

Feasibility of Plug-in Electric Cars in Today's Market

Prepared For

24-101: Fundamentals of Mechanical Engineering
Professor Philip Leduc

Prepared By

Michael Lin



December 3, 2007

Table of Contents

Abstract

Introduction

1. History

1.1 GM EV1

2. Advantages of the Electric Car

3. Shortfalls of the Electric Car

4. Modern Electric Cars: Battery Technology, The Tesla Roadster, and The ZAP-X

5. Comparison With Gasoline-Powered Car: Performance

6. Economics of Electric Cars

7. Conclusion

References

Abstract

This report will show that a purely electric automobile can be a competitive product in today's market. The report will cover the early electric cars through those of today, addressing the strengths of each and identifying the areas of improvement in order for electric cars to become a successful product. Battery technologies, the heart of an electric vehicle, will also be covered. The principle behind an electric vehicle is simple: a battery is connected to a controller, which regulates the amount of electricity sent to a motor. The motor then drives the wheels. Compared to the more complex internal combustion engine, with its precise timings and delicate components, the simplicity of the electric motor also allows it to be much more efficient and therefore more environmentally friendly. Finally, the ability to widely distribute electricity already exists, so new infrastructure does not have to be installed for an electric car to become a viable option.

Introduction

The automobile is undoubtedly among the most groundbreaking inventions of all time, placing first on the American Society of Mechanical Engineers (ASME) Top-Ten Achievements of the Mechanical Engineering Profession [1]. The automobile has made the transport of goods and people over long distances relatively inexpensive and reliable. Although Henry Ford's Model T is often cited as the beginning of automobile history, steam and electric cars were popular before the Model T and were more refined. Electric cars, in particular, were quiet and didn't exhaust foul-smelling gases.

This brings up the question: Why did gasoline power come to dominate the automobile industry? One explanation was the relatively high prices of and limited access to electricity in the

early 20th century. Whereas gasoline was burned off as a waste product in the production of kerosene, only the wealthy could afford to have their homes wired for electricity. Because there was no standard in place, the electricity supply varied across regions in voltage and type (Alternating Current vs. Direct Current) [2]. When Henry Ford introduced the immensely popular Model T with an internal combustion engine, a precedent was set for future automobiles.

Today, the opposite is true. Gasoline prices have been steadily increasing and worldwide production is expected to decline after the year 2030 [3]. Electricity is now widely available and relatively inexpensive when compared to gasoline. Electricity can also be harvested from renewable sources, such as the sun or wind, and therefore contributes far less to environmental pollution than smog-forming gasoline. Technology has improved to a point where electric cars have comparable range and features as their gasoline-powered counterparts. With many technological improvements since the early 20th century and relatively inexpensive electricity, plug-in electric cars are now viable, environmentally friendly alternatives to today's gasoline-powered cars.

1. History

In 1892, William Morrison created the first American electric automobile – a homemade six-passenger wagon with a twenty-four-cell homemade battery [4]. By the early 1900's, purely electric cars were the most quiet, refined, and easy-to-operate vehicles on the road. In fact, the New York automobile show of 1900 showcased more electric cars than gasoline or steam cars combined [4]. Although Morrison's electric wagon was received with marked enthusiasm in the World Columbian Exposition and the future of the electric car looked promising, the introduction of Ford's Model T and the limited access to electricity nearly wiped away the popularity of the electric car.

1.1 GM EV1

Introduced at the Los Angeles Auto Show in January 1990, the GM EV1 was the first modern electric vehicle from a major automobile manufacturer [5]. However, it was only offered for lease starting in the 1997 model year up through 2000. After the leases expired, GM would not renew them and cancelled the EV1 project, citing reasons such as lack of demand and lack of profitability [6]. The EV1's were eventually found crushed and recycled for scrap materials.

2. Advantages of the Electric Car



Figure 1: The Basic Components of an Electric Car

The electric car is a simpler car. When boiled down to the basics, it consists of a motor connected to a battery with a controller in between to vary the motor speed. Unlike an internal combustion (IC) engine, which needs to be constantly spinning in order to provide power, an electric motor can start from a standstill and still provide 100% of its torque. IC engines also require precise timings between many valves, injectors, and pistons. When the timing breaks down, the resulting damage is expensive to repair. Fewer parts in an electric car means less can go wrong, which results in lower maintenance costs. Fewer parts also means there are fewer places for energy loss, which in turn leads to higher efficiency. Electric motors today are between 80-95% efficient while IC engines are only 15-25% efficient [1]. Electric cars, then, are simpler, more efficient, and less expensive to own.

3. Shortfalls of the Electric Car

Historically, the primary disadvantages of electric cars have been the limited range and the long recharge times. The first generation GM EV1 could only travel 60-70 miles before needing a recharge; the second generation performed better, with a range of 110-160 miles [6]. Although this may be enough for 90% of American commuters, it is still not enough range for long-distance road trips and therefore could not be a replacement for conventional IC cars. Even worse, a full recharge for the EV1 took nearly eight hours [6]. As GM vice chairman Bob Lutz points out, “You can’t take a gas can and walk down the highway to pick up five bucks’ worth of electricity.” [7]. If an electric car ran out of charge, it would be at least a few hours before it would be back on the road. Such disadvantages never allowed the electric car to become competitive with gasoline-powered cars.

4. Modern Electric Cars: Battery Technology, The Tesla Roadster, and The ZAP-X

The latest pure-electric cars have begun to address the shortcomings of their predecessors. Since the introduction of the GM EV1, lithium-ion batteries have become widely available, as demand for them from consumer electronics has skyrocketed. Lithium-ion batteries offer twice the energy density as nickel-metal hydride (NiMH) batteries and *six times* the energy density of lead-acid batteries [8]. In other words, lithium-ion batteries can provide greater range with a lighter cell.

Perhaps the most publicized example of the modern-day production electric car is the Tesla Roadster, built by Tesla Motors of California’s Silicon Valley. At a cost of \$100,000, the Tesla Roadster uses several thousand laptop-sized lithium-ion batteries to provide 245 miles per

charge and performance that puts Ferrari's to shame. Recharging time has fallen to 3.5 hours [9]. Doubling of range from previous generations, reducing recharging time, and offering blistering performance, the Tesla Roadster is poised to compete with many existing super cars.

Altair Nanotechnologies, Valence Technology, and A123 Systems recently introduced a new battery chemistry called Lithium Phosphate. Lithium phosphate batteries are inherently more stable and can therefore be recharged much more rapidly than conventional lithium-ion cells. In a demonstration, Valence Technology fired a ballistic round into a lithium phosphate battery and lithium-ion battery. The lithium-ion battery exploded and caught fire while the lithium phosphate battery simply broke apart [10]. In May 2007, Altairnano demonstrated production lithium phosphate packs that can be recharged in ten minutes and still provide 120 miles of range. The Altairnano packs also offer 20,000 charge/recharge cycles and a service life of twenty years, compared to the three to seven year life cycle of conventional lithium-ion packs [11].

Zero Air Pollution (ZAP) Cars, a manufacturer of electric vehicles in California, announced in January 2007 that it would be developing a crossover vehicle in conjunction with Lotus Engineering called the ZAP-X. The ZAP-X will utilize four in-hub electric motors connected to the Altairnano lithium phosphate battery packs for a range of 350 miles and a recharge time of ten minutes. Being a crossover, it will be able to seat five passengers comfortably and will offer all of the features found in standard automobiles today [12]. While this car is not yet on the market, it is proof that by combining today's automotive and battery technologies, it is possible to build an electric automobile that provides the same, if not better, ownership experience.

5. Comparison With Gasoline-Powered Car: Performance

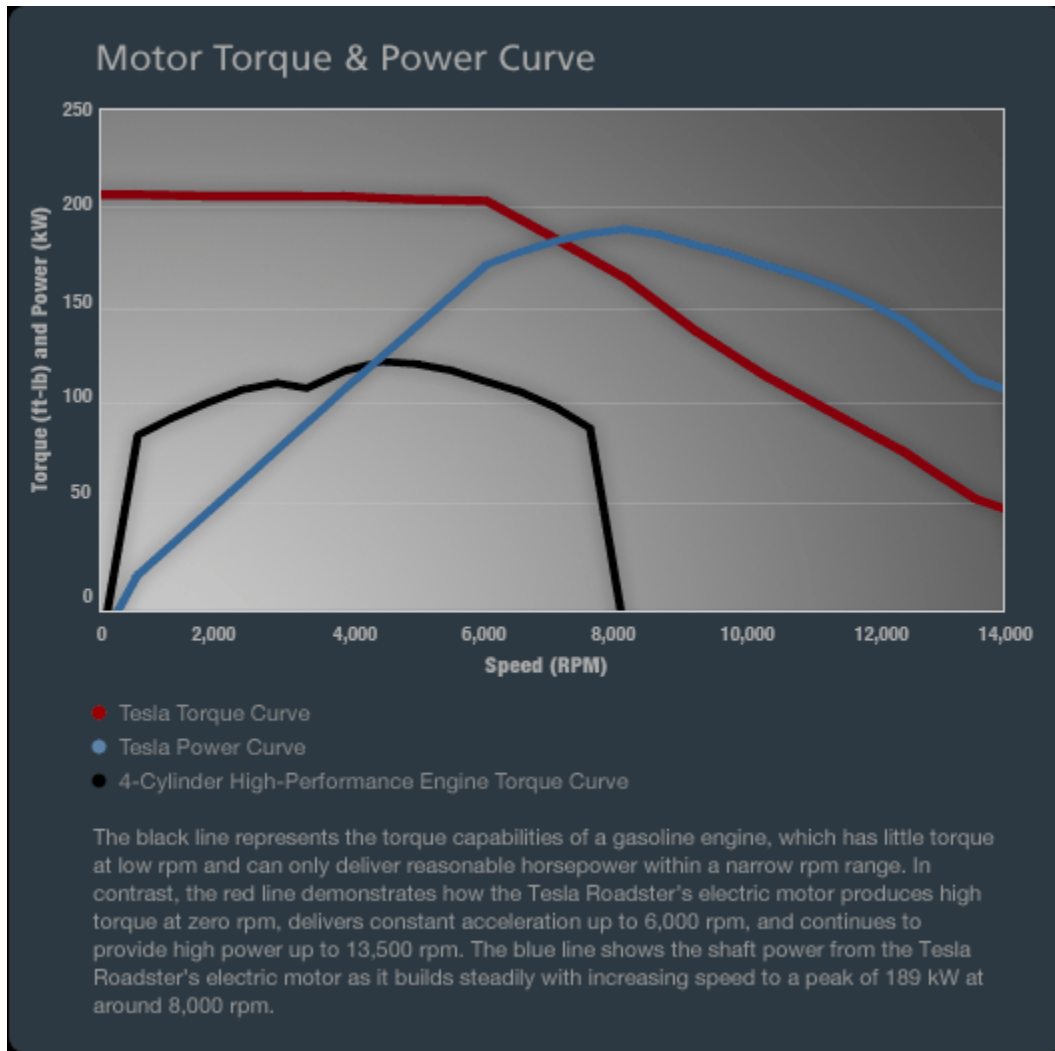


Figure 2: Torque Curve of All-Electric Tesla Roadster vs. 4-Cylinder IC Engine [13]

This is a graph of the torque and power curves of the Tesla Roadster compared to the torque curve of a 4-cylinder internal combustion engine. It shows that electric motors produce 100% torque starting from 0 RPM, which makes the car much more responsive off the line than those with IC engines. To show this fact mathematically, we can use Newton's Second Law of Motion and the equation for torque to derive an equation relating acceleration to torque:

$$\text{Torque} = \text{Force} * \text{RadiusOfWheel}$$

$$\text{Force} = \frac{\text{Torque}}{\text{RadiusOfWheel}}$$

$$\text{Force} = \text{Mass} * \text{Acceleration}$$

Solve for Acceleration :

$$\text{Acceleration} = \frac{\text{Torque}}{\{ \text{RadiusOfWheel} * \text{Mass} \}}$$

We can see that the greater the torque given, the greater the acceleration produced. Since electric cars produce 100% torque from 0 RPM, they are able to accelerate from a standstill at 100% of the motor’s acceleration capacity. In an IC engine, however, there is a limited RPM range where it is producing 100% torque – in the graph above, it is around 4500 RPM. This means that from a standstill, the car will not accelerate at 100% of the engine’s acceleration capacity until the engine is spinning at 4500 RPM. As the revs continue to build, the torque the engine produces quickly drops off.

A comparison between the Tesla Roadster and Lotus Elise in Table 1 illustrates the advantages of electric motors. The Tesla Roadster is based on the Lotus Elise and both cars have roughly 200 horsepower. However, the Lotus Elise is powered by a 1.8-liter internal combustion engine.

	0-60 mph	0-100 mph	Curb Weight
Lotus Elise	4.9 seconds	12.9 seconds	1984 lbs
Tesla Roadster	Under 4 seconds	11.0 seconds	2500 lbs

Table 1: Performance Figures of Lotus Elise and Tesla Roadster [9,14]

The Tesla is able to out-accelerate the Elise despite weighing an extra 500 lbs.

6. Economics of Electric Cars

Currently, the Tesla Roadster is priced in super car territory at \$89,000. As Elon Musk, the chairman of Tesla Motors, puts it:

“The strategy of Tesla is to enter at the high end of the market [with the roadster], where customers are prepared to pay a premium, and then drive down market as fast as possible [...] Without giving away too much, I can say that the second model [code name: White Star, scheduled for 2008] will be a sporty four door family car at roughly half the \$89k price point of the Tesla Roadster and the third model will be even more affordable” [15]

As electric car technology matures, prices will fall until they are within reach of mainstream consumers. This is already apparent by the ZAP-X which, when it comes to market, will be around \$60,000 [16].

Because they are more efficient, electric cars cost far less to run than gasoline-powered cars. The average price for a gallon of regular gasoline as of December 3rd, 2007 is \$3.00 [17] and the average price for a kilowatt-hour of electricity as of August 2007 was \$0.0968 [18].

Assuming the car is driven 10,000 miles per year, the fuel costs of the car is:

Gasoline Car: A typical gasoline car has a 20-gallon tank and can achieve 30 miles per gallon, giving it a range of 600 miles per tank

$$\frac{\{20 \text{ gal}\}}{\text{tank}} * \left\{ \frac{\{ \$3.00 \}}{\{ \text{gal} \}} \right\} * \left\{ \frac{\{ 10,000 \text{ miles/year} \}}{\{ 600 \text{ miles/tank} \}} \right\} = \$ 1000 \text{ per year}$$

Tesla Roadster: A Tesla Roadster's battery pack holds 53 kilowatt-hours of energy [19] and can travel 250 miles per charge [9]

$$\frac{\{53 \text{ kWh}\}}{\text{charge}} * \left\{ \frac{\{\$0.0968\}}{\text{kWh}} \right\} * \left\{ \frac{\{10,000 \text{ miles/year}\}}{\{250 \text{ miles/charge}\}} \right\} = \$202.20 \text{ per year}$$

In addition, the infrastructure to distribute electricity is already in place. This means charging stations can be built without needing a new supply chain and gives consumers the option to recharge their cars at home.

Electric cars contain fewer parts, meaning less can go wrong. When reliability increases, the amount of maintenance required and therefore the overall cost of ownership decreases. The reduced maintenance and operational cost will be a strong incentive to drive an electric car.

7. Conclusion

Despite being a leading design in the early years of automotive history, electric cars became obsolete when gasoline cars offered longer range and more accessible fuel in a lower-priced package. The lack of major breakthroughs in battery technology hindered the electric car from becoming competitive with gasoline-powered automobiles.

However, the skyrocketing demand for better battery technology from consumer electronics has prompted several important advancements, including the lithium-ion battery. Lithium-ion batteries and their next iteration, lithium phosphate batteries, can now propel electric vehicles to nearly the same range as gasoline counterparts. Recharging times have fallen to 10 minutes – just enough time to rest before driving another 350 miles.

As electric cars are produced in greater volumes, the future will only bring faster-charging batteries and less expensive cars. Consumers will be able to drive their electric cars the same way they use their gasoline-powered cars, all the while dramatically reducing the amount of pollution produced. The electric car is the next logical step in automobiles and, given modern technology, can be a competitive product in today's market.

References

- [1] Wickert, Jonathan. "Who Are Mechanical Engineers?" An Introduction to Mechanical Engineering. 2nd ed. N.p.: Thomson, 2006. 7-19.
- [2] "Some EV History." History of Electric Cars and Other Vehicles. 13 Nov. 2006. Econogics. 6 Nov. 2007 <<http://www.econogics.com/ev/evhistory.htm>>.
- [3] Campbell, Colin J., and Jean H. Laherrere. "The End of Cheap Oil." Scientific American Mar. 1998: 78-83.
- [4] Schiffer, Michael Brian, Tamara C. Butts, and Kimberly K. Grimm. Taking Charge. N.p.: Smithsonian Institution Press, 1994.
- [5] Shnayerson, Michael. The Car That Could. New York: Random House, 1996.
- [6] Who Killed The Electric Car? 2006. DVD. Sony Pictures Classics.
- [7] Hewitt, Ben. "The 110-Volt Solution." Popular Mechanics May 2007: 64-69.
- [8] Brain, Marshall. "How Lithium-ion Batteries Work." HowStuffWorks. 4 Dec. 2007 <<http://electronics.howstuffworks.com/lithium-ion-battery.htm>>.
- [9] Tesla Motors. 4 Dec. 2007 <<http://www.teslamotors.com/>>.
- [10] Battery Safety. Valence Technology. 4 Dec. 2007 <http://www.valence.com/technology/safety_video.html#>.
- [11] Kachan, Dallas. "Altairnano Power Play." Cleantech. 26 Feb. 2007. 4 Dec. 2007 <<http://media.cleantech.com/node/784>>.
- [12] "ZAP-X Crossover Electric Vehicle." ZAP Electric Cars. 4 Dec. 2007 <<http://www.zapworld.com/electric-vehicles/electric-cars/zap-x>>.
- [13] Tesla Motors Co., "Motor Torque & Power Curve," http://www.teslamotors.com/display_data/torquegraph_v2.gif, 6 Nov. 2007.
- [14] "Performance." Lotus Cars 2007 Elise. 4 Dec. 2007 <<http://www.lotuscars.com/Elise.aspx>>.
- [15] Treehugger, Elon Musk quote - Richard, Michael Graham. "Tesla Motors: Affordable Electric Cars Are Coming." TreeHugger. 3 Aug. 2006. 4 Dec. 2007 <http://www.treehugger.com/files/2006/08/tesla_motors_ev.php>.
- [16] Kachan, Dallas. "Look out Tesla... ZAP Building Electric Supercar." CleanTech. 30 Jan. 2007. 4 Dec. 2007 <<http://media.cleantech.com/node/677>>.

[17] "Weekly Retail Gasoline and Diesel Prices." Energy Information Administration. 3 Dec. 2007. 4 Dec. 2007 <http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_a_epmr_pte_cpgal_w.htm>.

[18] Electricity price " Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State." Energy Information Administration. 16 Nov. 2007. 4 Dec. 2007 <http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html>.

[19] Berdichevsky, Gene, et al. "Background." The Tesla Roadster Battery System. 1-2. Tesla Motors. 4 Dec. 2007 <http://www.teslamotors.com/display_data/TeslaRoadsterBatterySystem.pdf>.