PRIVATE AND CONFIDENTIAL

DESIGN OF XS NRG™ AUTONOMOUS ELECTRIC VEHICLES

LABOFEX Technical Report #5, S2-005
August 1993

CONTENTS

ISSN 1915-8408

PREFACE

Over the last decade, the need for a solution to the electric vehicle (EV) problem has become increasingly pressing, in light of growing urban smog and noise, dwindling oil reserves, increasing costs of both oil exploration and drilling passed on to the consumer, as well as a generally increased awareness of the detrimental environmental impact of continued fossil fuel burning. Many problems have hindered the development of a truly practical EV, but none more than the limitations of existing charge storage systems.

In this Labofex Technical Report, we will discuss the problems associated with present day EV designs and the recent advances that have been made towards overcoming the limitations imposed by charge storage systems. We will then focus on the application of the novel Labofex power generation technology, the XS NRG™ System, whose basic development has been described in another Labofex Technical Report **(1)**, to a radically new engineering solution of the problems of current EV technology.

It is our firm belief that the XS NRG™ technology (for which there are several patents pending) will make the electric vehicle not only practical, due to its self-sufficiency in terms of its available power, but also inexpensive and competitive. Aside from the multiple advantages presented by the Labofex power generation technology, the XS NRG™ autonomous EV has been designed to keep the drive train weight low without compromising acceleration or range. Distance capability, in fact, should be virtually unlimited within the constraints of normal maintenance, given that the onboard storage system is constantly replenished by an assembly of special plasma reactors (referred to as the Labofex Pulse Generators, LGEN™) which, in the context of the XS NRG™ System, are capable of producing energy outputs much greater than breakeven **(2)**. These LGEN™ plasma reactors are pollution-free, lightweight

ISSN 1915-8408

devices made of fully recyclable materials that are available in abundant and inexpensive supply. In addition, the projected drive trains employing the XS NRG™ System can provide substantial weight reductions over current EV drive train designs. Finally, the XS NRG™ technology is a flexible one, in that it may utilize diverse charge storage systems, including batteries, such as lead acid or nickel metal hydride, and acceleration boosters such as flywheels or capacitive devices.

Labofex is currently engaged in negotiating licenses for the utilization of its proprietary technology, and joint ventures to implement a second phase of technical development that targets the application of its pioneering technology to the basic power consumption markets of portable power supplies, energy-autonomous buildings and electrical vehicles. We believe that the introduction of our technology to solve the EV problem will make superfluous the current need for a large and costly expansion of existing infrastuctures which would be required to charge EVs, and thus prevent a prospect that can only aggravate existing demands on electric utilities.

The tangible XS NRG™ concept of an energy-autonomous vehicle that does not require external re-fueling, will allow the automobile to leave behind a century of its dependence upon the internal combustion engine, to become the palpable reality of the fast, quiet, range-independent and pollution-free EV of the next century. Lastly, the following applications of the XS NRG™ System have a more encompassing nature than the models and examples presented in this Report, given that the Labofex proprietary technology can be equally applied to the power requirements of any vehicle by simply scaling the XS NRG™ System modules, including the plasma reactors.

As many have hoped, we are indeed at the threshold of a new era.

P.N. Correa, MSc, PhD
Director of Research

I

The Impasse of Current EV Technology

1. Introduction

The short history of the automobile since the dawn of the XX century, has been inextricably tied to the internal combustion engine. Accordingly, the preferred fuels for driving such engines have been octane and diesel fuel, both obtained from the purification of crude petroleum, as the energy density of these compounds during combustion is relatively high when compared to other fuels that have been experimented with, such as alcohols, methane and propane. However, despite the recent exploration of alternative energy sources with which to power a vehicle, eg solar energy and hydrogen fuel cells, few are practical substitutes. Although recent developments in hydrogen fuel cells have allowed the production of a prototype urban bus with a 128 kWh capacity **(3)**, such cells are of doubtful application to the design of electrical automobiles due to their size and weight. On the other hand, cleaner forms of combustion, eg utilizing a Wankel engine to burn hydrogen **(4),** have only succeeded in producing showroom vehicles that are more reminescent of golf carts than high power vehicles. Hybrid cars, be they combustion hybrids, electrical-combustion **(5)** or electrical hybrids **(6)**, have not fared much better. Clearly, **if the car is to survive its present day obsolescent existence, a radically new solution must be found to power it**.

Despite inadequate power sources, electric vehicles have existed since the early part of the century. Throughout this time they have continually suffered from severe drawbacks that prevent them from becoming a practical reality. Chief amongst these obstacles are:

1) the need for an extensive, urban and extra-urban, support infrastructure that addresses battery recharging;

2) the limited range of vehicle operation on one charge;

3) the offroad time it takes to charge the vehicle's battery pack(s);

4) the difficulty in providing adequate power for acceleration while avoiding major additions of battery weight;

5) the relatively low efficiency and short lifetime of current power storage systems;

6) the need for very sophisticated aerodynamics;

7) the wear and tear of DC drive trains and, lastly,

8) the difficulties in controlling a suitable AC motor alternative.

Electric passenger vehicles typically require 114 horsepower (85 kW) from the engine during acceleration **(7)**. Once rolling on a swift acceleration, these EVs do not have much juice left in their storage devices and are condemned to 'glide' along, so to speak, until they meet the limit of their radius. Even at cruising speeds, with an average electric power consumption value of approximately one tenth of the peak demand, a considerable amount of power is required to

 ISSN 1915-8408

travel any significant distance. Consequently, the main problem of EVs has been the enormous weight of the battery pack (typically ~395 kg) which stores the energy required for the drive train **(8)**. Despite reams of research designed to improve electric energy storage using both battery and flywheel systems, the goal of making an EV which can travel greater than 320 highway km on a single charge remains, until today, elusive to the car industry **(9)**.

Nevertheless, because resolution of the clouded future of the automobile is a pressing need, car manufacturers all over the world have in recent years engaged in further research towards overcoming these major obstacles to the implementation of practical, affordable and attractive EVs. Forefront advances in battery systems aim to increase the practical energy density of battery storage systems beyond the levels of nickel metal hydride technology. As well, two new systems for fast energy delivery and retrieval are in the experimental stage of their application to the EV problem: the inertial flywheel and the supercapacitor, both made possible by advances in composite materials.

Even if these recent technologies become practical over the next few years, without the XS NRG™ technology, the electric vehicle will still require upgrading of the utility grid to meet battery charging requirements and the range of these vehicles will still be limited to a fraction of that of a conventional internal combustion vehicle. Lastly, the burning of fossil fuels will be merely displaced from the consumer level to the utility companies, who are heavily dependent upon non-renewable energy sources such as coal, oil, natural gas and nuclear fission reactors.

In the course of this document, the reader will realize how the XS NRG™ system of power generation can be directly applied to make an autonomous electric vehicle into a practical reality. The car, and implicitly, any other vehicles will then be free from their dependance upon non-renewable energy resources. And oil wars too, may become a thing of the past.

Fig. 1- Carts with solid wooden wheels mark the begining of wheeled locomotion, as shown in the Standard of Ur, ca 5,000 years ago; by 700 BC spoked wheel carts appeared in the Altai, Assyria and the Netherlands, as their utilization by nomad peoples disseminated the innovation. Only a century ago, did horsepower yield to the internal combustion automobile as the preferred means of wheeled locomotion.

2. EV Energy Storage Systems

2.1. Battery systems

Since the turn of the century, two secondary, or rechargeable, batteries have been available commercially: the lead acid pile and the Edison nickel iron pile. The lead acid battery is easier to manufacture and less expensive and, as a result, it has dominated the market. However, only in the last three decades has battery technology improved significantly.

Nickel cadmium batteries, which have been known since 1909, were re-introduced in the 1950's with improvements that made them suitable for electronic devices such as computers, consumer electronics, handheld radios, etc. Even so, these secondary batteries are not suitable for application to EVs, as they have a poor cycle life, cadmium is highly toxic and world supply of the metal is scarce. Further research on the nickel cadmium problem led researchers to the nickel-metal hydride battery which recently has shown promise of delivering up to 70 Wh/kg **(10)**, as compared to 33-37 Wh/kg **(11)** for existing lead acid batteries (typical life cycles of 200-250 at 50% withdrawable capacity). Nickel-metal hydride batteries are also capable of >5yrs. of operation (or 1,000 cycles at 100% withdrawable capacity **(10)**), as compared to 2yrs. for the present lead acid type.

Other manufacturers have concentrated their efforts in improving lead acid technology, eg the use of lead-calcium alloy grids and techniques to adsorb the acid to silica nodules have been employed in order to extend cycle lifetime 3-fold (~1,000 cycles at 50% discharge) and raise the energy density to 45 Wh/kg **(12).** Recent developments in bipolar battery technology may also allow improved energy densities. For example, bipolar Li/FeS_2 batteries, with an operating temperature greater than 300ºC, have attained an energy density of 180 Wh/kg **(13)**.

Another technical problem which still plagues secondary batteries is the length of time required for charging. A typical lead acid system requires from 2 to 8h of continuous charging **(8, 9, 14)**. EV battery charge time will be a particular problem in regions like Europe where few households have garages for private overnight charging. However, intermittent charge systems currently being investigated may reduce charging time considerably **(12)**. As well, research on experimental nickel cadmium systems, which are capable of being partially charged in 15 minute periods, is still ongoing **(15)**. While reduced charge time is advantageous, as explained above, nickel cadmium's widespread application to the EV market remains rather unlikely.

Other improvements in rechargeable zinc-air battery technology have projected energy densities up to 300 Wh/kg **(16)**. This technology has been experimentally applied to an average car to yield a range of ~335 km/charge **(17)**. However it appears to have a short service life and must be used with a power concentrator battery, such as nickel cadmium or lead acid, due to its low peak power output.

Aside from further developments of secondary or rechargeable batteries, metal manufacturers have recently dedicated much research to primary or mechanical batteries. Improvements in air cathodes have allowed aluminum-air/lead acid hybrid vehicles to reach a range of ~320 km, though, once started, the aluminum/air reaction will only stop when the aluminum anode is completely consumed over a lifetime of 1,000 hours **(6)**.

 ISSN 1915-8408

2.2. Flywheel systems

Aside from battery systems, flywheels are other charge storage devices that may be employed in an electrical vehicle. The best materials for flywheel rotors are carbon fiber composites. Alternative materials such as steel fibers, which are wrapped at the periphery of the rotor and encapsulated in an epoxy resin, have also been studied. A two cubic foot unit utilizing carbon fiber composite technology, which is presently being developed by Lawrence Livermore National Laboratory, is capable of delivering 25 kW of energy while operating at 20,000 rpm. The energy transduction efficiency of this flywheel system is ~95% **(18)**. However, for a flywheel system alone to provide, in a single charge, for both multiple accelerations and a driving range in the order of 320 km, stronger tensile materials and higher rotational speeds (as the energy stored increases as the square of the rotational speed) are required. Further engineering problems that will have to be addressed include the development of light weight, vacuum tight containment vessels of very high tensile strength capable of withstanding rotor disintegration in case of a serious accident; very high speed magnetic bearings capable of withstanding moderate shocks; and suitable suspensions to prevent the routine bumps of driving from being transmitted to the rotor.

An improved, high power, anisotropic dual flywheel system that addresses these concerns, has been described by American Flywheel Systems Inc. in its recent US patent **(19)**. This anisotropic flywheel system operates with rotor speeds up to 200,000 rpm under vacuum conditions of <0.001 Torr, and is coupled with magnetic and liquid bearings. With typical specific power of 5500 W/kg available and an energy density of 165 Wh/kg, its operational life is estimated to be greater than 25 years with at least 10,000 cycles obtainable. Assuming a start-up speed of 200,000 rpm, an electrical vehicle powered solely by this anisotropic flywheel system, would require a total flywheel rotor weight of 132kg. Due to the incredible stresses at these rotational speeds, composite materials with tensile strengths of at least 0.6 million psi are necessary **(19)**. Accordingly, the most promising composite materials are fused silica, with a tensile strength of 2 Mpsi and Technora, which has a tensile strength of 598 kpsi **(19)**. The energy densities for these materials are high, at 400 Wh/kg and 190 Wh/kg, respectively.

While progress in the field of composite fibers is expected to extend the energy density much further, this anisotropic flywheel system already has a much greater energy density than current nickel-metal hydride or lead acid batteries. The American Flywheel Systems patent also addresses the problem of accidental destruction of the rotor by surrounding the flywheel with a cylindrical composite fiber casing which has a heat resistant silicon carbide lining. Such a casing would be able to withstand both the heat generated and the rotor debris, should disintegration inadvertently occur. However, cost may be a key drawback of this device due to the precise machining involved.

The most promising recent application of flywheels in vehicles, has been in regenerative braking systems. Instead of dissipating the car's kinetic energy in the form of heat in the brakes, as cars normally do when braking, regenerative braking systems transduce most of this energy into a flywheel, where it is stored and then used to assist the engine during acceleration.

ISSN 1915-8408

2.3. Capacitive boosters

Until recently, capacitive energy storage systems for EV applications have not been practical because of their poor energy density. Nonetheless, capacitors have the advantage of being able to instantaneously deliver the entirety of their charge and be immediately recharged, making them particularly adapted to take on transient loading cycles. This fact makes them a prime candidate to act as a power booster during acceleration and as a temporary storage system to recover the energy from regenerative braking (via a flywheel). For this reason, research geared to increase the energy density and to decrease the volume of these devices has recently received much attention. Efficient capacitors with an energy density of 816 J/kg **(20)** are at present commercially available, and supercapacitors with an energy density of up to 7,200 J/kg (2 Wh/kg) have been experimentally tested in the United States **(21)**. The target figure for new designs is 18,000 J/kg or a minimum energy density of 5Wh/kg **(21)**. However, scientists at Kiev's Frantsevich Institute For Materials Science Problems have recently claimed to have already achieved supercapacitor energy densities in the order of 28,000 J/kg **(22)**.

It has been estimated that an electrical vehicle utilizing a capacitive booster for acceleration and able to re-charge its capacitive booster with regenerative braking, would require a 300 to 500 Whr capacity booster to load level its main energy storage battery **(21, 23)**. If an ultracapacitor with 5 Whr/kg may become available, a capacitive booster would weigh approximately 100kg. Although this will add a substantial amount of weight to the drive train, it will bring capacitive systems to a practical level of application to EVs and replace the flywheel in the regenerative braking system of electrical hybrid systems.

TABLE 1

A Comparison of Selected Energy Storage Systems

System	Specific Energy in Wh/kg	Peak Power in W/kg	Cycle Lifetime @100% withdrawable capacity
Regular Lead Acid **(11)**	33-37	228	200 cycles
Advanced Lead Acid **(12)**	45	NA	~600 cycles
Nickel Metal Hydride **(10,24)**	70	245	1,000 cycles
Zinc-Air **(16)**	300	NA	NA
Anisotropic Flywheel **(13)**	165	5500	>10,000 cycles
Capacitive **(15)**	2	7200*	NA

NA-information not available
* based on a 1 second drain

ISSN 1915-8408

3. Motors For Electric Vehicles

Two types of motors have been commonly used for high horsepower traction applications, AC and DC motors. The main subtypes of these motors which we shall now consider are compared in Table 2.

The **AC** motor category includes the utilization of both **induction** and **synchronous** motors. For high power applications, the preferred types have been squirrel cage induction motors and synchronous permanent magnet (PM) and wound rotor motors. In the case of AC motors, speed control presents the greatest difficulty. All of these types of motors need inverters to convert the supply DC into a variable frequency AC sine wave or other useable waveform, at the motor input, in order to control the speed and deliver the polyphase AC current. Variations of the frequency input to the motor must retain a constant voltage per cycle characteristic, and this demands complex frequency regulators **(25)**. In general, it is preferred that two, three or more phases be generated simultaneously to yield an efficient (>80%) utilization of power.

Synchronous motors, which lock into step with the rotating magnetic field, are built over a range of horsepower and speed greater than that of any other AC motor type **(26)**. The 3-phase synchronous motor also has one of the highest efficiencies amongst AC motors, however, it is one of the most difficult to control electronically **(27)**. Permanent magnets have been used to advantage by reducing both the weight of the wound rotor and the power demands, but rotor windings still require utilization of slip rings and carbon brushes for electrical contact. The inherent mechanical decomposition of the brush contacts due to friction, electrical arcing and carbon deposits, is also a continual problem in wound rotor AC motors. Another disadvantage of the synchronous AC motor is that it requires a second motor, either internal (typically, reluctance or induction start-up) or external (DC driven), to bring it up to synchronous speed, since there is no starting torque associated with this type of motor. AC synchronous motors are really intended for constant speed applications, as varying load conditions will affect their efficiency and power factor greatly.

Polyphasic squirrel cage induction motors present several advantages, in that they have strong start and stall torques and do not require slip rings or commutation. For these reasons, advanced EVs, such as the GM Impact, have utilized this type of motor **(7, 9, 28)**. However, the squirrel cage induction motors heat up rather quickly during acceleration. Due to higher core losses and the presence of "induced" currents, they are less efficient than 3-phase synchronous PM motors; though very reliable and of simple construction, they also have a worse weight to power ratio. Recently, however, developments in electronic commutation have yielded variable speed brushless AC induction motors that, so far, have had successful application to HVAC systems **(29, 30)**. Given their high stability and efficiency of operation, as well as their independence from rotor position at start up (unlike the electronically commutated DC motors discussed below), controlled induction motor systems will have an obvious application to the traction market.

The **DC** motors employed in traction applications can be divided into **three main groups**: field winding, permanent magnet (PM) and brushless PM. The advantage of using DC motors has been their ease of speed control, which is achieved by simply increasing the current to the field or rotor windings. However, this type of control is

 ISSN 1915-8408

imperfect, the mechanical commutator typically associated with such a system being prone to even more wear and tear problems than those associated with synchronous AC motors, and thus DC motors require frequent maintenance. The DC PM motor eliminates a sizeable percentage of both the weight and volume of the DC motor as well as reduces both the energy losses from heating and the power input requirements to the stator field. Nonetheless, this increase in efficiency still has to be balanced against the mechanical commutator problems.

Recent developments in brushless electronic commutation have allowed utilization of the PM DC motor with all of the benefits of this type of motor and with the low maintenance characteristic of the AC motors. This research has led to a vast number of designs using transistor or thyristor switching systems which may be coupled optically or magnetically to the motor shaft. The use of an electronic commutation controller that detects rotor-position and determines speed of rotation and torque, is advantageous because these parameters can be directly manipulated from an external system connected to the electronic commutator **(29)**.

DC motors have been used frequently for traction applications because of their high torque and ease of speed control. Design of these motors is very important in order to optimize their performance for the type of load to be encountered. Series wound DC has poor low-load characteristics and so, shunt wound DC motors that do not have this problem, are preferred. Shunt wound motors are speed stable, within 15% throughout their load range, whereas the speed of series wound motors varies 50% from maximum load to 10% load **(27)**. Efficiency for the DC motors mentioned above is typically 85% at full load **(27)**. While DC PM motors have high starting torques and are the lightest, smallest and most efficient of all motors, they can suffer from irreversible magnet damage caused by high stator fields in sub-zero temperatures. However, careful selection of permanent magnet materials that will withstand these conditions can eliminate this problem **(27)**. The efficiency of a brushless DC PM motor can be as high as 95% and in conjunction with the controller losses, it is still ~85% **(31)**. In comparison to AC induction motors for EV applications, DC PM motors of the same horsepower rating are somewhat heavier. Nonetheless, because of their favourable characteristics, the DC PM motors rank amongst the most likely candidates for application to future EVs.

TABLE 2

Performance Comparison of Selected high HP Motors

Motor type	efficiency	start torque	comment on EV appl.
AC synch **(25, 27)**	~85-90%	zero	needs start-up aux.; inverter required
AC PM synch **(25)**	~90-95%	zero	needs start-up aux.; inverter required
AC 3 ϕ Sq **(25, 32)**	~80-90%	high	inverter required
DC series **(27)**	85%	low	poor response during acceleration
DC shunt (27)	85%	high	requires mechanical or electronic commutator
DC PM **(27)**	>85%	high	poor low temp. endurance
DC BL PM **(31)**	95%	high	poor low temp. endurance

Abbr.- ϕ=phase; Sq=Squirrel cage rotor; BL= Brushless; PM= Permanent Magnet.

ISSN 1915-8408

4. The problem of the EV infrastucture

Given existing power generation technology, even if a suitable battery or other forms of energy storage systems, be they hybrid or not, are developed to adequately power an electrical vehicle, an extensive urban infrastructure of charging stations for EVs would still be necessary. Leaving aside the myriad of different charging methods possible or necessary (slow and constant, intermittent and rapid, replacement of electrodes in primary batteries, provision for hydrogen or gaseous hydrocarbons in fuel cell systems, etc) that might be contemplated for EVs produced by distinct manufacturers, there is the series of difficulties associated with having to everywhere introduce another support infrastructure into the crowded urban milieu. This EV charging infrastructure will require substantial improvements in Utility power grids in terms of energy storage and supply capacity, so that the enormous amounts of electricity required to recharge daily millions of EVs will be available. In fact, consumers will not be attracted nor convinced by EVs that after travelling for ~3 hours, would require overnight length periods of charging (~8h), before they may be re-utilized. If current EVs are to succeed and become a real commercial alternative, fast methods of charging uniformalized EV power systems will have to be found, and this could just as well stiffle the diversity of efforts on whose soil new ideas and methods arise.

Worse still, in the implementation path of existing EV technology, is the fact that Utilities are presently struggling to find alternatives to their environmentally hostile power generation systems (combustion of fossil fuels,

Fig. 3: The main problems associated with the present-day energetic urban infrastructure are smog, high humidity,low level ozone and the need for combustion support structures. The current solution for practical EVs is to create a new infrastructure of charging stations. Our XS NRG™ technology, once applied to the design of an autonomous energy EV, will eliminate both the problem and its current solution.

ISSN 1915-8408

nuclear fission plants, hydroelectric stations), such large increases in power demand required by an EV mass market, will force these Utility companies to further rely on forms of non-renewable energy generation and to further expand their facilities accordingly. Such a temporary solution can only drive up the cost per kWh of electricity for both the individual and the industrial consumer and increase long term environmental clean up costs. Economically and ecologically, these will turn out to be publicly unfavourable choices. For these reasons, and in light of the preceding technical considerations, **partial implementation of the current electrical vehicle on a mass scale is expected to be a protracted and difficult process**. It is predicted that it will take well over 10 years, before the current EVs will be able to gain even 10% of the market share, that is, if further battery development will permit and if a will to establish a massive EV infrastructure will prevail **(33)**. Many unsolved problems exist with current EV technology which makes its marketability dubious, since consumers would expect a reasonably fast recharge time, especially if the range of the EV is less than 320 km. To date, no battery or suitable hybrid power system has been able to fulfill the desired goals of a fast-charging time, a long life, low cost, and high power density.

The only EV solution that could truly be practical, is to endow it with its own onboard power-production system. However, such a vehicle will only be energy-autonomous if the energy density of the fuel will be very high, so that it does not require re-fueling, or at least, does so very infrequently, that for all effects and purposes, it is an autonomous, very long-range vehicle. Other than through the much taunted promises of "cold fusion" (see reference **1**), there is at present no power generation system that can even rank as a candidate to do so.

If the dream of the electrical vehicle will flounder, because of the high degree of improbability that such massive support infrastructures will be undertaken in the current absence of satisfactory EV designs, then we will be confronted with the inexorable progress of the internal combustion (IC) system and the litany of all of its consequences: depletion of oil reserves, lead, ozone and carbon monoxide pollution, tanker disasters, acid rain, etc. Furthermore, one may indeed argue successfully that the EV such as even its present conceptualization projects it, will not avoid this trend towards greater negative social, urban, biological and environmental impact of increased vehicular circulation, for all that it can do is to displace the problem of the existing IC vehicles to the hands of the Utility companies and those who might provide the EV recharging services. To these critics, the Utilities at best can only respond with the hope that in 50 years thermonuclear fusion will deliver on its already thirty year old promise of cheap, plenty and unending power. Therefore, current EVs with their need for a support infrastructure can only, at best, decrease the the pollution in major population centers, while contributing to, instead of detracting from, increased levels of pollution on a global scale. Moreover, **without energy autonomy, there will be only a weak stimulus for the development of EVs at best**.

It is thus easy to see that, if the energy and pollution problems associated with the transportation industry, and the car particularly, are displaced from being problems of the IC vehicle to become problems of the Utility power stations, the only possible outcome will be the burning of more fossil fuels, more reliance on nuclear fission plants (at a time when the public is not particularly receptive to the consequences of increasing the number of such reactors) and increased hydroelectric projects. If the consequences are the same whether existing EVs triumph or not, we must consider for a moment the toll that the car is taking and will continue to take on the planetary environment. Effectively, in these conditions, the EV will remain a polluter, but will have the appearance of being "clean".

ISSN 1915-8408

According to General Motors, total worldwide retail sales of cars and trucks in 1991 reached approximately 43.2 million units while in 1990 this figure was about 45.1 million **(34)**. In 1991, General Motors' automotive products net sales for that year totalled US$ 94,828 million, with just over 7.2 million vehicles sold worldwide **(34)**. Worldwide vehicle demand is expected to substantially increase throughout this decade, with more than half of this growth coming from the Asian and European markets. However, of the two, Asia is expected to increase the most with growth from places such as Japan, Thailand and Indonesia. In 1990, 7.26 million vehicles were sold in Japan alone, an increase of 8% from 1988. According to Toyota, approximately 9.4 million vehicles will be sold in Japan in the year 2000, while it is expected that, by this date, there will be 72 million vehicles in use in this country alone **(35)**. Another example of the growth of the Asian market is South Korea: it is expected that 2-2.5 million units will be sold there every year beginning in 1993, a total growth of 500% over the last four or five years.

As the density of vehicular traffic increases (there are presently almost half a billion vehicles on the road; by 2030 this figure is expected to double **(36)**), the use of fossil fuels to power cars, trucks and buses will soon make this sector both the world's largest consumer of energy and the single largest source of both local and global air pollution, as well as global warming **(36, 37)**. Motor vehicles burn more than 60% of the 17 million barrels of oil burned in the US every day **(37)**. One tank of gas produces about 300-400 pounds of carbon dioxide (CO_2) the most prevalent greenhouse gas. Motor vehicles now account for about 15% of the world's output of CO_2 and 25% of the US's domestic output **(37)**. Carbon monoxide is also emitted in substantial quantities and is estimated to be responsible for a 20-40% increase in global warming **(37)**. As well, motor vehicles account for 47% of nitrogen oxide emissions in OECD countries (70% within the US). The number of light vehicles is increasing at a rate well above that of population growth **(37)**.

These numbers are foreboding. They indicate that, if the electric vehicle could be introduced globally **without** displacing the combustion-generated pollution problem onto an equally polluting power generation infrastruture, then it would constitute one of the choice solutions to continued growth. It is clear that the electric vehicle could have a potentially vast market share, especially considering the size of the global automotive market and its rapid growth in regions with large population to land area ratios, such as Japan. It is equally impossible to ignore the deleterious impact on human health which is caused by the pollutants from internal combustion engines, especially in the concentrations which are present in cities such as Tokyo, L.A., Mexico City, etc, and other areas where there are high densities of internal combustion vehicles. A 1990 Ontario government report estimated that the public benefits of cutting the major ingredients of car-generated smog would represent a saving of >$1-billion a year in health costs alone **(38)**.

Aside from the facts that the EV, such as it stands, will neither solve nor contribute to the solution of the energy crisis and its attendant negative environmental impact, **the current EV is too expensive, its range too short, its speed too limited, and requires an extensive support infrastructure for its implementation**. For the EV to become a real non-polluting alternative devoid of secondary effects, and a practical and affordable one at that, the EV must be made energy self-sufficient. **Only with the XS NRG™ technology that Labofex has to offer, will the potential of the electric vehicle come to fruition with the design of truly autonomous vehicles employing their own clean method of power production**.

ISSN 1915-8408

II

The XS NRG™ Autonomous Electric Vehicle

1. The XS NRG™ System

After over a decade of research and development by the two inventors and founders of Labofex, a method for harnessing the energy stored in the valence lattices of certain metals has become a reality, in the form of an energy conversion apparatus, referred to as the XS NRG™ Power Generation System **(1)**. Central to the XS NRG™ System is the Labofex Pulse Generator (LGEN™), a plasma reactor designed and operated to generate >10x the energy it consumes (breakeven energy), and whose functioning depends upon a variety of controlling parameters **(1, 39)**. This energy output is then converted and stored by the XS NRG™ System **(1, 40)**. We have estimated that an experimental basic LGEN™ pack capable of supporting an XS NRG™ System output of 10 kW per hour, could last, if it were to run continuously at a repetitive rate of 24 PPS (utilizing 10 separate plasma reactors), circa 9 years for a partial consumption of 67% of the total fuel present in the reactors (see Table 3) **(1)**. This amounts to over 50,000 hrs of projected operation at this level. It could, therefore, easily outlast the lifetime of an electric vehicle.

A block diagram of a typical XS NRG™ system is shown in Figure 3 and illustrates its modular design. The entire XS NRG™ system, as described, comprises 9 separate XS NRG™ modules plus two LGEN™ packs of 5 plasma reactors each, two motors (one AC, the other DC), and a storage system integrated in the XS NRG™ system via a

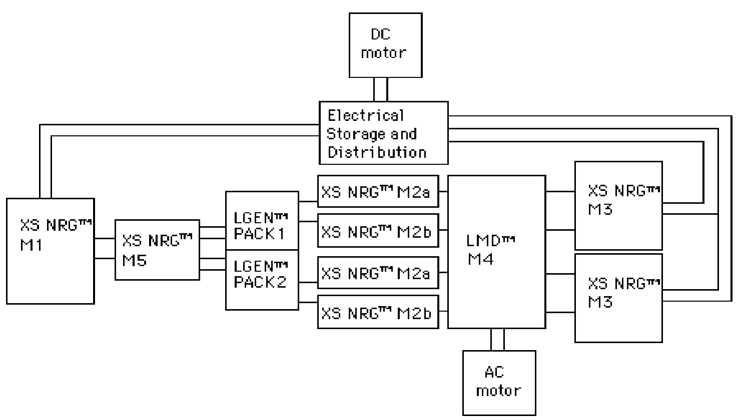


Fig. 3- A typical XS NRG™ Power Generation and Conversion System consisting of 14 components: the input module M1; the reactor distributor module M5; the two packs of LGEN™ plasma reactors; the two sets of M2 pairs of transducing interface modules; the Labofex Motor Drive™ M4 module and its associated AC motor; the regulator output modules M3; and the electrical storage and distribution modules, with the associated DC motor. The electrical storage is dual interfaced: at the input (load discharge), with the M1 module and at the output (recharge), with the M3 modules. Similarly, the two reactor packs are interfaced at the inport, to the M1 module, via the regulator module, and at the outport, to the M3 or M4 modules, via the M2 transducers.

ISSN 1915-8408

master controller and distributor. The two LGEN™ plasma reactor packs are two ported assemblies that communicate with an electrical storage system in two opposite directions: at the input, through the input module M1 and the distributor module M5; at the output, through transduction modules M2a and M2b, in conjunction with output modules M3 for the recharge function, or via the module M4 for AC electromechanical outputs. The reactor distributor module M5 controls and regulates the firing sequences of the two reactor packs.

The Labofex Motor Drive (LMD™) or M4 module is bypassed when the reactor output is channeled, through modules M3, to the electrical storage and distribution system. When AC motors are to be driven directly from the reactor, its output is shunted (partially or totally) and transduced via the LMD to the desired motor (see Fig. 3). The LGEN™ packs provide a variable frequency AC output suitable for single phase induction motors, when used with the LMD™ **(41)**. Polyphase versions of the LMD™ are equally possible and further technical development should make them suitable for powering 3-phase AC induction motors, without need for an inverter such as that employed in the GM Impact **(7, 42)**. Squirrel cage rotors could be employed to give adequate acceleration torques. The advantage of using the LMD™ direct electromechanical transformation method in an electric vehicle application, could be to drastically reduce the required capacity of the storage system. Assuming a conservative return of energy in excess of breakeven in the order of 500% from the plasma reactor **(1, 40, 41)**, and assuming a need for delivering 120.7 HP (90 kW) with an AC motor having an efficiency as low as 80% (and thus requiring 112.5 kW input to deliver the desired horsepower), a consumption of stored power of only ~25% of the delivered power at the motor input (or ~30% of the actual horsepower output) should allow for both motor acceleration at the LMD output and the recharging of the electrical storage system via the M3 output side circuits. For a peak consumption of 112.5 kW to deliver 90 HP of acceleration and still recharge the storage system by the breakeven amount, the storage drive requirement would be less than 28 kW. A lead acid battery system of 122.5 kg (228.6 peak watts/kg) could handle these power requirements in the XS NRG™ autonomous electric vehicle. If no recharge circuit is present or activated, the LMD™ output could require as little as 98.4 kg of identical lead acid batteries (22.5 kW peak power output), at the same 500% excess energy rate and the same motor efficiency of 80%.

The electric storage system can be a secondary battery system, a DC input/output flywheel system, a combination of the two or any other mechanism for the accumulation and delivery of direct current. The power storage system is managed by a power distribution controller which switches storage elements between the input and output of the XS NRG™ system so that they may alternately perform charging and driving functions in the most efficient manner. The power distribution controller is also capable of directing the stored energy to a load such as a DC motor. A DC motor or motor/generator set may equally be driven directly from the output(s) of the M3 modules (not shown).

On the other hand, AC input flywheel systems (with AC or DC outputs) can also be driven at the LMD™ output, ie directly from the outport modules interfacing the reactor packs, as was explained above for AC motors, thus bypassing the M3 regulator modules. The advantage of this LMD™/flywheel coupling would be further emphasized by the fact that flywheels have higher efficiencies of transformation than motors do, and higher storage efficiencies than batteries.

ISSN 1915-8408

2. The XS NRG™ Solution to the EV Problem

Technological improvements in power storage and converter equipment over the last decade, have gone a long way to allow the auto industry to make a practical and inexpensive electric vehicle, but the restrictions on horsepower, range and acceleration persist as a function of the limited charge that may be transported onboard; and this is fundamentally due to the still low specific steady and peak power of the charge and delivery systems employed. A typical EV requires 10 times more power during acceleration (peak power) than during cruising (steady power). Therefore, for an EV to be effective, this requirement must translate into a system which has sufficient storage capacity and high enough specific power to allow the storage system to deliver adequate acceleration while maintaining acceptable range. Recent research in battery technology has led to a practical solution of the acceleration problem but, as yet, it cannot solve the range limitations. Lastly, as we have already examined, there is the implicit need on the part of the modern EVs, for a recharging support infrastructure.

The key to making a practical EV independent of range and attractive for the mass market is to equip it with its own onboard power generation system, ie to make it energy autonomous. Utilizing this principle, the actual energy density of the storage systems employed to achieve range-independence, would not have to be as large as those required by conventional EV systems to reach the 320 km range barrier. This is just what the XS NRG™ System is potentially capable of doing, by using the excess energy extracted from the LGEN™ plasma reactor packs to replenish the batteries or flywheel(s), etc, at or above the average power consumption level. Energy self-sufficiency, under controlled conditions and at will, would effectively mean that there would be no limit to the distance such vehicle could traverse outside of the normal mechanical maintenance schedule. The weight to range ratio for such a vehicle would show a considerable improvement over present EV designs. Finally, due to the intermittent nature of the LGEN™ regime of plasma discharge, the cycling life of the battery storage systems stand to be significantly extended, as charge drainage will occur at lower levels of withdrawable capacity.

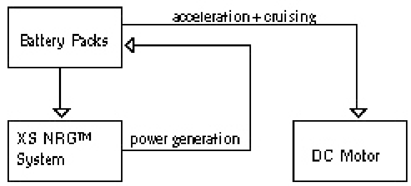
Three basic philosophies of approach are possible for the design of an XS NRG™ power plant integrated with the motor component of an electric vehicle:

- The first class of protoypes is based upon the utilization of battery systems for purposes of power delivery for acceleration and cruising, to drive the plasma reactors and to store the power generated by the XS NRG™ System;
- The second class of protypes utilizes hybrid battery/flywheel electrical storage systems, with variations in the delivery load allocation (power plant input, acceleration and cruising);
- The third class of protoypes also utilize hybrid battery/flywheel electrical storage systems, but the flywheel system and the motor(s) are coupled directly to the LGEN™ plasma reactors via the LMD™ modules.

The basic principles behind the three classes of contemplated prototypes are illustrated in Fig.s 4, 5 and 6. The first class of XS NRG™ autonomous EVs (AEVs) is described in Fig.s 4A and 4B, for its two Types, 1 and 2, respectively. Both Class 1 Types utilize the electrical storage system as the well for the power directly consumed by the vehicle motors for acceleration and cruising, and the power input source to the XS NRG™ power plant. Class 1, Type 1 vehicles utilize a brushless PM DC motor system (see Fig. 4A), whereas the Class 1, Type 2 vehicles utilize

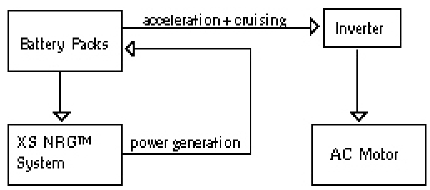
  ISSN 1915-8408

CLASS 1



TYPE 1

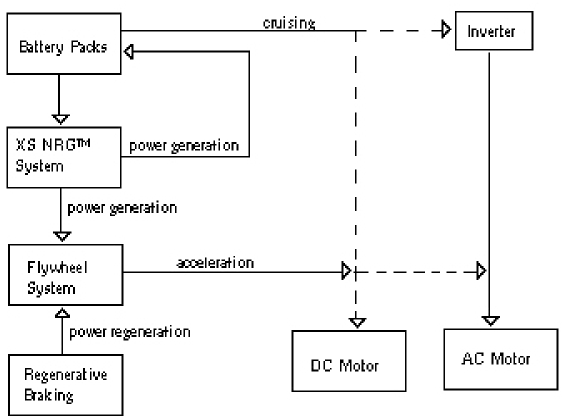
Fig. 4A- Basic power flow diagram for Class 1, Type 1 XS NRG™ autonomous EVs.



TYPE 2

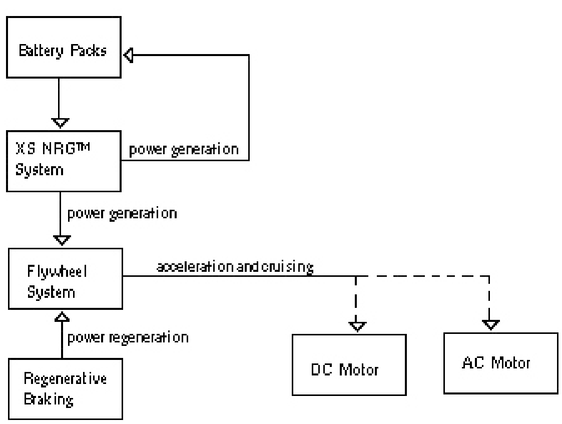
Fig. 4B- Basic power flow diagram for Class 1, Type 2 XS NRG™ autonomous EVs.

CLASS 2



TYPE 3

Fig. 5A- Basic power flow diagram for Class 2, Type 3 XS NRG™ autonomous EVs.

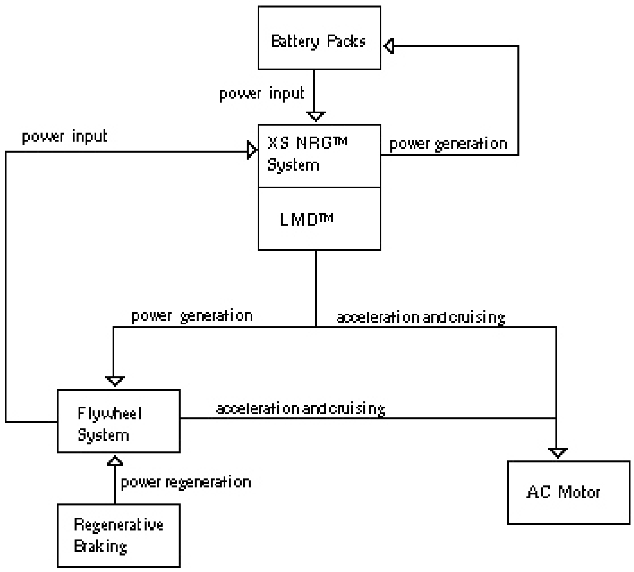


TYPE 4

Fig. 5B- Basic power flow diagram for Class 2, Type 4 XS NRG™ autonomous EVs.

ISSN 1915-8408

CLASS 3



TYPE 5

Fig. 6- Basic power flow diagram for Class 3, Type 5 XS NRG™ autonomous EVs.

instead the AC motor system, driven from an inverter interface with the battery system (see Fig. 4B). In both instances, the XS NRG™ power plant only recharges the battery system, hence the entirety of the charge produced by the XS NRG™ power plant must return to the battery before it can be utilized.

Class 2 XS NRG™ autonomous EVs are power storage hybrids. In both Types 3 and 4 of this Class, the XS NRG™ power plant recharges the battery and the DC input flywheel systems. Both Types 3 and 4 also employ a flywheel-coupled regenerative braking system to recover power lost during braking. Class 2, Type 3 vehicles utilize the battery system as the power source for cruising and to drive the XS NRG™ power plant, whereas the flywheel system is utilized as the power source for vehicle acceleration (see Fig. 5A). Conversely, Class 2, Type 4 vehicles utilize the battery system solely to drive the XS NRG™ power plant, and the flywheel system is exclusively in charge of power delivery to the motors, for acceleration and cruising (Fig. 5B). In this last Type of AEV, except for the breakeven energy which must be returned to the batteries, the remainder of the charge produced by the power plant never "sees" the batteries. As indicated in both Fig.s 5A and 5B, either Type of Class 2 may employ an AC or a DC motor system.

Finally, Class 3 XS NRG™ autonomous EVs utilize instead the plasma reactor packs as the direct well for the energy input to the parallel circuits of the AC motor(s) and the AC input flywheel system, the motor(s) being further serially coupled to the flywheel system (see Fig. 6). As in Class 2 prototypes, the XS NRG™ system recharges both the battery and the flywheel systems, and a regenerative braking system is equally present. The battery system is also employed solely to drive the XS NRG™ power plant. As we have have already examined in the preceding section, we estimate that the LMD™ method may be used in conjunction with the XS NRG™ power modules to considerably reduce the battery pack weight and size.

We shall now discuss some examples of these three engineering approaches.

ISSN 1915-8408

2.1. Class 1 XS NRG™ Autonomous EVs.

TYPE 1 AEVs

Shown in the block diagram of Fig. 7, for a Class 1, Type 1, is a front or rear two-wheel drive XS NRG™ Autonomous EV utilizing DC brushless PM motor systems. The following values for this design are estimates based upon a target maximum horsepower of 120 HP. For an XS NRG power plant output of 10-20 kW, built with improved plasma reactors **(1, 40)** and lightweight components (ultracapacitors, etc), 10 LGEN™ reactors operating at breakeven energy returns of ~2,000% should suffice for a maximum output of 20 kW per hour. Nevertheless, throughout the following descriptions, we shall utilize a paired set of two series of 10 LGEN™ devices each, for a total of 20 reactors in the entire XS NRG™ System. We have estimated a total weight of 24.7 kg for all the necessary XS NRG™ power modules, including the lightweight reactors. However, in accordance with the criteria of this approach, the battery system must account for the peak delivery of 90 kW, and the vehicle consequently gains considerable weight. With Pb-acid batteries having peak power outputs of 228.6 W/kg, 394 kg of batteries (with an overall energy density of 14.5 kWh/battery system for conventional Pb acid cells having a specific energy of 37 Wh/kg, and 17.7 kWh/battery system for advanced Pb-acid cells with a specific energy of 45 Wh/kg **(12)**) would be necessary to enable this peak power output. Utilizing instead Ni-Hy batteries (245 p W/kg), the battery pack weight could be reduced by ~27 kg, to ~367 kg (25.7 kWh/battery system, at a specific energy of 70 Wh/kg). These weight limitations of Type 1 XS NRG™ AEVs,

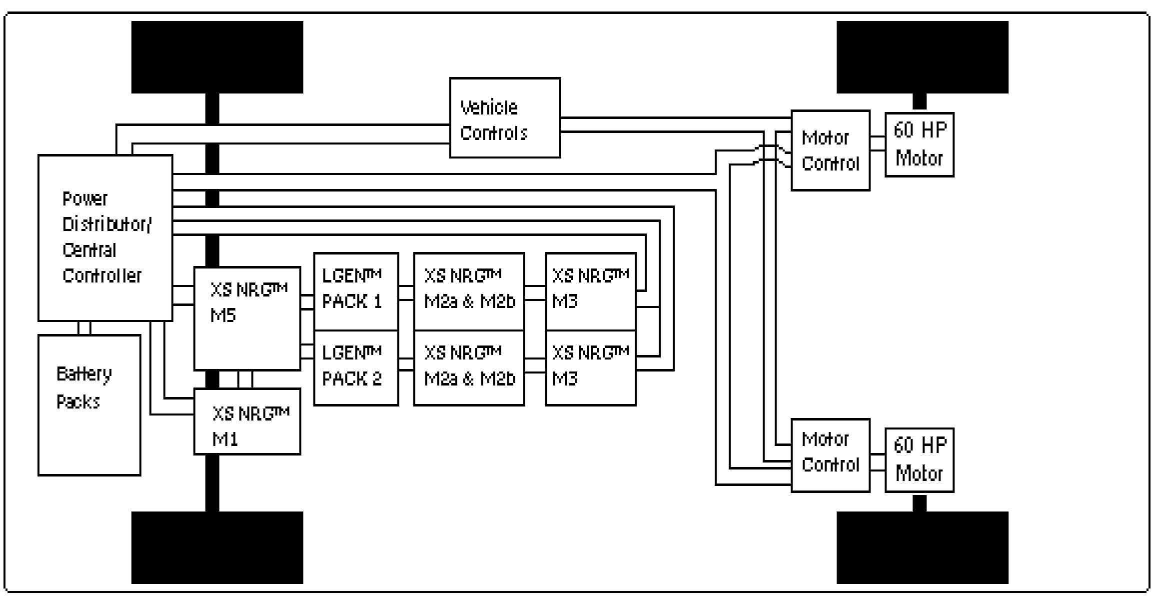


Fig. 7- Class 1, Type 1 XS NRG™ autonomous electrical vehicle (AEV) utilizing a DC motor system directly powered from the electrochemical charge storage system, which is in turn constantly charged by the plasma reactor-based XS NRG Power Generation System.

ISSN 1915-8408

stem fundamentally from the low peak power per weight ratio of these electrochemical storage systems. On the basis of these values, the entire drive train (motor(s) plus storage system, plus the "engine", ie the XS NRG™ power plant) of a Class 1, Type 1 XS NRG™ autonomous EV would weigh ~542 kg employing Pb-acid cells, and ~515 kg employing Ni-Hy cells (with estimated weight of the DC BL PM motor system put at 123.4 kg, see Table 3). The advantage of using Ni-Hy batteries over Pb-acid ones, in this Type 1 AEV, lies not so much in the small weight reduction it affords by the improvement in peak power per weight ratio, but on two other advantages, namely: **(i)** the fact that current commercial versions of these cells have a much longer cycling life (see Table 1), and **(ii)** the much higher energy density of these batteries (see also Table 1). These two characteristics result, respectively:

1) in a Type 1 vehicle that may require replacement of the battery system every 4 years (based upon an average of 1h/day of driving, with a very liberal power expenditure of 14.5 kW/h in driving the motor(s) plus ~2.9kW/h consumed driving the plasma reactors, (see Table 3), instead of every 1.6 years for even advanced Pb-acid cells; at the consumption rates of 6.2 kW attributed to the GM Impact when cruising at 88.5 km/h uninterruptedly **(8)**, the lives of the two battery systems would be more than double that, ie respectively, 9 years for the Ni-Hy cells, and 4 years for Pb-acid cells);

2) and in a Type 1 vehicle that has a larger power storage capacity and energy density (25.6 kWh/system with Ni-Hy cells vs 17.7 kWh/system with advanced Pb-acid cells).

Assuming a total of 60 accelerations per hour of continuous driving (1 acceleration/min.) and 10 seconds as the period of each acceleration from 0 to 120 km/h (75 mph), ten minutes out of an hour (17% of the time) may be spent in acceleration and would consume ~7.5 kW; a maximum of 7 kW may be further spent by continuous operation at cruising speeds up to 100-110 km/h (for 50 minutes out of each hour), to make a total liberal maximum expenditure of 14.5 kW per hour to move the vehicle. As the plasma reactors must equally replenish the breakeven energy lost in driving them, at conservative breakeven excess energy rates of 500%, this represents an expenditure of 2.9 kW to produce 14.5 kW, or a total consumption value of 17.4 kW per hour that need be replenished by the XS NRG™ System. At higher return ratios, this breakeven energy might be as low as 1-1.5 kW, for such XS NRG™ Power Generation Systems. By pushing the performance of the power plant to its upper limits (eg 20 kW), this power lost by the battery packs may be replenished by the XS NRG™ System in an hour or less, with a charging timing parallel to or faster than the timing of the power drain from the batteries, or be recovered by the charging operation of the power plant at slower rates of output power, when the vehicle is parked. Such central distribution of operations and co-ordination of timings, which involve the central controller and power distributor module and its associated control modules M1, M5 and M3 (see Fig. 7), could be easily automated for pre-selected options to be chosen by the consumer.

It is apparent that Type 1 AEVs can be made as 2WD vehicles with front or rear traction, having two DC motors of 60 HP each as illustrated in Fig. 7, or having a single 120 HP motor in either the front or rear shafts. Another possibility is to apply this Type 1 design to a 4WD vehicle utilizing viz. four separate 30 HP motors, one per wheel, whose differentials are synchronized by the central controller module.

ISSN 1915-8408

TYPE 2 AEVs

The second member of Class 1 XS NRG™ autonomous EVs utilizes the same basic power distribution and generation structure of Type 1, as described for Class 1 XS NRG™ AEVs (see Fig. 4B and Fig. 8); however, it deploys an AC induction motor system instead of the DC motor system of Type 1. As the AC motors are also directly driven from the DC power storage battery system (see Fig. 8), this Type 2 AEV will require an inverter coupled to its central controller module, much like that employed by the GM Impact electrical vehicle **(8).**

The battery packs for this Class 1, Type 2 AEV could encompass, as for Type 1, either a Pb-acid system or a Ni-Hy system having the same weights as in Type 1 (394 and 365 kg, respectively), and the total drive train weight, including the AC motor system (estimated at 125.4 kg) would be slightly higher, at 545 and 517 kg, respectively (Table 3). At the same power consumption and generation ranges discussed for Type 1 AEVs, the Ni-Hy battery system would have, once again, more than double the lifetime of the Pb-acid system, 4 vs 1.6 years, respectively (140,000 km vs 60,000 km, see Table 3), for an average of 1 h/day of driving at a maximum combined power consumption of 17.5 kW/h (motor input power plus breakeven power spent driving the reactors). If the cycling life, energy density and peak power to weight ratio are high, other battery systems can be equally considered for application to either Type 1 or 2 AEVs.

This Type 2 design would allow a major improvement in the range of an EV such as the GM Impact, with the utilization of similar Pb-acid batteries, by making it into an autonomous EV without a significant addition of weight: 545 kg for the entire drive train of Type 2 XS NRG™ AEVs vs 502 kg for the Impact **(7)** (see Table 3).

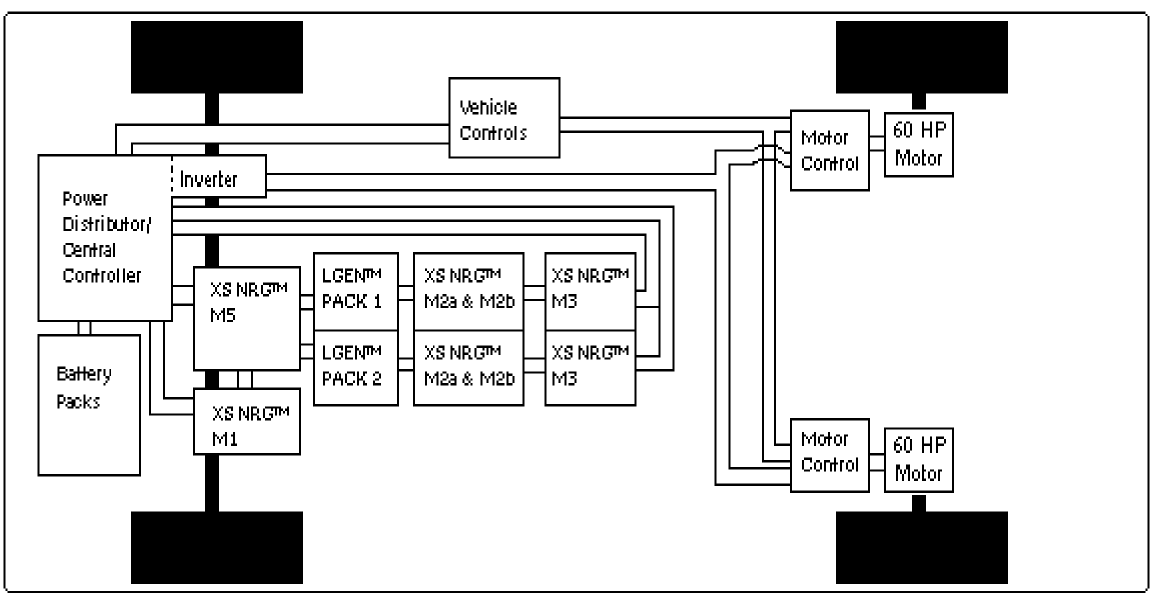


Fig. 8- Class 1, Type 2 XS NRG™ autonomous electrical vehicle (AEV) utilizing an AC motor system powered from the electrochemical charge storage system by a Controller/Inverter, which is in turn constantly charged by the plasma reactor-based XS NRG™ Power Generation System.

ISSN 1915-8408

2.2. Class 2 XS NRG™ Autonomous EVs.

TYPE 3 AEVs

New developements in carbon fiber composite materials and magnetic suspension principles have allowed small, lightweight flywheel systems having high peak power to weight ratios and high energy densities, to become practical storage systems that constitute an alternative to the electrochemical storage methods, for application to EV technology. In Figure 9, a Class 2, Type 3 XS NRG™ AEV equipped with a DC input flywheel energy booster is diagrammatically represented. In Type 3, the flywheel system takes on three functions (see also Fig. 5A):

1) It is charged at the DC input, directly by the output of the XS NRG™ Power Generation System;

2) It is charged directly with the power recovered by the Regenerative Braking System; and

3) It is discharged to provide for vehicle acceleration.

Aside from providing power to drive the XS NRG™ System (the breakeven energy), and being replenished in turn by this System, the battery packs in Type 3 AEVs are also utilized to deliver cruising power to the motor(s), which may be either DC or AC type. Assuming a maximal flywheel load of 7.5 kW spent per hour (during a total cumulative period of 10 minutes) in vehicle acceleration, as in the example given for Type 1 AEVs (p.22), and disregarding the ~80% efficient recovery of power lost in braking by the flywheel-coupled regenerative system, the batteries must

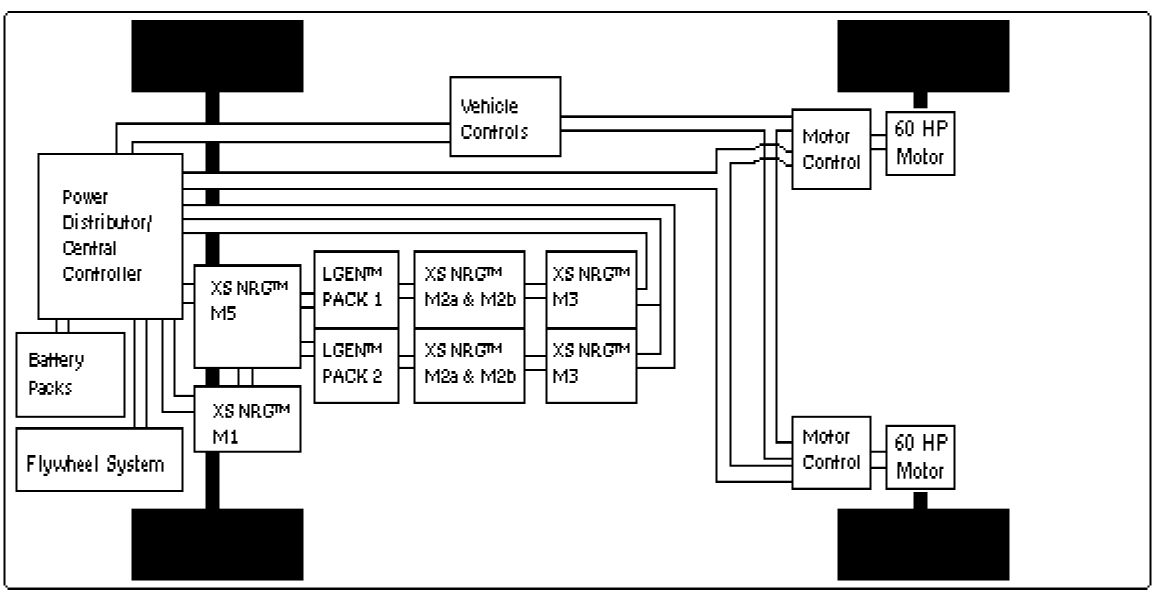


Fig. 9- Class 2, Type 3 or Type 4 XS NRG™ autonomous electrical vehicle (AEV) utilizing a DC (or AC, not shown) motor system directly powered from the joint electrochemical and flywheel charge storage systems, which are in turn constantly charged by the plasma reactor-based XS NRG™ Power Generation System.

ISSN 1915-8408

account for a drain of ~10 kW per hour (a maximum of 7 kW per hour for cruising consumption, plus 2.9 kW spent to drive the XS NRG™ System at ~500% breakeven efficiency). Under these conditions, the required weight of the anisotropic flywheel system having a practical energy density of 165 Wh/kg **(13)** and being applied to this Type 3 AEV, would be ~45.4 kg (see Table 3). When fully charged, such a flywheel system may supply up to 250 kW peak power, or nearly three times the peak power needed to accelerate a 120 HP vehicle. Swift acceleration would thus be possible with this Type 3 AEV.

In Class 2 AEVs, the minimum weight of the battery pack is determined by the energy density of the cells, rather than by the peak power per weight ratio which dictates the minimum weight of the battery pack in Class 1 AEVs. Accordingly, Ni-Hy cells having the higher specific energy of 70 Wh/kg can be advantageously employed to reduce the total drive train weight to 343.5 kg for a Type 3 AEV equipped with DC motor(s), and to 345.4 kg for a Type 3 AEV with AC motor(s). The required Ni-Hy packs would weigh together ~150 kg; if, instead, advanced Pb-acid cells were utilized, the battery packs would weigh 233.3 kg (vs 283.8 kg for conventional Pb-acid cells). Furthermore, unlike Class 1 AEVs, the reduction in size of the battery packs does not necessarily translate into a decreased life span for these packs:

(i) first, the load on the electrochemical system is reduced by >40% when compared to Class 1 AEVs, because the XS NRG™ power plant output that is utilized for acceleration comes directly from the flywheel system and never "sees" the battery system (hence it does not enter into the computation of the cycling life of the batteries); and

(ii) secondly, the battery power spent in cruising may be further offset by the flywheel which has an estimated lifetime of >10,000 cycles **(13)**.

However, ignoring any such offsetting by the flywheel system (which is fully exploited in Type 4 AEVs, see ahead), at an hourly average consumption of ~10 kW from the battery packs and a corresponding motor input of 14.5 kW per hour, a Ni-Hy pack will only last 2.9 years (100,000 km, see Table 3), and the advanced Pb-acid cells a comparable 2.8 years (90,000 km), making the latter a competitive option. As for the other values shown in Table 3, these estimates are made at an average 1h/day of driving (a maximum combined hourly power consumption of ~17.5 kW) and with a conservative 500% breakeven efficiency by the XS NRG™ power plant. Again, at hourly power outputs in the 88.5 km/h cruising range of the GM Impact (6.2 kW to the motor+breakeven energy=~7.4 kW, ie sensibly half of the maximum power output built into the XS NRG™ AEV examples so far discussed), the battery lifetime would be extended to approximately 4 years for both types of cells. The lower replacement cost for these smaller battery packs will more than compensate for these shortened lifetimes in relation to Types 1 and 2 AEVs, as the total expense incurred will be less than 50% for these packs of Class 2 AEVs, than for the Class 1 AEV battery packs.

Overall, Type 3 AEVs utilizing Ni-Hy batteries weigh approximately 33% less than comparable Class 1 AEV Types. On average, the weight reduction of the battery packs achieved by this Type 3 AEV, when compared to Class 1 Types, was ~60% for Ni-Hy batteries and ~30% for conventional Pb-acid cells.

Like Type 1 or Type 2 AEVs discussed, the type 3 AEVs may be front or rear two-wheel drive vehicles with one (eg 120 HP) or two (eg 60 HP) AC or DC motors, or a 4WD vehicle with eg 4*30 HP motors.

ISSN 1915-8408

TYPE 4 AEVs

Of the two Types (3 and 4) of Class 2 XS NRG™ AEVs, Type 4 (see Fig. 5B, and Fig. 9) affords the greatest reduction in the weight of both the entire drive train and the electrochemical charge storage system. By powering the DC or AC motors exclusively from the anisotropic flywheel system for both acceleration and cruising functions, the battery packs are left to exclusively power the XS NRG™ System, whose power generation, in turn, replenishes the breakeven energy lost by these batteries and charges the DC input flywheel, as for type 3 AEVs, directly from the output of the XS NRG™ System. With AC motor systems, the flywheel system would have an AC output, and with DC motor systems, it would have a rectified DC output. These alterations in AEV Type design result in concomittant increases in the flywheel weight, from 45 to ~90.8 kg (see Table 3), and decreases in the battery weight from 150 to 85.7 kg, for Ni-Hy cells, and from 283.8 to 162.2 kg, for conventional Pb-acid cells. This further decrease in battery weight represents a further improvement in both weight and maintenance costs, as it is greater by more than two-fold than the concomittant increase in flywheel weight. Hence, Type 4 XS NRG™ AEVs achieve a further reduction in the weight of the entire drive train, which is >40% lighter than Class 1 AEVs, with the utilization of Ni-Hy cells, and ~30% lighter when Pb-acid cells are utilized instead.

The block diagram of Fig. 9 thus describes as much the basic power circuits of Fig. 5A (Type 3 AEVs) as it does the Type 4 AEV circuit shown in Fig. 5B. The differences between the two Class 2 Types reside in the allocation of the driving load and the exclusive utilization of the batteries in Type 4 to drive the XS NRG™ Power Generation System. For a total of 17.5 kW per hour to be maximally spent in vehicle driving (see Table 3), the battery packs of a Type 4 AEV must deliver up to 3.5 kW to the XS NRG™ power plant (at 500% breakeven efficiency), for it to deliver in turn ~14.5 kW per hour to the flywheel system and recharge the breakeven energy lost by the battery packs (2.9+0.6=3.5 kW). This consumption of 3.5 kW by the XS NRG™ plant may be taken as the upper size of the battery pack of Type 4 AEVs, but as ~3 kW must exit and re-enter the battery system in one hour, the size of the battery pack should be increased to ~6 kW. Utilizing this value, a Ni-Hy battery system smaller by ~43% than that employed in Type 3 AEVs (and smaller by 76.6% than a comparable storage system employed in Class 1 AEVs), may be employed in Class 2, Type 4 XS NRG™ AEVs with an improved lifetime of ~3 years (100,000 km, see Table 3). If the operating breakeven efficiency of the XS NRG™ power plant is increased to ~1000%, or if the driving consumption is lowered to the cruising consumption levels of the GM Impact, the Ni-Hy battery pack would last as long as 6.6 years or 200,000 km. Another advantage over Type 3 AEVs, is that, in Type 4 AEVs, the battery replacement cost is further reduced by circa 40%, making this Type 4 AEV the cheapest to maintain.

In light of the above, Types 3 and 4 AEVs can be thought of as the two tendential poles of the drive train structure characteristic of the Class 2 XS NRG™ AEVs. A Class 2 AEV may be built such that the flywheel system offsets, up to 100%, the cruising load that might otherwise be taken up by the battery system. The resulting AEV is maximally flexible as to its source of power to be transmitted to the AC or DC motor systems employed. Higher, sustainable breakeven efficiencies by the XS NRG Power Generation System (**1**), would further contribute to make this Class 2 AEVs preferable over the Class 1 AEVs, in both maintenance cost and weight characteristics.

 ISSN 1915-8408

2.3. Class 3 XS NRG™ Autonomous EVs.

TYPE 5 AEVs

The flywheel systems (AC input) and the AC induction motors described in the preceding Class 2 examples, could both be optimally powered by the Labofex Motor Drive (LMD™) method, with its corresponding modules M4 integrated directly into the XS NRG™ power plant (see Fig.s 4 and 10), using a direct transformation technique of the excess power output from the plasma reactor packs. Practically the same savings in both weight and maintenance cost observed with Type 4 AEVs, would be obtained with this method, since the motor control circuitry could be simplified (no need for an inverter interface) and the battery size reduced just as substantially as in Type 4 AEVs, by driving the flywheel and the AC motors from the output of the plasma reactor packs (see Fig. 6 and Table 3). It is estimated that, with a 6 kWh Ni-Hy battery pack weighing 85.7 kg, the entire drive train would weigh a total of ~307.6 kg, and thus be slightly heavier than the Type 4 AEVs. The lifetime of these battery packs would be the same as calculated for Type 4 AEVs, but the AC motor systems of Type 5 AEVs would be driven, cumulatively and/or separately, from either the flywheel system, or directly, from the output of the plasma reactors. Like Class 2 AEVs, Type 5 AEVs may be front or rear two-wheel drive vehicles with one (eg 120 HP) or two (eg 60 HP) AC motors, or 4WD vehicles with eg 4*30 HP motors. Also like Class 2 AEVs, Class 3 may also utilize a Regenerative Braking System coupled to the flywheel.

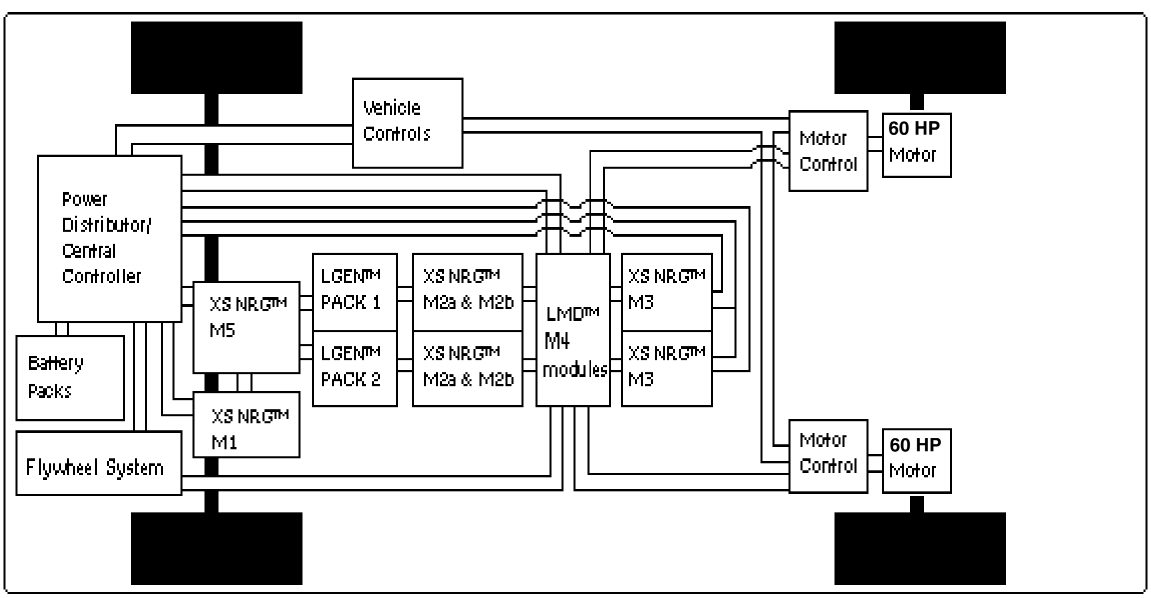


Fig. 10- Class 3, Type 5 XS NRG™ autonomous electrical vehicle (AEV) utilizing an AC motor system and an AC input flywheel directly powered from the LGEN™ plasma reactors by the LMD modules, which are in turn constantly charged by the battery-driven XS NRG™ Power Generation System.

ISSN 1915-8408

TABLE 3

Comparison of selected XS NRG™ AEVs with the GM Impact EV

EV GROUP	**XS NRG™ AEVs**								**GM EV**
AEV CLASS	**1**			**2**				**3**	NA
Vehicle Type	**1**	**1**	**2**	**3**	**3**	**4**	**4**	**5**	IMPACT [7,8]
				Weight characteristics					
Storage type	Adv Pb-acid	Ni-Hy	Ni-Hy	Ni-Hy	Ni-Hy	Ni-Hy	Cnv Pb-acid	Ni-Hy	Cnv Pb-acid
Battery weight, kg	394*	367	367	150	150	85.7	162.2	85.7	395
Flywheel weight, kg	NA	NA	NA	45.4	45.4	90.8	90.8	90.8	NA
T. drive train wt, kg:									
AC Induction	542		517	345.4		297.6	374	307.6	502 kg
DC Brushless		515			343				
				Power characteristics					
Battery sp E,Wh/kg	45	70	70	70	70	70	37	70	34.4
Flywheel sp E, Wh/kg	NA	NA	NA	165	165	165	165	165	NA
Pk pwr battery, kW	>90	90	90	36.8	36.8	20.1	37.1	20.1	90.3
Pk pwr Flywheel, kW	NA	NA	NA	250	250	500	500	500	NA
T. batt. capacity, kWh	17.7	25.7	25.7	10.5	10.5	6	6	6	13.6
Max XS NRG pwr,kW/h	20	20	20	20	20	20	20	20	NA
Max pwr to mtr,kW/h†	14.5	14.5	14.5	14.5	14.5	14.5	>16	>16	13.6
Max batt expend, kW/h¥	17.4	17.4	17.4	10.5	10.5	3.5	3.5	3.5	13.6
Av pwr output, kW/h‡	10	10	10	10	10	10	10	10	6.2
Sp pwr drive train,W/kg‡	18.5	19.5	19.3	29	29	33.6	26.7	37.5	13.5
Peak HP	120	120	120	120	120	120	120	120	114
				Range Limitations					
				Battery life, at a total 6.2 kW input to motor(s) per hour of driving (cruising at 88.5 km/h)					
in years (@1h/d)	~4	~9	~9	~4	~4	~6.6	~2.6	~6.6	~1.2
in km	130,000	305,000	305,000	125,000	125,000	215,000	85,000	215,000	39,000
				Battery life, at a total 11.9 kW input to motor(s) per hour of driving (cruising at 88.5km/h + 60 accelerations/h from 0 to 96.5 km/h)					
in years (@1h/d)	~2	~5	~5	~3.4	~3.4	~3.4	~1.4	~3.4	~0.4
in km	66,000	160,000	160,000	110,000	110,000	110,000	45,000	110,000	17,500
				Battery life, at a total 14.5 kW input to motor(s) per hour of driving (cruising at >180 km/h, or at 110 km/h + 60 accelerations/h from 0 to 120 km/h)					
in years (@1h/d)	~1.6	~4	~4	~2.8	~2.8	~3	~1.2	~2.8	NA
in km	60,000	140,000	140,000	100,000	100,000	100,000	40,000	100,000	NA

* This battery weight is a function of a peak power per weight ratio of 228.6 W/kg.

† This is largely determined as a combined function of the total capacity of the charge storage systems employed (batteries and flywheels) and the breakeven efficiency of the XS NRG™ power plant (in turn determined by the number of plasma reactors and the sizing of the XS NRG™ modules).

¥ Maximal battery power expenditure to accomplish a motor input equivalent to 14.5 kW per hour of operation of the vehicle (eg cruising at >180 km/h, or cruising at 100-110 km/h plus 60 accelerations per hour, from 0 to 120 km/h)

‡ Average power output and the average specific power of the drivetrain are determined for AEVs for an average urban driving consumption encompassing cruising at 60 km/h in between 2 stops per minute, and concomittant accelerations from 0 to 60 km/h.

NA- Not Applicable.

 ISSN 1915-8408

2.4. Comparison of XS NRG™ AEVs with current EV models

The characteristics of all these XS NRG™ autonomous electrical vehicles are summarized in Table 3 and compared with current EV models, particularly with the GM Impact which serves as a good reference parameter, in light of the fact that it still is the most advanced EV prototype so far. We shall thus first proceed to examine the characteristics of the Impact. As a typical EV, its range is limited by the size of the onboard charge storage system and, under specific conditions of power consumption, it will only travel as far as one cycle of discharge of this storage system will allow. As different driving conditions will determine correspondingly different power consumptions, these conditions must be clearly defined.

The total horsepower of the two Impact motors is 114 HP, its maximum range at a cruising speed of 55 mph (88.5 km/h) is 120 miles (or 193 km) **(7,8)**. The size of the Impact's Pb-acid pack is 395 kg, and it can store up to a maximum of 13.6 kWh (specific energy of ~34.4 Wh/kg) **(7,8)**. At the cruising speed of 55 mph, the Impact will spend ~6.2 kW per hour of driving, and will run for 2.18 hours (193 km) on a single battery charge. Utilizing this value, and in light of the fact that conventional Pb-acid cells, as were employed in the Impact, have a very short cycling life, in the order of 200 cycles at 100% withdrawable charge capacity (see Table 1), this average hourly expenditure of power in cruising would allow for a maximum lifetime of the batteries in the order of 439 hours or, translated into the range travelled by the vehicle prior to battery replacement, this gives ~39,000 km. If we are to utilize the same ruler as for the previous examples of XS NRG™ AEVs, at an average of 1 hour of driving per day, these Impact batteries would last only 1.2 years.

However, even abstracting from the actual power losses due to the efficiencies of the inverter and motor systems combined (circa 10%), this value greatly exaggerates the distance range imposed by the cycling life of the batteries employed. In fact, this range of power consumption abstracts from the great power expenditure incurred during acceleration, which is particularly frequent in suburban and city-driving conditions. For the Impact,~95 watts are spent per acceleration from 0 to 60 mph (96.5 km/h) in 8 seconds. City driving of an EV such as the Impact will typically oblige a driver to start and stop for short distances, and 2 accelerations per minute are common. As the acceleration maxima are targeted for speeds lower by ~40% (typically 37 mph, ie 60 km/h) than the rated 96.5 km/h of the Impact, we are safe to assume that these two slower accelerations per minute are approximately equal to one acceleration from 0 to 60 mph, per minute. Hence, for city driving, one must take into account 60 such accelerations from 0 to 96.5 km/h occurring per hour, or a total of 8 minutes spent accelerating out of an hour of circulation. This translates into 5.7 kW spent in acceleration per hour of vehicle operation. If, for the remaining 52 minutes out of an hour, the vehicle cruised, in between starts and stops, at a speed of 37.3 mph (60 km/h), corresponding to the maximum speed attained for two stops per minute, a consumption of 3.6 kW per hour of vehicle operation must be added to the acceleration consumption, to total 9.3 kW of power spent per hour of city driving. But if driving were in suburban highways, the maximum cruising speed between stops occurring more spaced apart, eg every minute, might easily reach 80-90 km/h, and thus attain the rated cruising consumption of 6.2 kW per hour at 88.5 km/h. Under these conditions, the power consumed in driving, would reach a maximum of 11.9 kW per hour of vehicle operation. The toll that these increasing power

ISSN 1915-8408

expenditures will take on the battery lifetime is readily apparent: for an average consumption of 9.3 kW spent per hour of driving (acceleration and cruising at 60 km/h max.), we estimate that the Impact Pb-acid pack would only last 292.5 hours, for a life of 200 cycles, which correspond to only 17,500 km travelled, or to a miniscule 0.8 years (a scanty 10 months) before battery replacement would be due, if the car were driven under these conditions at an average of 1 hour per day. Finally, if the total power consumption reached the maximum of 11.9 kW (for both acceleration, from 0 to 96.5 km/h and cruising at 88.5 km/h), the same Impact battery would only last 228.6 hours, and the car would have merely travelled ~20,000 km (see Table 3); this corresponds to a lifetime of six months for the Impact battery pack, before replacement is due. If the GM Impact serves as reference, it is easily seen that there are severe limitations to the implementation of EVs such as they presently stand. **Not only is their range limited by the size of their energy storage system, which adds considerable weight to the vehicle, but their battery storage systems have rather short lifetimes under the increasingly logjammed conditions of city driving**.

In Table 4, a comparison of various current models of electric vehicles is made with the proposed XS NRG™ autonomous electric vehicles. It is readily apparent that the EV group is severely limited in range and restricted in its maximum speed. The overall weight and the aerodynamic quality of present EV designs are crucial parameters to consider in current EVs, in order for the vehicle to have any practical range (~200 km), which none of the electric vans shown reach. These limitations arise, on one hand, from the low specific energy of the batteries employed, or when this is high, from low peak power per weight ratios (as in Al-Air battery hybrid EVs, see Table 4). Hence, the energy stored in the batteries is limited by their own contribution to the vehicle weight, and this results in severe restrictions on maximum horsepower available, maximum speed attained and maximum range reached.

As is apparent from Table 4, the XS NRG™ AEVs are projected and designed not to suffer from any of these limitations plaguing present-day EVs. The Labofex AEV Types are designed to free the EV from its present shackles of acceleration, top speed and range, by merging present EV technology with an onboard novel power-generation system that extracts large quantities of electrical energy from certain metals under vacuum conditions. Because of the very high specific energy of experimental fuels employed in the plasma reactors (see next section), and given that replacement of components such as the batteries (see Table 3 for these limits) is not an inherent limitation of these AEVs, and that the partial (66%) lifetime of an experimental reactor may last >9 years of continuous operation at 0.25 to 0.5 kW outputs (**1, 40**), **the XS NRG™-powered AEVs would have a virtually unlimited range of travel**, and thus compare favourably with the existing internal combustion (IC) engine vehicles. For the same reasons, the top speeds of the XS NRG™ AEVs are equally comparable to IC vehicles (see Table 4).

Moreover, it is easy to see how scaling of this technology for higher power models is readily performed by the simple addition of reactor series, sustaining higher breakeven efficiencies, sizing the charge storage apparatuses, and utilizing more efficient storage systems (eg electrolytic cells). The examples of the different Classes and Types given in this Report, were in fact uniformalized to a peak horsepower output of 120, only to impress upon the reader a comparison between XS NRG™ AEV Types, and with current EVs. They are in no way to be construed as limits to the design of any XS NRG™ powered AEV, which could just as easily be a car as a van, a bus, a truck, a bulldozer or a forklifter.

ISSN 1915-8408

TABLE 4

Range and speed comparison of XS NRG™ AEVs with current EVs

Vehicle	Make	Type	Range*, km @ Av. Speed	Av. Speed in km/h	Battery	Max. Speed in km/h
Iza (**43**)	TEPCO	car, 4WD	500	40	NiCad	176
Impact (**7,8**)	GM	car, FWD	193	88.5	Pb-acid	160
Future EV (**44**)	Nissan	car, FWD	250	40	NiCad	130
E1 (**45**)	BMW	car, RWD	230	40	Na-Sulphur	120
CRX (**17**)	SCE	car, FWD	346	100	Zn-Air	120
Altrek (**6**)	UM/A	car, RWD	322	48	Pb-acid/Al-Air	NG
Griffon (**31**)	GM	van, RWD	80-97	NG	Pb-acid	80
Aerostar (**31**)	Ford	van, NG	161	NG	NG	105
G. van (**46**)	SCE	van, NG	96	NG	NG	84
AAP (**47**)	UM/A	van, FWD	250	50	Pb-acid/Al-Air	110
Type 1	Labofex	DC m,FWD	>300,000*	100	Ni-Hy or Pb-acid	>180
		DC m,RWD	>300,000	100		>180
		DC m,4WD	>300,000	100		>180
Type 2	Labofex	AC m, FWD	>300,000	100	Ni-Hy or Pb-acid	>180
		AC m,RWD	>300,000	100		>180
		AC m,4WD	>300,000	100		>180
Type 3	Labofex	DC m, FWD	>300,000	100	Ni-Hy or Pb-acid	>180
		DC m,RWD	>300,000	100		>180
		AC m, FWD	>300,000	100		>180
		AC m,RWD	>300,000	100		>180
Type 4	Labofex	DC m, FWD	>300,000	100	Ni-Hy or Pb-acid	>180
		DC m,RWD	>300,000	100		>180
		AC m, FWD	>300,000	100		>180
		AC m,RWD	>300,000	100		>180
Type 5	Labofex	AC m, FWD	>300,000	100	Ni-Hy or Pb-acid	>180
		AC m,RWD	>300,000	100		>180
		AC m,4WD	>300,000	100		>180

* The Labofex examples of XS NRG™-powered AEVs are only limited in range by component failure and their normal maintenance schedule (eg battery replacement, see Table 3). In the case of the present-day EVs, range refers to the distance that the EV can travel on a single battery charge.

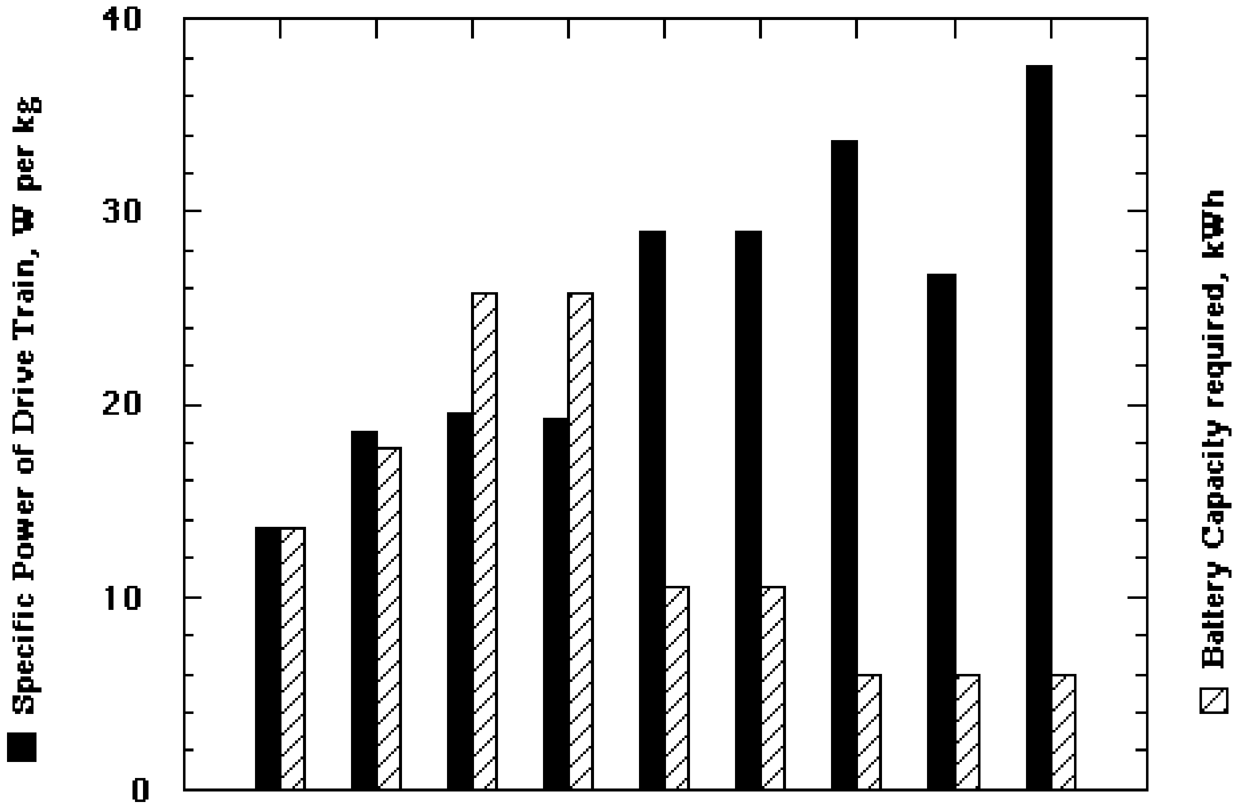
NG Values not available

ISSN 1915-8408

A comparison of the average specific power per weight ratio for all 3 Classes of XS NRG™ AEVs and the Type examples so far given, is presented in Fig. 11, together with the corresponding GM Impact values, introduced as reference. The total drive train weight, as defined, is composed of the charge storage systems (batteries and flywheels), drive motors, motor control and gear boxes, inverters (when present), power disribution systems, plus the LGEN™ plasma reactors, the XS NRG™ modules and the LMD™ modules (when applicable). The average power of the electric vehicle is defined as the power available during normal operation of the vehicle. In the case of the GM Impact EV, the batteries are designed to be run over a two hour period (2.2 h) at cruising speed. This would amount to an average available power of 6.2 kW **(7,8)** from the batteries to the power train. By stretching the power consumption to 6.8 kW (exactly half the power stored in the batteries), the Impact will run for exactly two hours, which corresponds to a case scenario of an hourly power consumption presented by urban driving at ~55 km/h between stops occurring every minute, and being followed by accelerations (60/h) from 0 to 60 km/h. In the case of the Type examples given for Labofex's AEVs, the energy storage and delivery systems have been designed to be capable of providing an average power of 10 kW. This corresponds to a case scenario of an hourly power consumption in urban driving at 60 km/h between stops occurring twice a minute, and being followed by accelerations (120/h) from 0 to >60 km/h.

By dividing the average power available by the weight of the drive train for each vehicle, a comparison of the power density of the vehicles and hence of the efficiency of the power train as a function of weight can be made (see closed bars, Fig. 11). The higher the W/kg figure is in the graph, the smaller is the power train for a given horsepower rating of the vehicle. It is clear from both Fig. 11 and Table 3 that the XS NRG™ AEVs readily outdo and outperform advanced electric drive trains such as that utilized in the Impact. The improvement is quite significant, even for AEV Types, like Types 1 and 2, Class 1, which, in relation to the power structure of the conventional Evs, just limit themselves to add the XS NRG™ power plant. In Class 2 AEVs, the utilization of more efficient charge storage systems with higher peak power per weight ratios and higher energy densities allows for a dramatic increase (250%, see Fig. 11, Class 2, Types 3 and 4, closed bars) in the average specific power of the drive train of the XS NRG™ AEVs over the reference value of the Impact EV (Fig. 11, closed bar). Finally, if the LMD™ modules are used for the direct electromechanical conversion of the LGEN™ surplus energy, the improvement in drive train power to weight ratio reaches 280% (see Fig. 11, Class 3, Type 5). Overall this means that, as the requirement for power becomes more independent from the electrochemical charge storage systems (as the batteries are freed from having to "see" the surplus energy generated by the power plant), as shown in Fig. 11, by the hatched bars that decrease inversely to the closed bars (specific power), the specific power of the drive train increases. Clearly, the ceiling for this increase depends on the power characteristics of the storage systems, which are far inferior to those of the XS NRG™ power plant, even in its experimental stages (see next section). From the above discussion, it can be seen that the XSNRG™ technology can substantially reduce the drive train weight while delivering substantially increased hourly power outputs.

Comparison of the average specific power of the drive train of XS NRG™ AEV's



CLASS	GM	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**
Type	Impact	**1**	**1**	**2**	**3**	**3**	**4**	**4**	**5**
Flywheel	**-**	**-**	**-**	**-**	**+**	**+**	**+**	**+**	**+**
LMD™	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**+**
XS NRG™ power	**-**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**

Fig. 11- Comparison of the average power to weight ratio (specific power) of the drive train of the XS NRG™ autonomous electric vehicles described in Table 3, and the GM' Impact. As the XS NRG™ power plant becomes more independent from the battery system (as we progress from Class 1 AEVs, on the left, to Class 3 AEVs, on the right), and the excess energy released from the plasma reactor is captured by means other than electrochemical (flywheel and LMD™ systems), the average specific power of the entire drivetrain increases (closed bars), while, concomittantly, the weight and the required capacity of the battery packs (hatched bars) decreases. The specific power and matched battery capacity of the GM Impact is shown for reference. It is apparent from this graph that there are definite advantages in combining recent technical advances in energy storage systems with the XS NRG™ technology.

ISSN 1915-8408

2.3 The significance of the first autonomous electrical vehicles

The fundamental difference between Labofex's XS NRG™-powered vehicles and all other EVs lies in their autonomy, that is, in their energy self-sufficiency, as afforded by their own onboard power generation plant, by the very high energy density (experimental studies have yielded ~425 MWh/kg(**1, 40**)) of the metal fuel utilized in the plasma reactor and the estimated high energy density of the XS NRG™ systems employed in the AEV examples discussed (up to 163 MWh/kg at 2000% breakeven efficiencies) **(1, 40)**. With a potential average 40 MWh per reactor fuel partial lifetime (67%) based on existing experimental investigations **(1, 39-40)**, a reactor pack for the AEV Types exemplified could generate ~45,000 hours of electricity at an output of 17.4 kW/h (to deliver a motor power input of 14.5 kW/h, at conservative 500% breakeven efficiency). This is enough potential energy to easily outlive the lifetime of the vehicle and would amount to an estimated 5 million km at cruising speeds of 100 km/h!

It is this energy autonomy that will permit the creation of an EV which is independent from recharging stations, independent from the need for a support infrastructure and independent from range restrictions of travel, and which could effectively, at the same time, compete and outdo modern IC vehicles in speed, weight, maintenance, freedom of travel, noise and cost. With the XS NRG™ Power Generation System, the EV will finally become not only practical because of its energy autonomy, but reasonably priced, non-polluting and capable of superior performance. Such an autonomous EV could easily overtake the automotive market, given the determination to do so. The materials used in the LGEN™ are totally recyclable, readily available, inexpensive and non-toxic. With the exception of the LGEN™ device itself, all the components of the power modules are commercially available. Furthermore, the LGEN™ reactors do not require or produce radioactive isotopes, nor do they work on the nuclear principles of fusion or fission.

Clearly, from the preceding, it is apparent that the advantages of the XS NRG™ system for the electric vehicle do not simply limit themselves to the removal of range restrictions brought about by the need for regular external recharging of the batteries in conventional EVs; indeed, for purposes of uniformalizing the comparisons, all the values of Table 3 regarding battery lifetimes in the diverse AEVs, were carried out at the same level of 100% withdrawable capacity from the batteries, as is customary to do when calculating the range of EVs. But the XS NRG™ System allows one to withdraw the same power at much lower withdrawable battery capacities (<50%), considerably improving the battery cycling life (at 50% withdrawable capacity, a conventional Pb-acid cell will last 400 cycles, instead of the 200 cycles shown in Table 1). This management of the battery cycling life may be easily automated, at the level of the central controller module of each AEV, and could easily double the battery lifetimes given in Table 3.

When using the XS NRG™ System, the most important characteristics of the storage system to be selected are high peak power per weight ratios and high energy densities. This is particularly so in Type 1 AEVs, where the storage system must be capable of delivering full power to the motors (the batteries "see" the surplus energy) while the XS NRG™ system replenishes the charge at or above the average consumption rate. The XS NRG™ System is capable of working with virtually any storage system in an AEV application as long as it has a peak power output greater than 200 W/kg and energy densities greater than 30 Wh/kg. The new generation of lead acid batteries, nickel metal hydride batteries and nickel cadmium batteries are all suitable for use in the secondary system. Zinc-air and aluminum-air systems could prove very effective in an EV application, if they were used in conjunction with the XS NRG™ System and in parallel with a power booster, such as a flywheel, to compensate for the poor peak power output of these primary or mechanical batteries.

Losses of inertial energy due to braking can, to a large extent, be recovered through the use of regenerative braking. This can be done in three ways depending on the type of mechanical interface. A flywheel type storage system can be used as a direct mechanical coupling to absorb or deliver energy, during moments of braking or acceleration, as shown for all Class 2 and 3 Types. In place of the flywheel, the drive motors themselves may be connected in reverse configuration to act as generators during moments of deceleration and, thereby, to return the charge recovered to the batteries. This latter system has the advantage of simplicity but it is not capable of acting as a power booster for acceleration, unless it is in turn coupled to a flywheel. The combination of a flywheel with a motor generator is thus the most appealing because mechanical energy can be converted to electrical energy and vice versa, as the need arises.

Research is presently being carried out at Labofex to increase the peak power output from an LGEN™ device so that the EV power systems utilizing the LMD™ technology can be reduced in weight without having to resort to power concentrators such as flywheels or supercapacitors. However, it is easy to grasp how, with reference to Fig.s 5A, 5B and 6, for vehicles that do not sit idle like a car being driven 1 h/d does (4% of a day's time), the battery system may be utilized solely to start up the XS NRG™ plant until the power output of the latter accumulates sufficient energy in the flywheel, for the flywheel to drive the XS NRG™ Power Generation System itself, as well as replenish the battery charge. Such system would permit, for vehicles being intensively operated, either a further reduction in battery weight (by ~50%), or an extension of its lifetime. Finally, current research at Labofex has shown that it is equally possible to couple DC motors and DC motor/generator sets directly to the XS NRG™ System output. This would represent still another way of designing the AEV power structure, such that DC motor applications could be run from the reactors, rather than from the batteries and/or the power boosters.

Lastly, but not least, the projected cost per kWh of XS NRG™ electricity, as based on experimental data, is at present ~0.4¢, at end-consumer prices for all the components and materials involved **(1, 2)**. Improvements in fuel consumption, breakeven eficiency, power output levels, and the reduced cost of other fuels could easily decrease this cost by >10x. Cost at the origin, for both components and materials employed, would further reduce this figure. The net result would be a power autonomous EV that generates electricity at very low cost to the consumer. Compared to the price of fuel and the mileage of the most efficient IC vehicles, which may attain 15/20 km per liter of gas (~0.7 kg of fuel) and cost~50¢, or ~2¢/km, at average speeds of 50/60 km/h, operation of an XS NRG™ AEV consuming ~4.2 kW while cruising at 60 km/h would have cost 0.028 ¢/ km, at the projected experimental XS NRG™ power cost of 0.4 ¢/kW **(2)**, for a grand total of 1.7 ¢ spent in one hour of driving. That is, the XS NRG™-generated power is >60x cheaper and the weight of the fuel spent cleanly in the operation of the XS NRG™AEV to travel 60 km at 60 km/h, is estimated at ~10 micrograms, more than 300,000 times less than the weight of fuel spent by an efficient IC vehicle for the same distance!

ISSN 1915-8408

"[On the problems of the electric vehicle:] First, it is too expensive. Second, the range is too short. Third, there are battery problems: they weigh too much."
H. Igarashi, Japan Electric Vehicle Association, 1992

"Labofex's design of the first XS NRG™ autonomous electric vehicle will breakdown the current barriers of the electric car. It will enable EVs to become inexpensive, faster, lighter, virtually unlimited in range, truly non-polluting and competitive with existing internal combustion vehicles."
P. Correa, Labofex's Director of Research, 1993

ISSN 1915-8408

REFERENCES

1. LABOFEX Technical Report #3: "Design of basic XS NRG™ power modules", 1993, LABOFEX Technical Report Series, June 1993, S2-003.

2. LABOFEX Development Report #1:"An advanced communication on a new power technology. LABOFEX Preliminary Development Report", LABOFEX Development Report Series, October 1992, S3-001.

3. This value is that of an hydrogen fuel cell powered bus protoype recently built by Ballard power Systems, in Vancouver, as reported in CBC Primetime news, June 1993.

4. Kenzie, J (1993) "The dream machines", Inside Guide, 7:25.

5. Kenyon, KE (1984) "Novel hybrid electric vehicle", U.S.P. 4,438,342.

6. Parish, DW et al (1989) "Demonstration of aluminum-air fuel cells in a road vehicle", SAE Technical Paper Series, #891690.

7. Freedham, DH (1992) "Batteries included", Discover, March: 90.

8. Gardner, G (1991) "GM goes electric", Detroit Free Press, Sept. 9: 8F.

9. Woodruff,D et al (1991) "The greening of Detroit: a push is on to make cars more environmentally friendly", Business Week, 3208:54.

10. Fetcenko, M et al (1992) "Advantages of Ovonic alloy system for portable and EV Ni-MH batteries", presented at the 3rd International Rechargeable Battery Seminar, Deerfield Beach, Fl., March.

11. "Sonnenschein Batteries dryfit maintenance-free, A200 series", Sonnenschein, 1989; also **"Mallory sealed Lead-Acid batteries technical handbook", Duracell, 1991.**

12. "MITI discloses plan to promote electric vehicles, Part 2", NTIS Alert Foreign Technology, US Department of Commerce, Vol. 92, No. 19, July 1, 1992.

13. Kaun, T (1992) "Bipolar battery", U.S.P. 5,162,172.

14."Mallory sealed Lead-Acid batteries technical handbook", Duracell, 1991.

15 "Green Cars Here Today, to Stay", Alternative Energy Network Online Today, Environmental Information Network Inc, Sept. 6, 1992

16. Cheisky, MC (1990) "Rechargeable metal-air battery", U.S.P. 4,957,826.

17. "Cars travel further on zinc-air batteries", News Trends, Machine Design, May 23 1991.

18. Crawford, M.(1991) "A modern-day flywheel appears from the closet" New Technology Week, 5:45.

19. Bitterly, J and Bitterly, S (1992) "Flywheel-based energy storage methods and apparatus", U.S.P. 5,124,60.5

20. This value was determined from measurements performed on a NEC 5.5 V, 0.47 F, high density capacitor.

21. "Electric Vehicles: EG&G Idaho Evaluates Pulse Power Devices for EVs", Battery & EV Technolgoy, 15:12, April 1, 1992.

 ISSN 1915-8408

22. **"In search of cash, Russian and Ukrainian new materials storm the west", Financial Times Business Reports Energy File, Energy Economist, Nov. 27, 1992**

23. **"Supercapacitor could make electric car viable", Technical Insights, Inc, 22: No 3, January 20, 1993.**

24. **Fetcenko, M et al (1991) "Selection of metal hydride alloys for electrochemical applications", presented at the Electrochemical Society, Phoenix, Arizona, October 15, 1991.**

25. **de Jong, HCG (1989) "AC motor design", Hemisphere Publ. Co., NY, NY.;** see also **Heumann, GW (1947) "Adjustable frequency control of high speed induction motors", AIEE Trans, 66:719.**

26. **Veinott, CG (1970) "Electric Motors", McGraw-Hill Book Co., NY, NY.**

27. **Anderson, E and Miller, R (1986) "Electric motors", Macmillan Publ. Co., NY, NY.**

28. **Gottlieb, I (1982) "Electric Motors & Control Techniques", TAB Books Inc, PA.**

29. **Babyak, RJ (1991) "Electronic motor control tackles energy and noise", APP M, p. 82, January 10.**

30. **Jancsurak, J (1992) "Switch to switched reluctance?", APP M, p. 29, January 3.**

31. **Tripp, MW and Anderson, WM (1990) "Electric vans: some current models", Automotive Engineering,Truck Engineering Supplement, January.**

32. **Puchstein, AF and LLoyd, TC (1942) "Alternating-current machines", John Wiley & Sons, Inc, London, UK.**

33. **Odza, M (1992) "Big Three-Energy Dept. battery deal: 'Manhattan Project II' or 'Huge step backwards' for Technology Transfer?", Technology Access Report, University R&D Opportunities Vol. 5, No, 31, Jan. 3.** This figure of 10% refers to areas where legislative pressures are having a great effect.

34. **"General Motors 1991 Annual Report", General Motors, Detroit, MI;** see also **Moody's Industrial Manual 1991, p. 1175.**

35. **"MITI discloses plan to promote electric vehicles. Part 1." NTIS Alert Foreign Technology, NTIS, U.S. Department of Commerce, Vol. 92, No. 18.**

36. **Revkin, A (1992) "Global Warming- Understanding the Forecast" The American Museum of Natural History, Environmental Defense Fund, Abbeville Press, NY, NY.**

37. **"World Resources 1990-91: A Guide to the Global Environment", A Report by the World Resource Institute in collaboration with The United Nations Environment Programme and The United Nations Development Programme, Oxford University Press, 1990, p. 142.**

38. **Sdhwartzel, E (1993) "Take a breather, but don't inhale", Globe & Mail, June 1.**

39. **Correa, PN and Correa, AN, "Pulse generator", patent pending.**

40. **Correa, PN and Correa, AN, "Energy conversion system", patent pending.**

41. **Correa, PN and Correa, AN, "Electromechanical transduction of plasma pulses", patent pending.**

42. **Thimmesch, D (1985) "An SCR inverter with an integral battery charger for electric vehicles", IEEE Trans Industr Appl, 1A-21:1023.**

43. **43.** Compiled from:**"Tokyo Elecric Power Company (TEPCO) Electric Car Features Carbon**

FiberComposites", Composite Industry Monthly, Composites Market Reports, Inc. No. 25, and **"Japan's High-Tech Electric Cars can't get on the Road". Inside DOT & Transportation Week, King Communications Group, Inc. Vol. 2, No. 43**

44. "Nissan develops 'Future electric vehicle' Prototype", Business JAPAN , Nov. 1991.

45. Kenzie, J (1992) "BMW electric car dimly satisfying in city", The Toronto Star, September 26.

46. Wrigley, Al (1991) "Skylights to replace steel in autos?" American Metal Market, Fairchild Publ. Inc., p.4.

47. "Aluminum-air fuel cell: compact, high energy to power electric vehicles", News from Alupower, Kingston, ON.

ISSN 1915-8408