THE RISE & FALL OF ELECTRIC VEHICLES IN 1828–1930: LESSONS LEARNED

The dawn of commercialization of electric vehicles is upon us. Nevertheless it is very interesting to note that commercialization of electric vehicles was in fact successful in the early 20th century. This paper scans our past in the research, development, and commercialization of electric vehicles commencing from their invention in 1828 until their almost nonexistence in 1930. Their features in the technology development, production from small scale to commercial scale, applications from private users to commercial ones, and the corresponding charging infrastructure and business model are all analyzed and compared with the present development. Therefore, lessons can be learned from history to speed up our present development and avoid the same mistakes as in the past.

Fig. 1. *Thomas Parker and his electric car; he is in the light suit in the front passenger seat.*

I. INTRODUCTION

Mobility means freedom. Mobility is the most apt function in our quest for happiness.

Since the invention of automobiles over a century ago, vehicles have changed the world. Automobiles have promoted and still promote global economic development and improve human standard of living by enabling mobile freedom. However, would this freedom of mobility be sustainable in the new era in view of major challenges in energy, environment, and traffic safety?

This month we review the very early history of electric vehicles which first became popular in the late 19th and early 20th centuries, before the widespread usage of the internal combustion engine.

To address these issues, the development of electric vehicles (EVs) has now gone into an accelerated pace. The dawn of commercialization of EVs is upon us. Without a doubt, EVs will become a paradigm of the new era of the environment, energy, and information, although there are still challenges ahead. The history of EVs should inspire us to tackle today's challenges.

The success of commercialization of EVs depends on the satisfactory tackling of four factors: initial cost, convenience of use, energy consumption, and exhaust emission. Only the latter two have been fulfilled and satisfied so far. Therefore, we need to pay further attention toward the following three fundamental factors:

1) availability of good performance products at an affordable cost;

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2) availability of efficient and user-friendly infrastructure;
3) availability of a good business model to leverage the cost of batteries.

In fact, we have gone through these challenges in the early 20th century. Nevertheless, thanks to the mass production of internal combustion engine vehicles (ICEVs), particularly by Henry Ford around 1910; the invention of an automobile starter by Charles Kettering in 1912; the discovery and hence large-scale production of oil, particularly in Texas around 1920; and the extension of highways by 1920, the ICEVs became more competitive than EVs.

The author has been engaged in the research and development of EVs for almost four decades and witnessed their ups and downs. It is envisaged to be the biggest change in the automobile industry in the next three decades. The author believes that creative development of clean, efficient, and intelligent vehicles will have significant impact on the welfare of our future generations [1], [2]. The lessons we learn from the history of EVs encourage us to tackle the problems today and avoid possibly the same mistakes in the future.

II. EARLY INVENTIONS AND DEVELOPMENT

In the history of the development of the human society, the basic needs are: clothing, food, shelter, and mobility, where mobility is considered an advanced level of a basic need, which confirms the importance of freedom of mobility. Carriages were the early means of mobility. In the beginning of the invention of carriages, horses were the main source of power. Even today, we still use horse power as the unit of power. In 1801, Richard Trevithick built a steam-powered carriage, opening the era of horseless transportation. After over 30 years of noisy and dirty steam engines, the first battery-powered EV was built in 1834 [3]. Over 50 years later, the first petrol-powered ICEV was built in 1885. So, the EV is not new; it is about 50 years older than ICEVs. In the early 1900s, it was even better than the ICEV. Having been out of use for almost 70 years, EVs became popular again in the 1970s. Currently, the EV may become a renewed and popular means of mobility.

Several inventors in Europe and the United States have been given the credit for the early inventions and development of EVs. In 1828, a Hungarian, Ányos Jedlik, invented a small-scale model car powered by an electric motor that he designed. In 1835, another small-scale electric car was designed by Professor Stratingh of Groningen, Holland, and built by his assistant Christopher Becker [4]. In 1835, Thomas Davenport, a blacksmith from Brandon, VT, built a small-scale electric car. Davenport was also the inventor of the first American-built direct current (dc) electric motor. In 1838, Scotsman Robert Davidson built an electric locomotive that achieved the speed of 4 mph (6.4 km/h) [5]. Between 1832 and 1839, Robert Anderson of Scotland invented a crude electrical carriage [6]. A patent for the use of rails as conductors of electric current was granted in England in 1840, and similar patents were issued to Lilley and Colten in the United States in 1847 [7]. Rechargeable batteries that provided a viable means for storing electricity onboard a vehicle did not come into being until the 1840s.

More practical and successful electric road vehicles were invented by both Thomas Davenport and Scotsmen Robert Davidson around 1842. Both inventors were the first to use the newly invented but nonrechargeable electric cells or batteries. Frenchman Gaston Plante invented a better storage battery in 1865 [8] and his fellow countryman Camille Faure further improved the storage battery in 1881 [10]. Better capacity storage batteries were needed for electric vehicles to become practical. In the late 1800s, France and England were the first nations to support the widespread development of EVs [6]. The lack of natural fossil resources in Switzerland resulted in the tiny European nation's rapid electrification of its railway network to reduce its dependence on foreign energy. In November 1881, French inventor Gustave Trouvé demonstrated a working three-wheeled automobile at the International Exhibition of Electricity in Paris, France [11]. English inventor Thomas Parker, who was responsible for innovations such as electrifying the London Underground, overhead tramways in Liverpool and Birmingham, and the smokeless fuel coalite, claimed to have perfected a working electric car in as early as 1884 [12], Fig. 1 shows Thomas Parker and his electric car.

It was not until 1895 that Americans began to devote their attention to EVs after an electric tricycle was built by A. L. Ryker, and William Morrison built a six-passenger wagon, both in 1891. Its "Victoria" model EV was an example of better designs in 1897. Many innovations followed and the interest in EVs increased greatly in the late 1890s and early 1900s. In fact, William Morrison's design with a one-passenger capacity is often considered the first real and practical EV.

The last decade of the 19th century was a blooming period in the early development of EVs. As shown in Fig. 2 (*The Horseless Age*, Vol. 1, No. 2, December 1895, p. 15; *Scientific American*, Vol. LXXIII, No. 20, November 16, 1895, p. 315), the "Electrobat" was converted from a delivery wagon, and ran on the streets of Philadelphia, PA, in 1894. The Pope Manufacturing Company had produced about 500 EVs of the "Columbia" model by the end of 1898. Apart from those EV manufacturers in the United States, the London Electrical Cab Company in England was inaugurated in 1897 with 15 taxis. Such an electric taxi is shown in Fig. 3 (*Scientific American*, Supplement, Vol. XLIV, No. 1141, November 13, 1897, p. 1897). Moreover, from 1899 to 1906, in France, Bouquet, Garcin & Schivre (BGS) manufactured various types of commercial EVs, including

Fig. 2. *Morris & Salom's Electrobat. Courtesy of The Horseless Age; courtesy of Scientific American; photo courtesy of History of the Electric Automobile [11].*

cars, trucks, buses, and limousines. Because the company designed and manufactured batteries especially for its own EVs, the BGS EV of 1900 held the world's longest range record of almost 290 km per charge. It is also interesting to note that the first vehicle running over the 100-km/h barrier was an EV, namely, the "Jamais Contente" (Never Satisfied), which was driven by Camille Jenatzy, a Belgian. It was a bullet-shaped electric racing car, and it captured the record of 110 km/h on May 1, 1899.

In addition, electric trains were used to transport coal, as their motors did not use up precious oxygen. Before the preeminence of internal combustion engines, EVs had held many speed and distance records [13]. In addition to the above mentioned record by a Belgium EV named "Jamais Contente," which reached a top speed of 105.88 km/h (65.79 mph), a notable record was Ferdinand Porsche's design and construction of an all-wheel drive electric car, powered by a motor in each hub, which set several

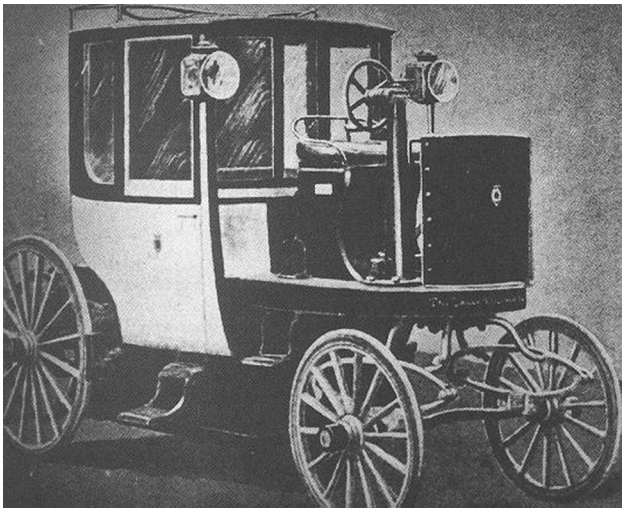

Fig. 3. *London Electrical Cab Company's taxi. Courtesy of Scientific American, Supplement; photo courtesy of History of the Electric Automobile [11].*

ELECTRIC CAR RECORD; MAKES 100-MILE RUN

Remarkable Test for Stock Runabout on Single Charge.

KILLS DOG ON JOURNEY

F. A. Babcock, Jr., Drives from Jersey City to Camden at Average of 14 Miles an Hour.

Special to The New York Times.

Fig. 4. *News clip from The New York Times on the speed record of an electric car.*

records in the hands of its owner E. W. Hart. Fig. 4 shows a news clip from *The New York Times* on the speed record of an electric car.

III. EARLY COMMERCIALIZATION

Electric vehicles found their first commercial application as a fleet of New York City electric taxis in 1897, as shown in Fig. 5, which were built by the Electric Carriage and Wagon Company of Philadelphia, PA. EVs were produced in the United States by Anthony Electric, Baker, Columbia, Anderson, Edison, Studebaker, Riker, and others during the early 20th century. Fig. 6 shows the social prestige of Baker EV. In Europe, a German electric car with a chauffeur sitting on top of a vehicle was commercialized in 1904, as shown in Fig. 7. It can be seen from this figure that behind the EV there was a horse carriage.

By the turn of the century, the United States was very prosperous and cars, available in steam, electric, or gasoline versions, were becoming popular. The years 1899 and 1900 were the high point of EVs in the United States, as they outsold all other types of cars. One example was the 1902 Phaeton built by the Woods Motor Vehicle Company of Chicago, IL, which had a range of 18 miles, a top speed of 14 mph and cost $2000. The Columbia Electric Runabout was the best-seller car in the United States in 1900 and the first to exceed 1000 sales. In 1911, the first gasoline-electric

Fig. 5. *New York City Taxi 1901.*

hybrid car was released by the Woods Motor Vehicle Company of Chicago. The hybrid was a commercial failure, proving to be too slow for its price, and too difficult to service [14], [17].

Electric vehicles had many advantages over their competitors in the early 1900s. They did not have the vibration, smell, and noise associated with gasoline cars. Changing gears on gasoline cars was the most difficult part of driving, while electric vehicles did not require gear changes. While steam-powered cars also had no gear shifting, they suffered from long start-up times of up to 45 minutes during winter. The steam cars were less productive needing water sooner than an electric vehicle needed a recharge. The roads were not well developed then, causing most travel to be local, a perfect situation for EVs, since their range was limited. The EV was the preferred choice of many because it did not require the manual effort to start, as with the hand crank on gasoline vehicles, and there was no wrestling with a gear shifter. Electric cars were often marketed as suitable vehicles for female drivers due to the ease of operation; in fact, early electric cars were stigmatized by the perception that they were "women's cars," leading some companies to affix radiators to the front to disguise the car's propulsion system.

While basic electric cars cost under $1000 (roughly $28 000 today), most early EVs were massive, ornate carriages designed for the upper-class customers that made them popular. They featured luxurious interiors, replete with expensive materials, and averaged $3000 (roughly $84 000 today). Sales of electric cars peaked in 1912. Fig. 8 shows Thomas Edison and an electric car in 1913.

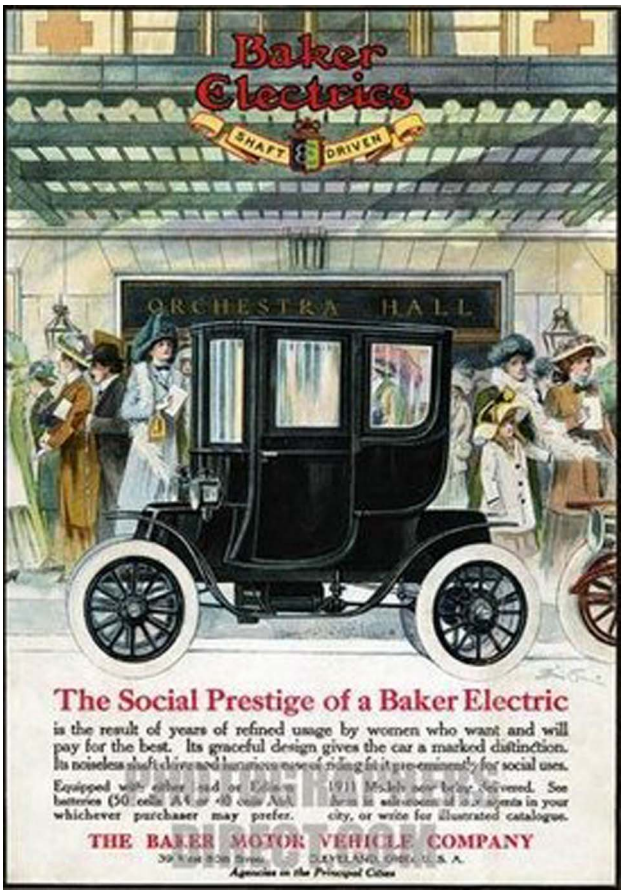

Fig. 6. *Baker electric vehicle.*

IV. EARLY CHARGING INFRASTRUCTURE

Acceptance of electric cars was initially hampered by a lack of power infrastructure, but by 1912, many homes were wired for electricity, enabling a surge in the popularity of the cars. At the turn of the century, 40% of American automobiles were powered by steam, 38% by electricity, and 22% by gasoline. In total, 33 842 electric cars were registered in the United States, and America became the country where electric cars had gained the most acceptance [15]. Fig. 9 shows the GE charging station with a Baker EV in the early 1900s.

Fig. 7. *German electric car with a chauffeur sitting on top of the car (1904).*

In order to overcome the limited operating range of EVs, and the lack of recharging infrastructure, an exchangeable battery service was first proposed as early as in 1896 [16]. The concept was first put into practice by the Hartford Electric Light Company through the GeVeCo battery service and initially available for electric trucks. The vehicle owner purchased the vehicle from General Vehicle Company (GVC, a subsidiary of the General Electric Company) without a battery and the electricity was purchased from Hartford Electric through an exchangeable battery. The owner paid a variable per-mile charge and a monthly service fee to cover for maintenance and storage of the truck. Both vehicles and batteries were modified to facilitate a fast battery exchange. The service was provided between 1910 and 1924 and during that period covered more than six million miles. Beginning in 1917, a similar successful service was offered in Chicago, IL, for owners of Milburn Light Electric cars who also were able buy a vehicle without batteries [16].

Fig. 8. *Thomas Edison and an electric car in 1913 (courtesy of the National Museum of American History).*

V. THE DECLINE OF EARLY COMMERCIALIZATION

Electric vehicles' popularity declined due to the following reasons. By the 1920s, the United States had an improved road system that connected different cities, bringing with it the need for longer range vehicles. The discovery of Texas crude oil reduced the price of gasoline so that it was affordable to the average consumer. The invention of the electric starter by Charles Kettering in 1912 eliminated the need for the hand crank. The initiation of mass production of ICEVs by Henry Ford made these vehicles widely available and affordable in the $500–1000 price range. By contrast, the price of the less efficiently produced electric vehicles continued to rise. In 1912, an electric roadster sold for $1750, while a gasoline car sold for $650. In 1923, Milburn was sold to its main body client General Motors. It is likely that no new Detroit EVs have been produced after the middle of 1926. In 1929, W. C. Anderson sold the company. The last Detroit EV under Anderson was shipped in November 1929. Fig. 10 shows the Detroit EVs advertisement in 1912.

Eventually, the expense of running an electric vehicle versus a gas-powered car became a decisive blow to the EV. Henry Ford's gas-powered cars had a relatively low cost compared to EVs. Recharging lead-acid batteries cost roughly 20 cents per kilowatt hour (about $2.07 today), compared with filling up with five cents a gallon gas back then. The first gas station was built in St. Louis, MO, in 1905. Standard Oil of California (now Chevron) built its first station in 1907 in Seattle, WA. By 1920, gas stations made their way across the United States and filling up a car with gas became very easy, therefore

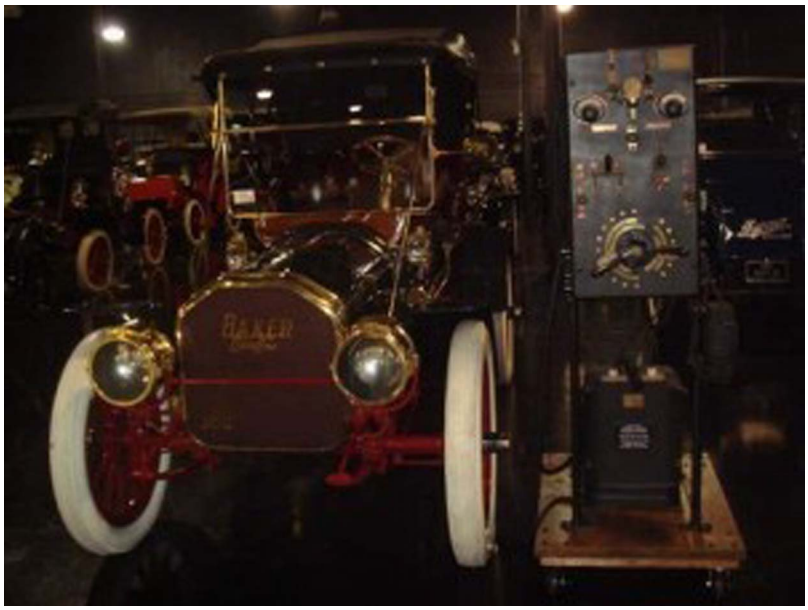

Fig. 9. *GE charging station with a Baker EV in the early 1900s.*

switching to the internal combustion engine was not a surprise.

Electric vehicles disappeared by 1935, until their revival in the beginning of the 1970s due to the oil crisis by the boycott of the Middle East.

VI. LESSONS LEARNED

The development of EVs has its own characteristics in different historical stages. The momentum or a driving force for the inventions, the technical features, applications, charging infrastructure, and business model were not all the same in different historical periods. However, the same spirit, fundamental principles, and philosophy remain today, inspiring us and providing useful references for current EV development.

In the middle of the 19th century, EVs were popular because they were clean, quiet, easy to start and drive, as compared to the steam cars or ICEVs that were noisy, smelly, produced a lot of smoke, and needed crankshaft to start an engine, as well as gear shift to drive. The technical features of the propulsion system in the early development were dc motor drives and lead-acid batteries; their applications were for low-speed, short-distance city driving for wealthy people. For example, EV was called an Opera Car in London, since its typical application was for driving to the opera house. Since the driving distance was short, the need for power was small, therefore lead-acid batteries with slow charging at home were sufficient, although the battery swapping scheme was also proposed. In the 1970s, the revival of EVs happened because of the energy issue, due to the oil crisis in the Middle East. Then, since the 1990s, the reason for the EV development was not only the energy issue, but also the environment protection issue. We needed a way to be mobile that would be clean, and that would provide energy flexibility and efficient, intelligent, and sustainable transportation means. Today, we need high energy density, high power density, high efficiency, long life, reliable and reasonable cost of modern EV batteries and modern EV motors that can suit the driving requirements of vehicles in urban as well as rural areas. Currently, we use lithium batteries. The main requirements for EV motors are high power density, high starting torque, high efficiency over wide speed range and over wide torque range, and a reasonable cost. The typical types of EV motors are permanent magnet motors, induction motors, and switched reluctance motors. Today, EVs are not only used for urban driving, but can also be used on highways, for long-range driving. In short, today's science and technology are much advanced as compared to over a century ago, from material sciences to electronics, control, computer, communication, and information technologies. We should take full advantage of these new technologies, particularly the integration of energy and information [18]. Although today's EV technical features are more advanced than those of the early days EVs, the spirit and philosophy of early inventions and development remain the same. The fundamental principles in the designs and the basic considerations for

Fig. 10. *Detroit EV advertisement (1912).*

commercialization and infrastructure remain the same in today's development of EVs. It is essential to note that when Henry Ford developed the first cars, they were not reliable and there were no gas stations, but he was very devoted to improving their performance, reducing their cost, and negotiating with oil companies to build the gas station infrastructure and to establish the maintenance service network. The philosophy of the availability of good product, good infrastructure, and good business model to achieve affordable cost, convenience of use, and energy savings remains valid. Most importantly, the philosophy of having an open mind and having courage to develop new things as well as the engineering philosophy of the system integration and optimization continues to inspire us.

VII. CONCLUSION

In the 21st century, the need for the development of modern EVs is even larger. This paper has reviewed the early inventions, development, and commercialization of EVs during 1828–1930. The philosophy, technical features, and commercialization process were analyzed and compared with today's development of modern EVs. Lessons to be learned from the past experience were summarized in order to accelerate today's development and commercialization. We should take full advantages of today's new technologies, particularly the integration of energy and information. The coordination, cooperation, and collaboration among the stake holders, particularly between the automakers and the energy providers, are crucial. The philosophy of having an open mind and having courage to develop new things is essential. It is really rewarding to learn from history and to look ahead at the challenges and opportunities. It is really exciting to be involved in the forefront of the evolution of modern EVs. With the increasing concerted efforts from the stakeholders, it is indeed gratifying to see the first glimpse of the dawn of the new EV age. ■

C. C. CHAN, *Fellow IEEE*

REFERENCES

[1] C. C. Chan and K. T. Chau, *Modern Electric Vehicle Technology*. Oxford, U.K.: Oxford Univ. Press, 2001.

[2] C. C. Chan, "The state of the art of electric, hybrid, and fuel cell vehicles," *Proc. IEEE*, vol. 95, no. 4, pp. 704–718, Apr. 2007.

[3] *Today in Technology History: July 6, The Center for the Study of Technology and Science*. [Online]. Available: http://en.wikipedia.org/wiki/Richard_Trevithick

[4] *Sibrandus Stratingh (1785-1841): Professor of Chemistry and Technology*, University of Groningen, Groningen, The Netherlands. [Online]. Available: http://www.rug.nl/museum/geschiedenis/hoogleraren/stratingh

[5] E. A. Moore, "As electric cars gain currency, Oregon charges ahead," *Christian Science Monitor*, Feb. 10, 2009. [Online]. Available: http://features.csmonitor.com/environment/2009/02/10/as-electric-cars-gain-currency-oregon-charges-ahead/

[6] M. Bellis, "History of electric vehicles: The early years, electric cars from 1830 to 1930," *About.com*, 2006. [Online]. Available: http://inventors.about.com/library/weekly/aacarselectrica.htm

[7] Mike's Railway History, *Electric Traction: A Vital Development in the History of the Railway*. [Online]. Available: http://mikes.railhistory.railfan.net/r066.html

[8] The Government of Australia, *Development of the Motor Car and Bicycle*, 2003. [Online]. Available: http://www.travelsmart.gov.au/teachers/teachers6.html

[9] NOW on PBS, *Life & Death of the Electric Car*, Jun. 9, 2006. [Online]. Available: http://www.pbs.org/now/shows/223/electric-car-timeline.html

[10] "The Electric/Hybrid Car," *Solution: Alternative Energy for Passenger Vehicles*, University of Minnesota. [Online]. Available: http://blog.lib.umn.edu/ernst102/architecture/pg15%20copy.pdf

[11] E. H. Wakefield, *History of the Electric Automobile*. Warrendale, PA: Society of Automotive Engineers, 1994, pp. 2–3, ISBN: 1-56091-299-5.

[12] "World's first electric car built by Victorian inventor in 1884," *The Daily Telegraph*, Apr. 24, 2009. Available: http://www.telegraph.co.uk/news/newstopics/howaboutthat/5212278/Worlds-first-electric-car-built-by-Victorianinventor-in-1884.html

[13] *Cub Scout Car Show*, Jan. 2008, Available: http://www.macscouter.com/CubScouts/PowWow07/SCCC_2007/CubScoutThemes/Jan_2008.pdf

[14] P. Valdes-Dapena, "Hybrid cars are so last century," *CNN Money*, Apr. 24, 2006. [Online]. Available: http://money.cnn.com/2006/04/18/Autos/alternative_fuel_history

[15] Automobile. [Online]. Available: http://www.britannica.com/EBchecked/topic/44957/automobile/259061/Early-electric-automobiles#ref=ref918099

[16] D. A. Kirsch, *The Electric Vehicle and the Burden of History*. New Brunswick, NJ: Rutgers Univ. Press, 2000, pp. 153–162, ISBN: 0-8135-2809-7.

[17] E. H. Wakefield, *History of the Electric Automobile: Hybrid Electric Vehicles*. Warrendale, PA: Society of Automotive Engineers, 1998, ISBN: 0-7680-0125-0.

[18] C. C. Chan and L. Jian, "Smart charging of electric vehicles—Integration of energy and information," *Proc. IEEE*, to be published.