

A recent report by the US National Research Council (Kramer 2010) highlighted the serious problems facing these plug-ins. The Chevrolet Volt, due for release in 2010, is a plug-in hybrid that can travel for 65km on the lithium battery pack. It is estimated that it would cost ‘about \$18,000 more to manufacture than a similar-sized conventionally powered vehicle’. Nearly all the extra cost arises from the size and complexity of the Li-ion battery pack the vehicle would need. Because Li-ion batteries are already a mature technology – for consumer electronics – the report foresees battery costs dropping by about one-third by 2020, but very little further reductions beyond that year.

Even if motorists were able to afford the higher costs of these vehicles, a potentially more serious problem concerns the future availability of lithium (OPEC 2009). Although lithium is widespread in the Earth’s crust, it is usually found at very low concentrations (Wikipedia 2010). The reserve base is estimated at 11 million tonnes (Mt) of lithium metal, but a recent assessment gives a value of only 4 Mt (OPEC 2009). Given growth of other lithium uses, even the higher estimated reserve base of 11 Mt might only support 6.3 million plug-in hybrid cars in 2020. This is negligible compared with the global car fleet OPEC project in 2020 of over one billion (OPEC 2009).

Another approach to using electricity as the transport power source is to fuel vehicles with hydrogen derived from electrolysis of water. At present hydrogen is made from natural gas, but in future it could come from carbon-neutral energy sources, such as wind turbines. The renewable electricity would be used to electrolyse water to produce hydrogen. The hydrogen could then be used either directly as a fuel in IC vehicles, or in fuel cells in HFCVs. When used in IC vehicles, hydrogen fuel distribution and storage are the only challenges, although fuel efficiency is lower than in HFCVs. But hydrogen use in HFCVs faces a variety of additional difficult challenges, including very high costs and limited durability for fuel cells, and the limited global availability of platinum for the catalyst needed to speed reactions at close to room temperatures (Moriarty and Kennedy 2004).

It makes little sense to use fossil fuel electricity to produce hydrogen for vehicles, because total primary energy use and GHG emissions will both be larger than for a conventionally fuelled ICE vehicle (Moriarty and Honnery 2008b). The overall conversion efficiency of electricity to electrolytic hydrogen is today around 70 per cent, and further heavy energy losses occur in compression or liquefaction of hydrogen, and its transport to the refuelling stations, particularly if it is carried by road tanker (Bossel 2006).

If the primary aim is to reduce GHGs, it will always be more efficient to use any climate-neutral electricity (wind, hydro etc) *directly* as electricity – including traction power for electric trains and trams – rather than lose most of it in conversion and transport of hydrogen. Only when all fossil fuel-based electricity was replaced by alternative energy sources could the production of hydrogen be justified. This prospect appears to be far in the future, given

that not only do fossil fuels provide over 80 per cent of electricity, but this share – despite all the talk about alternatives – is steadily rising (Moriarty and Honnery 2009a).

Implications for transport

Purchases of cars and commercial vehicles continues apace, with 13 million new vehicles – almost entirely conventional petroleum-fuelled vehicles – sold in China alone in 2009. New freeways and arterial roads continue to be built, and new car-dependent suburbs constructed on the fringes of expanding cities, both in Australia and elsewhere. Orders continue for new aircraft for the growing national fleets. What is going on here, what miracles are expected, given the challenges to transport's future identified in this paper? Clearly – assuming the problems are acknowledged – the answer is that new technologies, which will need to be adopted with a speed unprecedented in the history of transport, are seen as saving us.

All the world's people aspire to owning a car, and the number achieving this dream grows each year, as is evident from the strong sales in China and India. Establishment of a local car industry in a country further entrenches the aim of mass car ownership, as cars are no longer seen as 'foreign', and the industry itself is often perceived as an important driver of local economic growth. Following the successes of Japan and Korea, cars could even be a major export industry. Many commentators have seen this extraordinary popularity as proof that the long-term success of the car is assured.

However, globally, car travel is the victim of its own success. As long as mass car ownership was confined to the core OECD countries, it might have survived there for decades to come. That people everywhere want to own cars is a necessary, but not sufficient, condition for the survival of car-based travel systems. If all the world's people used oil at the US rate, proved oil reserves would last for only a decade or so (BP 2009). Rather than the huge growth in oil production needed to fuel OECD lifestyles for the entire world, I have produced evidence that per capita oil consumption will soon start to fall, probably halving by 2030.

The implications for large cities in Australia and other high car ownership countries of the OECD should be obvious. Per capita consumption of oil in Australia is more than three times the world average (BP 2009). If global oil production per capita is halved by 2030, even keeping the present inequitable distribution would imply a two-fold reduction in OECD countries overall by 2030, and four-fold by 2050. Any move toward global oil use parity would mean even greater cuts in oil use.

OECD per capita emissions of GHGs are likewise several times the world average. Taking the 2 °C limit seriously could require a near-cessation of CO₂ emissions by OECD countries, because a cumulative emissions quota approach suggests that they have already used up their quota. In summary, the annual rate and extent of reductions needed in both oil use and GHG emissions are far beyond what the past record of car fuel efficiency gains and alternative fuel take-up indicate are possible. Nor do realistic assessments of the possibilities for future technological breakthroughs in solving these two problems change this conclusion (Moriarty and Honnery 2009b).

Passenger transport will not be exempt from any reductions needed for either oil or GHG emissions in the overall economy. In the short term, freight transport can lay a far greater claim to oil use and its accompanying emissions. Modern cities typically have only a few days food supply in stock, so the importance of freight is evident in 'just-in-time' societies. Further, non-metropolitan passenger transport is presently much less easy to serve by alternatives to the car – and the energy and GHG benefits of replacing urban car travel by alternatives are also much greater than for rural areas. If the constraints imposed by limited oil supplies and limited pollution absorption capacity are as serious as many researchers believe, not only will a near-total shift to public transport be needed, but vehicular travel itself will need to be greatly

reduced. We will need to study carefully the history of our urban areas before car travel for clues on the likely shape of future urban transport.

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