AN ENERGY STRATEGY FOR PUBLIC TRANSPORT SYSTEMS

P. Michelberger, L. Lesley and P. Várlaki

Department of Transport Engineering Mechanics,
Technical University, H-1521 Budapest

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Abstract

The paper describes the energy consumption processes in a public transport system and identifies areas where savings can be made. An assessment is undertaken of the cost of achieving energy savings, the effectiveness of those savings and a priority proposed for realising them. The paper also discusses the role of different fuels and the trends in future availability. From this proposals are made for changing fuel sources, to make public transport less vulnerable to market price fluctuations.

Introduction

Global society is rapidly urbanising. By the turn of the millennium overhalf of the world's population will live in towns and cities. Countries are reducing agricultural employment by mechanisation and scale economies, and increasing industrial and service sector employment both of which are intrinsically urban activities. As living standards rise there will be a growth in private motor car ownership which will increase congestion on urban road networks. Even so urban areas built on a European scale of density and layout will be unable to accommodate high levels of motorisation (Buchanan 1963). Urban areas built on a North American Scale will face problems of differential access to motor cars, peak period road congestion and traffic generated air and noise pollution. Therefore there will be a role for public transport into the foreseeable future. In European style cities this role will be very important in accommodating the majority of trips to and from the Central area, and a substantial part of other traffic demands.

In less densely developed cities, public transport will only have a small, but growing share of the travel market, though for particular sectors, e.g. C. B. D., public transport will be significant.

In earlier papers (Michelberger et al. 1985) and Lesley (1986) we discussed in detail the availability of energy in two national economies (Britain and Hungary), in the context of the development of their respective transport systems, and the impacts on the design of vehicles. In this paper we concentrate upon urban public transport, firstly for the reason that it may be managed relatively easy by national government policies, and secondly because in developing and urbanising counties, it will be a significant consumer of energy and specifically diesel oil.

For various reasons most urban public transport systems rely on motor buses to provide a substantial proportion of services, and even where there is a metro or other rail based system, buses usually carry over half the public transport traffic.

For example for public transport and bus traffic:

	Total Public Transport Use	% by bus
Budapest (1983	8786 m km	49
Liverpool (1979)	1400 m km	75
London (1984)	1813 m journeys	64

Oil Resources

Nearly all Bus systems depend on diesel engined vehicles. These rely on fuel refined from petroleum extracted from underground wells. Historically the real price of oil has declined relative to other fuels, and the substantial rises in price in 1974 and 1979 have not raised the real price of oil compared to its earlier price, or with other fuels. One result of this has been to make oil engined buses more attractive to public transport operators, seeking to reduce operating costs. This has been particularly important as buses are usually massproduced, though with a short service life, compared to other forms of public transport especially rail. Buses also have an advantage of using as track, highways provided by public authorities or other agencies, while for rail based systems the operator is responsible for the capital investment in the right of way and its track. Therefore when there has been pressure on costs, operators have seen bus systems as being less capital intensive, with the vehicles cheaper to buy than rail systems. Therefore at the same time as bus systems have grown, there has been a relative decline in the importance of rail systems. In developing cities buses are also seen to provide a degree of flexibility, to provide new and altered services, quickly and cheaply (to the operator) and therefore have tended to be the choice in most developing country's and cities.

Oil Alternatives

Clearly with future new oil fields being in increasingly difficult areas (e.g. Artic), the cost of oil extraction will rise, and coupled with the imbalance between demand and supply, there will be a general rise in oil prices, which will increase public transport operator's costs, both relatively and absolutely to make fuel a significant element in the cost structure. In 1980 one estimate (Ford 1982) of global oil reserves was 25 years at current levels of consumption.

As oil supples decline and prices increase, marginal oil users, e.g. building heating, electricity generation, will switch to alternative energy sources which are cheaper or more abundant. However, road transport at present is uniquely dependent upon oil, a single fuel, and inspite of research, there is as yet no alternative system which offers the flexibility and range of the internal combustion engine. Fortunately urban public transport, operating to known schedules and fixed routes has available alternative fuel options which will be discussed, in a general and detailed examination of both reducing energy consumption and minimising oil use.

Energy minimisation and substitution

The options available for reducing energy consumption fall into three categories (Table 1) and these will be discussed in turn.

Table 1

Energy Saving Options

PRIMARY
Fuel-oil-engines-Diesel-combustion/exhaust
    — turbine
    — Stirling
    — electricity-AC/DC-motor Design.

SECONDARY
Transmission-mechanical-gear box-drive shaft-axles
    — fluid-storage-converter
    — electric-controller
Wheels
Regeneration-mechanical-flywheel-clutch/converter
    — fluid-storage-converter
    — electric-batteries-power distribution
Vehicle-shape-weight-service life/maintenance
Driver-selection-training-incentives-financial-physical

TERTIARY
Operations-timetable-coasting
Track-conditions control
    — congestion
    — priority
    — pre-emption of traffic signals
    — bus lanes/streets/ways
Fares-attract motorists-reduce congestion
Planning-city shape-distribution of functions-reduce public transport operating costs/fuel use.

Primary
The Engine

This area relates to the motive power source, and while the diesel engine remains the main propulsion unit of buses — there is a limit to the amount of energy saving possible, due to the basic thermodynamic processes of diesel engines. The theoretical maximum fuel efficiency is only 35%. To achieve that new cylinder and piston designs will be needed, together with modifications to valves and injectors. Coupled to that turbo charging and intercooling will be essential to feed back some of the energy wasted by gas exhaustion into the atmosphere. The main alternative fuels to DERV are Liquified Petroleum Gas (LPG) and Synthetic oil. LPG is a by-product of oil extraction, and so as oil supplies decline, so will LPG, added to which the fuel efficiency is somewhat lower than DERV, though with the benefit of virtually no air pollution. There are a number of possible sources for the manufacture of synthetic oil, of which coal is the most abundant. However, the coal-oil-diesel cycle is extremely inefficient, and any improvements in intrinsic engine efficiency, would be more than lost by coal-conversion technology, giving less than a 10% energy efficiency overall. Naturally occurring gases, e.g. methane, can also be manufactured, e.g. from domestic waste and sewage, but the quantity available is never likely to be sufficient to satisfy the demand for bus services, let alone other road transport.

Alternative Engines

Other engines have been considered and developed, e.g. Gas turbine, Stirling engine, but as yet none offers the unique advantages of the diesel, especially in terms of fuel efficiency, therefore the most likely route to further improvements of energy efficiency may be through different technologies of which electrification seems the most realistic. The electric motor after more than a century of development is highly efficient (about 90%) with good power to weight ratios and a tolerance to overloading not possible with internal combustion engines. The type of motor used depends on the input electric current. With Direct Currents the classical commutatored motor is universal, though may be replaced by the recently developed switched reluctance motor (Borup 1985). Alternating Currents, the squirrel cage motor is extremely efficient, therefore any improvements in electric motor design will hardly effect energy efficiency. In Summary the maximum improvement in the fuel efficency of diesel engines is likely to be only 10%, with little opportunity of improvement from using non oil based fuels, without a switch in technology to electric traction. Unfortunately most of these savings are outside the control of bus operators, lying with the designers and manufacturers. In order that more fuel efficient designs are to be produced, manufacturers will need to be more adventurous, and operators less conservative in their purchasing.

Secondary
Propulsion and Drive

After the vehicle engine, there are other areas of vehicle design that can be improved to reduce energy consumption. In the frequent start-stop cycle of urban bus operation, most of the energy consumed is in acceleration and then dissipated in braking. Less energy is used in overcoming air and rolling resistance. Two main factors affect this energy use: gross weight and maximum speed. Most bus designs are already quite light with under 100 kg vehicle mass per passenger at peak capacity, but nonetheless still over twice as heavy as for example in aircraft. So there is scope for reducing vehicle weights, either by using lighter materials, or using thinner materials and building with less over-design. In transmitting the traction from engine to wheels, mechanical drives are highly energy efficient, though gear boxes can be inefficient, particularly some automatic designs. As a guide, energy efficiency can be improved by reducing the number of friction interfaces in the drive chain. Although there are hydrostatic or electric transmissions, which both avoid mechanical drives and gear boxes, these are not yet energy competitive with straight mechanical drives. Air resistance is not a significant energy consumer in urban bus systems, nonetheless in seeking to minimize energy use better aerodynamic shape should not be overlooked in designing new buses.

The principle mechanical area for reducing energy consumption must therefore lie in capturing and storing kinetic energy presently lost during braking, for use in the next acceleration cycle. Various systems linked to diesel engines are being developed, which can be divided into three main types: mechanical, fluid and electrical.

Mechanical Regeneration

The main mechanical system is a high speed flywheel, mounted in an evacuated container. Such a flywheel weighs about 200 kg and revolves at 20000 revs/min. Although the technical and mechanical features have been shown to be practical — the energy efficiency is not very high.

Fluid Energy Storage

A more promising system is energy storage by fluid compression, either a gas or liquid (or a combination). This system needs a fluid pump and high pressure fluid storage. However, the results of tests have shown a better level of energy efficiency than in flywheels, and recently a new fluid storage bus was put into service in London (Miller 1985).

Electric Regeneration

For energy recaptured electrically, most systems in use are hybrid-using electric batteries which are charged up by a diesel engine, since the technology for recharging batteries from the high currents generated during braking are not yet fully reliably. However, in straight electrically powered public transport systems (e.g. Trolleybus, tram, light rail, metro) electrical regeneration is well, established with the regenerated power fed to other vehicles accelerating, and energy savings of at least 25% claimed.

Operating Practice

Once the vehicle has been designed and constructed, two further areas are open for energy savings, maintenance and driving. Preventive maintenance regimes avoid complete failures in service and save energy in rescuing and restoring crippled vehicles. The optimisation of lubrication based on weather conditions, engine age and operating factors can make a substantial impact on energy consumption particularly in diesel engines. Better maintenance can also increase vehicle life and so reduce the need for energy expenditure in scrapping old and building new vehicles.

Lastly energy can be saved by better driver behaviour. This can be achieved through training or fiscal measures. Many bus operators report a continuous turnover and often a shortage of drivers, partly because the work is physically demanding and stressful, and partly because bus drivers can often get better wages for less work by driving heavy goods vehicles. Electric operation and alternative technologies will make bus drivers less able to switch to lorry driving, which should make for a more loyal staff and reduce the costs associated with staff turnover. Bus operators devote a considerable effort to driver training — which usually emphasises safety, and with the short average employment of drivers, a training regime, which emphasises fuel savings, would soon have covered most of the staff and so begin to influence fuel consumption. Given that the cost of this training in fuel economy is effectively zero, then the benefits, reported to be up to 10%, are very worthwhile. Drivers can also be encouraged financially to save fuel, either on an individual or collective basis. Given an agreed target fuel consumption, savings could be passed to drivers as a fuel economy bonus. However, the lag between the fuel economy and the receipt of bonus is likely to make this ineffective by itself. Vehicles can be modified to make driving in a wasteful way difficult or impossible. Governors can be fitted to engines to make driving at high engine speeds impossible.

The spring resistance on the accelerator can be modified to be progressive so that hard acceleration becomes physically tiring.

Total Savings

Taking all these areas of fuel savings together, the minimum likely is about 30% compared to present fuel consumption. However, there will also be non fuel advantages. Vehicles which are driven more smoothly will need less maintenance and have a longer life. Passengers will enjoy a more comfortable and safer ride when drivers are less aggressive, for example by coasting to traffic lights to avoid the need to stop and start again. Less aggressive driving ought to make the job more satisfying and therefore reduce the turnover of staff with a saving of recruitment and training costs. Lastly the area of driver behaviour is one which bus operators have under their control and can be implemented irrespective of bus design. So operators should review their training procedures and driver's wage structures to see if fuel saving driving behaviour can be encouraged.

Tertiary

Operating Environment

This area relates wholly to bus operations and the environment in which services are provided. The less vehicles have to stop and start, or brake and accelerate, the less fuel will be consumed. Clearly vehicles must stop to set down and pick up passengers. It is the area of general traffic conditions which if improved will lead to reduced consumption. Generally this relates to smoother traffic flows, for example by the use of co-ordinated traffic signals and an average traffic speed nearer to bus operating speeds than the usual private car speed. Further buses can be equipped to provide an uninterrupted passage through traffic signals, either by being pre-empted by an approaching bus, or the use of a signal strategy controlled by a central computer which favours buses.

Traffic Management and Priority

The control of traffic conditions can be taken a stage further through the reservation of some or all of the road space for public transport operations on particular routes. This will mean that bus operating speeds can be increased or the maximum speed reduced and so save fuel overall. The use of reserved bus lanes, bus streets or busways, makes it much easier to avoid delay to buses at junctions so that bus operation becomes more like a railway, with a priority of junctions — which both saves fuel and increases operating speeds.

Fare Policy

There ought to be scope for using the fare policy to reduce traffic congestion and reducing bus fuel consumption. In general there will be at the margin car owners who only just find car use overall more attractive than public transport. A special fare package could be developed to attract those drivers. This has recently been tried successfully in Basel where drivers had to sign an agreement not to use their cars in order to qualify for an "Environmental" season ticket, priced at nearly half the normal fare. Initially about twice as many drivers took up the offer as were needed to make it balance, and the cheating rate was only 10% (Basler VB 1984).

Urban Planning

In the longer term town planning policies can shape cities to concentrate demand and make public transport operations easier and cheaper.

Coupled to that is the opportunity opened up for electrification. Planning policies can reserve land for rights of way which can be used incrementally, therefore requiring modest annual investments, but leading to the goal of partial or total oil independence, as well as producing environmental benefits, from quiter and less polluted urban areas. Nearly all these areas of savings are outside the direct control of the public transport operator. To gain them bus operators will need to show the political or economic advantages to the whole community, which can be gained by helping to reduce energy consumption in the public transport system. Taking the savings which can be made in all these areas it should be possible to reduce energy consumption by up to 50% compared to the present day conditions.

Overall savings

Fuel Savings in Transport

Clearly the savings which can be derived in the primary, secondary and tertiary areas outlined above are not cumulative but taken together could save up to 70% of the energy presently used in operating public transport systems. Is that a worthwhile saving, when compared to the effort involved, and investment needed to achieve it? As in all endeavours, some savings will be easily and cheaply made, while, some will be difficult and expensive. So the operator, or community will need to strike a balance between the fuel savings which can be made and the costs involved. In any case the maximum fuel savings which a public transport operator can make are small in comparison to those which can be achieved either by reducing car traffic in towns or making cars more energy efficient. While it may be important for public transport operators to save fuel, it might make very good sense to the urban community to encourage bus operators use more fuel by running more intensive services, in order to attract car commuters and save fuel use in motor cars, orders of magnitude greater. As a rule of thumb in typical urban conditions, if 6 car users get out of their car and into an empty bus there would be a fuel saving. This is an extreme. Normally car users diverted to public transport will only marginally increase bus fuel use and so the overall fuel savings will be much greater.

Use of Computers

Micro processors and computers are beginning to emerge as a powerful technology to capture, analyse and act upon information, impossible or very costly to achieve by manual methods. For example an on-vehicle processor can monitor fuel feed, exhaust gases and the drivers demand for power, to optimise diesel combustion and minimise fuel use. This can be extended to changing gear at the optimum point in the engines speed/power range. In reserved track electric public transport systems a central computer can monitor, by means of slave processors on each vehicle, the current state of the system, and direct vehicles to accelerate when there is a decelerating vehicle regenerating, can reduce rates of acceleration, or stagger accelerations to reduce the peak power demand. It can also initiate coasting to save energy and yet keep with the tolerance of running schedule. The scope for computers to advise or act in place of human operators has as yet hardly been realised in urban public transport, though air and sea navigation, and piloting show how powerful computers can be.

Observations

The major problem in achieving substantial fuel savings in a public transport system is that different agencies only have partial responsibility in achieving them. In the primary and some of the secondary measures, bus manufacturers have an important role to play. However, fuel efficient buses must be "sellable", that is the operators must see them as practical, reliable and easy to maintain. There may need to be discussion and agreements between manufacturers and operators to arrive at technical packages of fuel economy measures which are acceptable. Even so the full realisation of these fuel savings will take some time. Seven years in Hungarian conditions and 14 years in Britain, before a bus fleet is completely replaced, and of course it is progressive, in that further savings will be made even during the replacement of existing buses by even more fuel efficient vehicles.

In the secondary and tertiary areas operators can reduce their fuel consumption through timetabling and driver performance. However, the biggest fuel savings will come in the tertiary area and these are generally outside the direct control of the operator, being the responsibility of highway traffic control and planning authorities. In the short term with better traffic management and priority for buses will give smooth flows, less stopping and starting, and save fuel. In the medium term further priority measures including busways will enable average operating speeds to increase, and also reduce fuel consumption. In the very long term urban form better suited to public transport operation will provide significant operational economies, including those from fuel savings.

Switch from oil

The question of fuel saving is compounded with that of diversifying out of oil, which inspite of the present glut is a finite resource and might only last early into the next century at recent levels of consumption. Two approaches have been identified:

(a) replacement oils, e.g. synthetised from coal or other materials

(b) electrification, with electricity generated by a variety of fuels, including renewable resources e.g. hydro-power (Chapman 1976).

In some circumstances one option will be preferred due to local natural resources, elsewhere the other. In advanced industrial countries with a developed electricity generation and distribution system — electrification will normally be the preferred route, since the peak demands for transport do not coincide with the peak demands for electricity either on a daily or annual basis and so require little extra capital investment. The question then is what strategy to adopt in electrifying urban bus systems.

Electrification

There are two major options: battery buses and trolley buses. Unfortunately the capacity of current technology batteries gives a range of about 80 km operation in urban conditions. This is enough for morning and evening peak demand buses, that can be recharged between the peaks, and for services which have a daily duty of less than 80 km or in specialised locations, e.g. city centre distributors. However, there is a considerable amount of research being undertaken both to improve the power density/weight ratio of present battery systems, and on new batteries which promise significantly larger battery capacity. There is of course the option of hybrid battery/trolleybus operation which would enable electric operation at the ends of trolleybus routes, and allow partial electric operation to be introduced before trolleybus infrastructure was erected. However, the most available electrification technology is the trolleybus (Table 2).

Table 2

Fuel and Mode Substitution

Bus to trolleybus
    (economic where service 6 buses/hour)
Action
    Incremented electrification of busiest routes
    Bus replacement policy with trolleybuses
    Introduction of traffic management and bus lanes.

Bus (T/Bus) to Tramway (or light rail)
    (economic where service 30 buses/hour)
Action
    Incremented, tracks laid where possible on segregated right of way (up-graded bus lanes)
    Junction priority (e.g. pre-emption of traffic signals)
    Central computer vehicle tracking and system regulation (with or without drivers)

Trolleybuses

A wide ranging study undertaken in Britain concluded that at present for bus routes with a service of 6 buses per hour or more frequent, then trolleybuses are more economical than diesel buses (Harrison 1984). This broadly confirms an earlier study undertaken in San Francisco (Natvig 1982). Two problems then are the capital cost of the vehicles and that of the power distribution infrastructure. Since there is no series production, the cost is up twice as much as a diesel bus (in series production) of the same passenger capacity (Cobbe 1985). However, historic evidence indicates that the service life of a trolleybus is at least twice that of a diesel bus, and operators in Switzerland and Canada have in fact rebodied 25 year old vehicles, with the expectation of another twenty five years of service.

This financial problem could be overcome by a leasing system, with a Finance House purchasing the new vehicles and operator paying an annual charge for using them. This arrangement may also include the transfer of ownership after a set number of years. This would enable a public transport operator to obtain new trolleybuses without an initial need for capital investment greater than straight diesel bus replacements. If enough new systems are introduced, then it would be possible for trolleybuses to be built in series production, so that the first cost differential with diesel buses will be reduced, in which case operators could purchase through their usual depreciation allowances.

Electric infrastructure

The infrastructure is more problematic, since being fixed and of long life, at least 50 years, the option of a Finance House buying and leasing is very much less, as there would be a higher risk involved, and no residual value, or ability to transfer the assets to another location. However, it might be attractive for an Electricity Utility to consider trolleybus infrastructure as part of its power destribution system and so provide on the basis that its consumers (trolleybus) would normally have the power delivered by the Utility. In this case the electricity tariff would include an element to cover the capital charges of the infrastructure, though there would have to be a safe guard for the operator, in that the Electricity Utility would be in a monopolistic position.

Electrification Strategy

The strategy of implementing electrification would clearly be on the basis of the busiest routes being converted first, and over time, as the relative price of oil increases, routes which at present are marginal would become economic. However, the capital was obtained, an incremental programme of conversion over ten or fifteen years would mean only a modest annual requirement.

There is also strong evidence that people find trolleybuses more attractive to travel in than diesel buses because of the reduced noise and vibrations, and smoother accelaration. Indeed in one study in San Francisco on comparable routes, trolleybuses carry at least 10% more traffic than diesel buses (Natvig 1982). When faced with the choice of either the air and noise pollution of diesel buses or the overhead electric infrastructure for trolleybuses, cities have voted for the trolleybuses.

Trolleybuses will on average use about 30% less energy (non oil) than equivalent weight diesel buses, due to regeneration and reuse of electricity for accelerating vehicles elsewhere. Greater energy savings can be made by higher capital investments in light rail or tramway systems, where the rolling resistance of steel wheels on steel rails is an order of magnitude less than for rubber tyres on roads. However, under present economic conditions traffic demands must be much higher than for trolleybuses, and in one study in Toronto this was assessed as peak passenger flows of over 3000 per hour or more (Toronto Transit Commission 1983). However, with the use of articulated or trains of vehicles. Light rail or tramway systems can provide substantial manpower savings compared to bus systems, and the option at some future date for full automation, even when operating in public highways (Bell 1985) allowing for levels of service, day and night, that would make public transport extremely competitive in terms of travel quality compared to private cars. A switch from car to public transport will save considerably more fuel than is likely to be realised by all the methods outlined here for public transport operators.

Conclusion and recommendations

Because of the long life of Public Transport vehicles and the inevitable increase in price of oil based fuel, public transport operators should be planning now a switch to alternative fuel and traction systems. This is because the fuel savings achievable in the Primary and Secondary areas will not be enough to compensate for the likely escalation in the real price of diesel fuel. In small and medium sized towns (less than 100 000 population) traffic flows are unlikely to be high enough to justify at this time light rail or tramway investment and so trolleybus systems should be considered, although with time battery storage systems may advance to the stage where very small towns could be electrified with battery buses.

The process of electrification should begin on the busiest routes and capital finance should be made available, either from private sources, or else through a public energy conservation fund. Electrification is likely to attract car users and so provide a further fuel saving in the transport system overall. Highway and Police authorities should begin to introduce traffic management measures which favour public transport, reducing delays especially at juctions. This policy is likely to save considerably more fuel than would be possible by new diesel engine technologies, which in any case would also require a considerable capital investment in research and development of the order of the cost of about 300 new buses.

Public transport operators can influence energy consumption indirectly by buying fuel efficient vehicles and investing in oil substitution technology

Table 3

Comparison of Energy Saving systems

Energy Saving Recommendation	Authority Responsible	Vehicle Capital Cost	Maximal Fule Saving
Primary			
New Diesel	Manufacturer	+ 5%	10%
Secondary			
Reduce vehicle weight	Manufacturer	+10%	20%
New transmission	Manufacturer	+ 2%	1%
Regeneration	Manufacturer	+50%	30%
Driver training	Operator	0%	20%
Timetabling	Operator	0%	5%
Tertiary			
Traffic management and Bus priorities	Highway	0%	20%
Fares to attract	Operator and City	0%	200%
Electrification	Manufacturer and operator	50—200%	50% (and oil independence)
Synthetic oil	Government, oil and coal companies	0%	—50% (conversion is energy inefficient)

Table 4

Recommendations

Short term (under 5 yrs)

(a) Improve Driver Selection (training/motivation)
(b) Timetables realistic for traffic conditions, computer optimisation
(c) Lighter vehicles
(d) Regeneration
(e) New diesel engines (buses)

Medium term (5—10 yrs)

(a) Traffic management
(b) Public transport priority on highways
(c) Segregated rights of way
(d) Fiscal policy to attract autobuses (reduce congestion)
(e) Vehicles able to switch fuel.

Long Term (>10 yrs)

(a) Electrification
(b) City Planning to benefit public transport

(e.g. electrification), and directly by specifying timetables which permit fuel savings (e.g. by coasting) and by better training and incentives to encourage smoother and less aggressive driving (Tables 3—4).

The paper has reviewed the options available to a public transport operator and other agencies to save energy and to become less oil dependent. Already on busy urban routes trolleybuses are more economic than diesel buses but there is a capital penalty which must be overcome, either by means of increasing the capital investment available to public transport operators, or by institutional arrangements which encourage Finance Houses or Electricity Utilities to provide the capital, and reflect that cost in leasing or electricity tariffs. Electrification as well as saving fuel in public transport operation and breaking oil dependence will also by attracting car users greatly reduce the fuel used in the urban transport system.

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Prof. Dr. Pál MICHELBERGER }
Dr. Péter VÁRLAKI } H-1521 Budapest
Dr. Lewis LESLEY Liverpool Polytechnic, 98 Mount Pleazent, Liverpool, L3 5U2, G. B.