Chapter 11

The Media Laboratory City Car: A New Approach to Sustainable Urban Mobility

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With the exception of electric trains, trams, and trolleys which are continuously powered from rails or overhead wires, and elevators, cable cars, and ferries which are pulled along by motors located off board, mechanically powered vehicles must carry their energy supplies with them. When onboard supplies run out, they are immobilized. This, as we shall demonstrate, has some fundamental effects upon urban spatial structures and mobility patterns.

Furthermore, these effects have major impacts upon urban energy consumption. They can create barriers to achieving energy efficiency, or when appropriately understood, they can open up new opportunities for significant energy savings. Here, therefore, we will show how integrated design of mobility systems, energy distribution systems, and urban spatial patterns can significantly enhance overall energy efficiency and reduce carbon emissions. In particular, we will introduce the Media Laboratory City Car – a new concept that illustrates this design strategy, and that opens up exciting opportunities for creation of clean, energy-efficient, cities for the 21st century.

11.1 The Geography of Refuelling

The basic tradeoffs that are involved here are very familiar to mechanical engineers and transportation system designers. The more energy a vehicle can carry, the greater its range. But carrying more energy increases bulk and weight, and reduces energy efficiency. It is always necessary, in vehicle design, to find an appropriate balance.

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There has been little systematic study of the overall energy efficiency of cities. The pioneering work of Abel Wolman (‘The Metabolism of Cities’, Scientific American 213(3), 179–190 (1965)) introduced the term ‘urban metabolism’ and conceived of complete urban systems as organisms, the inputs and outputs of which could be modelled. For a general introduction to the topic of overall urban energy efficiency, see Droegge, Peter, Renewable City: A Comprehensive Guide to an Urban Revolution, Chichester, Wiley-Academy, 2006. The BP-Imperial College Urban Energy Systems Project is an ambitious current attempt to develop ‘a systematic, integrated approach to the design and operation of urban energy systems, with a view to at least halving the energy intensity of cities’ (First Annual Report, London, Imperial College, December 2006).
Fuels and energy storage media vary in their energy densities, and this profoundly affects the balance point. For example, fuel supplies for early steam-powered vehicles – coal or wood – were bulky and difficult to manage; this was not a fatal flaw for very large steamships and steam locomotives, but it limited the development of steam-powered locomotives. Gasoline, however, has very high energy density, and its liquid form makes it relatively easy to manage, so it became key to the development of the modern automobile – enabling fairly compact vehicles with ranges of 300 miles. Batteries, unfortunately, have low energy density (so far, at least) and other limitations, and this has traditionally presented designers of electric cars with a difficult dilemma. Either the car carries few batteries and consequently has very limited range (as with golf carts), or else it carries sufficient batteries for long range – but is bulkier, heavier, and less efficient.

Gasoline-electric hybrid vehicles cleverly combine the advantages of gasoline’s high energy density with the benefits of electric drive – providing an attractive combination of fuel efficiency, good performance, and normal automobile range. However, there is another tradeoff. They do so at the cost of vastly increasing the vehicle’s complexity.

Vehicles that carry their energy supplies also require infrastructures of energy supply points, such as coaling stations for steamships and trains, gasoline stations for automobiles, and charging stations for battery-electric automobiles. Clearly these supply points must be strategically located within transportation networks, and the density with which they are distributed will depend upon vehicle ranges. Short-range vehicles will either be limited to use within the immediate vicinities of their supply points, or will require many, closely spaced supply points. Longer-range vehicles will be less local to supply points in their use, and will require less dense distributions of supply points.

The effects of this simple logic can be traced in settlement patterns. In the pre-industrial era, settlements often grew up around points on stagecoach runs where horses were replenished. Similarly, railroad towns developed at locations where coal and water could conveniently be stored. Later, the automobile produced the emergence of gas stations at busy intersections, highway off-ramps, and so on. Frequently, energy supply points have a ‘village well’ effect – providing an attraction that creates opportunities for other businesses, and for social space.

Finally, energy supply points must themselves be supplied in bulk – and this can be difficult and expensive when they are located remotely from sources. Thus railway towns were supplied by coal trains – often running on the same tracks as the passenger and goods trains that they supported. Gas stations are now supplied by elaborate global networks involving pipelines, tanker ships, and tanker trucks. At remote stations, as, for example, in the Australian outback, the cost of getting gasoline there makes it particularly expensive.

This logic applies not only to today’s fuels, but also to the proposed use of hydrogen and hydrogen fuel cells. In a hydrogen economy, hydrogen would need to be transported in bulk from production points, stored at hydrogen filling stations – much like gasoline stations, and carried in hydrogen fuel cell-powered vehicles.

11.2 Mechanical, Pipe, and Wire Distribution Networks

For powering fixed rather than mobile machinery, there is an alternative tradition of mechanical, pipe, and wire distribution networks. For example, the mills of the early industrial revolution clustered around central sources of water or steam power, and networks of shafts and pulleys distributed power to the machines on the mill floor. These forms of mechanical transmission could not operate effectively over long distances, so mills were compact. (Furthermore, the worker housing of the mill towns tended to cluster...
tightly around the mills.) Occasionally, this principle was extended to powering vehicle movement at a small scale – notably, for example, in the cable car system that still operates in San Francisco, and in ski lifts.

During the 19th and early 20th centuries, many cities acquired elaborate pipe networks for distributing coal gas to gaslights and gas stoves. The infrastructure consisted of centrally located gasworks, large gas storage tanks, and the necessary piping. These networks could service considerably larger areas than shaft and pulley systems, but they were still limited in scale by the cost of constructing and maintaining the piping systems, and by the effects of transmission losses. In principle, these systems might have incorporated stations for refuelling coal gas-powered vehicles, but this never became popular – although, in later years, compressed natural gas has found some use as a vehicle fuel.

Eventually, electric lighting replaced gaslights, and electrical supply networks developed at urban scale. Early systems simply had generators at fairly central locations and wires distributing power to wherever it was required – much as with the gasworks and pipe networks that they partially supplanted. (Mostly, gas systems did not go away, but modernized, and shifted their roles to supplying heating and cooking devices.) There was a small zone of electrification around a source, much like an oasis around a well. Remote settlements and isolated dwellings, with diesel generators and the like, still follow this simple spatial logic.

As the scale of urban electrical use grew, it became evident that it was often more attractive, from many points of view, to transport electricity rather than fuel over long distances. Hydro electricity, for example, must be generated at points of availability of falling water, and these are often in locations remote from cities. Similar considerations apply to large-scale solar, wind, and wave power. Electricity is cheaper to transport than coal, so it made sense to locate coal-fired plants near to sources of coal rather than near to the demand for electricity. And considerations of safety, air quality, and political acceptability have often mandated the location of fossil fuel and nuclear power plants remotely from population centres. Thus the now-familiar infrastructure of long-distance power lines developed. However, physically inevitable transmission losses continued to impose some scale limits.

Over time (this simplifies a very complex story), individual power systems linked up to form vast electrical grids that extend across nations and continents. These incorporate numerous power plants, serve many cities, and have redundant transmission paths. Their behaviours, and the associated management strategies, are complex.

One of the problems with traditional power grids, as they have developed, is that they do not incorporate batteries or other storage devices on a large scale. There is, for example, considerably higher demand during the day than during late night and early morning hours, so it is not possible to run power plants at optimal output all the time. A second problem is that, while grids can efficiently service predictable base loads, random peaks – such as those that occur on hot summer days when all the air conditioners are turned on – often require the expensive measure of bringing standby generators online for relatively short periods. And a third problem is that clean but intermittent power sources, such as wind and solar,
obviously cannot be relied upon to produce when needed, since they respond to Mother Nature, not the energy market. All this leads to strategies of fast-paced buying, selling, and moving electricity around in grids, and of managing demand through pricing – in particular, by making off-peak power less expensive.

An emerging alternative strategy, and one that is made increasingly feasible by inexpensive embedded intelligence, is to think of cities as distributed virtual power plants. Under this model, each building would function both as a consumer of electricity, and – through incorporating solar panels, wind turbines, fuel cells, etc. – as a small-scale producer and seller. Smart devices would buy electricity when prices were low (for example, dishwashers would switch on in off-peak hours), and fuel cells would come online to sell electricity back into the grid when prices were high. Transmission losses would be reduced, since electricity production and consumption would be closely co-located. And the whole system would be decentralized and redundant – much like the internet – offering potential reliability and service advantages.

Such a system would be even more like the internet, and even more effective, if it incorporated storage everywhere. This could be accomplished by storing hydrogen for fuel cells in distributed fashion, or through batteries or capacitors. Feasibility clearly depends upon technological advances that reduce the cost of these measures, finding good ways to pay for them, or some combination of the two; we shall return to this.

11.3 The Geography of Battery Recharging

Generally, in the interiors of buildings, we opportunistically recharge mobile phones and laptop computers whenever we need to. This works out reasonably well, since power outlets are never far away. And it means that very long battery life, while desirable, is not essential – allowing designers of these devices to minimize battery bulk and weight.

However, this strategy does not currently work for battery-electric vehicles on the exteriors of buildings. This is partly because the power outlets aren’t provided. Partly because there aren’t ways of charging users for power that is tapped in this way. And partly because the larger amounts of energy that must be transferred tend to make the process lengthier, more difficult, and more dangerous.

But these problems don’t seem to be insoluble. Imagine, then, a city that provided automatic recharging of battery-electric vehicles whenever they came to rest, and maybe even when in motion. Vehicles would function much like electric toothbrushes, which recharge whenever they are put back in their holders. Without loss of functionality or reduction of effective range, they could carry far fewer batteries, which would make them simpler, lighter, and more energy efficient.

One requirement for this is the development of effective, reliable, automatic charging mechanisms – perhaps through automatic mechanical connection, through inductive charging (as with electric toothbrushes), or through emerging technologies of wireless charging. A second requirement is for some combination of battery and capacitor technology that allows sufficiently rapid charging, and that works well under this pattern of charging and demand. And a third requirement is an architectural and urban design strategy for providing ubiquitous charging points in vehicle-accessible zones – most obviously (but this is not the only way) by incorporating them into parking stalls.

11.4 Dual-Use Battery-Electric Vehicles

When battery-electric vehicles are connected to the grid in this way, in large numbers, they become dual-use devices. When they are in motion they provide mobility in the usual
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way, and when they are at rest they provide the grid with storage capacity – creating the benefits discussed earlier.

Imagine a city, then, in which all cars are electric, and all parked cars are connected to the electric grid. If the cars have sufficient intelligence, and they have knowledge of electricity price patterns and their own use patterns, they can play the electricity futures market. When electricity prices are low, and they can anticipate that they will soon need to drive, they can draw electricity from the grid to charge their batteries. Thus, for example, a commuter car that is parked at home and will be used in the morning can be charged during late-night off-peak hours. Conversely, when prices are high, batteries are charged, and they can anticipate that they will be parked for a while, they can sell electricity back to the grid. There is already a body of research on car-to-grid electrical systems, and the concept seems very promising.\(^7\),\(^8\),\(^9\)

A system of this type should be able to make particularly effective use of intermittent solar and wind power, simply by taking the opportunity to charge batteries when extra power from these sources is available. Solar power output, for instance, usually peaks around solar noon, while mobility demand peaks a few hours later during the evening commute. Storage in the batteries of parked cars can effectively bridge the temporal gap.

The vision that emerges from all this is of a city that has small-scale electrical generation, electrical storage, and points of consumption scattered throughout. It makes particularly effective use of clean, renewable power sources, and utilizes simple, clean, silent electrical vehicles that produce no tailpipe emissions. It gains efficiencies through co-location of power production, storage, and consumption. And, like the internet, it achieves robustness through high levels of redundancy.

All this depends upon embedded intelligence everywhere, and the capability to effectively manage complex, dynamic electricity markets. There are many technical and policy issues still to be explored in depth. But this type of urban energy system does seem increasingly feasible, and promises a major advance in urban energy efficiency and sustainability.

11.5 The Role of Private Electric Vehicles

In most cities today, most of the vehicles on the road – cars, motor scooters, etc. – are privately owned. Private vehicle ownership allows realization of many, though not all, of the benefits that we have described.

A private ownership model would be based upon providing charging capabilities at homes, and in parking facilities at workplaces, shopping facilities, subway stations, airports, and other popular urban destinations. Over time, vehicles would be able to learn the habits of their owners, and so adjust their electricity buying and selling patterns to match them optimally – although, obviously, override capabilities would be needed to allow for breaks in routine.


Like private vehicles today, most of these electric vehicles would spend most of their time parked. However, unlike today’s cars and scooters, they would not be uselessly taking up space and consuming materials and embodied energy while doing so; they would be serving as the city’s battery packs.

The private vehicle ownership model has the advantage of fitting with the current business goals of automobile manufacturers, and of allowing incremental introduction. A system could begin with fairly sparse distribution of recharging points, and correspondingly large battery packs in cars to provide sufficient range. Then it could evolve, over time, into a system of much denser recharging points – allowing correspondingly lighter, simpler, shorter-range electric vehicles.

11.6 The Role of Shared-Use Vehicles

An alternative to private ownership, and one that has some significant advantages, is to provide urban mobility services through shared-use vehicles. This has been demonstrated on a significant scale, with bicycles, in the French city of Lyon.

In Lyon, bicycles are available, at numerous locations throughout the city, in specially designed bicycle racks (Fig. 11.1). A customer walks to a nearby rack, unlocks a bicycle by swiping an electronic identification card, rides it to the destination, and deposits and locks it at another rack. Rental, then, is one-way; customers do not have to return bicycles to where they obtained them. Prices are very low, since this particular system is designed as a public utility that substitutes for mass transit; use is free for the first half hour, and equivalent to subway fares thereafter. Patterns of demand are carefully monitored, and there is a system of retrieving bicycles from locations where there are excess bicycles for the demand to locations where demand is higher. Users can access a simple online map that provides real-time information about the current availability of bicycles at any location in the city (Fig. 11.2).

A profit-making, car-based system with many relevant features is that of ZipCar – which began in Cambridge, Massachusetts, and has now successfully spread to many other cities. ZipCars are available in parking spaces scattered throughout the city. (At the time of writing, there were about 500 of them in the Boston/Cambridge area.) They are rented by the hour. Customers locate and reserve them online, go to the chosen location, unlock the car with an RFID card, drive it away, and eventually return it to the same location. This is still two-way rental (as with traditional car rentals), but it provides access distributed throughout the service area, minimizes the complexity and time of the rental transaction.


The ‘retrieval problem’ in shared-use vehicle systems has been quite extensively studied, and a variety of solutions have been proposed. See, for example, Barth, Mathew, Michael Todd and Lei Xue, ‘User-Based Vehicle Relocation Techniques for Multiple-Station Shared-Use Vehicle Systems’ (November 2003), Transportation Research Board, Paper 04-4161, www.communauto.com/images/TRB2004-002161.pdf
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and allows vehicles to be rented for short periods at fairly low prices. It is particularly
popular, for example, with students who cannot afford to own cars but occasionally need
them for supermarket shopping, weekend trips, and so on.

In general, shared-use systems have the potential to reduce the number of cars on the road.
It is claimed, for example, that one ZipCar typically substitutes for about seven personal cars.

11.7 The City Car

The MIT Media Laboratory’s City Car concept proposes extremely convenient, flexible,
one-way rental in the context of an electric vehicle, distributed urban energy and mobility
system as discussed above. There are many potential synergies between these two ideas.

In a City Car system, shared-use electrical cars are available at stacks densely located
throughout the service area. Cars can either be stacked in parallel, as with the Lyon bicycles,
or in a first-in-first-out (FIFO) arrangement, like luggage carts in a cart vending machine
at an airport. Cars recharge while they are parked in the stacks. Parallel stacks take up a
fixed amount of space, independent of the number of cars actually parked, and allow a
customer to choose any available vehicle – important if vehicles vary in style and price,
and if some may not be sufficiently charged. FIFO car stacks, on the other hand, are very
compact, can vary dynamically in length, allow cars to charge as they progress through

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Fig. 11.1. Lyon bicycle racks.
Fig. 11.2. Location of bicycle racks and relative numbers of bicycles in Lyon, France (image: Andres Sevtsuk).

the stack (arriving at the back of the stack discharged, and reaching the front charged), and work particularly well when cars are uniform (Fig. 11.3); like taxis, you take the first one that comes along. Both arrangements have advantages and disadvantages, and probably find appropriate roles in different contexts.

Providing acceptable levels of mobility service with a City Car system is a matter of efficient queue management within a network (there are some parallels with packet switching computer networks), and can be investigated using queuing theory models. Pedestrians walk to stack locations. If there are cars available at a stack, waiting time is zero. If there are no cars available, pedestrians must queue and wait for cars to arrive — much as with taxi queues. Customers will drive for varying periods, and then want to deposit their cars at stacks near their destinations. If there are spaces available in the chosen stack, then the car can be deposited immediately, but if not, the driver must wait or go to another stack. The dynamics of the system are basically determined by patterns of mobility demand (as expressed, in the usual way, by origin-destination data), and by network capacity. The key measure of mobility service quality is total time from origin stack to destination stack, including any waiting time. Systems with more cars available will provide better mobility service than systems with fewer cars, but the cost will be higher. System performance will
be affected by spatial factors – particularly number and location of stacks relative to the time-varying spatial distribution of the demand, and congestion points in the road network. It will also be sensitive to vehicle characteristics such as charging time, pricing strategies, and to fleet management strategies – particularly to strategies for moving vehicles around to meet demand. Monitoring the performance of the system and collecting information on the daily trends can allow ‘experience-based’ improvements to the allocations of vehicles on a daily or weekly basis.

Mobile connectivity can significantly enhance the performance of the system. Unlike traditional taxi dispatching systems that can be hard to contact at peak hours, every vehicle can be equipped with an accurate real-time information system that reports the availability of vehicles and parking spaces throughout the city. This information can also be made available through cellular phones. Knowing the exact location and availability of parking at each stack, the system can solve parking queues in a much more efficient manner than a traditional ‘race’ for parking spots, where several drivers compete for the same place, by managing several cars at a time and suggesting alternative parking or renting solutions to drivers according to their current locations and queue situation.

A well-designed and effectively managed City Car system should provide the equivalent of instant valet parking everywhere, reducing the presently excessive amounts of gasoline, time and congestion spent on the search for cheap street parking.\textsuperscript{12} Preliminary studies suggest (although much remains to be done) that, in many contexts, this can be done at a sufficiently low price to make it attractive, while allowing a sophisticated operator to run a profitable service business.

From a sustainability perspective, this system has many attractions. It achieves much higher utilization rates for vehicles – so reducing the amount of material and embodied energy that must be allocated to urban mobility. It is environmentally benign (small footprint and light weight, silent, no tailpipe emissions), and meshes well with the distributed, renewable-friendly

urban energy systems discussed earlier (Fig. 11.4). And, through embedded intelligence, sensing, networking, and use of optimization algorithms, it lends itself to effective management for energy efficiency and optimal use of available parking space and road real estate.

It is hardly to be expected that large automobile and scooter manufacturers would initially welcome the shared-use model. After all, the goal under this model is to minimize the number of cars on the road, while auto companies want to maximize. But these companies currently market products that generally aren’t much different under the skin, have low profit margins, and face intense price competition. Furthermore, in many parts of the world, cities are reaching automobile saturation point – beyond which it is not feasible to increase the number of cars on the road – leading to dramatically restrictive responses such as the London Congestion Zone. In contexts such as the cities of China, where incomes and aspirations are growing, and private automobile ownership offers the seduction of expressing new-found freedom, wealth, and prestige, it seems likely that producing and selling automobiles will remain an attractive business. But, in areas that are approaching automobile saturation, and where considerations of energy efficiency and carbon emissions translate into consumer demand and political pressure, it may be increasingly tempting to move from an old-fashioned commodity product business into an innovative mobility, energy, and information service business.

11.8 Shared-Use Electric Scooters and e-Bikes

In some contexts – particularly in the rapidly growing cities of Asia – electric scooters and e-bikes may make more sense, in this role, than electric cars. They are simpler than cars, considerably less costly, and even more compact. In China, for example, the popularity of e-bikes has been growing rapidly in recent years.13

As with electric City Cars, as another design from the Media Laboratory’s Smart Cities group demonstrates, electric scooters and bicycles can be designed to fold into very compact configurations (Fig. 11.5). When folded, they can be pulled along like wheeled luggage. When parked, they can be locked into special racks and recharged (Fig. 11.6).

11.9 Combination with rapid transit

It is conceivable that this sort of personal vehicle could substitute for mass transit (as the Lyon shared bicycle system seems to do), or substitute for private automobile ownership
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(which seems to be the primary effect of ZipCar). Probably there are some substitution effects. But the most likely scenario, in our view, is that City Cars would complement rapid transit – essentially by locating car stacks at transit stops to solve the ‘last kilometre’ or ‘last ten kilometre’ problem.

Rapid transit systems are unbeatably efficient for fast, high volume transport between fixed points, and in recent years advances such as high speed trains and bus-rapid-transit systems have increased their usefulness. But they suffer from the inherent problem that departure points are rarely exactly where you need them, and destination points are only an approximation to where you want to be. For example, the large subway network (over 500 subway stations) of New York City provides for a significant portion of mobility needs of the city; however, like most radial organized cities the density of the subway network decreases towards the periphery of the city (Fig. 11.7). Correspondingly, the number of
households with private automobiles increases as access to the subway network decreases. With the notable exception of the upper east side of Manhattan, an overwhelming percentage of registered automobiles reside in these outlying areas.\textsuperscript{14}

Private automobiles, on the other hand, offer the flexibility of arbitrarily chosen departure and destination points, at arbitrarily chosen times – but at comparatively very high cost, and with undesirable side-effects. A combination of City Cars with rapid transit offers the best of both – with City Cars providing flexibility at both ends, and rapid transit providing speed and efficiency in between.

In the context of linear transit systems, such as Taiwan’s new high speed rail system, City Cars (or even smaller and lighter electric scooters) could provide personal mobility within a zone around each stop (Fig. 11.8). In radial systems, such as that of the New York

Suburban City Car stacks
Placed at the end of subway and commuter rail lines
*Ten mile radius (grey)

Fig. 11.9. Placing stacks on the last stop of the subway system in New York City. Circles represent a five-mile radius (image: Ryan Chin).
metropolitan area, City Cars could provide personal mobility at the sparsely served extremities, where it is mostly needed (Fig. 11.9). In dense transit grid systems, such as that provided by the London Underground, City Cars could provide personal mobility ‘infill’ between Underground stations (Fig. 11.10).¹⁵

Radial transit systems often require travel to the city centre and out again in order to move circumferentially. City Car systems, with stacks of cars at transit stops, can reduce this problem by creating ‘virtual rings’, as illustrated in Fig. 11.11.

### 11.10 Conclusion

Strategies for achieving urban energy efficiency frequently focus upon reducing overall transportation demand, and upon shifting demand from automobiles to public transportation. But there is abundant evidence that high levels of interconnectivity are crucial to vibrant, flexible, creative cities, and that the inhabitants of cities greatly value personal mobility, so these traditional strategies have significant downsides.

Here, then, we have proposed an alternative – an urban mobility system that takes advantage of ubiquitous networking and embedded intelligence to enable combination of compact, simple, lightweight, battery-electric vehicles with ubiquitous recharging infrastructure and sophisticated electrical grids and markets. It is inherently energy efficient, it makes optimal use of clean, renewable energy sources, it keeps mobility costs low, and it does not compromise convenience or quality. By solving the 'last kilometre' problem, it can work in effective combination with transit systems. And there are no insurmountable technological barriers to implementation in the near future.