**If traction batteries don't improve soon enough, or even if they do, should PRT or other personal GCVs be deployed?**

Richard Gilbert

**Abstract**

Well over 90 per cent of all motorized transportation is fuelled by products of petroleum, but the end of such widespread use of oil may be in sight. Among alternative fuels for land transportation, electricity appears to be the most promising, in part because it can be renewably produced and readily transmitted. The inadequacy and high cost of on-board storage of electrical energy present major challenges to widespread deployment of electric traction, and may do so for many years. On-board generation of electrical energy also presents challenges. The third means of powering electric traction is to provide for connection to the electricity grid while in motion. Grid-connected vehicles (GCVs) are an established feature of many cities and of much inter-city transportation, chiefly as electric streetcars, buses, and trains. They may be more highly regarded by users than their counterparts fuelled by petroleum products, but they are nevertheless communal transportation, considered to lack the amenity of the private automobiles in which most land-based movement of people occurs. Private electric automobiles could in principle be grid-connected for some or all of their journeys, as electric buses are grid-connected. An alternative is to provide public transport that is more like private automobiles. This is generally known as Personal Rapid Transit (PRT), which could comprise relatively small, fully automated GCVs – often known as pods – that carry one to six persons along reserved guideways providing direct origin-to-destination service on demand. PRT could share infrastructure with private electric automobiles, although this may not be an optimal solution. Development of such GCV applications – for freight movement too – may be a more promising strategy than the current focus on improving traction batteries and fuel cells.

**The end of widespread use of oil may be in sight**

Petroleum oil is a finite resource, although this evident property of oil need not in itself cause concern about humanity's massive dependence on it. If we were on a trajectory to have consumed half of the world's recoverable endowment of oil a century or more from now, we might well continue present practices and be concerned only to mitigate the adverse effects of burning oil. However, our oil-using trajectory has been quite different. We appear to have consumed almost all of the first quarter of that endowment in the 50 years before 1985 and just about all of the second quarter in the 25 years since then (19). Thus, we may be at or near the halfway point in our consumption of this resource, although such estimates are highly susceptible to uncertainties about data and to disagreements as to what constitutes a proven reserve of oil.

The halfway point in the depletion of a resource is significant because of suggestions that it is when production of the resource can no longer rise and, perhaps after a plateau, will inexorably fall. This appears true of oil (1, 29, 36) and other resources including phosphorus (13). We seem in 2010 to be in the vicinity of a peak in oil production (28). Indeed, a case can be made that the economic and other convulsions of 2008 and 2009 were precipitated by the rapid rise in oil prices in late 2007 and early 2008, a rise that was in turn caused by constraint of world demand by stagnating world supply (19, 22, 33). The economic collapse in late 2008 reduced oil consumption dramatically in many countries, resulting in a sharp fall in price. It also fostered the suggestion that the arrival of 'peak demand' may have averted concern about 'peak supply' (24).

World consumption of oil did peak in the first part of 2008, as did world production (26), by which consumption is necessarily constrained. A focus on 'peak demand' could suggest that consumption may be falling independently of supply constraints. This may be true of richer countries, where oil consumption had begun to fall before 2008. It is not true of poorer countries, where oil consumption continued to rise (26) and may soon drive oil prices higher again. The events of 2007-2009 may have postponed the onset of oil depletion – the post-peak permanent decline in production – but the challenge of anticipating and accommodating oil depletion remains.

The challenge exists because of humanity's massive dependence on motorized transportation, which has become a necessary feature of almost every aspect of life in richer countries and is increasingly a necessary feature of life in poorer countries. This reliance on the motorized movement of people and freight is in turn hugely dependent on oil products: chiefly gasoline, diesel fuel, jet kerosene, and bunker fuel. In 2007, some 94 per cent of the energy used for transportation came from oil products (26). Oil has several other uses than as a transport fuel. Some of these are at least as important, including the use of oil products as feedstock for the manufacture of most fertilizers, pesticides, pharmaceuticals and plastics. Nevertheless, transport's share of oil consumption has been rising: from 48 to 61 percent between 1971 and 2007, a period during which world oil use for transport more than doubled, from 6.7 to 16.0 billion barrels per year (25, 26).

Disruption of transportation by insufficiency of oil – and insufficiency of alternative means of transportation – can be devastating, with effects ranging from inconvenience (such as when a long walk to work is required), through personal tragedy (such as when death results from inability to reach a hospital) to disaster (such as when mass hunger results from interrupted freight movement).

The events of 2007-2009 highlighted a related challenge: that modern societies have become so dependent on oil that a sharp increase in price can provoke a major economic recession. Some current thinking is that this begins to happen for the U.S. when the total cost of oil exceeds about 4 per cent of gross domestic product (33), which in 2010 happens when the price of a barrel of oil goes above about $80. Other thinking is that $80 is now the *lowest* price of oil required to develop the new supply required to offset some of the declining production in long-established fields (27). If this new supply – which would include production from bitumen deposits in Canada – is not developed, oil depletion could occur at a catastrophically higher rate.

Thus, because of its dependence on motorized transportation and, in turn, on oil, humanity may be between a metaphorical rock and a hard place. There are two ways to avoid being crushed. One is to reduce dependence on motorized transportation. Some reduction could be required, particularly in to aviation as we know it, for which no alternative fuel seems available. For movement of people and freight by land, there are other fuels. Such are the advantages of motorized land transportation over its alternatives, there is good reason to focus on how movement by land, within and between communities, can be transformed to accommodate oil depletion

**Electricity may to be the most promising future fuel for land transportation**

Before noting alternatives to fossil fuels, there should be a word about types of propulsion for motorized land transportation. There are essentially two types: heat engines and electric motors. The former include the internal combustion engines (ICEs) that propel most land transportation and also external combustion engines such as steam locomotives. Other systems, e.g., flywheels and air-pressure engines, have been deployed only rarely. ICEs are almost always fuelled by oil products, notably gasoline and diesel fuel, but they can be fuelled by other combustible liquids such as ethanol and biodiesel, and by combustible gases such as methane (natural gas) and hydrogen.

Biofuels, notably ethanol, have attracted much interest, particularly in Brazil, where ethanol is produced at low cost from sugar cane, and in the United States, where governments have mandated its use as a transportation fuel and subsidized its production and purchase. Late in 2009, the US was producing about 800,000 barrels of ethanol a day for use as a transportation fuel, equivalent in energy terms to about half of the roughly one million barrels of oil a day imported from each of Saudi Arabia and Venezuela. This amount of ethanol was equivalent to about four per cent of all imports of oil and oil products and about three per cent of oil consumption (15). Current plans are to triple US production of biofuels by 2022 (8). Other countries, including member states of the European Union, have relatively lower rates of biofuel production, but also have ambitious plans to increase production.

Even at the present levels of production, which are low in terms of transportation's total requirements, industrial biofuel production may be having a profound effect on food production and the costs of food. Estimates of how much the 2008 rise in food prices could be attributed to industrial biofuel production range from 20 to 75 per cent (2). Accordingly, much effort concerns development of methods of industrial ethanol production from the cellulosic portion of non-food plants. A recent review concluded, "Among the currently and foreseeable commercial biofuels, only cellulosic ethanol has the potential to be produced and consumed on a sustainable basis … [but this fuel] will not be produced on a significant scale for another decade or so" (42).

Deployment of other non-fossil fuels for ICEs could be similarly problematic, a consideration that is prompting renewed interest in electric traction. Electric automobiles were more common at the beginning of the 20$^{th}$ century than ICE-propelled vehicles. They were recognized, and still are, as being superior in every respect except those associated with the storage capacity of their batteries. They are quiet, energy-efficient, require little maintenance, have good acceleration at low speeds, result in lower noise levels, can capture kinetic energy through regenerative braking, and emit essentially no pollution at the vehicle. Moreover, the means of generation of electricity can change radically – say from coal-fired to solar-based – with no change to the vehicle and other parts of the transportation system (19).

The disadvantages of electric automobiles – that caused them to lose favour as the 20th century progressed – result from the challenges of storing electricity on-board vehicles. These disadvantages are short range, low power, and lengthy refuelling, as well as batteries' high cost. A tank of gasoline contains more than 100 times as much usable energy as the best available battery of similar size. Electric motors use energy four to five times as efficiently as ICEs, but this still leaves ICEs with at least a 20-to-1 advantage. Thus, unless a traction battery is made much larger – and thus heavier and more expensive – the range of a battery-electric vehicle (BEV) is a small fraction of the range of a comparable ICE-powered vehicle.

**Batteries may continue to be inadequate**

"Batteries are the big bottleneck between our world and a green future" (7). A Canadian industry-government task force estimated in mid-2009 that a BEV with acceptable performance must typically cost about twice that of a comparable ICE vehicle, almost entirely because of battery costs, and a reasonable projection based on technology improvements and economies of scale would still have the BEV costing at least 50 per cent more (17). The task force also concluded for the future comparison that the life-time costs of the BEV could nevertheless be lower because of lower energy costs.

In considering the prospects for plug-in hybrid ICE-electric vehicles, discussed in the next section, the U.S. National Research Council reached a similar conclusion about battery costs (37), giving these reasons.

> Costs will decline with technology improvements and economies of scale, but lithium-ion batteries are already being produced in great numbers and are well along their learning curves. The steep early drop in cost often experienced with new technologies is not likely. The cost to manufacture these vehicles is expected to decline by about one third by 2020 but only slowly thereafter. It is possible that breakthroughs in battery technology will greatly lower the cost. At this point, however, it is not clear what sorts of breakthroughs might become commercially viable. Furthermore, even if they occur within the next decade, they are unlikely to have much impact before 2030, because it takes many years to get large numbers of vehicles incorporating new technology on the road.

There are many claims of breakthroughs in battery technology that could substantially reduce the initial cost disadvantages of BEVs. Among the boldest and best known is that of the EEStor company, based in Cedar Park, Texas. Its Electrical Energy Storage Units (EESUs) are said to be barium-titanate-based ultracapacitors with an energy density approaching three times that of the best current lithium-ion batteries (400 vs. 150 watt-hours per kilogram), much shorter charge times, lower self-discharge rates, and lower cost (16). In common with other such claims, there are no publicly verifiable test results of EESU performance or other indications as to commercial feasibility. Even if the claims for EESUs are validated, BEVs might still not be viable as a practicable alternative to current automobiles because their ranges could be shorter and their purchase or leasing costs could be higher.

**On-board generation of electricity is problematic**

From the early days of electric vehicles, a solution to the inadequacies of batteries has been to generate electricity on board vehicles, obviating the need for storage, or at least for much storage. The generators have usually been powered by ICEs. The question arises as to why, when an ICE can provide traction directly, would it be arranged to do so via a generator and an electric motor? The answer is that under stop-start conditions the combination of an ICE and an electric motor can be much more efficient than that of the ICE alone. This is chiefly because ICEs have low torque when stationary and at low speeds, when torque is most needed and when electric motors have their highest torque. The advantages of hybrid ICE-electric vehicles have been exploited the most in railroad locomotives. Pure ICE locomotives are rare because so much gearing would be required to get heavy trains started. Diesel-electric locomotives are common although, as discussed below, they are being replaced by electric locomotives that draw power from the electrical grid while in motion.

Hybrid ICE-electric automobiles are growing in popularity because they use less fuel, particularly under urban driving conditions. Consider, for example, the 2011 Toyota Camry, which has hybrid and ICE-only versions that are similar except the former has an electric motor and a traction battery as well as a slightly smaller ICE and gasoline tank. The hybrid version is a little more streamlined, has 27 per cent less trunk space, and weighs 11 per cent more than the ICE-only version. The hybrid version is rated to use 34 per cent less fuel in city driving and 7 per cent less in highway driving – 24 per cent less overall (45). With the U.S. pump price of gasoline at $2.85 per gallon ($0.75/liter), it would take at least 17.5 years of typical driving to recover the 35-per-cent higher purchase cost of the hybrid version through fuel cost savings.

The apparent poor value of hybrids has not affected sales of them in the U.S. They rose at a much higher rate than sales of regular automobiles until 2007. Between 2009 and 2009, sales of both types fell, hybrids by 18 per cent and regular light-duty vehicles by 35 per cent. Hybrids comprised 2.8 per cent of total light-duty-vehicle sales in 2009 (23). In Japan, hybrid vehicles appear to have comprised about 10 per cent of the market in 2009. For the first time, a hybrid ICE-electric automobile, the Toyota Prius, led the ranking of sales by vehicle model (31). Contributing to hybrids' popularity in Japan could be high gasoline prices and subsidies by governments and manufacturers.

U.S. fuel economy standards are to be substantially tightened during the next few years: from a required manufacturer's 2010 fleet average of about 25.0 miles per gallon to a 2016 average of 35.5 mpg (46). (The hybrid and regular automobiles discussed above are respectively 4 and 21 per cent short of the proposed standard.) The tightening will favour hybrid ICE-electric vehicles, especially for urban use. Anticipation of it, and of higher oil prices, has spurred interest in development of plug-in hybrids as well as pure BEVs.

Plug-in hybrids have larger batteries than regular hybrids (and are therefore heavier and more costly). The larger batteries can be recharged from the electrical grid as well as by an on-board ICE-powered generator. At least one plug-in hybrid is in production in China, the F3DM manufactured by Shenzhen-based BYD Company Ltd. It is said to be able travel 100 kilometers propelled by its electric motor alone, and then much further on both its electric motor and its ICE, which can recharge the battery while driving the wheels. The battery can be charged overnight from a residential outlet (12). The F3DM costs about twice its ICE-only equivalent, the F3, which is the best-selling car in China. Sales of the plug-in hybrid version appear to have been much lower than BYD expected, while sales of the much cheaper ICE-only version exceeded expectations for 2009 (18).

More publicity has been given to a proposed U.S. plug-in hybrid automobile, the Chevrolet Volt, to be launched late in 2010 with a price that could also be about twice its ICE-only equivalent. It is to have a 64-kilometer electric-only range and may otherwise differ from the F3DM chiefly by being propelled only by its electric motor, with the on-board ICE serving only to charge the battery. General Motors Co. prefers to call the Volt an ‘extended-range electric vehicle’ rather than a plug-in hybrid.

Early in 2010, a General Motors vice-president was reported as saying that the company would always lose money on hybrid automobiles (presumably meaning both the plug-in and non-plug-in versions). He suggested they were being developed and deployed only to ensure compliance with fuel economy regulations, that they would never comprise more than 10 per cent of the U.S. market, and that the price of ICE-only vehicles would have to be raised to offset their high cost of manufacture (44).

On-board generation of electricity for traction can also be achieved using hydrogen fuel cells. In 2002, electric vehicles with fuel cells rather than batteries were expected to be affordable by 2010 (11). This has not happened, and U.S. Energy Secretary Steven Chu has concluded that mobile fuel-cell applications are for the “distant future” (10). Nevertheless, several vehicle manufacturers continue to work on them, and one assessment concluded that “fuel cell vehicles will be commercially launched in most regions of the world by 2014, and cumulative sales of fuel cell cars and trucks will surpass 2.8 million vehicles globally by 2020” (44). World total vehicle sales in 2008 were just over 70 million (39).

The main problem with fuel cell vehicles may not be their commercialization challenges but rather their inherent inefficiency, especially when their fuel, hydrogen, is produced using energy from renewable resources. (Presently almost all hydrogen is produced from natural gas. Promoters of hydrogen fuel cells often suggest it will be produced renewably.). Renewable resources — chiefly sun, wind and falling water — could produce electricity that would power electrolytic production of hydrogen that in turn would be used to produce electricity in fuel cells. The energy losses such a system have been estimated to range from 57 to 80 percent. By comparison, when the output from, say, a wind turbine is fed into the grid and the electric traction motor is powered directly by the grid – as is the case for the light-rail system in Calgary, Alberta – the energy losses are in the order of 10 per cent. In an energy-constrained world, a system that loses 57 per cent or more of available energy may not compete well with a system that loses only 10 per cent (19).

**Grid-connected vehicles (GCVs) are the well-established alternative**

GCVs have been in use for at least as long as vehicles using ICEs. Electric streetcars and trains were operating in many cities at the end of the 19th century. Today, about 150 cities around the world have or are developing electric train (metro) systems running at the surface, elevated or, most often, underground. More than three times as many cities — about 550 in total — have streetcar systems, also known as light-rail systems, including 72 cities in Russia and 70 in Germany. There are also more than 350 electric bus (trolleybus) systems. Where they are available, GCV systems generally provide the backbone of public transport systems. In Canada, for example, five of the six largest cities have one or more metro, streecar or trolleybus systems, and these GCVs carry most of the public transport passengers served in these cities. In three of these cities, the electricity fed to the GCVs is generated renewably: by wind turbines for Calgary's light-rail system, as noted above, and hydraulically for Montreal's metro and regional train systems and for Vancouver's rail and trolleybus systems.

Electrification of intra- and inter-city public transport grows. China is at the forefront, particularly in respect of inter-city rail. More than $1 trillion has been committed to what has been described as the "largest railway expansion in history," which involves increasing the length of the national rail network from 78,000 to 120,000 kilometers, with almost all of the addition being electrified and 18,000 kilometers of of it capable of supporting high-speed passenger service (200–350 km/h). Much of this is to be completed by 2012. A late-2009 breakthrough was inauguration of the high-speed line across the roughly 1,000 kilometers between Guangzhou and Wuhan, which is now the fastest rail service in the world. The longer term plan is to provide high speed lines to all 300 or so cities with a population of more than 200,000 (19).

China's expansion of intra-city electrified transportation is also remarkable, if not quite as astonishing as the work between cities. New subway lines or major extensions to existing lines are under construction in at least 15 cities, and 12 more are planning them.

Where they can be realized, transportation systems based on GCVs are preferred, particularly in cities, for all the reasons already given for electric automobiles. They include essentially no pollution at the vehicle, high efficiency of energy use, excellent stop-start performance, and lower noise levels. A barrier to installation of electrified systems, or conversion to them, is their higher initial infrastructure cost. A recent UK government report addressed the UK's relatively slow adoption of electrification of its main-line railways, in comparison with other European countries. It concluded that investment in electrification would be self-financing "paying for itself through lower train maintenance, leasing and operating costs" (14).

Another barrier to electrification is concern about the visual pollution caused by overhead wires, particularly on streets, and particularly for trolleybuses, which require pairs of wires. Streetcars powered from an underground conduit were in use a century ago in several U.S. and other cities. Interest in such systems, which are generally more expensive, has been revived with the installation of ground-level, on-road powering system for parts of the system in Bordeaux, France (20). Avoidance of visual pollution for trolleybuses is more challenging. One way is to use battery power in sensitive areas, as is done in Rome. A version of this is to replenish the on-board storage system only at stops, as is being tried in Shanghai (43). Another way would be to power the vehicles by magnetic induction, thereby providing a contactless system and possibly allowing powering from buried infrastructure. Induction systems are used for parts of the rail networks in Vancouver and Toronto (and also for Shanghai's maglev line), but not in ways that could be readily adapted to street use. Contactless systems tend not to use electricity efficiently. A system for street use would likely be much less efficient than one providing direct contact with the grid.

**Current GCVs provide public transport and thus lack the amenity of private automobiles**

The GCVs discussed above are all forms of public transportation and lack the numerous advantages of the personal automobile. These advantages include privacy, availability on demand, door-to-door service, and goods-carrying capacity. For the individual, the automobile's chief disadvantage is its high initial cost, which for most people with the means is offset by its advantages. Nevertheless, there are places where only a minority of people who could afford an automobile actually own one. These include in North America the areas adjacent to the central business districts of the New York and Toronto regions. Such places are characterized by dense land development and good public transit. The extreme example of a richer urban region where car ownership is not preferred is Hong Kong. There, where well under a quarter of households possess an automobile. Indeed, although average per-capita income is many times higher in Hong Kong than Beijing, there are twice as many cars per household in Beijing.

Refashioning communities to reduce automobile ownership could help with anticipation of oil depletion, but it would be a matter of decades and its effects could be too late to make a major contribution to reducing oil dependence in the short and medium terms. Early solutions are likely to involve changes in how automobiles are fuelled. The above discussion does not provide grounds for optimism that solutions based on biofuels or improved batteries will be adequate. Thus, we may be left with one possibility only: that personal automobiles be propelled by electric motors that are powered from the grid while in motion.

**Can cars be grid-connected?**

A recent study by the U.S. National Renewable Energy Laboratory assessed pathways to cost-effective automobile electrification (9). It concluded that hybrid ICE-electric vehicles could be cost-effective but would not slow petroleum demand sufficiently. Plug-in hybrid vehicles and BEVs would be cost-effective only if the cost of batteries fell by more than 55 per cent, or battery performance improved by a factor of ten, or some combination of the two. The authors found that

> One approach with current battery technology could be cost-effective. If an acceptable method for plugging in while traveling along the roadway can be devised, it may provide a cost-effective pathway to vehicle electrification. This approach benefits from the low electric fuel cost of a large battery without the high cost, cycling wear, weight, and efficiency loss. Even with assuming a $1,000 price for the connection device, the cost to the consumer was still lower than for today's conventional and hybrid vehicles. This pathway

> requires infrastructure, but only along a small fraction of heavily traveled roadways to gain the same gasoline saving benefits as plug-in hybrid vehicles.

Once vehicles are grid-connected while in motion they can also be controlled while in motion, which could relieve drivers of the need for continuous attention. It could also allow, among other things, arrangement of the vehicles into trains in order to reduce consumption of energy, which except when accelerating or hill-climbing is mostly expended to overcome wind resistance.

Gilbert and Perl (19) suggested how the evolution of grid-connected personal automobiles might occur,

> Extensive operation of [plug-in hybrid vehicles] could lead drivers to want more use of their electric motors. To facilitate this, governments or entrepreneurs could provide means of powering them along major routes, accessible by appropriately equipped vehicles while in motion. When such en-route powering is sufficiently extensive, EVs with only batteries and retractable connectors could prevail over plug-in hybrids. As the grid-connection system expands, the need for off-grid movement would decline. Roads could be supplemented and even replaced by lower-cost guideway infrastructure. At the same time, vehicles would evolve to move only on the guideways. They would be as light as possible and, where appropriate, be assembled into trains. They would comprise PRT [Personal Rapid Transit].

There is further discussion below of this possible evolution of electrification.

**Personal Rapid Transit is another solution**

Personal Rapid Transit (PRT) in the last quotation refers to transport systems comprising “fully automated, one- to six-person vehicles on reserved guideways providing direct origin-to-destination service on demand” (19). More specifically, it refers to a variant of PRT in which the PRT pods – as the vehicles are usually known – can be individually owned and operated off the system on regular roads.

An assessment of the potential for PRT for the European Commission (38) concluded,

> The ideal target of cities is a self financed public transport system. PRT has a relatively low capital and operating cost, e.g., lower operating cost per passenger-kilometer and lower capital cost per track-kilometer than light railway. PRT can cover its operating costs, and has the potential to even cover capital costs depending on the type of network, the discount rate and a reasonable fare (corresponding to the increased efficiency and quality). In the longer-term, large-scale implementation and mass production of PRT will lead to reductions in cost. The total investment costs for guideway, vehicles and stations of a PRT system have been compared with different public transport systems. The investment cost in million Euros per track-kilometer of three PRT systems has an average of six million euros per track-kilometer. This value is lower than for all other systems considered (Automated Guided Transit, light rail transit, bus ways and trolley bus routes).

Gilbert and Perl (19) also suggested how PRT might evolve from public transport systems,

> Another pathway could involve the evolution of public transport toward supplementation of or even replacement by PRT. This could be driven by PRT's low energy cost and, perhaps even more, by its potentially low infrastructure cost. If fuel prices for cars increase steeply, civic administrations will be pressed to provide alternative means of local travel. PRT could prove to be an attractive option. An analysis for Corby, a community of about 55,000 residents about 150 km north of London, compared costs of PRT and light rail. For similar initial investment, operating costs and fare structure, the PRT system would carry almost twice as many passengers annually, resulting in coverage from revenues of both operating and capital costs. Revenues from the light rail system would cover operating costs only, resulting in a net loss per rider of about 25 percent of the fare paid.

PRT could provide many of the advantages of the personal automobile, even systems not providing for individual ownership and off-guideway operation. Its infrastructure could be inexpensive enough to allow widespread penetration even in low-density areas. A user would signal for a pod by computer or phone. An empty pod would arrive nearby within a minute. In the pod, the user would signal the destination and be directly transported there at a speed exceeding that of an automobile or public transit, with the cost of the trip billed to the user's account or credit card. It could be as convenient on balance as having a car.

PRT has been mooted for decades and may be approaching more than experimental deployment. Experimental and initial installations include those being tested or under development at Heathrow Airport, London, UK (6, 32), Uppsala, Sweden (21), and Abu Dhabi, United Arab Emirates (34). An example of current proposals is one for Canberra, Australia (30). In the U.S., the most action seems to be in Minnesota, where the state's Department of Transportation has appointed a director of personal rapid transit and issued a request for expressions of interest by companies and municipalities capable of demonstration and/or full-scale implementation of PRT concepts and objectives (35).

**Should grid-connectable automobiles share infrastructure with PRT?**

Until recently, the challenges faced by implementers of PRT included the lack of adequate control systems for what would be sophisticated, complex networks with a very high premium on safety and reliability. Now that even laptop computers have sufficient processing ability, the challenges are chiefly to do with the design and adequacy of the guideway, "the most expensive item in a PRT system" (4). There are at least two key issues in guideway design. One is whether the pod should be supported by or hang from the guideway. There are merits to both types of system, with engineering and aesthetic considerations perhaps favouring supported pods and considerations of costs and weather protection perhaps favouring hanging pods (5).

Another guideway issue, somewhat related to the first, and also touched on above, is whether a PRT system should be single mode (SM), allowing on its guideways only pods limited to the guideways, or dual mode (DM), also allowing access to individually owned, street-capable vehicles. Relevant data are lacking, but analysis strongly favours SM systems. Here are some of the arguments (3):

- DM stations would necessarily be much more extensive and expensive to allow for DM vehicles' access to and exit from the guideway and inspection of these vehicles to ensure technical compliance.
- Guideways would have to be much more robust and expensive to allow for the necessarily greater mass of DM vehicles.
- The result of the previous two factors could be limitation of the extent of the guideway system and the number of stations, reducing the proximity of the PRT system to many potential users who do not own DM vehicles, and thereby obviating several potential advantages of PRT systems.

Anderson (3) has argued further:

> In SM one either walks or rides a street vehicle from home to a station, and at the destination (job, store, school, restaurant, theater, stadium, etc) one would walk a short distance, probably no farther than from a parking ramp into a building. Once a trip on SM is completed the vehicle is instantly available for the next trip. In the central city, SM guideways could be placed a quarter to a half mile apart. For its posts and stations, SM will occupy a tiny fraction of the urban land – about 0.02%. Moreover, with an optimally designed guideway, visual impact will be small and more land could be devoted to gardens and parks.
>
> DM does not answer the legitimate criticism of the auto system that everyone in an urban area should have equal access to transportation. In a DM system one boards a private DM vehicle at home and proceeds perhaps one to three miles away to a DM guideway, then perhaps ten to fifteen miles on the guideway to the destination, where the driver must search for a parking spot just as occurs today. The private DM vehicle then sits all day in that parking spot taking up valuable space, is of no use to anyone, and expensive land must be provided to park it. Improvement in land use is therefore not apparent. DM does not answer the legitimate criticism that the auto system promotes urban sprawl, with the encroachment of the auto on rural land possibly already past the point of sustainability. Due to DM being an extension of the current highway system through automation, its effect would be the same as adding more highway lanes. It will exacerbate already unsustainable land use patterns.

For, for the moment, the DM strategy and even that of powering street automobiles while in motion could appear to be unwise. However, much more research on this and other matters to do with PRT is required, as well as the skills, wisdom, and experience that can come only from demonstration projects.

**Development of such GCV applications may be as fruitful as focuses on batteries and fuel cells**

Frederick Soddy, winner of the 1921 Nobel Prize in chemistry for the discovery of atomic isotopes, wrote in 1920, “The history of man is dominated by, and reflects, the amount of available energy” (41). This fundamental observation has been largely neglected in the intervening 80 years during which energy availability has appeared to be less of a limiting factor than in previous centuries. If we are entering another era of chronic energy scarcity, as seems possible, humanity’s ability to live in relative comfort and convenience will depend critically on how energy scarcity is accommodated.

Moving motorized transportation from dependence on oil to reliance on electricity, mostly from renewable sources, will likely be a critical challenge in dealing with oil depletion, which could be an early feature of widespread energy scarcity. Present focuses of research and development – for example, on development of traction batteries and fuel cells – may be less promising than is hoped for. Adaptation of well-tried GCV applications to provide adequate substitutes for personal automobiles could be at least as fruitful. However, there is only a miniscule amount of investment in PRT by the public or private sectors in relation to the amounts invested in on-board storage and generation of electricity.

A substantial increase in investment in PRT research and development may be in order, and not necessarily at the expense of other research and development. A focus on PRT may well help ensure that the future histories of humanity speak to replacement of much automobile use by travel by systems that are no less convenient, while being less costly both financially and in terms of resource use. PRT appears to be pre-eminent among such systems and its development warrants every encouragement.

## References


1. D.M. Abrams and R.J. Wiener, "A model of peak production in oil fields," **American Journal of Physics** 78 (2010).

2. ActionAid, **Meals per gallon: The impact of industrial biofuels on people and global hunger**, (London: ActionAid UK, 2010), at http://www.actionaid.org.uk/doc_lib/meals_per_gallon_final.pdf

3. J.E. Anderson, **How does Dual Mode Compare with Personal Rapid Transit?** (PRT New Zealand, 2007), at www.prtnz.com.

4. J.E. Anderson, "How to design a PRT guideway," In R.R. Griebenow (ed.) **Automated People Movers 2009**. (Reston, Virginia: American Society of Civil Engineers Publications, 2009).

5. J.E. Anderson, **The tradeoff between supported vs. hanging systems** (PRT New Zealand, 2008), at www.prtnz.com.

6. BAA, **World's first Personal Rapid Transit System bursts onto scene at Heathrow** (London: British Airports Authority Heathrow (July 9, 2009), at http://www.heathrowairport.com.

7. D. Blankenhorn, "Battery evolution overwhelms mass production," **SmartPlanet** (February 2, 2010), at http://www.smartplanet.com/technology/blog/thinking-tech/battery-evolution-overwhelms-mass-production/2937/.

8. J.M. Broder, "President touts his alternative fuels plan," **New York Times** (February 3, 2010), at http://www.nytimes.com/2010/02/04/business/energy-environment/04biofuel.html?dbk.

9. A. Brooker, M. Thornton, and J. Rugh, **Technology improvement pathways to cost-effective vehicle electrification**, Report No. CP-540-47454 (Oak Ridge, Tennessee: U.S. National Renewable Energy Laboratory, 2010), at http://www.nrel.gov/docs/fy10osti/47454.pdf.

10. K. Bullis, "Q & A: Steven Chu," **Technology Review** (May 14, 2009), at http://technologyreview.com/business/22651/page1/.

11. L.D. Burns, J. B. McCormick, C.E. Borroni-Bird, "Vehicles of Change," **Scientific American** (October 2002).

12. BYD, **F3DM parameters**, (Shenzhen, China: BYD Company Limited, 2010), at http://www.byd.com/showroom.php?car=f3dm.

13. D. Cordell, J-O. Drangert, and S. White, "The story of phosphorus: Global food security and food for thought," **Global Environmental Change** 19 (2009).

14. DfT, **Britain's Transport Infrastructure: Rail Electrification**, (London: Department for Transport, 2009), www.dft.gov.uk/pgr/rail/pi/rail-electrification.pdf.

15. EIA, **Petroleum, U.S. data**, (Washington DC, Energy Information Administration, 2010), at http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html.

16. EEStor, **US Patent 7466536 – Utilization of poly(ethylene terephthalate) plastic and composition-modified barium titanate powders in a matrix that allows polarization and the use of integrated-circuit technologies for the production of lightweight ultrahigh electrical energy storage units (EESU)**. (Alexandria, Virginia: U.S. Patent Office, 2008), at http://patft.uspto.gov/.

17. EVTRM Task Force, **Electric Vehicle Technology Road Map for Canada** (Ottawa: Natural Resources Canada, 2010).

18. J. Garthwaite, **BYD Plug-in hybrid sales wallow in the hundreds** (December 30, 2009), at http://earth2tech.com/2009/12/30/byd-plug-in-hybrid-sales-wallow-in-the-hundreds/.

19. R. Gilbert and A. Perl, **Transport Revolutions: Moving People and Freight without oil,** 2nd edition (Gabriola Island, British Columbia: New Society Publishers, 2010).

20. C. Groneck, **Trams in France: Bordeaux**, (2008) at http://www.trams-in-france.net/reload.htm?bordeaux.htm.

21. J. Gustafsson, "Vectus—Intelligent Transport," **Proceedings of the Institute of Electrical and Electronics Engineers** 97 (2009).

22. J. Hamilton, **Causes and consequences of the oil shock of 2007-08**, Working Paper 15002 (Washington DC: National Bureau of Economic Research, 2009), at http://www.nber.org/papers/w15002.

23. HybridCars, **Hybrid Market Dashboard** (January 2010), at http://www.hybridcars.com/market-dashboard.html.

24. IEA, **Oil Market Report**, (Paris: International Energy Agency, January 2010), at http://omrpublic.iea.org/.

25. IEA, **World Energy Outlook** (Paris, International Energy Agency, 2000).

26. IEA, **World Energy Outlook** (Paris, International Energy Agency, 2009).

27. ITPOES, **The Oil Crunch: A Wake-up call for the UK economy**, First report of the UK Industry Taskforce on Peak Oil & Energy Security (London: Ove Arup & Partners Ltd, 2010), at http://peakoiltaskforce.net/.

28. ITPOES, **The Oil Crunch: A Wake-up call for the UK economy**, Second report of the UK Industry Taskforce on Peak Oil & Energy Security (London: Ove Arup & Partners Ltd, 2010), at http://peakoiltaskforce.net/.

29. Z. Jian, S. Zandong, Z. Yiwei, S. Youshun, and N. Toksoz, "Risk-opportunity analyses and production peak forecasting on world conventional oil and gas perspectives," **Petroleum Science** 7 (2010).

30. H.M. Jones, “Personal Rapid Transit for Canberra,” **Telecommunications Journal of Australia** 59 (2009), pre-publication version at http://engnet.anu.edu.au/DEpeople/Haley.Jones/publications/JonesTJAPRT2009.pdf.

31. Y. Kageyama, “Prius No. 1 in Japan sales as green interest grows,” **The Denver Post** (January 8, 2010) at http://www.denverpost.com/business/ci_14147168.

32. A.D. Kerr and R.J. Oates, “Heathrow PRT Guideway: Lessons Learned,” In R.R. Griebenow (ed.) **Automated People Movers 2009**. (Reston, Virginia: American Society of Civil Engineers Publications, 2009).

33. S.R. Kopits, “The most recent economic downturn is a peak oil recession,”. **Exploration & Production** (November 2009), at http://www.epmag.com/Magazine/2009/11/item47352.php.

34. Masdar, **Welcome to Masdar City: Transport** (2009), at http://www.masdarcity.com.

35. Minnesota, Request for Interest: Personal Rapid Transit (PRT) Viability and Benefits (St. Paul, Minnesota: Department of Transportation, 2010), at www.dot.state.mn.us/transit/docs/PRT%20RFI.pdf

36. I.S. Nashawi, A. Malallah, and M. Al-Bisharah, “Forecasting World Crude Oil Production Using Multicyclic Hubbert Model,” **Energy Fuels** (DOI: 10.1021/ef901240p, Publication Date (Web): February 4, 2010).

37. National Research Council, **Transitions to Alternative Transportation Technologies: Plug-in Hybrid Electric Vehicles** (pre-publication version), (Washington DC: National Academies Press, 2010), at http://www.nap.edu/catalog.php?record_id=12826.

38. NETMOBIL, **EU Potential for Innovative Personal Urban Mobility**, (University of Southampton, UK: NETMOBIL Project, 2005), at http://www.eukn.org/binaries/eukn/dg-research/research/2005/10/netmobil-d7-eu-potential-final.pdf.

39. OICA, **2008 Production Statistics**, (Paris:Organisation Internationale des Constructeurs d’Automobiles, 2010), at http://oica.net/category/production-statistics/.

40. Pike Research, **Fuel Cell Vehicles** (February 2010), at http://www.pikeresearch.com.

41. F. Soddy, **Science and Life; Aberdeen Addresses** (New York: E.P. Dutton, 1920).

42. B.D. Solomon, “Biofuels and sustainability,” **Annals of the New York Academy of Sciences** 1185 (2010).

43. Tbus, Trolleybuses in the future, (2009) at http://www.tbus.org.uk/futures.htm.

44. S. Terlep, “GM Exec: Hybrids Unlikely To Take More Than 10% Of US Market,” **Wall Street Journal** (February 13, 2010), at

http://www.nasdaq.com/aspx/stockmarketnewsstoryprint.aspx?storyid=201002121643dowjonesdjonline000566.

45. Toyota, **Camry 11**, (Toyota City, Japan: Toyota Motor Corporation, 2010), at http://www.toyota.com/camry/.

46. White House, **Press background briefing on White House announcement on auto emissions and efficiency standards by senior administration official**, (Washington DC: Office of the Press Secretary to the President, May 19, 2009), at http://www.whitehouse.gov/the_press_office/Background-Briefing-on-Auto-Emissions-and-Efficiency-Standards/.