Historical Case Studies of Energy Technology Innovation

CASE STUDY 9: HYBRID CARS.

HYBRID CARS: DEVELOPMENT & DEPLOYMENT IN JAPAN, THE US, AND CHINA.

Kelly Sims Gallagher
Tufts University

AUTHORS' SUMMARY

Many governments are interested in promoting hybrid electric vehicles (HEVs) and other alternatives to conventional internal combustion engines because of concerns about energy security, oil dependence, air pollution, and global climate change. HEVs achieve greater fuel efficiency than conventional vehicles, although the extent of improvement in efficiency depends greatly on the specific configuration of the HEV system.

The development of hybrid electric vehicles (HEVs) in three major markets - Japan, the United States, and China - was characterized by similar drivers of innovation. However, policy mechanisms and incentives for deployment diverged significantly. In all three countries, governments originally pushed harder for alternative automotive technologies other than hybrids, such as pure electric vehicles or hydrogen fuel cell vehicles. In some cases, private firms made research and development (R&D) choices that do not appear to have been strongly influenced by public policy but rather followed a commercial logic in exploring fuel efficient technologies. In other cases, government policies appear to actually have turned firms away from HEVs. Once HEVs emerged in the marketplace, however, the government response was completely different in each of the three countries, especially in terms of the extent to which each government was prepared to support their transition through the early deployment phase to facilitate widespread market diffusion.

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

1 INTRODUCTION

Hybrid electric vehicles (HEVs) add a parallel direct electric drive train with motor and batteries to the conventional internal combustion engine. Some HEVs are series hybrids and others are parallel hybrids - the main difference being whether the electric motor can be used alone, or whether it can only assist the engine. By combining the two propulsion systems, HEVs reduce the amount of fuel consumed and further save energy by reducing idling and braking losses (Demirdoven and Deutch 2004). Various technologies can be integrated into an HEV to reduce its demand for energy, thereby reducing the load and enabling a further downsizing of the engine. The extent of improvement in fuel efficiency of HEVs depends greatly on the configuration of the specific hybrid system. These range from 'mild' HEVs with modest fuel efficiency improvements to 'strong' HEVs producing substantial gains in fuel efficiency. Given potential fuel efficiency gains, governments have been interested in promoting HEVs and other alternatives to conventional internal combustion engines in line with concerns about oil security, air pollution, and global climate change.

This case study considers the development and deployment of hybrid electric vehicles (HEVs) through country reviews of Japan, the United States, and China, focusing particularly on the role of the three respective governments in supporting private sector innovation. Although the drivers of innovation were broadly similar between the three countries, the policy mechanisms and deployment incentives used diverged significantly. In all three countries, the governments originally pushed harder for alternative automotive technologies other than hybrids – pure electric vehicles or hydrogen fuel cell vehicles. In some cases, private firms made R&D choices that do not appear to have been strongly influenced by public policy; in other cases, government policies appear to actually have turned firms away from HEVs.

Once HEVs emerged in the marketplace, however, the government response to them was completely different in the three countries, especially in terms of the extent to which each government was prepared to support their transition through the early deployment phase of commercial application to facilitate widespread market diffusion.

2 HYBRID ELECTRIC VEHICLES IN JAPAN, THE US, AND CHINA

2.1 Japan

Japan was the first country to commercialize hybrid electric passenger cars. The history of HEV research and development (R&D) in Japan, however, is opaque. Private industry, most notably Toyota and Honda, developed HEVs seemingly independently from the Japanese government (and from each other). The industry nonetheless benefited from government support for major HEV components through the government's battery electric vehicle (BEV) R&D program which began in 1972 with the creation of a BEV public-private R&D program.

The program produced a first BEV prototype by 1976. Applications for patents on electric vehicles appeared as early as the mid 1970s (Yarime et. al 2008). It was not until 1997 (after Toyota produced its first hybrid) that the government officially broadened this program to explicitly encompass R&D for HEVs. Indeed, the government was mainly focused on development and deployment of pure battery electric vehicles until the mid 1990s. This strategy apparently derived from the government's interest to move to nuclear-fueled BEVs, which might have afforded the Japanese greater energy security (Åhman 2009). Other alternative-fueled vehicles including compressed natural gas, methanol, and fuel cell vehicles, were also considered and supported as well in the 1997 revision to the program to include HEVs. Meanwhile, a special public-private R&D program focused on improving batteries was established in 1992, and different combinations of battery and vehicle manufacturers joined forces to develop and produce advanced batteries. Although the government was mainly focused on BEVs, there were spillovers to HEVs from the government investments in electronic control techniques, permanent magnet motors, and the nickel metal hydride (NiMH) battery programs (Åhman 2006).

An important feature of Japanese government policy towards HEVs is its consistent and complementary support for the commercialization of alternative-fueled vehicles. The Clean Energy Vehicles Introduction Program which supported deployment was initially restricted to BEVs. But HEVs were quickly added as an eligible technology in 1998 after Toyota and Honda released their first hybrid models, a case of deployment incentive lagging commercial applications.

In the first couple of years of the program more than half the vehicles received major subsidies (Åhman 2006). The comprehensive deployment support policy for hybrids included preferential acquisition taxes, preferential annual automobile taxes, and subsidies (up to one half of the incremental cost over a conventional gasoline vehicle). In addition, fuel efficient and low emission vehicles received rebates (in a so-called “feebate” scheme). These feebates were so effective that the government’s projected revenue from the fees imposed on inefficient and polluting vehicles were much lower than anticipated due to the consumer popularity of the fuel-efficient, low-emission vehicles (Ito 2006). As a result of the popularity of the rebate, the Japanese government began to adjust it annually to support a continual shift to more efficient cars. Finally, Japanese fuel taxes undoubtedly contributed to stimulating demand for the more fuel efficient HEVs.

The best known and bestselling hybrid vehicle in the market today is the Toyota Prius, but the Ministry of International Trade and Industry (MITI) was reportedly unaware of the extent to which Toyota was developing the Prius during the 1990s (Åhman 2006), and also therefore, presumably unaware of Honda’s development of its own HEV, the Insight. It is not clear what motivated Japanese industry to develop HEVs as the government did not encourage or support this particular technological system, but there are various possible explanations.

First, the 1992 Earth Summit in Rio may have motivated some company leaders to develop a new vision for reducing the fuel consumption of popular vehicles. Both Toyota and Honda had strong internal environmental leadership. In 1992, Toyota set up an environmental committee directly chaired by the president, which was “of decisive importance as an institutional framework” (Yarimi et. al 2008, 198). In the same year, it also published its first Global Environmental Charter, followed by an environmental implementation plan in 1993. In September 1993, Toyota initiated a project, Global 21st Century, to develop more fuel efficient automotive technologies, with the aim of improving fuel efficiency by more than 50 percent.

Second, R&D programs and market incentives in the US may have spurred Japanese industry on to out-compete the major US manufacturers. In 1993, the US Partnership for Next Generation Vehicles set targets for three-fold improvements in fuel efficiency, and in 1990, California’s Zero Emission Vehicle mandate signaled future demand in a sizeable market niche for highly efficient vehicle technologies (see below for further details). These competitive incentives likely played a role in Japanese automakers' efforts to commercialize electric vehicles.

Third, innovation efforts may have led Japanese industry to discover or revisit the potential benefits of HEV systems. Through its 'Global 21st Century' project, Toyota engineers 'rediscovered' older Toyota hybrid technology, which had been originally developed in 1977 for a sports car. In contrast to the Toyota case, Nissan and Honda were more reactive, waiting for clearer policy signals in support of HEV deployment before focusing innovation efforts. Using patent applications as a proxy for innovation activity, full-scale development of hybrid vehicles did not occur until after California's Zero Emission Vehicle regulation was strengthened in 1996 (Yarimi et. al 2008). Patent applications on electric vehicles remained very low throughout the 1980s and 1990s, but applications on series hybrid vehicles rose in the early 1990s before falling again after it was discovered that parallel hybrids were more efficient. Patent applications for parallel hybrids rose after 1995, and peaked in 2000 (Yarimi et. al 2008).

In summary, a combination of these firms' leaders' acceptance of environmental challenges as legitimate, and a long uninterrupted history of electric vehicle development supported by government, led Japanese firms to realize the potential for HEV technology before most competitors (Åhman 2009).

2.2 The United States

The US government apparently recognized the potential for HEVs relatively sooner than the Japanese government. Although the US Department of Energy had supported investments in vehicle efficiency technology R&D since the 1970s (Gallagher & Anadon 2009), the first marquee effort to develop a hybrid electric car was launched in 1993. The Partnership for a New Generation of Vehicles (PNGV) was launched as a public-private R&D partnership by the federal government together with the US Council for Automotive Research, a partnership of Ford, Chrysler and General Motors. Ultimately, 7 federal agencies, US national laboratories, and multiple private companies joined the PNGV effort, which was placed under the leadership of the US Department of Commerce. At the onset of the program, the specific goals were to develop a vehicle that achieved up to three times the fuel economy of mid-sized 1993 cars (a goal of approximately 80 mpg) with no sacrifice in performance, size, cost, emissions, or safety. Industry participation was apparently motivated more by an interest in trying to avoid new federally-mandated fuel efficiency and/or emissions standards by participating in the partnership than by a true interest in innovation (Sperling 2001). Separately, a cooperative agreement between the Department of Energy and the US Advanced Battery Consortium was formed to develop nickel-metal-hydride (NiMH) battery technology.

The US government relied mainly on this type of public-private partnership model for technology-push innovation efforts to develop HEVs. No complementary policies to create market demand or niche markets were used during the 1990s to support the deployment of HEVs, relying instead on fuel economy performance standards imposed on car manufacturers. But these corporate average fuel economy (CAFE) standards had no effect on demand for HEVs or on encouraging automakers to produce HEVs because the level of the standards was static throughout the 1990s and early 2000s, and were insufficiently stringent to be technology-forcing. A National Academy of Sciences review of the CAFE standards found no evidence that it had led to the development of HEVs, but it did find that a combination of the standards and higher fuel prices resulted in technological improvements which nearly doubled the fuel economy of new passenger cars (NRC 2002). The review also concluded that

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

CAFE did not constrain most imported vehicles because they were so much more energy efficient than those produced by US automakers.

US automakers provide different explanations for why they were slow to develop and market HEVs. Some industry representatives have claimed that the firms were derailed by California's Zero Emission Vehicle mandate, and overly focused on pure electric vehicle technology. General Motors spent $1 billion developing its EV1 car, which was leased in California and Arizona starting in 1995. The EV1's range of 100 miles ultimately proved to be too limiting, and GM discontinued the vehicle in 1999. After abandoning its EV program, General Motors decided to focus on fuel cell vehicles to the apparent exclusion of HEVs. According to Gary Cowager, President of North American operations: "EV1 was frankly what held us back on hybrids. When the hybrid thing started, people said, show me the business case" (Maynard 2004). DaimlerChrysler also leaned towards fuel cell vehicles, forming a partnership with the leading Canadian fuel cell developer, Ballard, in 1997. ('FreedomCar', the successor to the PNGV program which was considered not to have met its cost targets, was also largely, but not exclusively, focused on fuel cell vehicles).

Chrysler had developed a hybrid version of its Dodge Durango that was ready to be introduced in 2002, but parent company DaimlerChrysler pulled it back, believing that diesels were a better way to go (Maynard 2004). Ford Motor Company came the furthest and fastest in developing and deploying HEVs, perhaps driven by the interest of its CEO at the time, Bill Ford, who as a self-avowed environmentalist wanted results sooner than was likely with hydrogen fuel cells. Oddly, General Motors later returned to its electric vehicle roots, committing strongly to its Chevy Volt project, which was touted as the first US plug-in hybrid electric vehicle. The Volt finally began production in 2010.

Despite the PNGV program and CAFE standards, no hybrid vehicles were produced by US automakers prior to 2005, and none were available for sale in the US market prior to 2001 when Honda and Toyota brought the Insight and Prius, respectively, to the US market. To the surprise of many, American consumers enthusiastically embraced the Japanese-produced hybrid passenger cars as soon as they reached US shores. It is not clear why US automakers were unaware of the evident market demand, but Japanese HEVs had been available for four years before the first US-produced HEV was introduced by the Ford Motor Company. Both the Insight and the Prius were a big success in the US market, especially the larger second-generation Prius. In 2004, Toyota's redesigned model brought improved styling, passenger room, cargo area, and power, and was well positioned for success when gasoline prices started to rise in 2005 (Gallagher and Muehlegger 2011). Indeed, US HEV sales, especially the highly fuel-efficient models, surged that year. In 2008, more HEVs were registered in the United States than in any other country, including Japan: 62% of global registrations were in the US, compared with 17% in Japan, 4% in Canada, 3% in the UK, and 2% in the Netherlands (HybridCars 2009).

Tax credits were the only federal deployment policy for hybrid vehicles implemented in the United States in the 2000s aside from the CAFE standards. Originally provided as an income tax deduction to HEV purchasers, in 2006 the government converted this subsidy into a tax credit, which is more valuable for consumers. Numerous states created additional deployment incentives, including sales tax reductions or exemptions, permission to use high-occupancy vehicle lanes with only one driver, free parking spots, reductions in state income taxes, exemptions from emission testing requirements.

It continues to be a puzzle why HEVs have proved so popular in the US market. One would expect that the combination of relatively low retail gasoline and diesel prices in the United States, weak deployment incentives, and the higher cost of the HEV would result in weak consumer demand. In contrast, Japanese gasoline prices are typically two to three times higher due to gasoline taxes (see Figure 1). Insights into consumer behavior provide some explanation for the unexpectedly high rate of HEV adoption in the United States. In one study, state-level sales tax reductions, average income, and environmentalism were all found to be significant in explaining state-level market shares of HEVs (Gallagher and Muehlegger 2011). Sales tax waivers were more significant than income tax credits presumably due to the immediacy of the sales-tax reduction at point of sale. The federal income tax credit, which is uncertain in value and more distant in the future, does not seem to have lured consumers. Rising gasoline prices also appeared to affect consumer decisions – gas-price conscious consumers tended to buy very fuel-efficient 'strong' hybrids rather than so-called 'mild' hybrids, which only provide modest fuel economy improvements (Gallagher and Muehlegger 2011). Other studies have similarly found that retail fuel prices matter to consumers of energy efficient products (Jaffe, Newell, and Stavins 1999), that social preferences can be a powerful factor in purchase decisions, and that environmentally-motivated consumers were more likely to purchase HEVs irrespective of the differential in price with conventional vehicles (Turrentine and Kurani 2007, Kahn 2007).

In line with long-standing evidence on the diffusion of innovations (Rogers 2003), these early adopters willing to take the risk of purchasing an expensive, unproven, potentially unreliable new technology allowed other consumers to observe the quality and performance of HEVs. The outcome of this "information cascade" is observable when later adopters make the same choices as early adopters without having gone through the same investment in "learning by experience" (Geroski 2000).

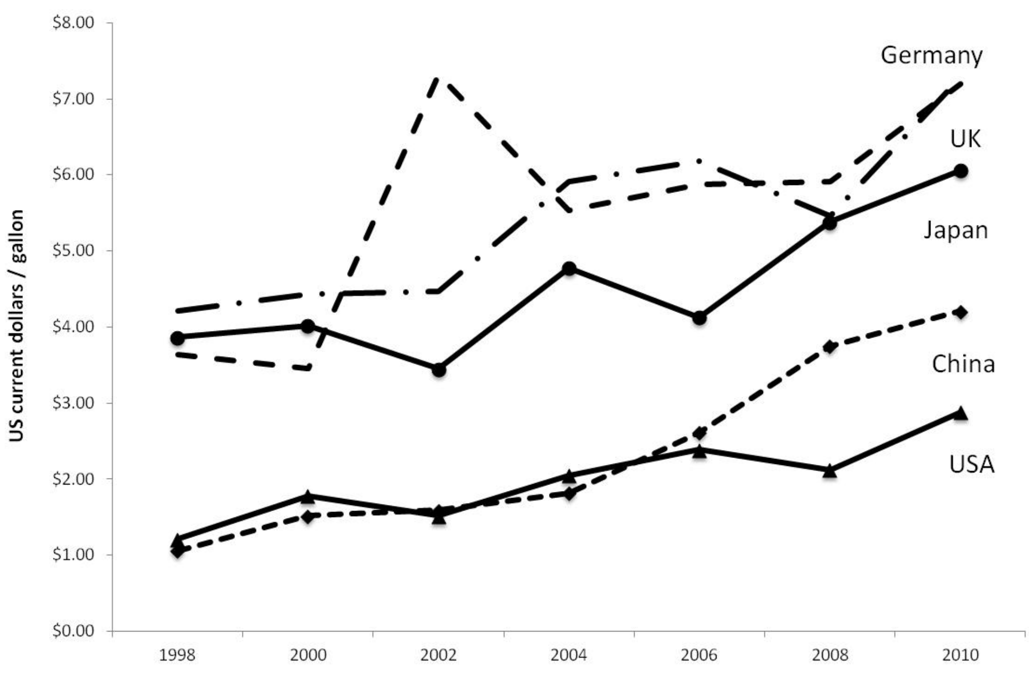

FIGURE 1. RETAIL GASOLINE PRICES (1998-2010). SOURCE: GTZ 2012.

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

2.3 China

Even more strongly than the United States, China is in a ‘catch-up’ mode of innovation for HEVs. (For further details on the Chinese case, see: Gallagher 2006). HEVs currently represent only a tiny fraction of Chinese passenger car sales. Only 2,100 HEVs were sold in China in 2008, out of a total of 6.4 million passenger cars produced that year (Bradsher 2009). Chinese domestic manufacturers are trying to acquire and develop indigenous HEV capabilities, but most do not yet produce HEVs on a commercial basis (though many have developed prototypes).

The standout Chinese firm, BYD, launched its F3DM plug-in hybrid in December 2008. Similar to the case of Toyota, BYD’s successful development of electric vehicles was strongly influenced by the founder and CEO of BYD, Wang Chuan-Fu. BYD was established in 1995 as a battery manufacturer, primarily supplying the cell phone market. In 2003, BYD acquired the Shaanxi Qinchan Auto Company and established the BYD Auto Company, and within 2 years, began producing its first passenger car, the F3. In 2006, BYD produced its first electric car prototype, and two years later launched the F3DM for sale (DM stands for dual mode). The F3DM is advertised to run up to 100 kilometers on a charge before reverting to its gas engine (Kurtenbach 2009; BYD 2009). It can also run as a pure plug-in electric vehicle, or it can be run as an HEV because it has a back-up gasoline engine. The F3DM sells for about $22,000. Wang Chuan-Fu’s commitment to environmental sustainability extends beyond fuel efficiency. The company has set a goal of making its batteries 100 percent recyclable, and has developed a non-toxic electrolyte fluid (Gunther 2009).

A major barrier to the development and deployment of HEVs in China is price. Toyota and First Auto Works (FAW) began assembling the Prius in China in 2005, but the price of the Chinese-assembled Prius was about 300,000 RMB (US$40,000), nearly twice the price of a Prius sold in the United States. One reason for this higher price is the 10-28 percent tariff that is paid on imported parts and components. Also, few, if any, Chinese parts and components producers were able to supply the Toyota-FAW facility, so parts were sourced internationally. Domestic manufacturers have been reluctant to produce HEV components because of the small volume and lack of economies of scale. Also, the technological capabilities of the parts and components firms in China may be inadequate to the task of producing to specification. Some have argued for standardization of the key components of HEVs in China to facilitate greater economies of scale and cost reductions for domestic manufacturers.

Many Chinese manufacturers have stated that another big barrier is the Japanese firms’ ownership of many of the relevant patents for key components, and that lack of Chinese intellectual property has proven to be a constraint. Although a lack of leapfrogging in the development of China’s automobile industry was observed until the turn of the century (Gallagher 2006), BYD’s production of the F3DM represents a big leap forward.

China’s Ministry of Science and Technology (MOST) provided considerable ‘technology-push’ support through its high-tech “863” applied R&D program. Similar to the cases of the United States and Japan, the MOST program originally focused more heavily on pure BEVs rather than hybrids, and also fuel cell vehicles in line with US FreedomCar program. Research began on electric vehicles in 1990, and an EV demonstration zone was established in Shantou in 1997, beginning operation in 1998 with a budget of approximately $2.5 million, one quarter of which was supplied by MOST, and the rest by local government and Chinese firms. Both GM and Toyota donated electric vehicles for testing. Some vehicles were used as taxis, and all were monitored closely (Shantou EV Project Personal Communication 2001;

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

Ming et. al 2008). This program catalyzed a number of Chinese firms to focus on HEV development, and to add some of their own funds as well.

Aside from FAW, the auto companies Chery, Dongfeng, and Chang'An all have HEV R&D programs co-funded by MOST. Many other firms are actively developing BEV and fuel cell vehicles as well. As of 2006, Chery was pursuing a strategy of licensing and hiring of foreign design firms. Dongfeng and Chang'An had not succeeded in convincing their foreign partners to collaborate on HEV R&D, but were pressing ahead on their own. The city of Tianjin is pursuing a 'cluster' strategy, supporting and co-locating electric vehicle manufacturers with battery developers, together with one of China's top research and testing institutes, the China Automotive Technology and Research Center.

To create market niches and underwrite demand for these technology-push efforts, subsidies of up to $8,800 are being offered to taxi fleets and local government agencies in 13 Chinese cities for each hybrid or all-electric vehicle they purchase. The state electricity grid was also ordered to set up electric car charging stations in Beijing, Shanghai and Tianjin. The government target is to produce 500,000 HEVs or EVs per year by the end of 2011 (Bradsher 2009).

Yet in terms of consumer demand, the relatively low gasoline and diesel prices in China create a strong disincentive for purchase of HEVs. The Chinese government still controls the price of retail fuels, and until 2006 often held domestic prices below world prices (see Figure 1). Chinese consumers lack awareness of HEV technology, and for those who are aware, the lack of product diversity is a drawback. The Chinese government imposed its first passenger car fuel efficiency standards in 2005, and they were strengthened in 2008. These standards are imposed by weight class. The government also imposed purchase fees on a sliding scale based on engine size. Both of these policies theoretically favor HEVs, but neither is strong enough to overcome the price hurdle.

3 COMPARATIVE ANALYSIS OF FACTORS INFLUENCING HEV DEVELOPMENT

Political and economic factors were initially the main drivers for government technology policy and investments in alternative vehicle technologies in all three countries reviewed. In the United States and Japan, concern about energy security in the wake of the oil crises of the 1970s spurred investments into battery electric vehicles and hydrogen fuel cell vehicles. Japan committed itself to nuclear energy during the 1980s and 1990s, offering a seemingly secure pathway for electrifying the vehicle fleet. In the United States, relatively abundant resources of coal could be used to supply the electricity for electric vehicles.

In the early 1990s, environmental factors emerged as a driver for advanced vehicle technologies when California began to push for zero emission vehicles. For China, energy security has been the dominant driver of its policy for advanced vehicle technologies, although there is reason to believe that its new focus on a low carbon economy might also provide additional impetus for the development and deployment of alternative vehicles and fuels.

But in all cases, governments were either not sufficiently knowledgeable about the costs of BEVs (and the associated technical constraints), or they thought these costs could be overcome with effort. Although none of the governments supported HEVs initially, public investments into BEVs were the basis of important spillovers to the eventual development of HEVs since BEVs and HEVs share many components and systems.

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

The role of private firms differs substantially across the three countries. US firms appear to have lacked the foresight or capacity of Japanese firms to develop HEVs even in the absence of government R&D programs. This is ironic because the conventional wisdom is that Japanese firms work closely and harmoniously with their government and received much subsidization for their hybrid vehicle programs. An alternative explanation is that US firms were overly responsive to policy. By letting the California zero emission vehicle mandate steer their R&D programs away from hybrids, the US firms lost ground against the Japanese firms. Even when the public-private PNGV program was established, US firms failed to accelerate investments and research into HEVs. Given their disinterest, perhaps the best explanation is that the US firms were too enthralled by the profits to be made with large inefficient vehicles in the short-term to see that there might be a time when consumers would demand smaller, more fuel efficient vehicles.

Indeed, internal corporate leadership appears to have been a major factor explaining the relative success among the major national automotive manufacturers. The personal commitment of Toyota's President during the early 1990s clearly set Toyota's course as did Bill Ford's interest in environmentalism and fuel efficiency, seemingly at odds with the company culture at times. In China's BYD Auto, the founder and CEO Wang Chuan-Fu capitalized on the company's expertise in batteries to fulfill a vision of selling an environmentally sustainable car.

In all three countries, policy for government investments in the R&D and also demonstration of advanced vehicle technologies was initially poorly coordinated with policy for the early deployment of these technologies. Japan and the United States reactively established policies to support the early deployment of HEVs once they were introduced to the market. From that point, Japan implemented much more effective policies to support commercialization than did the United States.

In the United States, US firms routinely cited lack of consumer demand as the main reason for not investing in more fuel efficient technologies, and indeed, consumer demand would have been stronger if policies like fuels taxes had existed to support the purchase of more fuel efficient cars. Hybrid car consumers are clearly responsive to increased gas prices and other fiscal incentives, including sales tax reductions or exemptions and feebate schemes, and they also appear to buy hybrids out of concern for the environment or energy security. Higher fuel prices in Japan associated with high fuel taxes were correlated with strong consumer interest in HEVs from the moment of their introduction. The Japanese government also displayed flexibility and adaptive policymaking, correcting its purchase incentive system quickly once hybrids were available to greater spur the early deployment of HEVs.

The Chinese government appears to have studied the US and Japanese cases carefully. While it was perhaps unduly influenced by the technological choices in the United States in terms of its RD&D policy, it supported HEVs all along. Similar to the situation in the United States, the Chinese government was reluctant to increase fuel prices for many years, but is now displaying a modest willingness to let them rise. The Chinese government has also been more aggressive than the US government at implementing fiscal policies akin to the Japanese ones that support the purchase of highly fuel efficient vehicles.

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

4 FURTHER READING

Gallagher, K.S. 2006 *China Shifts Gears: Automakers, Oil, Pollution, and Development,* The MIT Press: Cambridge, MA.

Ozaki, Ritsuko and Katerina Sevastyanova 2011, “Going Hybrid: An Analysis of Consumer Preference Motivations,” *Energy Policy*, 38:5, pp. 2217-27.

Pohl, H. and M. Yarime 2012 “Integrating innovation system and management concepts: The development of electric and hybrid electric vehicles in Japan,” Technological Forecasting and Social Change, 79:8, pp. 1431-46.

5 REFERENCES

Åhman, Max 2006, “Government policy and the development of electric vehicles in Japan”, Energy Policy, Vol. 34, No. 4, March 2006: 433-443.

Åhman, Max 2009, Personal Communication.

Bradsher, Keith 2009, “China Vies to Be World’s Leader in Electric Cars” The New York Times, 1 April 2009.

Demirdoven, Nurettin, and John Deutch 2004, “Hybrid Cars Now, Fuel Cells Cars Later,” Science, Vol. 305, 13 August: 974-976.

Gallagher, Kelly Sims 2006, “Limits to Leapfrogging in Energy Technologies: Evidence from the Chinese Automobile Industry,” Energy Policy, Vol. 34, No. 4, pp. 383-394.

Gallagher, Kelly Sims 2006a, “Roundtable on Barriers and Incentives for Hybrid Vehicles in China: A Roundtable Report,” based on roundtable held in Beijing 19 May 2006, Belfer Center: Cambridge, MA.

Gallagher, Kelly Sims and Laura Diaz Anadon 2009, “DOE Budget Authority for Energy Research, Development, and Demonstration Database,” Energy Technology Innovation Policy, John F. Kennedy School of Government, Harvard University, June 2, available at energytechnologypolicy.org.

Gallagher Kelly Sims and Erich Muehlegger 2011, “Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology,” Journal of Environmental Economics and Management 61:1, pp. 1-15.

Geroski, P.A. 2000, “Models of Technology Diffusion,” Research Policy 29: 603-625.

GTZ 2012, "International Fuel Prices" 7th Edition, GTZ.

Gunther, Marc 2009, “Warren Buffet Takes Charge, CNNMoney.com, April 13.

Ito, Shinsuke 2006, Personal Communication, Automotive Division, Ministry of Economy, Trade, and Industry, Japanese Government.

Jaffe, A., Newell, R. and R. Stavins 1999, “The Induced Innovation Hypothesis and Energy-Saving Technological Change,” Quarterly Journal of Economics, 117: 941-975.

Kahn, Matthew E 2007, “Do Greens Drive Hummers or Hybrids? Environmental Ideology as a Determinant of Consumer Choice,” Journal of Environmental Economics and Management, 54:2, pp. 129-145.

Kurtenbach, Elaine 2009, “China Automakers Focus on Hybrid and Electric Vehicles,” USA Today, 20 April 2009.

Maynard, Michelle 2004, The End of Detroit: How the Big Three Lost Their Grip on the American Car Market, Broadway Business pp 284-290.

Ming, Pingwen, Lun, Jingguang, and Lynn Mytelka 2008, "Hydrogen and Fuel-Cell Activities in China," in Making Choices About Hydrogen, Mytelka, Lynn and Grant Boyle (eds), United Nations University Press: Tokyo, New York, Paris.

NRC 2002, "Effectiveness and Impact of Corporate Average Fuel Economy Standards," National Research Council Committee on the Effectiveness and Impact of Corporate Average Fuel Economy Standards, Transportation Research Board: Washington, DC.

Rogers, E. M. (2003). Diffusion of Innovations. New York, Free Press

Shantou EV Project Director Wen Zong Kong, Personal Communication 2001, "Interview with Deputy Director and Senior Engineer, Vice Director, and General Manager of Shantou EV Project," Shantou, Guandong, September 6-7.

Sperling, Dan 2001, "Public-Private Technology R&D Partnerships: Lessons from US Partnership for a New Generation of Vehicles," Transport Policy, Vol. 8: 247-256.

Turrentine, T. and K. Kurani 2007, "Car Buyers and Fuel Economy," Energy Policy, 35, 1213-1223.

Yarime, Masaru, Shiroyama, Hideaki, and Kuroki, Yusuke 2008, "The Strategies of the Japanese Auto Industry in Developing Hybrid and Fuel-Cell Vehicles," in Mytelka, Lynn and Grant Boyle (eds), Making Choices About Hydrogen, United Nations University Press: Tokyo, New York, Paris: 187-212.

6 ACKNOWLEDGEMENTS

I gratefully acknowledge the comments and suggestions of Charlie Wilson and Arnulf Grubler, as well as the other lead authors of Chapter 24 on innovation systems in the Global Energy Assessment.

If referencing this chapter, please cite:
Gallagher, K.S. (2012). Hybrid Cars: Development & Deployment in Japan, the US, and China. Historical Case Studies of Energy Technology Innovation in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.