A Long Range, Ultra-Safe, Low Cost Electric Vehicle

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Abstract

Electrovaya has developed a long-range, zero-emission electric vehicle based upon its proprietary *Lithium-Ion SuperPolymer*® battery technology, some unique system design and a proprietary high efficiency motor. This paper describes Electrovaya's 250-350 km range, compact 5-passenger SUV. Design targets include adequate acceleration, vehicle curb weight to be within 1% of the original body shell/glider for the internal combustion engine vehicle and with unchanged weight distribution across the axles. Several interesting approaches to ensuring ultra-safe and high reliability operation are also discussed. A new high efficiency motor design is also outlined which operates at 90-95% efficiencies. With Electrovaya's battery, controls, system and motor technology, a low cost ZEV with comparable performance to a similar sized ICE is possible and is complemented by a 300+ km driving range between charges. The potential markets and applications, primarily in the area of fleet vehicles, are outlined.

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The history of electric vehicles is characterized by the inherent limitations of available battery technology. Traditionally, electric vehicles have relied on a 19th century technology, the lead acid battery, with its severe limitations of weight and low energy density. Introduction of other old technologies such as nickel metal hydride (NiMH) or nickel-cadmium (NiCd) battery batteries, while improving the performance, still failed to provide acceptable performance and driving range to meet the target for consumer acceptance.

However, the past decade, fuelled by the computer/IT market demand for portable power, has seen major advances in battery technology. The most dramatic advances have been in the field of lithium ion chemistry where lithium ion batteries are now standard in the computer industry. Increased production levels is reducing the cost of these systems to a point where they are becoming feasible as a power source for EV transportation as well as providing an option for auxiliary storage for hybrid gas-electric vehicles (HEVs) and as a bridge to fuel cell EVs (FCEVs) and the hydrogen economy, if that ever happens.

Electrovaya's award-winning proprietary *Lithium Ion SuperPolymer*® technology presently has an energy density of about 225Wh/kg and about 475Wh/litre. At more than five times the energy density of lead acid at less than a quarter of the weight this technology has opened new horizons for true zero-emissions sustainable transportation (Figure 1 below).

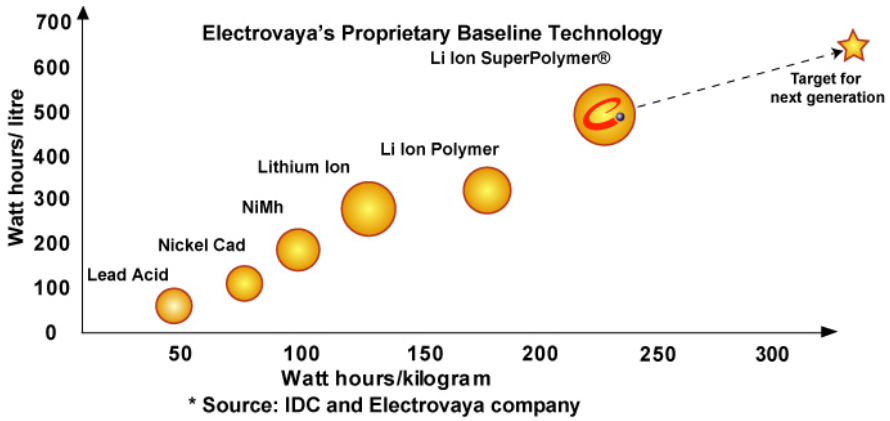

Figure 1: Energy Comparison for Battery Technologies.

Electrovaya is a global mobile energy leader forging new ground in the mobile computing, aerospace & defense, electric vehicle, and other power intensive industries. Within each of these vertical market sectors, high energy, low weight power is the catalyst to creating significant advances and improvements.

Electrovaya has a proven track record of successful technical innovation and has developed a portfolio of "portable power" products all of which demonstrate reliability, durability and performance. These include external battery packs (*PowerPads*™ for laptop, special purpose batteries for military/aerospace applications, standby power

systems for telecommunications), the *Scribbler*™ Tablet PC (the most mobile Tablet computer with run time of 6-9 hours) and most recently the prime contractor for NASA, to develop the astronauts' life support power pack for space suits in shuttle and space station missions.

The experience in developing critical mobile applications for consumer use has led to high reliability batteries and power systems and concurrently Electrovaya is coming down the cost curve with production growth and maturity.

In 2001, Electrovaya initiated its electric vehicle program. An initial evaluation by the US Advanced Battery Consortium (USABC) successfully confirmed that Electrovaya's *Lithium Ion SuperPolymer*® technology surpassed the energy density criteria set as the barrier to customer acceptance of EVs.

In the following year Electrovaya started the development of its prototype Maya-100 electric vehicle with an MOU with CAMI (a GM-Suzuki joint venture, based in Canada). This vehicle was based on a body-shell/glider of a compact 5-seater SUV. Electrovaya's technology is independent of chassis and glider design and can be incorporated into most automotive chassis.

The design criteria called for a 40 kWh battery pack that was projected to deliver a driving range between charges of over 300 km. A battery weight under 300 kg was forecast with a requirement of 7-year calendar life and a cycle life equivalent to 150,000 km operation. Charging time was 6 hours (overnight, off-peak charging) with a capability to retrofit a rapid-charge option.

Figure 2: Maya-100 at the 2004 Tour de Sol where it won the *Technology Award* and *Battery Electric Award*.

Several key issues are addressed, including:

- Safety and reliability;
- Performance (acceleration, driving range, rapid-charge capability);
- Technology highlights;
- Market niche;
- Progress to date and the future ahead.

Safety & Reliability

It was assumed that the safety of Electrovaya's ZEV electric vehicle must exceed all IC engine vehicles as well as hydrogen/fuel cell vehicles. In Electrovaya's battery and EV development, safety concerns are paramount and include very rigorous safety testing protocols. We address this issue in several ways: all cells, batteries and systems are UL certified, our in-house safety test facility has been UL approved, and we comply fully with IATA. In addition to employing a safe, environmentally benign, chemical formulation, the design of our cells incorporates a special membrane and includes certain internal electronic circuitry and mechanical safety features that will shut down the cell if any overheating occurs. We have very strong industry acceptance, symbolized by our NASA contract for CRIT ONE Missions where we meet very rigorous safety and reliability standards.

Inherently, electric vehicles are simpler to engineer than IC engine, hybrid or fuel cell based vehicle. The maintenance cost is low and the engineering, easy to do. This directly affects the safety, reliability and cost of the vehicle.

Performance

While traditional lead acid powered EVs exhibited poor performance due to the need to transport large amounts of lead, typically one ton or more, *Lithium Ion SuperPolymer*® powered EVs have no such drawbacks. Performance of the Maya-100 is at least equivalent and in many cases superior to similar sized ICE gasoline vehicles. Top speeds of 140kmph in the highways have been achieved. The acceleration of the vehicle is adequate, and can be further improved with a larger electric motor.

Reducing the weight of the battery to below 300 kg enables driving range in excess of 300 km to be achieved. While this is more than adequate for typical urban consumer use patterns, which is generally between 100-150 km daily, a rapid charge facility can be retrofitted that will enable 30% of the battery capacity to be replenished during a 20-minute charge.

Technology Highlights

1. Ultra-safe and Low Cost Battery Material: There are no expensive specialty chemicals in the Electrovaya system. Electrovaya has developed an ultra-safe and low-cost cathode material for its transportation applications. This is a phosphate-based compound. Electrovaya has designed and built the largest production facility in the world for this cathode material. The anode material is graphite along with various polymers and includes a shut down separator. Multiple tests have shown this battery does not ignite under conditions of internal and external shorts, crush and temperature excursions. The cost of the battery system is expected to go down with increased production and we can envisage $270-300/kWh at moderate production.

2. Surge Power: Typically the usage of lithium ion and lithium ion polymer battery technology has been limited in EV applications due to problems of surge power requirements in acceleration and hill climbing and associated battery problems such as thermal management, cycle life degradation and over discharge concerns. Electrovaya has a unique and patented system that solves the problems and is planning license the technology to interested parties.

3. Regenerative DC Motor: Electrovaya has also developed a proprietary regenerative DC axial brush system motor with permanent magnets. This 30 kg motor has an efficiency of 90%-95%, a long brush life, compact and rugged construction, turbofan cooling, and a voltage of 120-150 V. Continuous power is 25 kW (120 V, 230 A) 59.5 Nm at 4000 RPM on the main shaft and 8000 RPM on the motor shaft. Maximum power is 42 kW (120 V, 390 A) 100 Nm at 4000 RPM on the main shaft. The peak torque is 200 Nm. This unique technology may be licensed to interested parties.

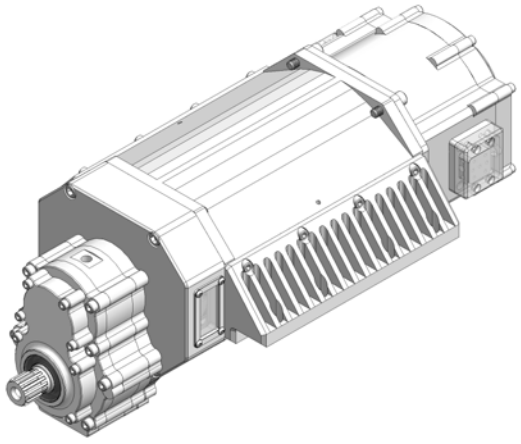

Figure 3: Electrovaya's Proprietary Regenerative DC Axial Brush System Motor with Permanent Magnets.

Market Niche

Electrovaya has identified several major market niches in its business plan. The first is the commercial fleet electric delivery vehicles. The usage profile of this class of vehicle, where overnight charging is available, is ideally suited to EV drive technology. In addition, the frequent stop-start patterns create the opportunity to capture surplus energy via regenerative braking. The fleet vehicle market is already well attuned to the beneficial features offered by electric vehicles especially lower operating and maintenance costs that are further enhanced by steadily increasing oil prices.

Another class of users is the early adopters, especially governments and municipalities who are keen to introduce green vehicles into their service fleets. Electrovaya also has an active program designing and building specialty vehicles for selected clients.

Progress to Date

The Electrovaya Maya-100 prototype has received intense consumer interest. During launch trials in the summer of 2004, Maya was entered into the North American Tour de Sol Rally. After completing the rally the Maya-100 received the "*Technology Award"* and "*Battery Electric Vehicle Award"*. In conferring the prize the technical committee noted, "The critical search for the next generation of clean automobile is accelerating. Amongst emerging technologies, which include hydrogen fuel cell vehicles and hybrid electric gasoline cars, Electrovaya's *Lithium Ion SuperPolymer*® battery technology has the greatest potential to succeed."

Electrovaya is moving ahead to develop the phase-2 commercial prototype that will include an improved control technology and a battery management system that will detect, bypass and compensate for any defective cells within the battery pack. A regenerative braking capability will also be a feature of the phase-2 prototype.

With its substantial research and development arm and links to several academic research groups, Electrovaya is constantly pushing the frontier of battery technology and electric drive systems. A research program is presently underway that is designed to increase the cell energy density to beyond 330 Wh/kg and 650Wh/litre. Initial laboratory tests on small cells show excellent results. This will have important implications for EV applications in terms of increased power and reduced weight and battery cost.

The Way Ahead

With worldwide production of new vehicles rapidly approaching 50 million annually there are increasing demands that a significant portion of this market be filled by zero or low-emission vehicles. Steadily increasing oil prices, energy security, environment concerns and urban health issues including increased healthcare costs caused by gasoline and diesel vehicle pollutant emissions are creating this demand. Global warming and climate change is a major concern with over 25% of greenhouse gases generated by the transportation industry. Since most countries have signed on to the Kyoto Protocol, there are pressures to increase usage of low or zero-emission vehicles where fuel cell vehicles, hybrid EVs or pure battery (ZEVs) are the available technologies.

It is clear that the conventional auto industry provides a very tough competition and views battery electric vehicles as a disruptive technology. Nevertheless, hybrid EV manufacturers such as Toyota who have invested over $8 billion in development have convincingly demonstrated that battery electric drive technology is both technically and economically viable. There is a steady demand from HEV users for increased battery capacity and/or a plug-in capability for their vehicles. In addition, expectations created by optimistic forecasts of fuel cell EVs have created a large market for pure battery ZEVs and hybrid gas-electric (HEVs).

Market forecasts predict that low or zero-emission vehicles will fill some 10% of new vehicle production by 2010. Electrovaya believes that its *Lithium Ion SuperPolymer*® technology will provide the power source for a significant fraction of this market.

References

1. S. Das Gupta, J. K. Jacobs, R. Bhola and others: 75 patents issued and 84 patents pending.