Zinc Air Battery-Battery Hybrid
for Powering Electric Scooters and Electric Buses

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Keywords

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Abstract

The rapid growth of urban air pollution from transportation vehicles necessitates the introduction of sustainable technologies that will enable us to meet our commitment to a cleaner environment. Buses in large cities in the US and scooters in Asia present a major opportunity for conversion to electric drive systems. Public awareness is backed by legislation world wide, from New York to Shanghai.
Existing battery technologies do not offer a solution that meets all market requirements for range, power and economy. While certain technologies may individually address one or two of these requirements — none really address all three.

The Electric Fuel zinc-air battery technology has been successfully demonstrated in Europe. Deutsche Post in Germany and Edison (Italy's largest private energy supplier) have incorporated the battery in electric fleet vehicles. Kema in Holland and Japan's Tomen Corporation have also recently joined Electric Fuel in developing the technology for their regions.

The Electric Fuel zinc-air battery system offers an alternative technology that is both technically viable, environmentally sound, and economically achievable. To date, Electric Fuel has been powering electric commercial vehicles with the zinc-air battery only. The unique and challenging requirements for propelling the two extreme sizes of electric transportation — buses and scooters — require a different solution: an all electric battery-battery hybrid propulsion system. The high *energy* zinc air battery is coupled with a high *power* auxiliary battery. The combined system offers zero emission, high power and long range, all required for viable environmentally friendly vehicles.

Introduction

Electric Fuel is an international provider of advanced energy systems for electric powered vehicles and other applications. The company has developed a high-energy zinc-air battery system, designed to allow electric powered vehicles to compete with conventional vehicles in price, performance, convenience and safety, while offering superior range, highway speed, equivalent cargo capacity and quick refueling. Electric Fuel concentrates its current technology and commercialization effort toward fleets, which it envisions to be the early adopters of electric vehicles.

The Electric Fuel zinc-air battery system consists of an in-vehicle zinc-air battery built from cells with replaceable zinc air anode cassettes, an automated battery refueling method for replacing discharged cassettes. This unique "refuelable" battery system overcomes the "Achilles Heel" of electric vehicles—range—and permits regular travel of more than 400 km (250 miles) in city and highway driving.

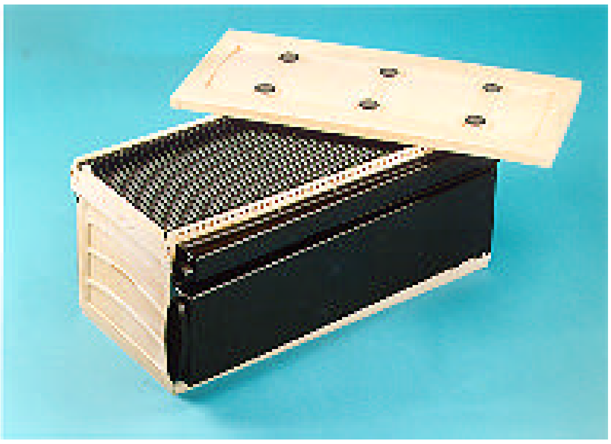

Fig. 1: Electric Fuel Zinc-Air Battery Module

The Electric Fuel zinc-air battery system offers significant advantages over other electric vehicle batteries, making it ideal for fleet and mass transit operators. Fleet operators require a long operating range, large payload capacity, operating flexibility, all weather performance, fast vehicle turnaround, and competitive life-cycle costs. Electric Fuel powered full size vehicles, capable of long-range, high-speed travel, fill the needs of the transit operators, in all weather conditions, with cost effective fast refueling. An all electric, full-size bus, powered by the Electric Fuel system can provide transit authorities with a full day's range for both heavy duty city and suburban routes in all weather conditions.

On November 2, 1997, Electric Fuel Corporation set an endurance record for electric vehicles by powering a Mercedes-Benz MB410E van from central London to central Paris on a single charge. Despite harsh weather conditions and freezing temperatures of 1-2°C the vehicle traveled 439 km, from the streets of downtown London, through the highways of England and France, to the congested traffic conditions in central Paris.

In October 1996, Electric Fuel Corporation was the first to cross the Alps with an electric vehicle. The electric fuel vehicle climbed over 244 km of mountainous terrain to the 2,089 meter summit, The historic drive began at Chambrey, France and ended at the Edison Electric Fuel regeneration plant in Italy.

Electric Fuel vehicles are particularly suited to large fleet operator requirements. Gaining widespread acceptance for electric vehicles as a viable alternative to today's internal combustion engine would be more effectively done through those institutions motivated by environmental concerns and through proposed legislation. Many major cities throughout the world are barring gasoline-powered vehicles from entering city centers due to the high levels of pollution. Public transportation and fleet operators are more likely than the individual consumers to be targeted by regulators. This is because fleets, which mostly drive on inner city routes, are a major contributor to urban air pollution. Fleets use central hubs for their large numbers of vehicles and are well suited for the installation of the infrastructure required to adapt to new technology. As large fleet operators adopt electric vehicles, an expanded infrastructure will become available to smaller fleet operators and individual drivers.

The Clean All Electric Hybrid Bus

Buses are a major source of urban air pollution. They travel in downtown city traffic all day in stop-and-go duty cycles. The equivalent "pollution miles" caused by one bus are comparable to dozens of passenger vehicles. Due to existing clean-air legislation, electric buses provide a large opportunity for urban environments and, thus, can be the first to demonstrate the new electric propulsion system:

- Buses are controlled by municipal authorities — many of them in cities that do not meet federal air pollution attainment levels and are required to act.
- Buses use large central hubs, easing both issues of new infrastructure and maintenance of new technology.

Consequently, a technology that offers municipal authorities the potential of a full-size all-electric bus capable of performing a full day's duty cycle with comparable performance to a conventional bus would find an eager market.

Clearly, an all-electric zero emissions 40-ft transit bus that has four times the gross vehicle weight of today's electric powered vans, and is required to have one and a half to two times the range, cannot be realized using conventional electrically rechargeable storage batteries. For example, to meet New York City Transit Authority's performance and range requirements in an electric transit bus using today's lead-acid batteries would require approximately 9,000 kg of batteries. The curb weight plus the lead-acid battery pack would exceed the gross vehicles weight of the bus, with zero passengers on board. At the same time, the conventional electric propulsion system using only the high-energy density zinc-air battery package in the available space under the floor will not fully meet the power and acceleration goals for the New York City Transit Authority transit bus.

The all-electric hybrid propulsion system for powering buses (and other heavy-duty trucks and utility vehicles) has the unique ability to operate for a full day's uninterrupted service at the same power and performance levels as a conventional diesel powered vehicle. The system is shown schematically in figure 2.

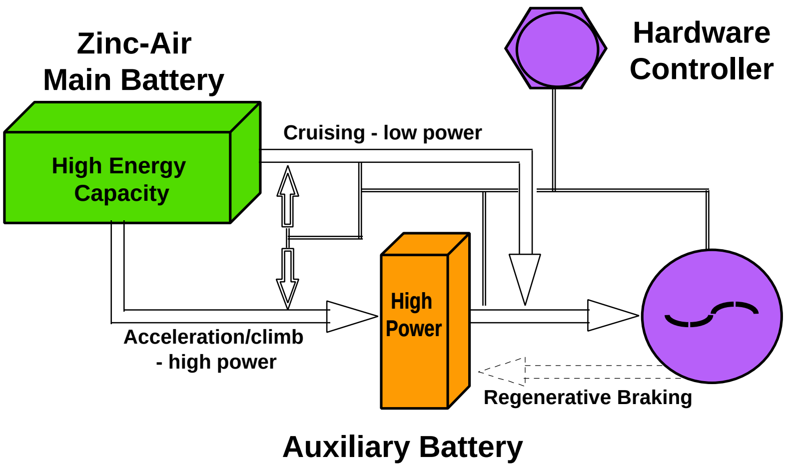

Fig. 2: Schematic of All-Electric Hybrid Electric Propulsion System

This system provides three features that are vital for commercial applications:

- Increased driving range due to improved system efficiencyduring acceleration and regenerative retarding (capture of energy during vehicle deceleration).
- Increased power for acceleration, merging into traffic, and hill climbing.
- Significantly lower vehicle maintenance cost from reduced brake wear and tear.

Moreover, a hybrid propulsion system allows the designers to select and specify propulsion system components without compromising or trading-off the inherent attractive properties of each system element, a step usually necessary in arriving at acceptable power/energy ratios in single battery electric vehicles.

Fig. 3: A Nova Transit bus, similar to the one used in the battery/battery hybrid demonstration

The main Electric Fuel zinc-air battery is designed for energy carrying capacity, reaching an extremely high specific energy (>200 Wh/kg). The battery is based on individual cell units electrically connected in series and packaged in a plastic modules that provides electrical connection plus reaction air and cooling air to each battery cell. Six of these zinc-air battery modules mounted on a tray allow quick battery exchange from/to the all-electric transit bus. A total of three battery trays of zinc-air batteries (total of 18 battery modules) comprise the energy storage portion for the transit bus. This battery provides approximately 314 kWh of on-board energy, and weighs in at less than 1600 kg.

The auxiliary “power” battery has been selected for its power and cycling characteristics with minimal reference to its energy density. The high power density Ni-Cd batteries provide acceleration and a “power” absorption function during vehicle deceleration or regenerative retarding.

It should be noted that there are several available configurations (and subsequent operating strategies) for this hybrid system, in much the same manner as diesel-electric hybrids can be classified from series through parallel configurations. For instance, the main zinc-air battery can be used to continuously charge the NiCd battery, which is then performs as the traction battery (permanent source of drive power) in a series arrangement. Alternatively, the NiCd battery can be used in parallel with the main zinc-air battery, providing “topping” power whenever high power is demanded. Several variations on these basic configurations are possible. The optimal hybrid configuration will reference system characteristics as well as battery characteristics such as cycle life and efficient charge/discharge rates.

Table I: Preliminary Battery Configuration of All-Electric Hybrid Bus

	Zinc-Air	Ni-Cd [1]	All-Electric Hybrid
Weight	1566 kg	600	2166 kg
Energy Capacity	314 kWh	(21 kWh)	314 kWh [2]
Peak Power	(140 kW)	240 kW	240 kW [2]
Specific Energy	200 Wh/kg	35 Wh/kg	145 Wh/kg
Specific Power	90 W/kg	400 W/kg	110 W/kg

1. SAFT high power STX-600 NiCD cells.
2. The hybrid energy capacity is associated with the zinc-air battery, whereas the peak power rating is associated with the NiCd battery.

Shown in table I are the characteristics of a parallel-type hybrid configuration in which drive power is derived directly from the Zn-air main battery during cruising, and which switches completely to draw from the NiCd during peak demand. The battery-battery hybrid when viewed as one unit will provide the bus with approximately 240 kW of peak power, and 314 kWh of energy capacity, in a total battery package weighing approximately 2166 kg.

The Electric Scooter

In many cities, particularly in the Far East, the scooter is established as the principal mode of private transport. In Taiwan, for instance, it is estimated that there are over 12.5 million of these vehicles on the roads. Scooters are a major source of the choking pollution that blankets cities such as New Dehli, Djakarta, Taipei, Bangkok and Shanghai. Several of these cities are developing programs for the limitation of gasoline-powered scooter numbers and their eventual replacement by electric scooters.

Within the scooter markets in these countries, two distinct segments have been identified, each requiring distinct performance and cost targets. Another related (and growing) market is for electric power-assisted bicycles.

The wealthier countries such as Taiwan favor a larger, more powerful scooter. Mainland China, however, is aiming for a smaller, cheaper scooter with a more modest performance specification. The Taiwan-type product we can accurately characterize as high power/higher cost, or “high-end,” in contrast to the mainland China-type product as lower power/lower cost, or “low-end.” There is overall consensus on the specifications for the power assisted bicycle.

Electric scooters cannot be electrically recharged in large numbers in congested urban areas such as Shanghai or Taipei. Millions of cables and plugs would be required. An alternative that is often mooted involves the daily removal and handling of batteries for home and office recharging. Given that a lead acid battery which would support a minimal daily scooter range of 40-50 km weighs approximately 40 kg, this is clearly an impractical proposition.

In contrast to this, the requirements of the low-end scooter can be effectively met by an Electric Fuel zinc-air battery weighing just 16 kg (consisting of two modules each weighing 8 kg). The power assisted bicycle will have just one 8 kg battery module. Once a week, the user will drive up to a convenience store, service center or any other designated location, and exchange his depleted battery for a fully charged one. The depleted batteries will be sent to the Electric Fuel regeneration facility for recharging.

Table II: Characteristics of Different Electric Scooter Market Segments

	Electric Scooter High-End Market (Taiwan)	**Electric Scooter Low-End Market (Mainland China)**	**Electric Power Assisted Bicycle**
Power @ 80% DOD (W)	4000	800-1200	400-600
Energy Capacity (kWh)	3.0	2.5	1.0
Range (km)	200	200	N/A
Max. Speed (km/h)	60	30	N/A
Climb	12° at 30 km/h	4° @30 km/h	N/A
Max. Battery Weight (kg)	25 kg	25 kg	Target: <10 kg

In the high-end market, designing a zinc-air battery capable of reaching the 4000W peak power demand within the constraints of scooter battery size — though practical technically — would involve the unacceptable trade-off of reducing the energy capacity and increasing the cost beyond reasonable limits. To side-step this problem, the more powerful high-end scooter will employ two batteries in a hybrid arrangement similar to that employed in the all-electric hybrid bus: a main high-energy density zinc-air battery designed for maximum energy capacity to provide extended driving range and cruising power, alongside a small (and therefore low cost), rechargeable auxiliary battery designed for power boost and capturing regenerative retarding energy. The main battery will be identical to the one employed in the low-end scooter, consisting of two 8 kg modules.

As implied above, a single modular zinc-air battery will be applied to the different propulsion system configurations for high-end scooters, low-end scooters, as well as electric-assisted bicycles, as described in Table III. This modular design will yield efficiencies in the battery development, manufacture and infrastructure support.

The specifications of this preliminary concept zinc-air battery module are as follows:

Dimensions:	300 x 150 x 220 mm	
Voltage:	OCV 30V, Operating 25V - 19V	
Energy Capacity:	1.5 kWh	
Peak Current:	36A	
Peak Power:	750 W	
Weight:	7.5 kg	
Specifics:	200 Wh/kg	100 W/kg
Densities:	152 Wh/l	76 W/l

It should be noted that the sizes given above for this module are indicative only: a great deal of design flexibility exists in this respect.

The motor and motor controller will be designed to take maximum advantage of the specific characteristics of the main and auxiliary batteries and thereby facilitate optimal and uncompromising battery design — a focus on high specific energy for the main battery and high specific power for the auxiliary battery.

The low cost of the zinc-air battery (less than any other competing technology), a refueling cost comparable to gasoline, and an automated central battery regeneration fwill enable electric to compete directly with gasoline in powering scooters.

Table III: Electric Scooter Propulsion System Configurations

Market	**Requirements**	**Propulsion System Configuration**
High-End Scooter	Energy Capacity: 3.0 kWh Power: 4000 W	Electric-Electric Hybrid **[1] Two zinc-air modules:** Energy - 1.5 kWh x 2 = 3 kWh Power - 750 W x 2 =1500W Weight - 8 kg x 2 = 16 kg *plus* **[2] Auxiliary battery** to boost peak power to 4000W
Low-End Scooter	Energy Capacity: 2.5 kWh Power: 1200 W	Electric **[1] Two zinc-air modules:** Energy - 1.5 kWh x 2 = 3 kWh Power - 750 W x 2 =1500W Weight - 8 kg x 2 = 16 kg
Electric-Assisted Bicycle	Energy Capacity: 1.0 kWh Power: 400-600 W	Electric **[1] One zinc-air module:** Energy - 1.5 kWh Power - 750 W Weight - 8 kg

A scooter thus configured would meet all the technical design targets of the high-end markets, including the high power requirement, and would offer a scooter with peerless performance and driver convenience. Importantly, the power, range and refuelable character of the scooter would mimic the popular gasoline-powered scooters, easing consumer acceptance and making the scooter both useful and desirable.