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The Eco-Vehicle: A Sustainable Personal Transportation System

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Abstract

The automobile is one of the most popular technologies ever developed. However, automobiles are presently responsible for about 20% of global energy consumption and the effluents from internal combustion engines (ICEs) in cars pollute our air. The dominant role of the automobile in the economic development of the world's richest nations and the addictive convenience cars provide to consumers have created powerful socioeconomic momentum which will resist either shifts away from automotive transport or rapid changes in the mature technology used in modern cars. Nevertheless, substantial changes are unavoidable if are cars are to become sustainable.

Electric vehicles (EVs) offer considerable promise to reduce the negative impacts of automobiles on the environment. In principle, EVs are far more efficient than ICE vehicles in converting energy into motion. Most EVs currently on the market have been converted from ICE vehicles. However, the potential benefits of using electric rather than combustion engines to drive automobiles can only be fully realized with innovative, ground-up designs which are optimized take advantage of the unique characteristics of EVs. Since 1994, our team has worked to develop a tandem EV with innovative technologies in a ground-up design.

A safe, high performance prototype for city commuting and general use purposes has recently been completed. Design specifications predict energy efficiency of 50 km/l of crude oil, about triple that typically achieved by today's ICE automobiles. The maximum speed of our Eco-vehicle is 150 km/h. The time for acceleration from 0 to 50 km/h is 4.9 seconds. On 1 charge, this car goes about 140 km at a constant 80 km/h or about 130 km on a defined city driving schedule. We discuss some steps to further improve performance, reduce costs, win consumer acceptance and make EV technology sustainable over the long term.

Introduction

Industrialization has created unprecedented wealth, longevity, and convenience for many of the people fortunate enough to live in the industrialized countries. Unfortunately, negative impacts of this same industrialization are poisoning the air, land, and water, altering our climate, and irreversibly extinguishing substantial portions of our rich natural heritage of biodiversity. Perhaps no other product epitomizes so well addictive convenience and devastating consequences of our industrial society than the automobile.

Modern internal combustion engine (ICE) automobiles convert fossil deposits of ancient forests into CO_2, water, carbon monoxide, nitrogen oxides, sulfur dioxide, and other exhaust gases which foul the air we breath and warm the climate. People use cars for about 20% of global energy consumption. The hulks of discarded autos blemish the landscape and leach toxic materials into the environment. Fuel additives containing lead, which are still used in many countries, poison the air and soil and may be especially dangerous to the intellectual development of young children.

Despite the serious negative effects of cars on the environment, it seems unlikely that people will voluntarily forego the unparalleled convenience they provide. What would it take to make automobile manufacture and use sustainable? To answer this question, we must define the characteristics of sustainability with respect to personal transportation equipment. Sustainable development was defined by the United Nations Conference on Environment and Development as development which meets the needs of the present, without compromising the needs of future generations. To make automobile manufacture and use sustainable over the long term, automobiles must consume much less energy per distance travelled, be readily recyclable, and not emit toxic or climate altering substances in significant quantities.

We maintain that while ICE cars can be improved, they will never meet these requirements. Electric Vehicles (EVs), in contrast, have the potential to become sustainable in the near future. Even in the present case in which most electricity is generated from combustion of fossil fuels, using electricity to power a car is about 3 times more efficient, in terms of distance travelled per unit of fuel, than are typical ICE cars on the road today. Eventually, EVs can be completely powered by batteries charged by solar energy. Here we discuss the present state of the art in EVs and the requirements for EVs to be accepted in the marketplace and, eventually, to drastically reduce the negative impacts of automotive industrialization on the environment.

Convincing consumers to purchase commercial EVs will require performance similar to that available from concurrent ICE vehicles. Although environment-friendly products are popular, few buyers are willing to spend substantially greater amounts of money for inconvenient products with inferior performance. Most drivers today have the impression that EVs are expensive, slow, in both acceleration and top speed, and have very limited range. However, today's best EV technologies rival the performance of ICE vehicles in most respects. Electric vehicles can be also be expected to make rapid gains in those categories in which they lag.

Here we describe an example of the state-of-the-art in EV technology. Since 1994 the Eco Vehicle Project has been developing a tandem style EV which is small, light, and delivers high performance. The car, recently completed, was delivered to our team last week.

A state-of-the-art EV

Most electric vehicles which have been built to date have been based, to a greater or lesser extent, on conventional automotive technologies; these are termed 'converted EVs'. In some cases, for example low rolling resistance tires, such technologies are excellent for use in EVs. However, there are fundamental differences in the structural and functional requirements of cars powered by internal combustion and those powered by electricity. Use of many ICE vehicle components can reduce the performance of EVs. For this reason, we endeavoured to create a ground up design which optimized EV performance and avoided constraints which might have been imposed by some off-the-shelf ICE vehicle components. We used many innovative technologies designed specifically for EVs.

a b

Figure 1: *Conceptual drawing (a) and photograph (b) of the in-wheel drive system*

The Eco Vehicle is powered by small, highly efficient, brushless DC motors built into each of the back wheels (Figure 1). Each of these motors can output up to 36 kW of power (48 HP). The motors are integrated with the hub bearing, drum brakes, and a reduction gear into the wheel assembly itself, which is mounted on the suspension arm. The motor achieves an energy efficiency of 92%. The brakes incorporated in the back wheels are regenerative, recapturing the kinetic energy of vehicle motion and generating electricity to store in the batteries. Under typical driving conditions, only these back regenerative brakes are used. When additional braking power is required for safety, the front mechanical brakes are engaged. The total weight of each of the power units, including the motor, gear, bearings, and brake is a remarkably light 25 kg.

In ICE vehicles, the space below the floor is required for the driveshaft, subframe, exhaust pipe, and muffler, none of which are necessary for EVs. We use this below floor space for a battery-built-in-frame (BBF) which holds the batteries, keeping the center of gravity of the Eco Vehicle low, thereby improving stability (Figure 2). This frame was made from extruded aluminium. Fifty-six 4V sealed lead-acid batteries, weighing a total of 269 kg, are used to supply the 224 V required by the motors. In typical serial battery systems, uneven temperatures and charge/discharge cycling greatly shortens the lifetime of some of the batteries in the series. We minimize this problem by including a heat pipe in each battery cell of the BBF and using 18 individual intelligent chargers to optimize charging for 16 groups of 3 batteries and 2 individual batteries.

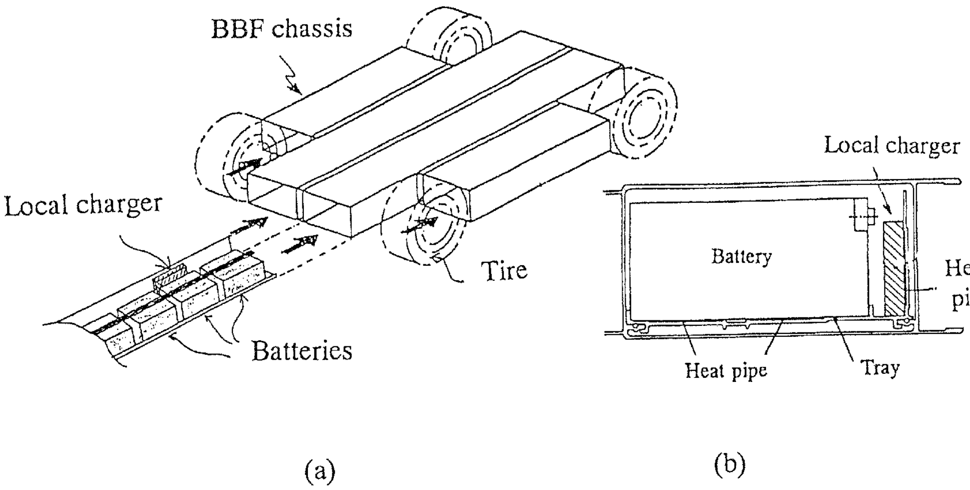

Figure 2: *The Battery Built-in Frame (BBF) structure (a) and associated battery system (b)*

Complete charging of the batteries from standard house current to the onboard charger takes about 4 hours. A quick recharge to 70% of capacity can be done in only 15 minutes with an external charger. The Eco Vehicle's roof and spoiler have been fitted with a total of 0.6 m^2 of solar panels (12% efficiency) which make a small contribution to charging the batteries during sunny weather. Under Japanese conditions (≈1800 hours of sunshine/year), a square meter of solar panels with energy efficiency of about 10% would recharge the batteries enough to power 1500 km/year of driving. Thus, about 5 m^2 of such panels would be necessary to generate the electricity to power this EV over the 7500 km which an average car in Japan is driven annually.

The Eco Vehicle's body was optimized to reduce aerodynamic resistance with iterative testing of models in a wind tunnel until an air drag coefficient of 0.25 was achieved (Figure 3). The final design was molded of carbon-fiberglass reinforced plastic (FRP) for strength and lightness. This body was mounted to an extruded aluminium frame built on the BBF described above.

The only performance characteristic in which the Eco Vehicle (Table 1) is clearly inferior to present ICE vehicles, for practical use, is range. Lead acid batteries have a very low power density. Use of an equal weight of the newest lithium ion batteries instead of lead acid would extend the range of EVs by about a factor of 3, bringing them close to the typical range of ICE cars. Battery technology is the bottleneck to improved performance in many commercial products, and the intensive research and development efforts now underway can be expected to produce dramatic improvements in the coming years.

Figure 3: *Body optimised to reduce aerodynamic resistance*

Attribute	**Value**
Length	3.3 m
Width	1.2 m
Height	1.3 m
Passenger capacity	2
Gross vehicle weight	910 kg
Range: constant 80 km/h	140 km
Range: 10.15 mode driving schedule	130 km
Acceleration: 0 to 40 km/h	3.9 s
Acceleration: 0 to 400 m	17.9 s
Maximum speed	150 km/h
Energy consumption	50 km/l crude oil

Table 1: *Eco Vehicle Specifications: Actual dimensions and computer projected performance.*

EV sustainability

A holistic evaluation of the impact of all aspects of automobile use, including not only manufacture, energy consumption and disposal, but also the associated infrastructure, suggests that complete sustainability is not feasible for the foreseeable future. For example, automobiles require paved surfaces on which to run. Paving seals the road surface, preventing infiltration of rain water which is necessary to recharge groundwater aquifers. When the proportion of paved and otherwise impermeable land surface increases to a large proportion of a region's total land area, then aquifer recharge is reduced and flooding is intensified, as is evident in large portions of Western Europe. However, despite such seemingly intractable environmental problems, there is little realistic prospect in the near future of societies voluntarily curtailing automobile usage to any great extent. On the contrary, the rapid growth of the industrializing countries is accelerating automobile production and use, a trend which seems likely to continue for the near future. Therefore, reducing the adverse environmental impacts of automobiles is urgent. Development of EVs is a promising way to accomplish this goal.

When electric vehicle technology matures, we can expect EVs to be more durable and reliable than present day conventional cars because they have fewer moving parts and are structurally simpler. Repairs also should be easier. Simpler cars should also be easier to disassemble for recycling at the end of their useful lives. This simplicity also permits wider, more comfortable passenger compartments (Fig. 4) than is possible in an ICE vehicle of comparable exterior size. Although EVs can be lighter than ICE vehicles, the side walls can be structurally reinforced to enhance safety. Perhaps the most sustainable feature of EVs is that they are ideally suited for the switch to renewable solar energy.

Any dramatic increase in the use of lead for EV batteries or any other application would be of great environmental concern due to this metal's toxicity. Several recent studies have projected that large increases in the demand for lead based batteries would require expansion of lead mining, recycling, and processing operations, and necessarily increase environmental lead release. However, these studies ignore the trend in commercially available electric vehicles to use newer battery technologies such as metal hydride and lithium ion batteries.

The dominant role of the automobile in the economic development of the world's richest nations and largest industrial corporations and the addictive convenience cars provide to consumers have created powerful socioeconomic momentum which will resist either shifts away from automotive transport or rapid changes in the mature technology used in modern cars. Nevertheless, substantial changes are unavoidable if cars are to become sustainable. EVs are far more efficient than ICE vehicles in converting energy into motion and emit virtually nothing while being driven. Given further technological development, effective marketing, and price reductions, as economies of scale reduce costs, EVs have tremendous potential to reduce the negative impacts of automobiles on the environment.