To be presented at the Advanced Workshop in Regulation and Competition
Center for Research in Regulated Industries – Rutgers University
28th Annual Eastern Conference
Skytop, Pennsylvania
May 13–15, 2009

ELECTRIC DRIVE VEHICLES FOR MAIL DELIVERY: IDENTIFYING KEY ISSUES*

Michael Ravnitzky

Postal Regulatory Commission

May 2009

* The views expressed in this paper are those of the author and do not necessarily represent the opinions of the Postal Regulatory Commission.

Abstract

Electrification of the postal fleet should be an integral part of the nation's energy goals. Most daily mail delivery routes are short, repetitive and well-defined, and include many stops, making the postal delivery fleet a prime application for electric drive vehicles. The electrification of the postal fleet could significantly reduce gasoline and maintenance expenses while reducing the fleet's carbon footprint.

Furthermore, the postal operator can earn substantial revenue in the wholesale electric markets by aggregating and offering on the wholesale electric market access to ancillary electric power from the vehicle batteries. Off-peak charging, grid operator control of off-peak charging, and particularly the availability of aggregated storage capacity would enhance the ability of the nation's electrical grid to incorporate renewable sources of electricity, sources such as wind and solar power which tend to be variable in output.

1. Introduction

Electrification of the nation's vehicular traffic is an important national goal,[1] and electrification of the postal fleet would be a logical first step in advancing this goal. The United States Postal Service owns and operates the world's largest civilian vehicle fleet for delivery and transportation purposes. Most of that fleet travels relatively short distances on repetitive, predictable routes on a daily basis. Electric drive vehicles using current technology provide more than sufficient range for city carrier postal requirements.[2]

Adoption of electric drive vehicles by the Postal Service would reduce net delivery costs, and in the process provide operational experience valuable to other transportation sectors. The Postal Service may benefit from the sale or trade of pollution credits, carbon credits or tax credits, or related partnership opportunities. Moreover, fleet electrification offers the Postal Service the potential to provide valuable energy storage and electricity regulation services for electric grid operators, particularly those managing increasing generation from renewable energy sources with uneven output. As a result, vehicle to

---

[1] President Barack Obama's energy plan called for 1 million electric plug-in hybrid vehicles on the road by 2015. *See, e.g.*, Remarks by the President at the Edison Electric Vehicle Technical Center, Pomona, California, March 19, 2009, *http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-Edison-Electric-Vehicle-Technical-Center/*.

[2] The term *city carrier* is a term of art that refers to urban and suburban routes served by salaried, uniformed letter carriers. Rural letter carriers and highway contract route operators handle the remainder of the routes.

grid (V2G) power technology could provide a valuable revenue source to the Postal Service.

Electric drive vehicles present much fewer maintenance requirements than gasoline vehicles do. They comprise far fewer moving parts, components and systems overall, reducing maintenance and the use of consumables. Historical experience with electric drive vehicles suggests maintenance cost reductions of at least 30 percent to 50 percent.[3] Technological advances in batteries, electrical inverters and charging systems have also made electric power train systems a practical option for postal delivery purposes. Recovering braking energy through regenerative braking, a feature of electric drive vehicles, helps make optimum use of available battery power and extends vehicle range.

Electric drive postal vehicles offer significant environmental benefits. Unlike conventional vehicles powered by fossil fuels, they do not directly emit pollutants. (Although it is true that the production of the electrical energy used to charge electric drive vehicles does emit pollutants, this production generates less pollution per kilowatt-hour of energy than that generated by internal combustion motors accomplishing the same task. In addition, it occurs farther away from locations where the pollutants are most immediately harmful — i.e., near people.) Electric drive vehicles result in much lower levels of emissions overall compared to those of conventional gas vehicles.

Because electric drive vehicles don't consume oil in the form of gasoline,[4] they help reduce the Postal Service's financial exposure from price volatility and cost risks associated with petroleum. Electrification of the postal fleet provides a model for moving the country away from dependence on oil, furthering national security interests and the balance of trade.[5] This initiative will also create jobs, encourage entrepreneurship and rely on a domestic power source helping build an infrastructure that will reduce dependence on oil.

---

[3] The Postal Service spent approximately $1.39 billion in vehicle maintenance costs in FY2008, including $447 million in personnel costs (5,419 maintenance personnel) and $926 million in supplies/materials, according to the FY08 USPS Financial Summary, Cost Segment 12, published online at *http://www.usps.com/financials/csc/welcome.htm*. *See also* Postal Regulatory Commission Docket ACR2008, Library Reference USPS-LR-FY08-5, Cost Segment 12, published online at *http://www.prc.gov*. Most of the $926 million in supplies/materials is fuel expenditures.

[4] Electric drive vehicles use electricity generated from a mix of sources including nuclear, coal, hydropower, oil, natural gas and renewables. But oil and gas make up a rather small fraction of the "system-wide fuel mix."

[5] An organization called Securing America's Future Energy (SAFE) has been highlighting the threats to national security and the American economy as a result of an almost exclusive dependence on liquid petroleum products (currently 97 percent) for America's transportation system. *See http.secureenergyfuture.org.*

The Postal Service has played a critical role in the bootstrapping, initial subsidization and ultimate development of several essential transportation infrastructures in the United States: stagecoach routes, railroads, transatlantic shipping, long-haul trucking, Alaskan Bush air services and passenger airlines. The Postal Service has the opportunity today to yet again lead the way in developing a new form of transportation — electric drive vehicles.

2. A History of Reliable Delivery

Electric drive vehicles were, even decades ago, considered highly practical and useful, and were in many countries used for delivery purposes, including for postal delivery.[6]

More than 100 years ago, as early as 1897–1899, the Post Office Department made an early foray into electric drive vehicles by purchasing several electric trucks. Experimentation continued, both throughout the early part of the 20th century and throughout the period of 1959 through the present.[7]

At the outset of the 20th century, electric drive vehicles comprised an important and valued segment of automotive and delivery transportation.[8] In 1900, 38 percent of all vehicles throughout the United States were powered entirely by a battery. A great variety of gasoline cars, steam-driven cars and electric cars appeared on the road, and many models of each were offered for sale.[9] Electric cars were comfortable, silent, odorless and easy to control. They started immediately, with no need to deal with dangerous hand-cranked starter mechanisms that could kick back and were known to even break an arm on occasion, or in the case of steam cars, wait for steam to reach the correct temperature. But electrics were also more costly to purchase and had limited range and

---

[6] Nancy A. Pope, Historian & Curator, Smithsonian National Postal Museum, "Charged Up: A Shocking History of Postal Trucks." Panel Discussion "Green Ways to Move the Mail: A Challenge for the New Century," Thursday March 20, 2008. *See also* presentation slides at: *http://www.postalmuseum.si.edu/Greenways/Pope_video.html*

[7] Some highlights: 1959: Electric three-wheeled mailster. 1960: Postal Service Electruk Jeeps. 1960–1977: Various electric drive vehicles. 2001: Purchase of 500 Ford electric drive vehicles. April 2009: Evaluation of four Chrysler electric drive vehicles. Source: United States Postal Service brochure entitled Alternate-Fuel Vehicle Techology (2008).

[8] Notably, the first postage stamp to portray an automobile was issued in 1901 — it showed a Baker Brougham electric taxi parked before the U.S. Capitol.

[9] For several years, there were roughly equal numbers of gasoline cars and electric cars on the road in some locations.

hill-climbing ability due to the weight of the batteries then available. Also, charging facilities outside the cities were few and far between.[10]

Five main factors spurred the pre-eminence of gasoline engine cars. First, gas became cheap and widely available. The oil well "Spindletop" started producing on January 10, 1901 in Beaumont, Texas, thereafter making gasoline an affordable commodity available at every crossroads general store for about $.05–$.10 per gallon (in today's dollars, between $1.20–$2.40 a gallon). By commencing the era of relatively cheap gasoline, this event helped cement the coming supremacy of the ICE (internal combustion engine) vehicle.[11]

Second, electricity was quite costly. In 1903, the average cost of electricity in the United States was reportedly an extravagant 23 cents/ kW·h (the equivalent to $5.24/kW·h today), while gas had become reasonably affordable. Electricity was used primarily for lighting rather than for other purposes.

Third, gasoline or diesel fuel has much higher energy density than batteries: i.e., it could carry much more energy for a given amount of weight. Lead-acid batteries of the day stored at best a mere 30 watt-hours/kilogram (W-h/kg), while gasoline stores the equivalent of 13,200 W-h/kg.[12] However, the energy density of gasoline should be discounted to account for energy losses that occur before gasoline's energy gets to the wheels, about 85 percent. With this adjustment factor, the effective energy density of gasoline is 1980 W-h/kg, still considerably above the best batteries today.

The fourth factor that encouraged growth of gas cars at the expense of electric cars was the development of roads. Early on, there were few good intercity and rural roads, so most drivers generally stayed in the urban areas. Once better roads became available, drivers wanted to use them and roam outside the cities. Unfortunately, charging locations were scarce, and owners of local businesses were often reluctant to allow drivers to charge vehicles from their location. Considering the average price of electricity, it was no wonder.

---

[10] In 1901, charging stations were installed in a series of New Jersey towns, enabling owners to drive from New York to Philadelphia. Yet that still necessitated time-consuming battery charging at each such stop. Within the next few years, power companies in major urban areas installed a number of 24-hour-a-day charging stations. For example, by mid-1903, Boston had 32, and by 1905, New York City had 41.

[11] Gas stations constituted the primary fueling "infrastructure" needed for internal combustion cars to take root. The first gas station dispensing gasoline to vehicles in the modern sense is considered to be one that opened in 1915 in Seattle.

[12] A NiMH (nickel metal hydride) battery stores about 30–80 W-h/kg. Li-Ion batteries now provide about 150 W-h/kg.

Finally, Ford Motor Company began mass production of the Model T gasoline-powered car on an assembly line in 1915, thus lowering the price and making ICE vehicles economically available to the mass public.

But for a while, electric drive vehicles were very popular. No one anticipated that they would be the only cars used, but, at that time, the electric drive vehicle satisfied some niche roles, such as a "doctor's car" or a fancy "opera car" for evening excursions by the wealthy, or as urban delivery trucks. For a physician who made night house calls, an electric vehicle was dependable, quiet and would not disturb neighbors. Nor did it require the engine to be warmed up, so it could be driven immediately on urgent errands. But it was noted that doctors often preferred to use gasoline motor cars when they went out for ordinary motoring or touring. (The appeal of "real" motoring required the sound, noise and range elements of a gasoline engine.)

Electric drive vehicles were quiet, smooth running, dependable and clean. Over time, the gasoline car manufacturers adopted some of the more useful features, neutralizing a key advantage of the electric cars. For example, in 1912, Cadillac introduced the electric starter for gas engine cars.

In 1912, *tens of thousands of fully electric cars and trucks were used throughout the world* as taxis, delivery vans, buses and city cars.

In 1914, Harry Dey, an engineer working for noted scientist Dr. Charles Steinmetz, invented several innovative pieces of automotive equipment, including a special split armature motor designed for regenerative braking.[13] Regenerative braking was not entirely new — it had been developed for use on electric trains. However, this particular design was quite innovative. It was likely the first time that such a mechanism was packaged for practical use on automobiles; the two-horsepower motor and axle weighed less than 100 pounds. At about this time, Henry Ford and Thomas Edison[14] prepared to

---

[13] Regenerative braking entails recovering and directing a portion of the vehicle's kinetic energy during braking to charging the battery; it thus greatly improves electric vehicle range, or the fuel efficiency of a hybrid gas-electric vehicle. Because it handles a portion of the braking function, regenerative braking also reduces the wear on brake components.

[14] Thomas Edison had spent years and tremendous sums on research to develop a practical vehicle battery. His team made tremendous strides and developed several novel types of batteries, but achieving a useful combination of energy density, cost and lifespan was quite difficult.

announce a mass-produced everyman's electric car with an improved battery for the affordable price of $750. However, it was not put into manufacture.[15]

As late as the outset of the First World War, most urban commercial fleets were dominated by electric trucks. Among the electric companies, Commonwealth Edison owned 114 electric trucks and zero gasoline trucks. New York Edison owned 144 electrics and five gas trucks. Other commercial corporate fleets were similarly weighted toward electric drive.[16]

World War One sounded the end of widespread use of the electric vehicle. The U.S. government and its allies undertook substantial research on gasoline engines to support the war effort. After the war, the large number of surplus military trucks were given new life working on the streets of cities in the United States and Europe. These inexpensive trucks proceeded to displace many of the electric trucks that had established a foothold in previous years.

Nevertheless, some electric drive vehicles continued to live on in particular applications. In England, electric drive vehicles known as "milk floats" were used for daily home delivery of dairy products. At their peak usage in the 1920s, some 40,000 such vehicles were operating in that nation. Dairy delivery routes were of limited distance, with frequent stops at most houses. Furthermore, most deliveries occurred during the early morning hours, when still-sleeping residents undoubtedly appreciated the lack of engine noise.

In 1922, American Railway Express was operating a fleet of 1,194 electric delivery trucks for parcel delivery. The fleet continued to operate into the 1950s, and a few even lasted into the 1960s, demonstrating the innate longevity possible with electric drive vehicles.

---

[15] In 1922, Steinmetz unveiled an electric truck as well as an electric car. The truck could carry a 1,500-pound load. The car could travel 200 miles on a charge, achieve speeds of up to 40 mph, weighed 2,000 pounds and could sell for less than $1,000. However, Steinmetz died the next year, and his company, the Steinmetz Motor Car Corp., folded soon thereafter as a result of poor management.

[16] Electric utilities are well represented in the contemporary ranks of companies with the largest alternative-fuel powered fleets, including PG&E (ranked fifth with 2,102 vehicles), Commonwealth Edison (ranked seventh with 1,918 vehicles), Consolidated Edison (ranked eighth with 1,752 vehicles), and Florida Power & Light (ranked tenth with 1,285 vehicles). The Postal Service reports ownership of several thousand alternative fuel capable vehicles. *See* State of Green Business 2009, a report by GreenBiz.com and Automotive Fleet Magazine, February 2009. Definitions vary as to what constitutes an alternative fuel vehicle.

In 1935, the German postal system operated a fleet of 2,400 electric mail delivery vehicles. They reportedly had lower maintenance costs, 30 percent savings on tire replacement and longer vehicle life, making them more economical in the long run. In Berlin alone, 1,300 electric trucks were used for parcel delivery; operating costs averaged 40 percent less than regular fleets.

Car manufacturers today are applying substantial resources to developing electric drive vehicles, a task made difficult because of the driving distance range they believe consumers require and want. This particular difficulty does not apply to postal delivery.

3. Postal Delivery Requirements and the Existing Delivery Fleet

The U.S. postal fleet of more than 200,000 vehicles includes approximately 142,000 right-hand drive LLV delivery trucks, now approaching the final years of their service lifespan. Chassis components for these vehicles are in some cases no longer being manufactured, and LLV maintenance inevitably increases as a result of vehicle aging. The Postal Service has announced plans to stretch the lifespan of the fleet by seven years, but this does not forestall the need to replace the fleet in coming years.[17]

It is possible to get a general sense of the overall needs for postal vehicles by examining the current vehicle fleet characteristics.[18]

The existing Postal Service LLVs were produced between 1987 and 1994. They combine a purpose-built aluminum body built by Grumman, a GM chassis/suspension based on a Chevrolet S-10 pickup truck, and either a 2.2 liter or a 2.5-liter piston engine. The engines had a power output of approximately 85 hp with a torque output of about 123 ft-lb-f. The LLV's have a three speed automatic transmission, vacuum assisted brakes and rear wheel drive, with a very tight turning radius. They are right-hand drive because a large number of deliveries are made to curbside mailboxes, typically heading in the direction of prevailing traffic. They are 85 inches high, 76 inches wide and 175.5 inches long. They have a cargo volume of 121 cubic feet.

The LLV's have an EPA-rated average fuel economy is 18.5 miles per gallon (mpg), but in actual use, the LLV gets about half that fuel mileage (i.e., *about 8–10 mpg*) given the

[17] The Postal Service also owns approximately 8,000 two-ton trucks. These are the larger type, walk-in trucks. In addition, the Postal service owns approximately 26,000 minivans (including 10,000 minivans purchased in 1997–98, also approaching the end of their practical service life), as well as 21,000 Flexible Fuel Vehicles (FFVs).

[18] The current specification for existing Postal Service delivery vehicles is publicly available. However, specifications for postal vehicles under development and draft specifications are not public.

extent of its start-and-stop driving routes, the typical profile of low speed operation, and some performance degradation from vehicle and engine wear and tear.

The performance specifications (and actual test figures) for the existing LLVs have been reported as follows:

Acceleration:		
0–15 mph:	5 sec. (spec.)	3.1 sec. (test)
0–50 mph:	27 sec. (spec.)	19.5 sec. (test)
0–55 mph:	35 sec. (spec.)	24.8 sec. (test)
Top speed:	55 mph	
Braking from 30–0 mph:		46–54 ft
Hill-climbing ability:[19]		ability to transcend and brake on a 20% slope

Clearly, the acceleration, braking and power requirements for an electric drive train required to perform the postal mission are quite modest and can easily be handled by today's electric drive trains.

The power requirements of an electric delivery vehicle were assessed in 1995 by performing measurements on an electrified postal vehicle carrying actual mail on an actual set of routes in 1995. The resulting energy requirements were:

1.36 kW·h /mile (in California)
1.23 kW·h /mile (in Virginia)

However, it is important to remember that vehicle and component designs have evolved in the intervening 14 years, and thus the electrical requirements would likely be fewer today.

Durability is important. The Postal Service has identified a need for vehicles that have a lifespan of 20–24 years. Postal vehicles endure substantial wear and tear in their daily use. The ability to maintain postal vehicles and obtain replacement parts when necessary is also important.

LLVs deployed for mail delivery achieve a gas mileage of 8–10 mpg; a gasoline price of $2.00/gal. equates to a fuel cost of 20–25 cents per mile. In contrast, fuel costs from

[19] The term gradeability is sometimes used to describe a vehicle's ability to transcend (climb up) a steep hill or grade.

electricity would run far less, some 8–12 cents per mile, depending upon the local unit cost of electricity, but battery costs spread over usage per mile are also a factor.

Battery costs are expected to follow typical technological and manufacturing production curves, and costs will drop with production volume. In general, electricity for electric drive vehicles costs the equivalent of about 80 cents per gallon, making it competitive with gasoline.

Carbon taxes or caps will, if imposed, raise electricity costs, perhaps as much as 1.5–2.0 cents per kW·h. Any calculations involving electric drive vehicles should take such factors into account.

4. Operating Characteristics of Electric Drive Vehicles

The operating characteristics of electric drive vehicles are well suited to postal delivery. Drive motors in electric drive vehicles operate smoothly and silently. Good acceleration and torque are available from a standing start, in comparison to ICE vehicles that require some engine speed to achieve high levels of torque and horsepower. As a result, initial acceleration at low speeds can be better than gasoline vehicles. This may help reduce the time interval between stops, within the confines of safety considerations.

Ride quality is better as a result of smoother acceleration and deceleration, and there is less mechanical stress on the parts. The use of regenerative braking in electric drive vehicles, which feeds braking energy back into the batteries to maximize battery power, tends to reduce wear on brake components.

Though electric drive vehicles have shorter traveling ranges per "fill-up" compared to ICE vehicles, the difference is not particularly detrimental for postal applications. Electric drive vehicles are equipped with power gauges that identify the remaining estimated range, identifying for the driver the remaining power and thus driving range as would a gas gauge on an ICE vehicle.[20]

[20] Car manufacturers often cite "range anxiety" (the fear of running out of power while driving somewhere) as a reason why electric drive vehicles would not be accepted by consumers. Because postal routes are well-defined and the capacity of today's lithium-ion batteries hold more than enough energy (including ample reserves) for most city carrier routes, the merits of this argument are not material to this paper.

Postal routes traverse less than 25 miles in the case of city carrier routes and average 45 miles in the case of rural carrier routes.[21] For city routes, mail delivery vehicles serving a defined area are parked in the same lot for the entire night and part of the morning, remaining stationary for more than ample time to recharge batteries. Current vehicles and batteries provide more than sufficient range at present for city carrier routes. The use of ordinary charging capability permits the vehicle to be recharged within a brief period.[22]

The recharge time for electric drive vehicles varies with recharging voltage applied and the current carrying capacity of the charging circuits. Applying greater voltage with the associated current capacity shortens the recharge times. Practical recharging levels and the wiring needed for those charging levels are more than ample for the ordinary requirements of postal vehicles.

Infrastructure such as the necessary charging stations and equipment for fleet vehicles and accompanying systems will comprise an essential part of any cost estimates. Estimates of infrastructure cost are uncertain, ranging as high as $6,000 per vehicle. Parking and lot size constraints need to be addressed. Such installation must take into account safety considerations associated with the amount of wiring and other structure required. Sufficient physical space is required to perform the extended charging required, but no more than is currently used for parking. The needed charging space could in theory be located in any parking lot, provided the lot can be wired to supply the necessary levels of electric power.[23] Electrical panels, circuit breakers, metering and wiring will likely require upgrades, and neighboring transformers will need to be able to handle the expected current. It is yet uncertain the extent to which such neighborhood grid or transformer upgrades would be the responsibility of the Postal Service.

---

[21] The anticipated consolidation of letter carrier routes due to reorganization and diminished mail volume is not expected to lengthen the mail routes appreciably. City carrier routes are not expected to shorten appreciably in average length as a result of delivery point density increase or redesign of routes for efficiency. Rural routes have shrunk in size from 70 miles/route in 1976 down to 45 miles/route in 2008 due to increasing density, but the level has reached a plateau and is not expected to drop much further.

[22] Charging time depends upon the battery type and capacity as well as the voltage and current available in the charging stations. Increasing voltage level and current capacity reduces the required charging time but increases wiring installation costs. Postal vehicles would likely use 220 volts and 50 amps of current capacity per vehicle as a suitable tradeoff of wiring costs versus charging times. Significantly, provision of suitable voltage and current capacity is not expected to present any major costs or particular difficulties.

[23] The use of inductive charging methods that do not require a physical plug in connection have been proposed as an alternative to ordinary charging methods that utilize a plug or other solid conductive connection. Inductive charging may offer some safety advantages. In addition, it is possible to envision a scenario in which cars can be charged safely and easily simply by parking in a particular spot.

Electric drive vehicle performance may be constrained in at least two ways by ambient temperature conditions. First, battery performance is affected by cold temperatures. This can be remedied by an auxiliary battery heating element, but that expends battery power, even when the vehicle is idle. Second, any heating (or cooling) of the driver's space requires substantial additional electric power.[24] In addition, windshields require energy for defrosting on cold days.

The worst extremes of cold temperatures can be avoided by simply using hybrid- or gasoline-powered vehicles on the fraction of routes that require them. The Postal Service should conduct a study to help distinguish routes suitable for electric drive vehicles from those that are not, with regard to weather, climate, route length and terrain.

Power Management During Starting and Stopping

Regenerative braking reclaims electric vehicle energy during the braking process by using the motor as a generator and recharging the battery. Regenerative braking is an integral part of most electric drive vehicles. Modern power management controls make regenerative braking practical. However, regenerative braking also requires batteries that can quickly and efficiently move power in and out of the drive train. Currently, energy losses from moving power in and out of a battery once are about 15 percent. This is satisfactory for the requirements of postal delivery.

Some have suggested incorporating technologies that can rapidly and efficiently move power in and out of temporary storage for functions such as braking and accelerating. These may include ultracapacitors (also known as supercapacitors, electrochemical double-layer capacitors or ultracapacitors), secondary battery units, flywheels or hydraulic storage. Such added regenerative capacity would add cost and complexity but also may offer substantial benefits and performance such as added range. The technical literature suggests that ultracapacitors, in particular, are improving rapidly. [25]

[24] Postal vehicles usually have a heating system for the driver space, but are not equipped with air conditioning.

[25] Ultracapacitors are electrolytic double-layer capacitors that have high-power density that declines slowly at low temperatures. They are extremely durable and long-lived. Their energy density is lower than that of batteries, and the voltage sags with state of charge (SOC). But their remarkable power density characteristics and charging efficiency are well suited for absorbing and delivering power quickly for regenerative braking purposes. Ultracapacitors might provide opportunities for improvements in the regenerative braking efficiency.

5. Factors Encouraging Postal Fleet Electrification

A number of factors serve to encourage the electrification of the postal delivery fleet. These include:

- The existence of short-duration, repetitive, predictable routes
- High fuel prices with significant volatility
- Operating costs of gasoline engine trucks compared with electric drive trucks
- The importance of controlling costs of delivery to the home
- Potential limitations on the use of gas engine vehicles in some cities
- Environmental benefits and pollution reduction
- Revenue opportunities from the sale of pollution credits or carbon credits
- Continued availability of ICE or hybrid vehicles for routes unsuited to electric drive vehicles
- Opportunities for retrofit of existing vehicles for test and evaluation purposes

Predictable Routes

There are three main categories of postal delivery routes: city carrier, rural letter carrier and highway contract routes. The names are somewhat misnomers since the city routes are not limited to cities, and rural routes are not limited to rural areas. The distinctions are based on the type of union work rules or contracting arrangement established for each group. In general, city routes are operated by uniformed, salaried letter carriers and rural routes are driven by non-uniformed carriers who are more autonomous and whose compensation is based generally on how much mail they deliver.

Today's postal routes (both city and rural) are very well suited to current-technology electric drive vehicles in both driving and handling characteristics. An electric power train is very responsive, reacting rapidly to control inputs. It also turns on and off instantly and does not require the burst of fuel and electricity needed to start up an internal combustion engine. From a standing start, the horsepower and torque of an induction motor, say at 100 kilowatts (kW), is typically better than that of a gasoline engine vehicle.

One of the biggest impediments to widespread public adoption of electric drive vehicles today is the high variance in consumer driving patterns. That is, even though the average automobile daily drive is 35–40 miles, the amount can vary greatly. A typical U.S. car owner may drive zero miles one day, 10 miles the next, and hundreds of miles the day after. In contrast, the Postal Service operates a large number of highly predictable, repetitive routes of limited length and limited duration. The letter carriers haul moderate loads that lighten over the course of the route,[26] and they engage in frequent stop-and-start driving. These are all characteristics well matched to the finite power reserves, regenerative braking and generation of high torque at low speeds offered by electric drive vehicles.

High Fuel Prices

High fuel prices and their volatility impair the cost-effectiveness of delivery using existing ICE postal vehicles such as the LLV. Although the LLV is rated at 13–15 miles per gallon in steady driving, the stop-and-go driving required on a typical postal route means a much lower mileage in practice (as stated earlier, 8–10 mpg). The large quantity of gasoline required annually by the postal fleet (an estimated 68 million gallons) means that the Postal Service is highly susceptible to fluctuations in the price of petroleum.[27]

Transition to electric drive vehicles offers the opportunity to reduce the large fuel purchases currently required by the Postal Service, and also to shift toward energy sources more amenable to negotiated bulk purchase.

Operating Costs

Electric drive vehicles have lower fuel costs but higher upfront capital investment costs because of the still-significant cost of the battery pack. Even when manufacturing large quantities of vehicles, there will likely be a significant upfront cost increment for electric drive vehicles as compared with ICE vehicles. This presents a challenge because the Postal Service is constrained financially as a result of the economic downturn, electronic diversion of mail volume, increasing numbers of delivery points and rising costs.

The difficulty of securing funds for the purchase of new electric drive vehicles is substantial. However, it is likely that efficiencies to be gained from an electric vehicle fleet create an attractive return on investment that should quickly pay back this initial

---

[26] Although the carriers are responsible for picking up mail from their delivery points and end their routes with some collected mail, they finish their routes with much less mail than what they deliver. Some (but not all) letter carriers retrieve the mail deposited into the blue collection boxes on their routes, but this is a small fraction of the mail they deliver.

[27] The Postal Service has generally avoided fuel hedging (locking in fuel prices with long-term contracts) for their vehicle fuel supplies. In fact, many postal delivery vehicles are fueled at neighborhood retail filling stations. The oft-spoken rule of thumb that a penny increase in the price of gasoline results in $8 million in annual added costs for the Postal Service overstates the relevant impact because such rules of thumb, of questionable accuracy, apply to the entire postal system, and not just delivery vehicle costs which are only one component.

capital outlay. Partnering methods may help overcome the difficulties of frontloaded electric vehicle costs:[28]

- Direct federal assistance from Congress
- Treasury Department loans to purchase vehicles and build needed infrastructure, with payback from savings on fuel and maintenance
- Working with state agencies or regional consortia
- Partnering with the Department of Energy or the EPA
- Partnering with electric utilities or regional transmission operators
- Establishing leasing arrangements or securing private venture capital
- Integrating electric drive vehicles into the replacement plan for the existing postal fleet

Partnerships with mobility providers are another possible option. A mobility provider is a company that would own and service electric drive vehicles for customers and lease vehicles to fleets. This would reduce battery ownership risks because the provider would own the battery and handle all the servicing and warranty considerations. While this concept has been promoted recently as a novel idea by companies such as Better Place and Coulomb Technologies[29], there were companies at the start of the 20th century that offered such services and had even established a series of locations for swapping in fresh batteries.

Cost of Delivery to the Home

A key strength of the Postal Service is the ability to deliver to every home and business every day, the so-called "last mile of delivery." While efficiencies of scope and scale mean that the cost to deliver a particular mail piece or package to any particular destination is relatively small, the overall cost of delivery is an appreciable fraction of the overall costs of operating the postal service.

The cost of delivery over the last mile is also significant because of increases in the use of worksharing for business and bulk mail. Businesses are increasingly using worksharing and presorting in order to reduce their cost, leaving the Postal Service to perform the final delivery, from the delivery unit to the destination point. Competing parcel shipping services such as UPS and FedEx are in some cases using the Postal

[28] One hurdle to obtaining federal funding to purchase vehicles is that Congress enacted laws directing the Postal Service to be self-supporting. However, nothing precludes government support for this important federal government function.

[29] Coulomb Technologies has recently moved away from battery-swapping technologies and focused more on establishing a network of charging stations.

Service for final delivery (and in some cases, pickup) of packages that are less time-sensitive or more cost-sensitive. As a result, a stated priority of Postal Service leadership is to focus on ways to reduce the cost of delivery.

The use of electric drive vehicles can reduce operating and per-mile costs to achieve an important reduction in delivery costs, assisting the Postal Service in constraining costs and in remaining competitive.

Limitations on Internal Combustion Engine Vehicles in Cities

Many cities are considering or even imposing means of limiting the number of vehicles in the city core. These may include raising parking fees, limiting the number and availability of parking spaces, imposing entry fees for bridges or tunnels. Some cities may even go as far as to bar vehicles from parts of the city. It is possible that electric drive vehicles could receive favorable treatment over ICE vehicles in order to encourage the purchase of electric drive vehicles and to minimize urban pollution levels. For example, a local government could allow zero-emissions (electric) vehicles into special express lanes such as High Occupancy Vehicle (HOV), carpool or bus lanes. The Postal Service considers itself legally exempt from certain types of municipal traffic restrictions,[30] but these types of constraints on gasoline engine vehicles are likely to become more visible (and more ambitious) over time.

Environmental Benefits and Pollution Reduction

Pollution reduction is a significant societal and organizational benefit of operating electric drive postal delivery vehicles. Employee health will likely benefit because letter carriers, vehicle mechanics and other workers will be exposed to less pollution, fumes and particulates. This may result in lower health-care costs.

Lessened pollution may present societal and organizational advantages in communities that exceed Environmental Protection Agency (EPA) pollution limits, such as in certain metropolitan regions. In addition, reduced pollution could provide economic benefit to the Postal Service in the form of pollution credits or carbon credits that can be sold in emerging carbon- or pollution-trading markets.

At a broader level, a large number of postal vehicles operate in daily mail delivery missions in urban areas that the EPA has designated as air pollution non-attainment

[30] *See* Federal Trade Commission, Accounting for Laws that Apply Differently to the United States Postal Service and its Private Competitors, December 2007, pp. 28-29.

zones, and introducing zero-emissions vehicles will aid in meeting those federal objectives. Removing the need for gasoline fueling results in secondary reductions in pollution by emissions from the refining process and fuel transportation, and release of vapors from evaporative losses at the gas tank and during refueling. Acoustic pollution is also lessened: Electric drive vehicles are quieter.[31]

Some argue that using electric drive vehicles means shifting from one source of pollution (at the vehicles) to another source of pollution (at the generating plants). While true in part, this ignores the benefits of reducing emissions near population centers. That is, fixed location emissions from power stations are not interchangeable with mobile source emissions for at least four reasons.

First and foremost, electric power generation results from a mix of generating sources, some of which are relatively nonpolluting and some of which are carbon-neutral. Second, generating plants release emissions from tall stacks typically outside urban areas, and the emissions are dispersed rapidly above the ground. The plants are not adjacent to population concentrations or residential areas. In contrast, vehicle emissions are literally in our faces; the proximity of the compounds and particulates exacerbates the health risks. Third, a large proportion of emissions from electricity production are released at night when sunlight is not present to form ozone, a key health risk. Fourth, pollution controls and scrubbers on a few large generating plants are usually more cost-effective than a multiplicity of controls on each vehicle. Finally, ICE cars incur greater opportunities for volatile organic compound (VOC) emissions as well as evaporative emissions when cars are fueled and carrying around their fuel in tanks.

That said, the environmental costs and implications of battery production, recycling and disposal do constitute an important component of any environmental assessment. The most common types of Lithium-based batteries do not appear to impose a significant life-cycle environmental burden.

Revenue Opportunities From Pollution Reduction

There may be opportunities for the postal operator to gain revenues from operating electric drive vehicles. Governments are taking steps toward allocating responsibility for

---

[31] Because quieter vehicles provide less warning to pedestrians, electric postal vehicles would likely be required to incorporate some sort of suitable signaling noise to reduce the possibility of accidents. Ironically, the ancient international symbol of postal service has for centuries been the coiled posthorn, originally carried by the letter carriers in Europe to alert a town that the mail had arrived and to avoid untoward hazards to the postman and the mail, and later sounded by the mail coach to announce that the mail coach had arrived in town or to give warning on narrow roads to let the mail through.

pollution and carbon costs, but this may create revenue opportunities for the incumbent postal operators using electric drive vehicles if the operators can market or transfer pollution credits or carbon credits. There may be opportunities for mutually beneficial cooperative programs between utilities and the Postal Service (or other fleet owners considering acquiring electric fleets) based on cap and trade or carbon credits and pollution emission credits.

Although the U.S. Postal Service is usually unable to benefit directly from tax credits or other tax benefits offered to the commercial sector, there may be opportunities to partner with other for-profit entities in order to leverage such opportunities. These merit further exploration by the U.S. Postal Service and postal operators in other nations.

Continued Availability of Traditional Vehicles for Some Postal Routes

Although the average postal route is less than 25 miles, routes can vary in length, difficulty and conditions. Some routes traverse difficult terrain. Others may encounter soft sand, ice and snow, or poor road conditions. Some may be located in areas where they must operate in temperature extremes during some portion of the year. In short, there are certain routes that will require additional flexibility of operation, and for that small fraction of routes, a vehicle with an onboard fuel supply (such as an ICE, hybrid or compressed natural gas–powered vehicle) may be better suited.

The biggest challenge for electric drive vehicles may be on the routes that encounter cold conditions because of the need to heat the interior compartment for the driver, along with the need to keep the battery within nominal temperature conditions (both during driving operation as well as before departure), all of which require electrical power. Hot weather presents its own challenge, requiring cooling for the batteries. Most postal delivery vehicles are not equipped with air conditioning for cooling.

Opportunities for Vehicle Retrofit

Conversion of a limited number of existing Postal Service vehicles may provide benefits in the electrification of the fleet. The Postal Service continues to evaluate possible reuse of the existing purpose-built aluminum LLV body, along with newly manufactured components as the basis for an electric delivery vehicle.[32] This approach would provide greater familiarity by the maintenance crews and letter carriers. Electric drive vehicles could be added into the postal fleet on an incremental basis, allowing controlled

---

[32] United States Postal Service. Prequalification EV Conversion of LLV, Sources Sought Solicitation, PREQUAL001-LLV, April 23, 2009. Published at *http://www.FBO.gov*.

deployment into selected areas. Conversion would also allow data collection about operating and maintenance characteristics that would be invaluable during the design and procurement phase of any new vehicles.

Ultimately, though, recycling old vehicles can only go so far. From a fresh start, or even by using commercially available vehicles, the design of the vehicle, batteries and drive mechanism would be optimized for its intended purpose. Appropriate materials and construction methods could be used. The lifespan of the vehicle would not be constrained by already-aging components. The overall vehicle would be more efficient from a systems approach, and scaled-up production volume could minimize production costs.

6. Maintenance and Infrastructure

Maintenance is a significant portion of overall life-cycle costs. The Postal Service spends large sums on vehicle fleet maintenance.

Electric drive vehicles have been observed to incur less than half the maintenance costs of ICE vehicles. This stems in large part from the fact that battery-only electric drive vehicles have many fewer components and assemblies than their gas-powered counterparts.[33] The radiator assembly, if any, is likely to be smaller and less complex because it must only cool the batteries. There is no emissions inspection expense, and consumables such as oil, lubricants and radiator fluid are reduced. Much of the ordinary transmission drive train is no longer needed for electric drive vehicles, leading to lower maintenance of this complex item.

Lower maintenance requirements of electric drive vehicles provide a substantial cost benefit to the owner of a fleet. Furthermore, less maintenance means that fewer vehicles are out of service at any particular time, and thus electric drive vehicles have a higher availability factor for the fleet. As a result, fewer extra-contingency vehicles are needed to ensure that a sufficient number are performing their jobs.

The adoption of electric drive vehicles will require different maintenance skills from those required today. Because of reduced maintenance requirements, the complement of

---

[33] Parts required on a traditional gasoline vehicle but not found on a battery-only electric drive vehicle include: pistons, transmission, engine oil, spark plugs, valves, starters, clutches, distributors, oil filters, fuel pumps, fuel filters, air filters, water pumps, timing belts, fan belts, catalytic converters, mufflers and exhaust pipes. Also unnecessary are these maintenance items: oil changes, radiator flushes, smog tests, valve adjustment, etc. Also missing: engine noise, warm-ups, gas lines, fumes and exhaust. *See* U.S. Congress, Senate Committee on Energy and Natural Resources. Vehicles Powered by the Electric Grid: Hearing before the Committee on Energy and Natural Resources, September 16, 2008.

fleet maintenance workers would likely be reduced by approximately 40-50 percent, but those remaining workers would require training in a number of additional specialized skills. Initially, additional workers would be required to install charging stations, prepare vehicles and train for anticipated maintenance issues. The need for fueling locations will substantially decrease in regions where electric drive vehicles are stationed. In addition, a strong focus on safety will be required from the outset in working with electrical systems in a variety of weather conditions.

Charging Infrastructure

A fleet of electric drive vehicles by necessity requires charging stations for the vehicles. Let us reasonably assume that 50–60 amp, 240-volt circuits are preferred for efficient charging. Postal facilities will require evaluation to assess the level of electrical system upgrades required for them to handle the required power throughput needed. Most facilities will not require extensive refitting. In certain cases, a nearby transformer or neighboring line will require upgrading or replacing, but this does not appear to be a major undertaking.

Electrical safeguards would be required to ensure the safety of the charging station and any maintenance locations. Fortunately, this last step is considered rather simple to accomplish.

Using the vehicles for V2G applications (see below) requires some additional infrastructure, such as a provision for additional handshaking between the vehicle and the charging system, as well as a different wiring network and metering.[34]

7. Service Life

The existing conventional engine LLVs were designed to be used for about 20 years, reportedly long enough to last through two engine replacements and a transmission replacement. Everything else held equal, it is thought that electric drive vehicles will last longer than ICE vehicles because of the smaller number of moving parts and less mechanical stress on the vehicle.[35] The Postal Service is in the process of extending the

[34] SAE, the automotive engineering society, has established recommended practices for physical connection between vehicles and the grid (SAE J1772) and to define how vehicles communicate with smart metering and other smart grid systems (SAE J2836).

[35] Conventional vehicle manufacturers have learned much in recent years about rust prevention, quality improvement and other means of extending vehicle life. As a result, passenger cars tend to last longer than in previous years.

service life of LLVs by seven years. However, the prospect of increasing maintenance and repair costs on those aging vehicles-as well as possible shortages of key replacement parts-- presents concerns.

The history of electric drive vehicles shows that they lasted much longer than ICE vehicles, and the maintenance was simple. Some electric trucks were in service for decades. Electric motors are not subject to extremes of heat, pressure, imbalanced shaking or synchronized movements, which wear down ICEs. Electric motors do not experience the repetitive pounding from internal combustion following spark plug ignitions, nor is there any irregular engine operation due to knocking, pinging, cold starts or altitude-related effects.

8. Batteries

Today's electric drive vehicles have reliable and safe lithium-ion batteries, low-cost lightweight DC-to-AC power inverters, computerized power management controls and high-efficiency AC induction motors.

The most important qualities are specific energy, specific power, cycle life and cost.[36] Some of the required battery characteristics include:

- High energy per unit mass/volume – required for long driving range
- High peak power – required for acceleration and hill climbing (slope or gradient)
- Low self-discharge – required for minimizing energy loss on standing
- Fast recharge – needed to permit rapid refueling
- Long service life (many cycles)[37] – required for low depreciation cost
- Low battery cost – required for customer acceptance
- Low maintenance – needed to keep the downtime to a minimum
- Independence from ambient conditions – provides resistance to extremes and variations in local climate
- Robust design/operation – tolerant of abuse (electrical and mechanical)
- Proven safety – safe to use in normal driving and crash conditions
- Environmentally benign – built from nontoxic recyclable materials

[36] Rand, D.A.J.; Woods, R.; Dell, R.M. Batteries for Electric Vehicles. Research Studies Press (1988), pp. 90-91.

[37] Conventional vehicle manufacturers have learned much in recent years about rust prevention, quality improvement and other means of extending vehicle life, and as a result, passenger cars last longer now than they did in previous years.

- Readily available constituents – made from nonstrategic materials

The battery package for electric drive vehicles also includes a number of other supporting components: fuses, contactors, fan control, and the monitoring system, mounting system and cooling system.

Battery Availability and Cost

The primary battery types presently being examined for electric drive vehicles are nickel-metal hydride (NiMH) and lithium-based types (lithium polymer, lithium ion).

The most promising type appears to be lithium ion (Li-ion) batteries, which offer the prospect for lower weight, volume and efficiency compared with NiMH. Li-ion cells will be cheaper when produced in quantity; NiMH batteries offer less opportunity for production-related cost reduction.

One battery manufacturer (A123 Systems) has been selling Li-ion batteries that achieve 130 W-h/kg for use in power tools.

A variety of materials have been used for the cathodes of lithium batteries. Cobalt oxide is the most common in consumer electronics applications. Hitachi, Panasonic and Sanyo use nickel cobalt manganese. Toyota and JCI/Saft use nickel cobalt aluminum. GS Yuasa, LG Chem, NEC-Lamilion Energy and Samsung use manganese oxide spinel. A123, Gaia and Valence Technology use iron phosphate, and A123 fabricates its iron phosphate cathode material using nanotechnology.[38]

Lithium-ion cells for consumer electronics currently cost $450/kW·h, but this is achieved by mass production of battery packs smaller than found in automobiles The U.S. Advanced Battery Consortium has set a target price of $300/kW·h for automotive lithium-ion packs. This value is expected to be achieved by 2015 as a result of volume manufacturing, but until then, the price for the vehicle market will be much higher.

As battery technology evolves, it seems quite likely that new battery packs could be retrofitted into the existing electric drive vehicles.

[38] *See generally* Voelcker, John. Lithium Batteries Take to the Road. IEEE Spectrum, September 2007, pp. 27-31.

Many battery designs require the use of strategic metals that are rare, costly or produced in unstable regions. Fortunately, lithium availability is not likely to be a constraining factor because lithium carbonate reserves are relatively plentiful.[39]

Battery Reliability and Safety

Battery reliability is a product of cell reliability, and a battery hosts many cells. When a lithium-ion cell fails by shorting out, it starts an exothermic oxidizing reaction, instantly raising the temperature of the cell to hundreds of degrees Celsius. This sudden heat shorts out the adjacent cells and can produce a runaway thermal reaction and thus a fire. The fire problems experienced several years ago by certain computer laptops equipped with lithium-type batteries highlight the importance of solving this challenge. Battery manufacturers have reportedly identified and corrected these previous problems.

Car batteries used for electric drive have substantial capacity, and thus contain more cells. As a result, to preserve acceptable battery reliability levels, the individual cells must meet much more stringent reliability targets and manufacturing controls. Some manufacturers are focusing on the fundamental cell reactions.

In addition, battery manufacturers are designing their battery packs to isolate cell failures so they do not spread to set the entire battery on fire. The battery pack in the Tesla sports car, for example, links cells in a network arrangement to separate them adequately.

Additionally, it is important to note that the benchmark for safety is not necessarily zero fires, but the number and severity of similar incidents in the incumbent technology. For example, some 250,000 gasoline cars catch fire each year in the United States alone, resulting in hundreds of deaths annually. The lack of gasoline fuel in electric drive vehicles, along with elimination of the need to periodically fill the gas tank, represents a tremendous safety enhancement for electric drive vehicles.

Battery Recharging

The time to recharge an electric postal vehicle using reasonable levels of electrical current and voltage is more than ample to satisfy the postal delivery daily cycle in which the postal vehicle is parked for at least16 hours each day.

[39] *See generally* Andersson, Björn A. and Råde, Ingrid. Metal Resource Constraints for Electric Vehicle Batteries. Transportation Research Part D 6 (2001), pp. 297-324.

However, improvements in recharging speed would not only permit the use of electric drive vehicles for other applications, but may also provide additional flexibility in their use for mail delivery as well as for V2G power regulation applications. (Specifically, V2G drawdown cannot negatively affect the availability for the next delivery cycle.)

Several ideas for faster recharging have been proposed, such as mechanical recharging (physical exchange of components or electrolyte solution), swapping out entire battery assemblies,[40] or pulse-charging methods. The merits of these methods need not be assessed here because ordinary electrical recharging provides sufficient charging speed for the postal delivery application.

Battery Lifespan and Salvage

Battery lifespan is an important cost consideration for assessing the savings available through the use of electric drive vehicles.

Electric vehicle batteries will likely no longer be suitable for use in vehicles once they have degraded to some 40 percent to 70 percent of their original energy storage capacity. It has been proposed that these partially expended batteries, can be used instead by utilities or by businesses for electrical storage capacity in a fixed location. This would not only extract further life out of the already-amortized batteries and help vehicle owners reclaim a portion of the battery cost, but would also reduce the need for battery recycling. It remains to be seen the degree to which batteries will retain useful service life after they have been removed from the vehicles. The marketplace itself will determine the value of partially expended batteries, but this is an area likely to produce economic benefits and entrepreneurial activity.

Future Batteries

Battery technology is sufficient to perform the requirements of most postal delivery vehicles. The advancement of battery technology is important for electric drive vehicles because as battery performance increases, the fraction of ICE vehicles that can be displaced by electric drive vehicles increases. Battery technology has progressed steadily over the past 20 years, and it is reasonable to assume that it will continue to advance. An understanding of how batteries actually store and retrieve chemical energy has helped battery designers achieve new performance levels and cost reduction. Another factor in developing better batteries has been the ability to fabricate nanostructures and other

[40] Swapping out discharged batteries for fully charged ones was actually used in a vehicle network for several years at the start of the 20th Century. Although batteries are heavy, a system of conveyers, pulleys or other mechanical and hydraulic aids can help.

substrates with high surface area-to-mass ratios. There appears to be substantial room for development of lithium-based batteries through the use of innovative anode and cathode designs and other structures.

Substantial development work proceeds apace with a variety of battery configurations, such as silicon nanowires or silicon nanoparticles and tin nanoparticles for use in the anode, and composite or superlattice cathodes.

One development warrants special mention: batteries that use the "Spin Seebeck" effect by storing energy directly in the subnuclear "spin" of electrons.[41] This discovery may revolutionize energy storage by offering the potential for tremendous energy density, far above that of existing battery types. The energy is stored not in chemical energy but in the actual spin of the electrons themselves. Spin Seebeck is still in the early laboratory phase but will likely be the subject of intensive research and development in coming years.

9. Electric Drive Vehicles Separate Power Source From Drive Motor – Mitigating the Risk of Technology Obsolescence

The Postal Service is obliged to evaluate the risk of inadvertently "locking in" a specific technological approach during a time of rapid technological development and flux in purchasing large quantities of long-life vehicles of a particular type for postal delivery. Alternative-fuel vehicles purchased by the Postal Service for postal delivery purposes have largely fallen short of expectations because of the lack of industry infrastructure and widespread local availability of the alternative fuels.[42]

But in the case of electric drive vehicles, this concern may be less important because it is reasonable to believe that, provided battery efficiency continues to improve, new batteries can be retrofitted into the vehicles. Perhaps a charging module and vehicle integration components would have to be replaced and the power management software updated. Sufficient battery cooling provisions should be included from the start to handle any new battery configurations that require additional cooling. Vehicle wiring should

---

[41] K. Uchida, S. Takahashi, K. Harii, J. Ieda, W. Koshibae, K. Ando, S. Maekawa, E. Saitoh, ChemInform Abstract: Observation of the Spin Seebeck Effect., Nature *(London, UK)* , 2008, **455**, 778-781. *See also* K. Uchida, S. Takahashi, K. Harii, J. Ieda, W. Koshibae, K. Ando, S. Maekawa, E. Saitoh. Letter: Observation of the Spin Seebeck Effect. Nature **455**, 778-781 (9 October 2008) | doi:10.1038/nature07321.

[42] The Energy Policy Act of 2005 requires that agencies purchase alternative fuels for alternative fuel vehicles unless it is not feasible, which is defined as availability within 5 miles or 15 minutes of the applicable postal facility. *See generally,* Government Accountability Office, Federal Energy Management: Agencies are Acquiring Alternative Fuel Vehicles but Face Challenges in Meeting Other Fleet Objectives, GAO-09-75R (October 2008), published at: *http://www.gao.gov/new.items/d0975r.pdf*.

incorporate sufficient design margin to be able to handle higher electrical loads for faster charging as needed in the future.

In short, should better batteries become available, the new batteries can likely be retrofitted into the electric postal vehicle and installed at a point when it makes economic sense to do so, such as when the original battery pack reaches the end of its service life. Because an electrical supply is inherently generic within the energy density and performance requirements, the risk of technological obsolescence for the mail delivery mission with electric drive vehicles seems quite low.

10. Use of Postal Vehicles for Storage of Electrical Energy

Electrical power systems must continually balance supply and load because electrical power generally cannot be stored, and the demand for electricity fluctuates each day and throughout the year. The operators of the electrical grid are essentially running a massive just-in-time delivery system and it can be tricky to keep this system balanced.[43] Most electrical power is supplied by a group of continuous generators such as nuclear, coal or hydroelectric plants (called base load), but there are other sources such as wind and solar power that are more erratic. As these variable sources become more prevalent, grid management problems such as “intermittency” and “fast ramping” occur.

The use of electric drive vehicles in fleets, such as the postal fleet, has the capability to improve the reliability and reduce the costs of operating the electric grid by adding off-peak consumption and offering the opportunity for vehicle-to-grid electrical regulation and contingency reserve. While electric drive vehicles can be used for three primary purpose: providing peak power, spinning reserve and regulation; the characteristic scheduling of postal delivery operations suggest that providing peak power is not practical for a postal vehicle fleet.[44]

This offers postal operators such as the U.S. Postal Service the opportunity to earn revenue by brokering the electrical storage capacity in the fleet. Electric utilities, independent system operators (ISOs), regional transmission organizations (RTOs) and other power market participants may be particularly interested in the value of establishing a large fleet of electric drive vehicles for postal delivery if the grid operator was able to

[43] Statement of Thomas Key, Electric Power Research Institute, in U.S. Congress, Subcommittee on Energy and Environment, Committee on Science and Technology, House of Representatives. Energy Storage Technologies: State of Development for Stationary and Vehicular Applications. October 3, 2007, pp. 30-31.

[44] Discussion with Willett Kempton, April 9, 2009.

exert some control on vehicle charge rates (subject of course to some level of override by the Postal Service).

First, utilities could develop postal vehicle charging as a steady off-peak customer base. And it would be valuable to the utility to be able to exert some control over vehicle charging rates – estimated at one eighth of the value of full V2G.[45] Second, utilities can use the postal vehicle fleet as a test bed to help evaluate the value of vehicle batteries supplying "peak power"[46] and reactive power. Third, the postal service itself or an intermediary could aggregate the sale of electric capacity from postal vehicles to provide "ancillary services" such as contingency power[47] and regulation services for the ISOs/RTOs.[48] Finally, utilities, ISOs/RTOs and wind operators are examining their need for temporary storage to permit the efficient use of larger quantities of renewable resources such as wind power and solar energy, which have fluctuating outputs.

With 140,000 Long Life Vehicle (LLV) ordinary delivery vehicles and 200,000 vehicles total in the entire fleet, the Postal Service could serve as an excellent test bed to evaluate such concepts regionally or nationally. This initiative would provide the economic incentive and critical mass that would encourage entrepreneurship in this area as well as accelerate the development of a national grid.

The existing power grid includes minimal storage capacity — there is only 2.2 percent capacity in pumped (water power) storage. Generation and transmission must be continuously managed to match the fluctuating customer demand load.

The electric power grid and electric vehicle fleet could be exceptionally complementary as systems for managing power because the electric drive vehicle fleet can store power and release it quickly upon demand — a cheaper alternative to building expensive generating equipment used only a fraction of the time, or expensive and controversial

---

[45] *Id.*

[46] Peak power is that provided to supply fairly predictable daily or seasonal peaks in demand that cannot be satisfied by the steadily running baseload generators. Because of the timing of operation of postal vehicles and the cost of expending battery lifespan for peak power purposes, the postal fleet is unlikely to be utilized efficiently as a peak power grid supplier.

[47] Contingency power is that kept available to provide substitute power in the event of a generator shutdown or failure of a transmission line or transformer, or some other unforeseen circumstance requiring additional power on short notice.

[48] Regulation services are small quantities of power provided or absorbed on short notice to accommodate the grid operators' need to conform electrical demand to the available supply. This also includes reactive power,

power transmission lines. The high capital cost of large generators motivates their near-continuous use. Vehicles, in contrast, are used for only a portion of the time for transportation and thus may be available for secondary grid regulatory functions.

As a crude means of comparison, 140,000 postal vehicles at 150kW (mechanical) per vehicle yields approximately 21 gigawatts (mechanical) (GW_m). This can be compared against approximately 600GW of electric utility generation in the United States and 209GW from nonutility generators. Significantly, a relatively small number of vehicles (50-60) provide 1 megawatt (MW) capacity, which is considered the minimum quantity traded in the wholesale power market.

Despite the size of this resource, grid operators will, in the long term, be more interested in a larger pool of household vehicles to provide a deeper power capacity with greater availability during the peak power times. The use of postal vehicles for energy storage will pave the way and provide critical mass for the move into the household vehicle market.

Renewable Portfolio Standard (RPS) legislation, requiring increased use of renewable energy sources as part of the fuel mix, has been enacted in more than 20 states.[49] If federal, state and local authorities are successful in increasing the fraction of renewable electric sources such as wind and solar added to the grid, energy storage by electric drive vehicles will likely be required as a cost-effective means of managing intermittency and fast ramping effects, balancing power flows, maximizing grid resilience and strengthening the stability of the national power infrastructure.

System Operator Interest

Grid operators are interested in encouraging additional entrants into the wholesale power markets in order to improve competition for providing these important services. Increased competition in the wholesale market is helpful in limiting spikes in electric power pricing and improving the overall workings of those markets.

More specifically, most ISOs and RTOs have established mechanisms that would permit use of V2G. For example, a recent filing with the Federal Energy Regulation Commission (FERC) by the New York Independent System Operators (NYISO) seeks permission to include batteries and flywheels in the tariffs for purposes of frequency and voltage control. This demonstrates the high level of interest among the electrical system

---

[49] *See* U.S. Congress, Senate Committee on Energy and Natural Resources. Vehicles Powered by the Electric Grid: Hearing before the Committee on Energy and Natural Resources, September 16, 2008.

operators, who control the power network. Other system operators in the East, such as New England and PJM Interconnect ISOs, may also be examining such an approach. According to a NYISO white paper on the dispatch of wind power:[50]

> "The NYISO is currently evaluating changes to its market rules and scheduling tools to better accommodate energy storage technologies, such as flywheels or batteries, into the regulation markets. These types of devices have limited energy storage, but they have a fast dynamic response rate that allows them to quickly switch from absorbing to injecting real power into the transmission system, and thereby provide frequency regulation and short-duration Area Control Error (ACE) regulation."

V2G and Postal Fleets

Kempton and Tomić (2005, 2007) describe in detail the concept of V2G power. Vehicle batteries have low durability and high cost/kW·h, and thus V2G power is most suitable for high-value, short-duration power markets. The authors suggest that all the technical elements needed for V2G already exist now.[51]

The vehicle operator needs stored energy in the vehicle at one predictable time (when the scheduled trip begins). The grid operator needs power but does not care which power plant or vehicles it comes from.

V2G appears practical for use with postal vehicle fleets. However, V2G appears less suitable for supplying one particular type of power, peak power, because of the timing issues. Postal vehicles are used six days a week[52] but are left unused for approximately 16 hours or more each day.[53] The vehicles must be charged and available for their driving route by a specified time each morning.

---

[50] NYISO Service Tariff Filing, Proposed Tariff Revisions to Integrate Energy Storage Devices into the NYISO-Administered Regulation Service Market. Filed March 11, 2009.

[51] Discussion with Willett Kempton, April 9, 2009.

[52] Although postal vehicles could be used to supply peak power on Sundays, holidays or other days in which they are not being used for mail delivery, this represents a lesser benefit that will not be addressed in any further detail.

[53] Most city letter carriers first perform their office duties, including any required mail sorting, and then begin their routes mid-morning.

Kempton and Tomić discuss vehicles that can adopt their charging patterns to accommodate actual vehicle usage habits recorded over time for optimal V2G availability. They also include an override button for situations in which a longer-than-normal trip or unusual hours or conditions are expected. Pressing this button would disable the V2G for that vehicle for a 24-hour period and thus ensure full charge when the vehicle is needed.

Implementing V2G will require improved electrical metering systems. V2G adoption would be expedited by the establishment of standard communications protocols for the various utilities and regions in order to expand such activity to a larger set of vehicles. An important step in this program would include an economic study to determine potential cost savings and revenue opportunities from electrification alone, as well as in conjunction with V2G services.

Demand Smoothing and Growing the Off-Peak Customer Base

Utilities have a strong business interest in growing the off-peak customer base for electricity. The use of electric drive vehicles can smooth demand by encouraging off-peak use. It may also serve as a household or fleet electric power management tool, which, if combined with time-of-day metering, could be used to reduce electric demand peaks. Growing off-peak use is a useful adjunct to ordinary demand-side management that focuses on peak power shaving.

A study conducted by Professor Andrew Ford for Southern California Edison (one of the largest electric utilities) concluded that if electric drive vehicles are recharged primarily at night, a company could accommodate 1 million electric drive vehicles without adding electrical capacity to its existing resource plan. With smart charging, up to 2 million electric drive vehicles might be accommodated.

Greater off-peak utilization makes more efficient use of the baseload power plant base and less use of costly peak load sources. As such, it may reduce costs for all users.

Providing Contingency Reserve

Contingency reserve is the name given to reserve power sources available within several minutes that must be kept available to handle ”loss of load” and other emergencies, contingencies or sudden needs.[54] It is referred to in part as “spinning reserve.”

---

[54] Special circuitry may be required to keep the vehicles connected to the grid during the complex and rapidly changing waveform associated with a failure of regional generation or transmission. The difficulty

Generators allocated for this purpose are run at low or partial speed and are already synchronized to the grid. This is the most valuable type of operating reserve.

Typically, contingency reserve is offered as an option just for providing availability, and any actual power required and provided is paid at the market clearing price. Contracts limit the number and duration of calls for power, permitting about 20 power calls per year up to one hour (sometimes able to be extended to two hours) each. In actuality, the usage is usually briefer.

One of the challenges is the complexity of keeping the vehicles connected to the grid during the complex and rapidly changing waveform associated with a failure of regional generation or transmission. The difficulty is that some charging systems may be designed to cut out when presented with this type of voltage transient.

Electric drive vehicles are well suited to supplying contingency reserve because they have the capacity to provide power for the duration required without any appreciable start up delay in the availability of electricity. They can also be kept available without the costs required for similar availability of generator power. The response time for generating systems to respond to frequency regulation signals can be three or four minutes. In contrast, fast acting storage systems can respond within cycles (fractions of a second), which is much more useful.

It is often stressful on the components of large generating plants to perform this up-and-down regulation. Furthermore, fast-acting storage can provide valuable R-control (reactive power control) to adjust electrical phase, in addition to providing real power.[55]

Evidence suggests that shallow cycling of the sort that would occur during contingency service reduces battery lifespan much less than deeper cycling. The key point is that most of the revenue from contingency service is derived from selling the option of access to electrical power rather than from electrical power actually purchased, but revenue is provided by both functions.

---

is that some ordinary charging systems may be designed to cut out as a protective measure when presented with this type of voltage transient.

[55] Testimony of Brad Roberts, Chairman, Electric Storage Association. In U.S. Congress, Subcommittee on Energy and Environment, Committee on Science and Technology, House of Representatives. Energy Storage Technologies: State of Development for Stationary and Vehicular Applications. October 3, 2007, p 36.

Providing Regulating Reserves

Demand for electric power varies over time. Utilities can match generation to load demand by adjusting the frequency and voltage of the grid. Regulation is from minute to minute and may involve automatic generation control or frequency control. Adding power, or "up regulation" requires access to electrical power on the grid; "down regulation" requires access to places to dump electrical power from the grid as necessary.

Regulation and contingency reserves are considered ancillary services[56] that account for 5 percent to 10 percent of electric costs (on the order of $12 billion). Eighty percent of that cost is regulation alone. But the cost of electrical disruptions, outages and problems in electrical quality in the United States is far higher: an estimated minimum $53 billion per year.[57]

Electric drive vehicles are, in theory, able to serve as an asymmetric sink for down regulation only, or can serve as a symmetric regulation source. If supplying regulated power does expend battery cycles in a harmful manner, the vehicles can earn revenue by simply serving as a power sink.

However, Kempton believes that offering V2G down regulation only presents two challenges. First, the service would be much more limited in scope and potential revenue because the battery would tend to get filled up. Second, a V2G broker offering only down regulation would earn just a small fraction of the revenue available to a broker offering both up and down services. In other words, the revenue is not symmetric in that regard.[58]

The power needed for regulation service in practice is much less than the maximum specified by contractual availability. The dispatch to contract ratio is a measure of how often the source of spinning reserve is actually asked to supply the power in comparison to the contractual maxima. Kempton and Tomić point out that the dispatch to contract ratio is an important measure of assessing the actual burden on V2G vehicles. They find an empirical ratio of 0.08 and conservatively assume 0.10 for purposes of calculation.

---

[56] Slower regulating adjustments also exist, such as balancing service (intra-hour and hourly) and load following (extending over a period of time).

[57] LaCommare, Kristina Hamachi and Eto, Joseph H. Understanding the Cost of Power Interruptions to U.S. Electricity Consumers. Ernest Orlando Lawrence Berkeley National Laboratory. LBNL-55718, September 2004. *http://certs.lbl.gov/pdf/55718.pdf*, p. 14.

[58] Discussion with Willett Kempton, April 9, 2009.

Thus, the value of these electric fleets for regulation service is significantly greater than that suggested by the aggregated power in the batteries alone.

Bolstering Grid Stability and Accommodating Renewable Energy Sources

Electrical grids are complex structures — their stability can be reduced with increases in the percentage and number of erratic or fluctuating electrical sources such as wind power[59] and solar power.[60] Electrical utilities and grid operators are obliged in many states to make increased use of renewable sources. As a result, they must have a mechanism to help them regulate and control these relatively variable electrical sources.

One way to increase stability in such circumstances is to increase the number and capacity of long-distance transmission lines so as to average power sources over a larger pool. But transmission lines are constrained by several factors: They are expensive to construct, require long stretches of land, and frequently raise neighborhood concerns over effect on scenic views, property values and possible long-term health and environmental effects.

In light of the difficulty and expense of building long-distance transmission lines, an alternate and cheaper way to increase the overall resilience and stability of the grid would be to add blocks of decentralized sources and sinks such as those associated with V2G.

Kempton and others believe that the broad use of wind power (such as that directed in national and state-level energy policies) will necessitate energy storage such as V2G, batteries, flywheels or other mechanisms.

Incorporating renewable energy sources into the grid provides unique storage and regulation challenges to the electric utilities and system operators. V2G has been shown to level solar and wind, and thus accommodate increased use of renewable energy sources in the grid.[61]

---

[59] Wind energy is less predictable, more erratic and varies geographically, with time of day, with month of year and with weather conditions.

[60] Solar energy has a daily (diurnal) cycle that rises and falls during the day, peaking about four hours (about 2 p.m.) before the peak local demand (about 6 p.m.). At night and during inclement weather or cloudy conditions, of course, no power is provided.

[61] Kempton, W. and J. Tomic, 2005, "Vehicle to Grid Fundamentals: Calculating Capacity and Net Revenue" J. Power Sources Volume 155, Issue 1, 1 June 2005, pp. 268–279. doi:10.1016/j.jpowsour.2004.12.025. *See also* Henrik Lund and Willett Kempton, 2006, "Integration of renewable energy into the transport and electricity sectors through V2G," Energy Policy 36 (2008) 3578–3587, doi:10.1016/j.enpol.2008.06.007.

Providing Peak Power – Not Well Suited to Postal Vehicles

The Postal Service is a poor candidate for using V2G to supply peak power service, according to Kempton.[62] Peak power is generated or purchased at times of the day when high levels of power consumption are expected. This power is either generated by use of expensive, gas-fired turbine generators or is purchased elsewhere at the spot market price. Typically, a utility only needs a few hundred hours of peak power per year. The required duration of peak power runs about three to five hours, but this could be drawn sequentially from available sources.

Peak power will not be a primary V2G application for postal vehicles. First, the postal vehicles complete their deliveries at approximately 5 p.m., which limits the fleet's ability to provide peak power. More important, provision of peak power close to the end of the delivery may incur disproportionately high battery depletion costs (from cycling) in comparison to other potential V2G applications in the area of ancillary services. As a result, while contingency and regulation service is an effective role for Postal fleet V2G services, providing peak power is not.

11. Conclusions

The attributes of electric drive vehicles are well matched to the delivery needs and driving profiles of the U.S. Postal Service. Electric drive vehicles can reduce delivery costs through fuel savings and lowered maintenance, a valuable objective for the Postal Service. They would provide a net reduction in pollution. They offer lower fuel costs and higher upfront capital costs, but partnering may overcome the challenge of those upfront costs. Physical conversion of some existing LLV postal vehicles, and use of electric minivans of the type now used for suburban-type routes, would help gain useful experience quickly.

Battery technology has achieved a performance level suitable for postal delivery vehicles. Electric drive vehicles, because their power source is distinct from their drive mechanism, are resistant to risks of "locking in" or technological obsolescence. The primary difficulty in the purchase of fleet vehicles will be the availability and cost of batteries. There is a strong need for careful life cycle cost comparisons of various delivery fleet options. Such analysis should take into account not only fuel costs, but also battery costs, maintenance costs and other savings or costs.

For utilities and electrical grid operators, an electrical postal fleet offers a unique opportunity to explore the concept of V2G energy storage systems on a centralized basis.

[62] Discussion with Willett Kempton, April 9, 2009.

Electrical vehicle fleets offer early exploitation and evaluation of ancillary services provisions such as contingency power and regulation service. The electrical power industry should establish robust utility interface/communication standards on a nationwide basis for V2G purposes. Partnering may provide a means of tapping financial benefits from tax, pollution and carbon credits currently unavailable to the Postal Service because of its governmental nature.

The Postal Service could earn substantial revenue from electric drive vehicles by undertaking brokering of V2G services from its fleet, particularly contingency and regulation grid services. In this way, the Postal Service would be capitalizing upon the fact that the postal fleet is used for only a small portion of the day. This new revenue would be useful in an environment where revenues from mail volume are declining.

The next steps of such a program would consist of detailed analysis to further prove the benefits of this strategy, including an environmental study to gauge reduction in the USPS carbon footprint; a study of electrification's effects on postal operations; and a look at electrical and maintenance infrastructure requirements. Following this would be a limited and highly instrumented test bed to show technical feasibility, and then the drafting of vehicle procurement requirements.

Electrification of the Postal Service delivery vehicle fleet is practical, achievable and desirable, and should be initiated now. Though cost studies are essential, the case is obvious. As a government agency performing a constitutionally mandated critical public service, the Postal Service should be a first mover on electric drive vehicles, and the federal government should encourage and support that effort.

Sources:

*I am thankful for the many helpful comments and suggestions made by readers of earlier drafts.

Adler, Cy A. Electric Vehicles at a glance: an illustrated chronology of the birth and rebirth of the electric automobile in America and elsewhere. Compiled by the Editors of EV Focus. McGraw-Hill, 1978.

Andersson, Björn and Råde, Ingrid. Metal Resource Constraints for Electric Vehicle Batteries. Transportation Research Part D 6 (2001), pp. 297–324. doi:10.1016/S1361-9209(00)00030-4.

Brookings Institution Conference; Plug In Vehicles 2008: What Role for Washington? Published online at *http://www.brookings.edu/events/2008/0611_plugin_vehicle.aspx*.

Brooks, A. and Gage, T. Integration of Electric Drive Vehicles with the Electric Grid—A new value stream. Proceedings of the 18th International Electric Vehicle Symposium and Exhibition (EVS 18). October 20-24, 2001. Berlin, Germany.

Chobatov, Michael V.; Chua, Kita and Dinh, Han. A Feasibility Demonstration of an Electric Postal Delivery Vehicle. Paper No. 961694. In "Technical Solutions to Alternative Transportation Problems," Society of Automotive Engineers, SP-1189, 1996, pp. 83–89.

Christian Science Monitor. Auto May Soon Replace Horses in Postal Service: Superintendent of Mails at Washington Tells Electric Vehicle Association About the Work Now Being Done by Motor Vehicles in Place of Horse Drawn. June 26, 1915, p. 13.

Cowan, Robin and Hulten, Staffan, eds., Electric Vehicles: Socio-economic prospects and technological challenges. Aldershot, Ashgate, 2000.

Delucchi, Mark A.; Wang, Quanlu and Sperling, Daniel. Electric Vehicles: Performance, Life-cycle Costs, Emissions and Recharging Requirements. Transportation Research A, Vol. 23A, No. 3, pp. 255–278, 1989.

Delucchi, Mark A. and Lipman, Timothy E. An Analysis of the Retail and Lifecycle Cost of Battery Powered Electric Vehicles. Transportation Research Part D 6 (2001), pp. 371–404.

Electric Postal Vehicles: Experience of the German authorities proves their advantages. The Electrical Review, August 2, 1935, p. 140.

Elliott, T.C., Electric Vehicles in the Postal Services. The Electrician. Vol. 143, November 11, 1949, pp. 1553–4.

Engardio, Pete. The Electric Car Battery War. Business Week, Feburary 23, 2009, pp. 52–54.

Eyre, N.J.; Ozdemiroglu, E.; Pearce, D.W. and Steele, P. Fuel and Location Effects on the Damage Costs of Transport Emissions. The Environment and Transport. Hayashi, Yoshitsugu; Button, Kenneth and Nijkamp, Peter, eds. Elgar, 1999.

Federal Trade Commission, Accounting for Laws that Apply Differently to the United States Postal Service and its Private Competitors. December 2007.

Funk, Karina and Rabl, Ari. Electric versus Conventional Vehicles: Social Costs and Benefits in France. Transportation Research Part D (1999), pp. 397–411.

Goldway, Ruth Y. Plugging in the Postal Service. New York Times, February 9, 2009.

Goldway, Ruth Y. Stimulus Green Stamps. Parcel, March 2009.

GreenBiz.com and Automotive Fleet Magazine, State of Green Business 2009, a report, February 2009), cited in Energy Resource, Top 10 Alternative-Fuel Fleets in U.S., JeraOne, February 26, 2009.

Jang, Ronald O. Environmental and Economic Analysis of Electric Vehicles in Service Fleet Operation – U.S. Postal Service – Cupertino, California. Masters Thesis, University of San Francisco, 1987 (not consulted).

Jerabek, Elihu C. Load Leveling with Electric Vehicles in the Urban Environment. In: Intersociety Energy Conversion Engineering Conference, 11th, State Line, Nev. Sept. 12-17, 1976. Proceedings Vol. 1 (A77-12662 O2-44) New York. American Institute of Chemical Engineers (1976), pp. 382-389 (noted but not consulted).

Karden, Eckhard; Ploumen, Serve; Fricke, Birger; Miller, Ted and Snyder, Kent. Energy Storage Devices for Future Hybrid Electric Vehicles. Journal of Power Sources, Vol. 168, pp. 2–11, 2007.

Kemp, Rene and Simon, Benoit. Electric Vehicles: A Socio-Technological Study. In Feitelson, Eran and Verhoef, Erik T., eds., Transport and Environment: In Search of Sustainable Solutions, pp. 103–133. Elgar, 2001.

Kempton, W. and J. Tomić. "Vehicle to Grid Fundamentals: Calculating Capacity and Net Revenue." J. Power Sources Volume 144, Issue 1, 1 June 2005, pp. 268–279.

Kempton, W. and Tomić, J. "Vehicle to Grid Implementation: from stabilizing the grid to supporting large-scale renewable energy." J. Power Sources Volume 144, Issue 1, 1 June 2005, pp. 280–294.

LaCommare, Kristina Hamachi and Eto, Joseph H. Understanding the Cost of Power Interruptions to U.S. Electricity Consumers. Ernest Orlando Lawrence Berkeley National

Laboratory. LBNL-55718, September 2004. Published online at
http://certs.lbl.gov/pdf/55718.pdf.

Lund, Henrik and Kempton, W. "Integration of renewable energy into the transport and electricity sectors through V2G." Energy Policy 36 (2008) 3,578-3,587, doi:10.1016/j.enpol.2008.06.007.

Makarov, Yuri V.; Yang, Bo.; DeSteese, John G. et al. Wide Area Storage and Management System to Balance Intermittant Resources in the Bonneville Power Administration and California ISO Control Areas. Pacific Northwest National Laboratory. NNNL-17574, June 2008. Published online at *http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17574.pdf*.

Mom, Gijs. The Electric Vehicle: Technology and Expectations in the Automobile Age. Johns Hopkins University Press, 2004.

New York ISO White Paper: Integration of Wind Into System Dispatch, October 2008. Published online at:
http://www.nyiso.com/public/webdocs/documents/white_papers/wind_management_whitepaper_11202008.pdf.

NYISO Service Tariff Filing, Proposed Tariff Revisions to Integrate Energy Storage Devices into the NYISO-Administered Regulation Service Market. Filed March 11, 2009.

Obama, Barack. Remarks by the President at the Edison Electric Vehicle Technical Center, Pomona, California, March 19, 2009,
http://www.whitehouse.gov/the_press_office/Remarks-by-the-President-at-the-Edison-Electric-Vehicle-Technical-Center/.

Postal Regulatory Commission Docket ACR2008, Library Reference USPS-LR-FY08-5, Cost Segment 12, published online at *http://www.prc.gov*.

Philadelphia Inquirer. Electric Vehicles, Parcel Vans and Omnibuses Run by Storage Battery System. June 10, 1894, p. 22.

Rand, D.A.J.; Woods, R. and Dell, R.M. Batteries for Electric Vehicles, Research Studies Press, John Wiley & Sons, 1998.

Sperling, Daniel; with contributions by Delucchi, Mark; Davis, Patricia M. and Burke, Andrew F. Future Drive: Electric Vehicles and Sustainable Transportation, Island Press, 1994.

Tomić, J. and Kempton, Willett. Using Fleets of Electric Drive Vehicles for Grid Support. J. Power Sources, vol. 168, Issue 2, June 1, 2007, pp. 459–468.

Swiss Electric Postal Vehicles: An Interesting Automatic Battery-Charging Installation. The Electrical Review, vol. 111, August 5, 1932, p. 186.

U.S. Congress, Senate Committee on Energy and Natural Resources. Vehicles Powered by the Electric Grid: Hearing before the Committee on Energy and Natural Resources, September 16, 2008.

U.S. Congress, Subcommittee on Energy and Environment, Committee on Science and Technology, House of Representatives. Energy Storage Technologies: State of Development for Stationary and Vehicular Applications. October 3, 2007.

United States Postal Service, FY08 USPS Financial Summary, Cost Segment 12, published online at *http://www.usps.com/financials/csc/welcome.htm.*

Voelcker, John. Lithium Batteries Take to the Road. IEEE Spectrum, September 2007, pp. 27-31.

Wald, Matthew L. A Study Urges Governments to be the Vehicle Buyers of First Resort. New York Times, June 28, 1993, p. D1.

Walter, C.E.; Kong, M.K. and Mullenhoff, D.J. Route Profile Analysis to Determine Suitability of Electric Postal-Delivery Vehicles. UCRL-86707. Lawrence Livermore National Laboratory, 1981.