Case Number 1932.0

Electric Vehicles in Cities

Electrifying San Francisco

In 2010, the City of San Francisco was beginning to implement a plan to encourage the use of electric vehicles in the metropolitan area. San Francisco was an affiliate of the Large City Climate Leadership Group, an association of major cities around the world that recognized that climate change required global action but were not waiting for others to act. The group—commonly referred to as the C40 since it had 40 full members in addition to a growing list of affiliates—first met in London in 2005 and reconvened every two years to share information on how members could reduce their greenhouse gas emissions. At the United Nation's Conference on Climate Change in Copenhagen in December 2009 almost 80 city mayors participated in a "Climate Summit for Mayors", at which, 14 C40 members announced the formation of a "C40 Electric Vehicle Network" to help promote the use of electric vehicles by, among other measures, working with local utilities to develop the charging infrastructure for electric vehicles. Transportation accounted for 14 percent of global greenhouse gas emissions in 2000, and its share was growing rapidly as the developing countries motorized (Exhibit 1). Electric vehicles could make a key contribution to reducing transportation emissions, the mayors argued, and they would be most easily introduced in cities.

San Francisco's plan had been announced a year earlier at a press conference in which the mayors of San Francisco, Oakland and San Jose proclaimed their intention to make the San Francisco Bay Area known as the "Electric Vehicle Capital of the World." By 2010 the City of San Francisco had made good on several of the promises in the plan. The building code had been amended to require that parking spaces in all new buildings have the wiring needed to charge an electric vehicle. The process of obtaining a building permit to install a charging device in an existing home had been streamlined to take as little as one day instead of up to two weeks. And the City had established a program to allow residents to finance the cost of upgrading their outlets for electric charging over 20 years through a lien on their property tax. However, the process of installing charging stations in public parking spots was going more slowly than planned. The proposal called for installing over 200 charging points on streets, and in garages and lots in the first year and a half, but so far there were fewer than 70 charging points in the entire Bay Area.

This case was written by Yennga Khuong, graduate student in urban planning, and José A. Gómez-Ibáñez, Professor of Urban Planning and Public Policy at Harvard University. Preparation of this case and the teaching note were supported in part by a grant from the U.S. Department of Transportation through the New England Region University Transportation Center. The authors are responsible for the facts and the accuracy of the information in the case, which does not necessarily reflect the views of the U.S. Department of Transportation. HKS cases are developed solely as the basis for class discussion. Cases are not intended to serve as endorsements, sources of primary data, or illustrations of effective or ineffective management.

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Although San Francisco's efforts to accommodate electric vehicles had not been controversial or much noticed by the general public so far, there was substantial uncertainty about whether they would prove adequate. The San Francisco metropolitan area was home to 7.3 million people and 3.9 million cars, of which 800,000 people and 350,000 cars resided in the city itself and the remainder were in San Jose, Oakland, Berkeley and the 97 other cities that made up the Bay Area. Roughly five percent of the cars were scrapped and replaced every year, and the total number of operating cars was projected to increase by 1 million between 2006 and 2030 (Exhibit 2). Bay Area residents had proven to be receptive to new types of motor vehicles. One in five cars sold in Berkeley was reportedly a hybrid gasoline-electric Toyota Prius, for example; and San Francisco Mayor Gavin Newsom owned a Tesla, made by a company headquartered in Palo Alto and the only highway-capable all-electric vehicle currently sold in the United States. The region was also home to Better Place, a company pioneering a revolutionary battery leasing scheme for electric vehicles. If even a modest number of the region's replacement and new vehicles were electric, then the demand for charging—at home or elsewhere—might be enormous. Already the local electric utility, Pacific Gas and Electric, was identifying areas of its grid likely to overload if electric vehicles became more common. If electric vehicles proved less popular, however, then the investment in wiring for charging stations in new buildings and at public parking spaces would be wasted.

The Environmental Mandate

The interest of San Francisco and other C40 cities in electric vehicles stemmed from the promise that they would be substantially environmentally cleaner than vehicles powered by gasoline, diesel or other alternative fuels. Motor vehicles pollute the air both at the ground level and in the stratosphere. Ground-level pollutants from cars include fine particulates, volatile organic compounds (VOCs) and nitrogen oxide (NOx), with the last two compounds combining in the atmosphere to form ozone. Both particulates and ozone contribute to respiratory and heart diseases, and particulates are implicated in cancers as well. The primary stratospheric pollutant from cars is carbon dioxide (CO_2) and believed to cause global warming.

The motor vehicle's contribution to ground-level air pollution had been reduced considerably since the 1970s when Congress mandated that new cars and trucks meet strict federal standards for emissions of VOCs, NOx and particulates. The U.S. Environmental Protection Agency (EPA) was also empowered to set standards for the emissions of stationary sources, such as power plants, and for the maximum permissible ambient concentrations of ozone, particulates and other ground-level pollutants. State governments were responsible for developing and implementing plans to achieve these ambient standards by, if necessary, imposing additional controls on stationary and mobile emission sources. The EPA had recently proposed tightening its ambient standards for ozone so that 96 percent of monitored counties, including the city of San Francisco, would no longer be in compliance.

There was no comparable federal program to control the CO_2 emissions of motor vehicles. The prospects that Congress would develop such a program soon were dimming, moreover, because of the failure of the U.N. Conference on Climate Change in Copenhagen to produce a meaningful global agreement and the growing preoccupation of the Democratic and Republican parties with the November 2010 midterm elections. The closest analog was the Corporate Average Fuel Economy (CAFE) program established to set fuel efficiency standards for new cars after the energy crisis of 1973-74. The CAFE standards were motivated by a desire to make the United States less vulnerable to oil imports, but they had the effect of controlling greenhouse gases as well since CO_2 emissions were roughly proportional to the amount of fuel burned. Congress had gradually increased the CAFE standards for cars from 18 miles per gallon (mpg) in 1978 to 27.5 mpg in model year 1990, where they remained unchanged. Congress set more lenient standards for light trucks of 14 mpg in model year 1980, and rising to 20.7 mpg in the 1990s. Many of the sports utility vehicles (SUVs) that became popular in the 1990s were classified as light trucks, thus diluting the effect of CAFE standards on the efficiency of personal motor vehicles. Congress recently ordered the standards tightened to 35 mpg for cars by model year 2020 and 23.5 mpg for light trucks by model year 2010. The new standards would still fall far short of Europe where average new car fuel economy was 42 mpg.

Improving vehicle fuel efficiency was only one of several options for reducing motor vehicle CO_2 emissions. The carbon emissions from motor vehicles were the product of the number of person miles traveled (PMT), the number of vehicle miles traveled (VMT) per PMT, the energy consumed per VMT, and the carbon intensity of the energy:

$$CO_2 = PMT \times \frac{VMT}{PMT} \times \frac{Energy}{VMT} \times \frac{Carbon}{Energy}$$

In theory, emissions could be cut by reducing any of the four elements in the equation but in practice many observers thought that major reductions in PMT or in VMT/PMT were unlikely. The problem was that reducing PMT or VMT/PMT required "lifestyle" changes, including traveling less, switching to other modes such as walking or public transit, and moving to cities and denser suburbs where there were more alternatives to driving. Indeed, the trends were in the opposite direction as VMT per household in the United States had increased from 16,400 miles per year in 1970 to 24,300 miles per year in 2005.[1] Since Americans seemed to value personal mobility highly it would be much more palatable if the bulk of needed emissions reductions could be achieved by improving the energy efficiency of the vehicle or reducing the carbon intensity of the energy it used.

Vehicle and Fuel Options

Among the vehicle and fuel options there were two different types of internal combustion engines:

- **Spark Ignition Engines (SIEs)** burned conventional gasoline or ethanol and got their name from the fact that a spark was required to ignite the fuel-air mix. A study of vehicle technology options done by a respected MIT research group estimated that the typical new SIE currently consumed the equivalent of

[1] Robert Cervero and Jon Murakam, "Shrinking Urban Transportation's Environmental Footprint: Evidence on Built Environments and Travel from 370 U.S. Urbanized Areas," Paper Prepared for the Institute of Urban and Regional Development, University of California, Berkeley and National Science Foundation, 2008.

8.9 liters of gasoline per 100 kilometers (26 mpg) but that by 2035, fuel consumption could be reduced to 5.5 liters per 100 kilometers (43 mpg) through improvements in aerodynamics, more efficient transmissions and other measures. A further reduction to 4.9 liters was possible with turbo-charging (Exhibit 3).

- **Diesel** engines ignited the fuel-air mixture through compression and were more fuel efficient than comparable SIEs. The MIT researchers thought that by 2035 new diesel vehicles would consume only 4.7 liter equivalents per 100 kilometers (50 mpg).

There were three different types of electric vehicles:

- **Hybrid Electric Vehicles (HEVs)** combined a small spark-ignition engine with a small battery. The SIE provided the drive power and charged the battery while the battery assisted with acceleration and braking. An HEV could not drive in an all-electric mode for long. HEVs cost more to buy than SEIs but the combination of the two power sources was projected to reduce fuel consumption to 3.1 liters per 100 kilometers (76 mpg) in 2035.

- **Plug-in Hybrid Electric Vehicles (PHEVs)** were similar to HEVs except that they had a larger battery that could be charged by plugging into the electric grid. The plug-in feature and larger battery meant that PHEVs did not rely entirely on petroleum for fuel but could use electricity, some of which might be generated by hydro, wind, solar or other clean methods. The larger the battery the less reliant the vehicle was on petroleum but the higher the purchase price. The MIT group estimated that a 2035 PHEV capable of traveling 30 miles before switching to the SIE would produce emissions equivalent to those from 2.2 liters of fuel per 100 kilometers (107 mpg).

- **Battery Electric Vehicles (BEVs)** obtained all of their power from the electric grid and had no supplementary engine. Most studies assumed that the driving range of a BEV would not match that of a current SIE or diesel in order to keep the size and cost of the battery reasonable. The MIT researchers estimated that a 2035 BEV would consume the equivalent of only 1.7 liters of petroleum per 100 kilometers (138 mpg).

A final and more speculative option was:

- **Fuel Cell Vehicles (FCVs)**, which ran on hydrogen power and offered the promise of being completely clean. The future of FCVs was highly uncertain, however, since many issues with hydrogen supply, storage, and distribution had yet to be resolved.

The environmental advantages of a PHEV or a BEV depended in part on how the electricity they consumed was produced. Burning coal produces the most CO_2 per megawatt hour (MWh) of electricity generated with gas and oil close seconds. Solar, wind, nuclear, hydro and other renewable sources are not completely emissions free but generate one-twentieth or less of the CO_2 per kilowatt hour (kWh) of coal (Exhibit 4). The MIT estimates of the equivalent fuel economy of PHEVs and BEVs assumed a mix of generating sources typical in the United States, where 50 percent of the electricity was generated by coal and 18 percent by gas or oil. Europe, by contrast, was much less dependent on coal, oil and gas, while Pacific Gas and Electric, the principal utility serving the Bay Area, burned very little coal although a fair amount of gas (Exhibit 4).

It would be difficult for utilities to increase their use of renewable sources of electricity quickly, although many were trying to do so. Renewable sources were typically more expensive than coal or gas, absent special government incentives or subsidies. And there were technical challenges as well, especially since the output of some renewable sources was intermittent or could not be easily adjusted to match demand. Solar, wind and hydro were not completely reliable, for example, and wind and nuclear plants typically ran all night when electricity demand was at its lowest. Proponents saw BEVs and PHEVs as assets in integrating renewable sources into the energy system since electricity could be stored temporarily in millions of car batteries. At the very least, cars could be charged overnight to take advantage of any excess of nighttime wind, hydro or nuclear production, or to stabilize loads and improve utilization of fossil fuel plants. In a more sophisticated system electric cars could be plugged into the grid when not in use so that their batteries would serve as storage for the entire system, charging and discharging to help balance generation and peak consumption. Such a system was a long term possibility, requiring the development of a "smart grid" capable of monitoring and controlling millions of dispersed sources of electricity storage, generation and consumption.

While much of the focus was on electric-powered personal vehicles, some policymakers were intrigued by the potential of reducing carbon emissions with electric heavy rail and light rail mass transit systems, more popularly known as metros and street cars. (The terms heavy and light rail were misleading in that the distinction between the two modes was not the weight of the cars or the rails, but whether they drew their power from wires overhead, and thus could operate safely in city streets, or from rails beside the tracks, and thus required an exclusive right of way). For example, the San Francisco metropolitan area was served by both a metro (the Bay Area Rapid Transit System, or BART) and a streetcar system (The San Francisco Municipal Railway, or Muni), in addition to thousands of diesel-powered mass transit buses; together these several forms of public transit carried 11 percent of work person trips but less than 4 percent of non-work person trips (Exhibit 2).

The CO_2 emissions savings gained by switching from personal vehicles to electric- or diesel-powered mass transit depended not just on the sources of the electricity employed but on the average occupancy of the vehicles as well. If transit vehicles were fully loaded, then heavy and light rail cars, and diesel transit buses would generate slightly less CO_2 emissions per passenger mile than a BEV, and about half the emissions per passenger mile as a HEV. If transit vehicles carried only their actual average passenger loads, however, then heavy and light rail cars would have emissions similar to an HEV, while diesel buses would have emissions similar to a SIE. BART emissions per passenger mile were estimated to be significantly lower than those of the average U.S. heavy rail transit system because BART bought an unusually high percentage of its electricity from hydro and other relatively clean sources (Exhibit 5).

Consumer Experience to Date

If electric cars were to become an important contributor to greenhouse gas reduction then they would have to be built and bought in large numbers. Both vehicle manufacturers and consumers had shown considerable interest in HEVs in the last decade. Honda offered the first HEV, the Insight, for the U.S. mass market in 1999; Toyota's famous Prius debuted in 2000, and American manufacturers began to offer HEVs, including hybrid SUVs, beginning in 2004. Sales of new HEVs increased from around 10,000 in 2000 to 350,000 in 2007, but then fell to 290,000 in 2009 reflecting the 2008-2009 economic recession and the decline in oil prices from their 2008 peak (Exhibits 6a and 6b). In 2007, Opinion Research Corporation International asked consumers whether their next new vehicle purchased would be an HEV, diesel or SIE vehicle assuming HEVs and clean diesel cars had a $3,000 price premium over a standard SIE but reduced annual fuel costs by 30 percent. Sixty-percent of all respondents claimed they would buy hybrids and 15 percent would buy clean diesel vehicles for their next car purchase.[2]

PHEVs had begun to appear, but mass market versions were still a year or two away. Specialty auto shops were converting production model HEVs into plug-ins for auto enthusiasts and several manufacturers, including Toyota, were promising to offer plug-in versions of their HEVs in limited numbers in 2011 or 2012. Most of the attention was devoted to the 2011 Chevrolet Volt, which General Motors (GM) was scheduled to launch in California and Michigan in late 2010 with full availability promised for calendar year 2011. The four-door Volt had been designed from the start as a PHEV and, perhaps as a result, differed from most hybrids in that its SIE only charged the battery while its wheels were powered just by electric motors instead of both the SIE and electric motors. The Volt would plug into a household outlet and charge overnight, and it had a range of 40 miles solely on a fully charged battery and 600 miles if the SIE was used as well. GM had not announced the price yet but it was rumored to be around $35,000, or about $15,000 more than a comparable SIE.

BEVs were also not in widespread use yet, unless one counted specialized low-speed, short-range vehicles such as golf carts. There had been a flurry of interest in highway-capable BEVs in the early 1990s in response to a 1990 requirement by California that by 1998 two percent of new cars sold in that state by the seven largest car manufacturers had to be "zero-emitting" vehicles. The mandate stimulated extensive research and the development and limited leasing of several prototypes, the most famous of which was GM's EV1. In 1996 the car makers won a lawsuit that California's requirement was unreasonable and promptly cancelled the leases and scrapped the vehicles, provoking a documentary film titled, "Who Killed the Electric Car?"

As of early 2010 the only highway-capable BEV for sale in the United States was produced by the specialist manufacturer Tesla. Between 2008 and 2010, Tesla had sold over 700 of its Roadster model, a sports car capable of 0-60 mph in 3.9 seconds with a claimed range of 291 miles on a full charge and a price

[2] "Would You Buy a Hybrid Vehicle," U.S. Department of Energy: Energy Efficiency and Renewable Energy Department, July 3, 2006, http://www1.eere.energy.gov/vehiclesandfuels/facts/2006_fcvt_fotw431.html

tag of $110,000. In 2012 Tesla is planning to introduce a more affordable four-door Model S with a price tag of $57,400 and a range of 160 miles. Many major manufacturers around the world were at various stages of researching BEVs, but the only one with a well-developed plan for mass production was Nissan, whose Leaf model was scheduled to go on sale in late 2010. The five-door hatchback Leaf was projected to have a range of 100 miles on a full charge. Nissan had yet to announce Leaf's price, but auto industry sources thought it would be between $25,000 and $33,000. To keep the selling price low it was rumored that Nissan would require consumers to lease the battery on a monthly basis in addition to the initial purchase price of the car.

Obstacles to Acceptance

Battery Technology. The failure of the first round of BEVs introduced in the early 1990s was blamed in part on the low gasoline prices at the time but mainly on the state of battery technology. The batteries of the early 1990s were expensive, heavy and deteriorated with repeated charges. Auto designers had since switched to lithium-ion batteries that had a higher energy density and lasted through more recharge cycles. Lithium batteries delivered 100 percent power for the first 2,000 full charging cycles and 80 percent for another 2,000 charging cycles.[3] The new batteries still had a lower energy density than gasoline, however, so that the batteries had to be many times the size and weight of a standard gas tank for equivalent driving range. And lithium batteries currently cost about $2,000 per kWh of capacity, although mass production was projected to reduce prices rapidly to $500-$700 per kWh by 2020.[4] A car used 1 kWh of electricity to travel 4 or 5 miles so that a BEV with a 100 mile (161 kilometer) range needed a battery with 20 to 24 kWh of capacity; such a battery would cost $40,000 to $48,000 at the current price of $2,000 per kWh, but as little as $10,000 to $12,000 if prices dropped to $500 per kWh.

Exhibit 7 shows estimates of the retail price differentials between diesel and electric vehicles and a comparable SIE vehicle in 2009 and 2035. The estimates, made by MIT researchers, suggest that the price of an SIE powered car will increase by about $2,000 between 2009 and 2035 due to improvements to make it more fuel efficient. The difference in cost between an HEV and an SIE will drop, however, from $4,900 to $2,500. The PHEV and BEV, not available in 2010, are projected to cost $5,900 and $14,400 more, respectively, than an SIE in 2035.

Lifecycle Costs. The higher retail price of a HEV, PHEV or BEV was offset, at least in part, by the lower cost for energy consumed over the vehicle's lifetime. Which type of vehicle was more economical to operate on a lifecycle basis depended on the assumptions about battery costs, gasoline and electricity prices, and on the interest rate used to discount future costs. Exhibits 8 and 9 show the battery cost per kWh at which a PHEV or BEV is cheaper than a comparable HEV or SIE. The estimates, based on an analysis by researchers at the University of California, Berkeley assume a car driven 15,000 miles per year for 10 years and a discount rate of 10 percent per year. For example, if gasoline cost $3 per gallon and electricity

[3] Dan Galves, Rod Lache and Patrick Nolan, pg. 42.

15 cents per kWh, the approximate retail prices in California in early 2010, then a PHEV would save $474 in fuel costs every year compared to an SIE. The discounted present value of the fuel savings in the year the vehicle was purchased would be $2,914, enough to justify spending as much as $570 per kWh for the vehicle's battery. Using the same assumptions the breakeven battery cost for a BEV compared to an SIE was $208 per kWh.

How sensitive car buyers would be to the purchase price differentials and whether they would make basic lifecycle cost calculations was unclear. Some studies of consumer behavior suggested that consumers discounted future costs and benefits heavily and avoided complex calculations. The price differential between current HEV and SIE vehicles did not seem to be discouraging HEV sales unduly, however. And Tesla offered car buyers the option of leasing its Roadster and Nissan was expected to do the same with Leaf. Leasing spread the retail price differential over the vehicle's lifetime and reduced buyer concern about battery life and performance.

Range Anxiety. A final issue was whether car buyers would worry about the limited range of BEVs. Motorists were accustomed to SIEs with ranges of around 400 miles on a full tank of gas and HEVs and PHEVs could go as far. The price and weight of batteries made a BEV with a comparable range prohibitively expensive. According to a 2001 survey, 57 percent of car trips in the United States were 30 miles or less and 82 percent of trips were 60 miles or less.[5] In addition, 55 percent of American households owned two or more motor vehicles. A 20-24 kWh battery with a 100-mile range would cover most everyday trips but some households would require either another car for longer trips or infrastructure for recharging along the way. Range anxiety was one of the reasons that San Francisco and other cities were working hard to establish public charging stations.

Better Place

An Israeli-American entrepreneur, Shai Agassi, was promoting a strategy to address both the problems of range anxiety and lifecycle costs. His Palo Alto-based company, Better Place, proposed to make owning and operating a BEV as convenient and flexible as a conventional car by separating the vehicle and the battery both physically and financially. The physical separation would come by making the battery removable from the car, allowing motorists to quickly exchange a discharged battery for a charged one at a Better Place battery switch station. Even the fastest charging stations were projected to take 30 or more minutes, and a full charge would take 4 to 8 hours at the voltages normally available in households. Exchanging a battery at a switch station would take only a few minutes, about the same time it took to fill up at a gas station. The financial separation was achieved by separating the ownership of the battery and the vehicle. Better Place would own the batteries and lease them, charging by the mile much as mobile phone companies sold telephone calls by the minute or the month. The client could charge up at Better

[4] "Electric Cars: Plugged In," *Deutsche Bank Global Markets Research*, June 9, 2008, pg. 12.

[5] "2001 National Household Travel Survey," Department of Transportation, 2004, http://www.bts.gov/programs/national_household_travel_survey/

Place's expense through a charge spot at home, work or in public, or exchange batteries at one of Better Place's switch stations. Paying for electric vehicle services by the mile would make it easy for car buyers to compare electric and gasoline cars without making lifecycle cost calculations. And Better Place was projecting that the cost of mobility (i.e., amortized cost of the battery plus cost of electricity) at only 7 or 8 cents per mile in the United States, would be less than the cost of fueling a conventional gasoline powered car.

Better Place had captured the world's imagination several years earlier after it signed agreements with the Israeli government to set up its battery switch system in that country, and with Renault, Nissan's parent company, to produce and sell a BEV with a removable battery. The Israeli agreement required that Better Place spend $200 million to roll out a network of switch stations and charge spots in advance of mass sales of BEVs by Renault in 2011. In return, the government, which hoped to replace imported petroleum with solar-powered electricity for security and environmental reasons, promised to keep the existing tax on new conventional cars and hybrids at 72 percent but to reduce taxes on new BEVs to 10 percent. By 2010 Better Place seemed to be on schedule. The firm had opened a prototype battery switch station, reached an agreement with a large Israeli gasoline retailer to install the battery switch system in the retailer's gas stations, and signed up most of Israel's major fleet operators to convert to electric cars when their current vehicle leases expired. Renault was gearing up to produce its BEV at a plant in Turkey, starting with an output of 1,000 units a month in 2011 but with a commitment to produce at least 100,000 by 2016.

Better Place had subsequently announced agreements to promote electric vehicles with Denmark, Hawaii, Australia, the west coast of Canada, a small taxi operation in Japan, and San Francisco. In Denmark, Better Place partnered with DONG Energy, the biggest Danish electric utility that hoped to charge vehicle batteries with nighttime wind and hydro power. The two companies committed to build a $300 million network of battery switch stations and charge spots while the government, in return, agreed to waive its customary 180 percent tax on new car registrations for BEVs, at least until 2015. Most of the other agreements were less specific and firm. In San Francisco, for example, Better Place had followed Mayor Newsom's announcement of the city's intention to become the electric vehicle capital of the world by announcing that the firm planned to invest $1 billion in charge points and switch station infrastructure in the region beginning in 2012.[6] Better Place estimated that 100,000 to 200,000 charging points would be needed for 100,000 Bay Area subscribers, but so far the firm had built only a few points for employees at its Palo Alto headquarters.[7] The auto manufacturers were still skeptical about battery switch and none of the major automakers had joined Renault in its commitment to build cars with removable batteries. Only Tesla planned to design its new Model S with a removable battery, although they had had no negotiations about possible integration with Better Place's system. Nevertheless, Better Place was a hit with investors, who

[6] http://www.betterplace.com/global-progress/california/

[7] Martin Zimmerman, *Charging Ahead in Push for Electric Cars; Better Place Wants to Install Thousands of Plug-in and Battery-replacement Stations*, *L.A.TIMES*, Dec. 27, 2008, at C1.

had poured $700 million into the firm so far, and Agassi seemed on the verge of seeing his dream become a reality in Israel and Denmark.

Sister Cities

Meanwhile, San Francisco's sister cities in the C40 were developing a variety of different approaches to making their cities EV-ready. Most cities were promoting charging points both at private homes and at offices, shopping centers and other public places. But the relative importance cities placed on charging points at home and elsewhere varied, as did the number of public charging points they thought were necessary. The plans also differed in the degree to which the public sector or the private sector was expected to take the lead and how deeply local electric utilities or carmakers were involved.

One of the leaders in the C40 electric vehicle network was London's Mayor Boris Johnson, who announced an ambitious Electric Vehicle Delivery Plan in May 2009.[8] The plan called for installing 25,000 charging points in public spaces by 2015, enough so that every Londoner would live or work within a mile of a charging point. Five hundred of the points would be on city streets, 2,000 at public car parks, and 22,500 at workplaces and shopping centers. The plan included a requirement that 20 percent of the parking spaces in new developments be equipped with electric charging infrastructure, but in the short term the bulk of the points were expected to be installed in existing garages, parking lots and streets. The city's transportation agency, Transport for London (TfL), projected the cost of the 25,000 spaces at £60 million ($90 million), and had budgeted £20 million of its funds to support the effort. The remaining £40 million was to come from private firms that would propose schemes to build and operate charging points. TfL was also committed to electrifying its enormous fleet of diesel buses, but intended to purchase hybrids since a bus powered only by batteries could not meet its operational requirements.

Berlin was piloting a different approach with a partnership between its local electric utility RWE and the German car manufacturer Daimler to offer a coordinated package of BEVs, electricity and charging points. Daimler would lease subscribers an electric car and RWE would install a charging station in their home, allow them access to a network of 500 public charging points across the city, and sell them electricity at a discounted price depending on when and where they charged with all costs charged to the customer's utility bill. The effort was a pilot, and Daimler was committed to supplying only 100 BEVs to the scheme. As of early 2010, the 500 charging points were open and Daimler had turned over a handful of electric-powered versions of its two-passenger Smart ForTwos car to subscribers. Daimler intended to supply electric versions of the Mercedes Benz E class cars later in the pilot.[9]

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[8] "London's Electric Vehicle Infrastructure Strategy: Turning London Electric," Mayor of London December 2009.

[9] Daimler website accessed March 1, 2010 at http://www.daimler.com/dccom/0-5-7153-1-1262502-1-0-0-0-0-0-9293-7145-0-0-0-0-0-0-0.html and Carolin Reichert, "RWE E-Mobility: Market Expectation, Strategy/Business Model, Implementation Status," RWE, Presentation in Frankfurt: September 15, 2009.

What Next San Francisco?

Compared to the visions of London, Berlin or Better Place, San Francisco's plans seemed anemic. The requirements for charging points in new buildings would take decades to have much effect since they affected only new construction. In San Francisco's suburbs, most homes had an attached garage where a home charging point could be installed. But 84 percent of the city's residents who owned cars had no garages and parked their vehicles on the public streets at night.

As of early 2010 the metropolitan area had only about 70 public parking spots equipped with charging points, many in the parking lots of Tesla and Better Place, and most of the rest built and maintained by a small private company called Coulomb Technologies. The firm had designed a universal plug-in station that could be easily mounted on street light poles and was activated via a smart card. Coulomb installed its first three charging points on the street across from San Francisco's City Hall in 2009 and by 2010 had 29 charging stations scattered throughout the Bay Area.[10] Coulomb stations cost $2,000 to $4,000 each to build and the firm charged a monthly subscription fee with the amount depending on when and how often one charged. The monthly fee increased from $15 for 10 or fewer nighttime charges to $50 for unlimited charges at anytime. It was too early to know whether Coulomb's business plan was realistic and the firm was thinly capitalized.

In February 2010 the Bay Area Air Quality Management District, the region's air quality regulator, tried to help by announcing $428,200 in grants to build another 226 public charging points throughout the Bay Area. The grants included $100,000 to the City of San Francisco to open 60 charging points in public garages, $286,200 to the governments of four surrounding counties to build 130 points in their territories, and $42,000 to the City of Palo Alto and Better Place to build 36 points in that city.[11]

The grant program would leave a metropolitan area of over 7 million persons with only around 300 public charging points. How important was it to promote electric vehicle use in San Francisco? Would a shortage of public charging points inhibit the spread of electric vehicles in the metropolitan area? Or was the plan prudent given the limitations of the available technologies and the uncertainties surrounding consumer acceptance?

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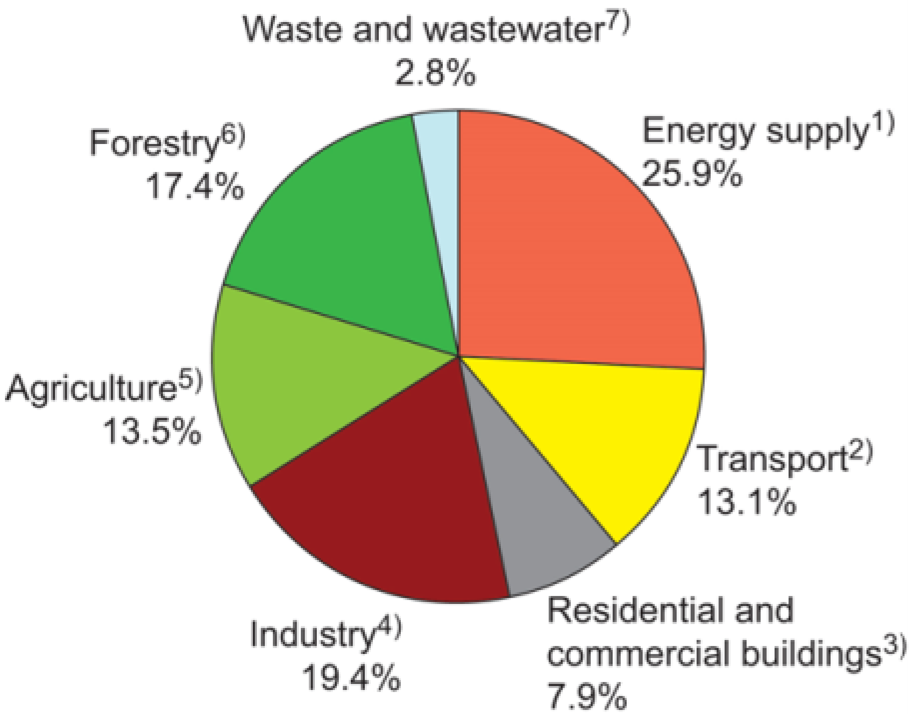
[10] http://www.coulombtech.com

[11] http://abclocal.go.com/kgo/story?section=news/local/san_francisco&id=7296724

Exhibit 1

Global Anthropogenic Greenhouse Gas Emissions by Sector, 2000.



Source: *Climate Change 2007: Mitigation of Climate Change. Working Group III Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Figure TS.2b. Cambridge University Press.

Exhibit 2

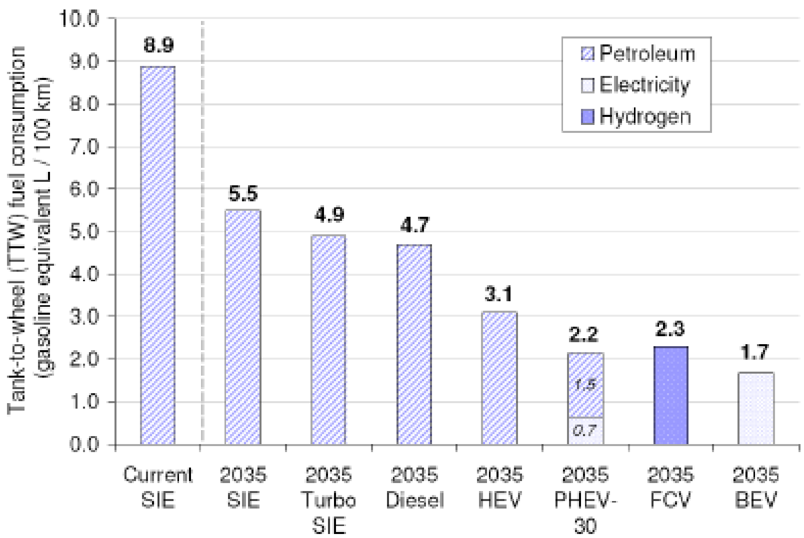
San Francisco Metropolitan Area Demographic Trends and Projections, 1990-2030

Characteristic	1990	2000	2006	2015	2025	2030
Demographics						
Total Population	6,020,100	6,783,700	7,260,600	7,840,200	8,457,900	8,780,300
Total Households	2,245,900	2,466,000	2,605,500	2,824,000	3,065,400	3,186,600
Average Household Size	2.61	2.69	2.73	2.72	2.71	2.71
Total Employment	3,206,100	3,753,700	3,919,100	4,509,800	4,982,800	5,226,300
Employed Residents	3,149,300	3,377,400	3,541,300	4,066,600	4,562,200	4,754,900
Mean Household Income (1989$)	$53,400	$64,900	$65,900	$71,900	$79,400	$83,300
Vehicle Ownership						
Total Vehicles	3,974,100	4,325,000	4,722,000	5,146,600	5,555,100	5,746,700
Average Vehicles per Household	1.77	1.75	1.81	1.82	1.81	1.8
Zero-Vehicle Households	232,100	247,200	243,600	260,500	291,200	311,400
Share of Zero-Vehicle Households	10.30%	10.00%	9.30%	9.20%	9.50%	9.80%
Transit Travel						
Transit Work Trips	470,400	572,200	596,100	750,900	885,400	944,700
Total Work Trips	4,565,400	5,248,300	5,376,000	6,252,000	7,157,600	7,555,500
Transit Share of Total Work Trips	10.30%	10.90%	11.10%	12.00%	12.40%	12.50%
Transit Non-Work Trips	695,200	603,400	633,200	756,000	810,300	849,300
Total Non-Work Trips	13,517,900	15,785,500	17,041,100	18,632,500	20,120,000	20,937,300
Transit Share of Total Non-Work Trips	5.10%	3.80%	3.70%	4.10%	4.00%	4.10%
Total Transit Trips	1,165,600	1,175,600	1,229,300	1,506,900	1,695,700	1,794,000
Total Trips	18,083,300	21,033,800	22,417,100	24,884,500	27,277,600	28,492,800
Transit Share of Total Trips	6.40%	5.60%	5.50%	6.10%	6.20%	6.30%
Total Daily Transit Boardings	1,568,200	1,714,300	1,773,000	2,220,400	2,508,600	2,656,200
Vehicle Travel						
Daily Vehicle Miles of Travel (VMT)	NA	143,495,300	152,093,900	172,631,100	192,040,900	202,756,400
Daily Vehicle Hours of Delay (VHD)	NA	355,600	433,100	609,400	850,400	993,200
Daily Vehicle Trips	14,707,400	17,074,300	18,084,000	20,288,600	22,510,800	23,626,200
Non-Motorized Travel						
Daily Bicycle Trips (All Purposes)	224,200	310,600	327,800	356,300	384,500	402,900
Bicycle Share of Total Trips	1.20%	1.50%	1.50%	1.40%	1.40%	1.40%
Daily Walk Trips (All Purposes)	1,698,600	1,950,400	2,088,500	2,321,000	2,516,100	2,638,900
Walk Share of Total Trips	9.40%	9.30%	9.30%	9.30%	9.20%	9.30%
Roadway and Transit Supply						
Roadway Lane-Miles	NA	19,940	20,620	20,900	20,980	20,980
Transit AM Peak Passenger Seat-Miles	NA	3,941,300	3,646,600	4,228,100	4,278,400	4,278,400

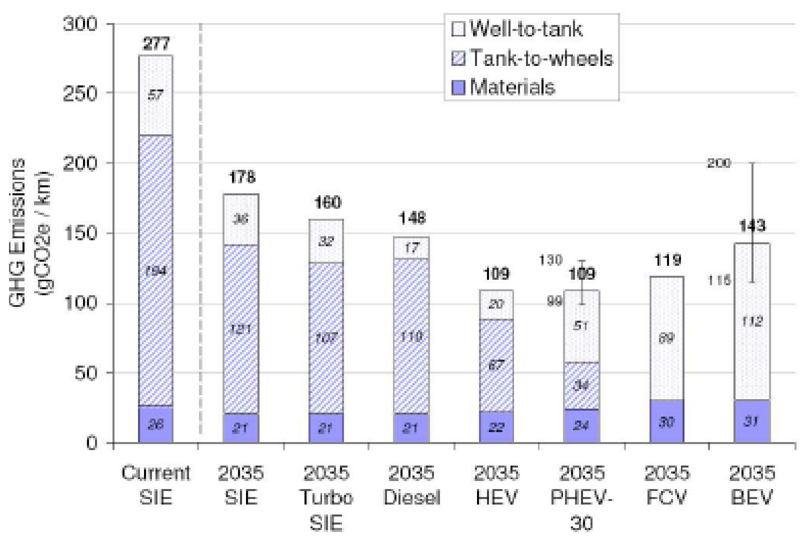
Notes:
1) Revised: September 13, 2006
2) Household population excludes persons residing in group quarters.
3) Average household size is computed as household population divided by total households.
4) Sources of Data include Association of Bay Area Governments (ABAG) Projections '05 demographic/economic/land use forecasts; and MTC travel demand forecasts based on ABAG's Projections '05.
5) Data is for the nine-county San Francisco Bay Area, including the counties of: San Francisco San Mateo, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma and Marin.
6) Land area of the San Francisco Bay Area region is 7,149 square miles (18,594 square kilometers).

Source: http://mtc.ca.gov/maps_and_data/datamart/stats/baydemo.htm

Exhibit 3:
Estimates of Relative Fuel Economy of Different Vehicle Types in 2035



(a) Tank-to-wheel gasoline-equivalent (GE) fuel consumption.



(b) Lifecycle greenhouse gas (GHG) emissions

Source: Report, MIT Laboratory for Energy and Environment, "On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions", July 2008.

Exhibit 4:
CO2 Emissions from Electricity Generation by Energy Source

		Share of sources		
Energy source	Emissions in kilograms of CO2 per MWh	United State average	European average	Pacific Gas and Electric
Coal	990	50%	23.8%	2%
Oil		18%*	23.5%*	
Gas	653			44%
Nuclear	21	20%	16.9%	22%
Hydro	18		23%	17%
Wind	37	11%**	4.6%	
Solar	59		6.6%***	15%***
Other renewables				

* Gas and oil together
** Renewables
***Other renewables

Sources:

Emissions: "Energy Technology Life Cycle Analysis that Takes CO2 Emission Reduction Into Consideration," Central Research Institute of Electric Power Industry, Japan, Annual Research Report, 1995.

United States: “Carbon Reduction of Plug-in Hybrid Electric Vehicles,” U.S. Department of Energy: Energy Efficiency and Renewable Energy Department, March 16, 2009, ://www1.eere.energy.gov/vehiclesandfuels/facts/2009_fotw562.html

European Union: “Factbook: General Capacity in Europe,” Rheinisch-Westfälisches Elektrizitätswerk (RWE), June, 2007.

Pacific Gas and Electric: .pge.com/

Exhibit 5:
Pounds of CO_2 per Passenger Mile in Personal and Public Transportation

Personal Vehicles

	Lbs of CO_2 per PMT	Assumptions: VMT per gallon	Wh per VMT	Lbs of CO2 per VMT	Occupancy (PMT/VMT)
Average SUV	0.719	18		1.078	1.5
Average SIE	0.577	22.4		0.866	1.5
HEV (Toyota Prius)	0.278	46.6		0.416	1.5
BEV (Nisan Leaf)	0.141		240	0.211	1.5

Assumptions: 1 gallon of gasoline causes 19.4 lbs of CO_2 emissions, Pacific Gas and Electric emits 0.879 lbs of CO_2 per Wh. These are just the direct tank-to-wheel emissions; well-to-tank emissions would add 25 percent to these figures.

Public Transportation: National Average

	Lbs of CO_2 per PMT: Average occupancy	Full occupancy
Diesel bus	0.65	0.16
Heavy rail	0.24	0.11
Light rail	0.41	0.15
Commuter rail	0.35	0.11

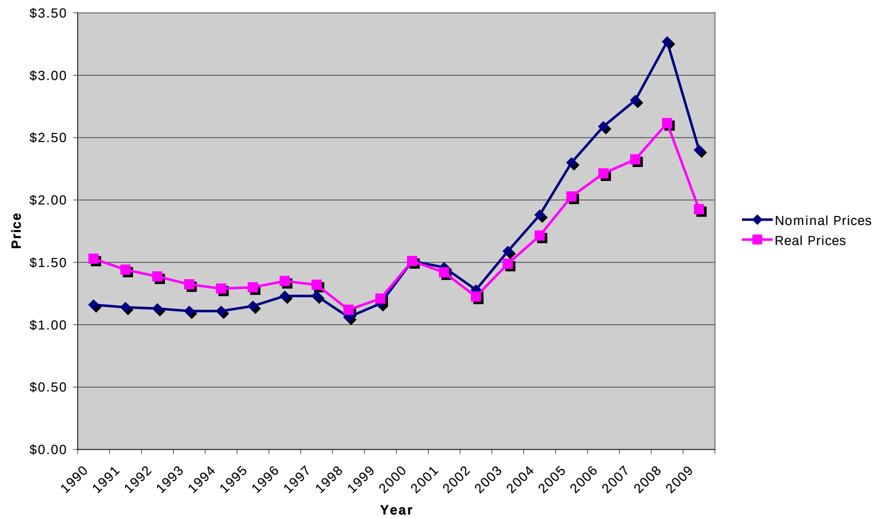
Public Transportation: San Francisco Metropolitan Area

	Lbs of CO_2 per PMT: Average occupancy	Full occupancy	Assumptions: kWh per seat mile	Lbs of CO2 per MWh	Occupancy
Bus (Muni)	0.559	0.179			32%
Heavy rail (BART)	0.089	0.026	0.071	399	37%
Light rail (Muni)	0.410	0.152	0.172	879	32%

Note: BART purchases electricity with lower carbon emissions per Wh than the Pacific Gas and Electric average.

Source: Federal Transit Administration, “Public Transportation’s Role in Responding to Climate Change”, January 2009.

Exhibit 6a:
Retail Gas Prices per Gallon 1990-2009
Real Prices Adjusted with Consumer Price Index (2000=Base Year)



Source: Bureau of Labor Statistics (CPI for all Urban Consumers) ://www.bls.gov/cpi/#tables

Retail Gas Prices per Gallon 1990-2009

	Nominal Prices	Real Prices	CPI (2000=100)
1990	$1.16	$1.53	75.88
1991	$1.14	$1.44	79.09
1992	$1.13	$1.39	81.48
1993	$1.11	$1.32	83.89
1994	$1.11	$1.29	86.08
1995	$1.15	$1.30	88.49
1996	$1.23	$1.35	91.09
1997	$1.23	$1.32	93.22
1998	$1.06	$1.12	94.66
1999	$1.17	$1.21	96.73
2000	$1.51	$1.51	100
2001	$1.46	$1.42	102.83
2002	$1.28	$1.23	104.46
2003	$1.59	$1.49	106.83
2004	$1.88	$1.71	109.69
2005	$2.30	$2.03	113.41
2006	$2.59	$2.21	117.07
2007	$2.80	$2.33	120.41
2008	$3.27	$2.62	125.03
2009	$2.40	$1.93	124.59

Source: Energy Information Association ://www.eia.doe.gov/emeu/steo/realprices/index.cfm

Exhibit 7:
Incremental Retail Price Increase of Diesel and Electric Vehicles Over an SIE Vehicle in 2009 and 2035

	Retail Price Increase ($2007)	
Vehicle Type	**Cars**	**Light Trucks**
Current Gasoline SIE Retail Price*	$19,600	$21,000
Increment relative to current Gasoline SIE		
Current Diesel	$1,700	$2,100
Current Turbo Gasoline	$700	$800
Current Hybrid	$4,900	$6,300
2035 Gasoline SIE	$2,000	$2,400
2035 Gasoline SIE Retail Price	$21,600	$23,400
Increment relative to 2035 Gasoline SIE		
2035 Diesel	$1,700	$2,100
2035 Turbo Gasoline	$700	$800
2035 Hybrid	$2,500	$3,200
2035 Plug-in Hybrid	$5,900	$8,300
2035 Battery Electric	$14,400	$22,100
2035 Fuel Cell	$5,300	$7,400

* SIE = spark-ignition engine vehicle

Source: MIT Laboratory for Energy and the Environment, *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions,* July 2008, p. ES-5.

Exhibit 8:
Breakeven Battery Cost per kWh for PHEV Relative to HEV and SIE Vehicle

Annual PHEV fuel savings relative to each type of vehicle

Gasoline price		$3		$4		$5	
		HEV	ICE	HEV	ICE	HEV	ICE
Electricity price ($/kWh)	$0.05	$292	$574	$406	$782	$519	$991
	$0.10	$242	$524	$356	$732	$469	$941
	$0.15	$192	$474	$306	$682	$419	$891
	$0.20	$142	$424	$256	$632	$369	$841
	$0.25	$92	$374	$206	$582	$319	$791
	$0.30	$42	$324	$156	$532	$269	$741

Discounted value of fuel savings

Gasoline price		$3		$4		$5	
		HEV	ICE	HEV	ICE	HEV	ICE
Electricity price ($/kWh)	$0.05	$1,792	$3,529	$2,492	$4,808	$3,191	$6,087
	$0.10	$1,485	$3,222	$2,184	$4,501	$2,884	$5,779
	$0.15	$1,177	$2,914	$1,877	$4,193	$2,577	$5,472
	$0.20	$870	$2,607	$1,570	$3,886	$2,270	$5,165
	$0.25	$563	$2,300	$1,263	$3,579	$1,963	$4,858
	$0.30	$256	$1,993	$955	$3,272	$1,655	$4,550

Break-even battery cost ($/kWh)

Gasoline price		$3		$4		$5	
		HEV	ICE	HEV	ICE	HEV	ICE
Electricity price ($/kWh)	$0.05	$616	$691	$856	$941	$1,097	$1,191
	$0.10	$510	$630	$751	$881	$991	$1,131
	$0.15	$405	$570	$645	$821	$886	$1,071
	$0.20	$299	$510	$539	$760	$780	$1,011
	$0.25	$193	$450	$434	$700	$674	$951
	$0.30	$88	$390	$328	$640	$569	$890

Assumptions
ICE: 37.7 MPG
HEV: 49.4 MPG; 2.2 kWh Battery
PHEV-20: 52.7 MPG; 5.11 kWh Battery; 5 miles/kWh
Miles Traveled a Year: 15,000; Vehicle Life: 10 years; Discount Rate: 10%

Source
Adapted from DM Lemoine, DM Kammen and AE Farrell, "An Innovation and Policy Agenda for Commercially Competitive Plug-in Hybrid Electric Vehicles," Environ. Res. Lett. 3, 2008

Exhibit 9:
Breakeven Battery Cost per kWh for BEV Relative to HEV and SIE Vehicle

Annual EVs fuel savings relative to each type of vehicle							
Gasoline price		**$3**		**$4**		**$5**	
		HEV	**ICE**	**HEV**	**ICE**	**HEV**	**ICE**
Electricity price ($/kWh)	$0.05	$761	$1,044	$1,065	$1,442	$1,368	$1,839
	$0.10	$611	$894	$915	$1,292	$1,218	$1,689
	$0.15	$461	$744	$765	$1,142	$1,068	$1,539
	$0.20	$311	$594	$615	$992	$918	$1,389
	$0.25	$161	$444	$465	$842	$768	$1,239
	$0.30	$11	$294	$315	$692	$618	$1,089

Discounted value of fuel savings							
Gasoline price		**$3**		**$4**		**$5**	
		HEV	**ICE**	**HEV**	**ICE**	**HEV**	**ICE**
Electricity price ($/kWh)	$0.05	$4,675	$6,412	$6,541	$8,857	$8,407	$11,302
	$0.10	$3,754	$5,491	$5,619	$7,935	$7,485	$10,380
	$0.15	$2,832	$4,569	$4,698	$7,014	$6,563	$9,457
	$0.20	$1,910	$3,647	$3,776	$6,092	$5,642	$8,537
	$0.25	$988	$2,726	$2,854	$5,170	$4,720	$7,615
	$0.30	$67	$1,804	$1,933	$4,249	$3,798	$6,693

Break-even battery cost ($/kWh)							
Gasoline price		**$3**		**$4**		**$5**	
		HEV	**ICE**	**HEV**	**ICE**	**HEV**	**ICE**
Electricity price ($/kWh)	$0.05	$236	$291	$330	$403	$425	$514
	$0.10	$190	$250	$284	$361	$378	$472
	$0.15	$143	$208	$237	$319	$331	$430
	$0.20	$96	$166	$191	$277	$285	$388
	$0.25	$50	$124	$144	$235	$238	$346
	$0.30	$3	$82	$98	$193	$192	$304

Assumptions
ICE: 37.7 MPG
HEV: 49.4 MPG; 2.2 kWh Battery
EV: 22 kWh Battery; 5 miles/kWh
Miles Traveled a Year: 15,000; Vehicle Life: 10 years; Discount Rate: 10%

Source: Adapted from DM Lemoine, DM Kammen and AE Farrell, "An Innovation and Policy Agenda for Commercially Competitive Plug-in Hybrid Electric Vehicles," Environ. Res. Lett. 3. 2008.