Half Way Home in Electric Vehicles: A Strategic Reassessment

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ABSTRACT *The time originally allotted in 1990 by the California legislature for the introduction of commercializable zero-emissions vehicles is about half gone. Using frameworks developed to help analyze product substitution dynamics in emerging industries, this paper discusses the economic and market dynamics of ongoing attempts to commercialize electric vehicles, as they compete against internal combustion engine automobiles. Relative value/price, switching costs, and buyer propensity to substitute are emphasized. An assessment of forces is made and recommendations for the strategic direction of individual firms and the industry at large are offered.*

Keywords: electric vehicles, emerging industries, relative value/price, technological substitution, signalling.

Introduction

In 1990 the California legislature stipulated that all automobile manufacturers selling significant numbers of vehicles in the state must make 2% of expected total sales completely non-polluting by 1998. In late 1995, political resolve softened and the deadline for compliance was moved to the year 2003, though the new target became 10%. Thus, at the time of writing, the amount of time given for compliance is about half gone, assuming that political resolve remains essentially intact.

In light of these strategic horizons, the present is a good time to reassess the electric vehicle (EV) movement in the US. Though there are parallel, interrelated and very important movements elsewhere—especially in Europe and Japan—the automobile market/industry in the US continues to be the largest in the world and maintains a leading role in political and technological developments. California constitutes 15% of the US automobile market. The purpose of this paper is to help evaluate, in one specific and systematic way, the developing commercializability of EVs, as circumscribed by California legislation. The perspective chosen is the likelihood of product substitution in emerging industries (as distinct from the concept of technological substitution), as developed in the Strategic Management literature.[1]

Characteristics of Emerging Industries and Strategic Implications

Before too quickly embarking on an analysis of EVs, it is first wise to consider whether the EV-technology paradigm constitutes the basis of an emerging industry. The characteristics of an emerging industry are not exactly the same as the characteristics of a

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rejuvenated mature industry and strategic implications can differ.[2] In particular, it is important to identify the 'boundaries' of an industry under consideration because assumption about industry boundaries map patterns that define industry rivalry, entry and exit barriers, functional and technological substitutes, and upstream and downstream relationships.

First, the literature asserts that emerging industries are typically (though not always) characterized by technological uncertainty. There is often relatively unfettered competition for the best overall product technology configuration.[3] As of the mid-1990s, automobile developers were still uncertain as to the best overall configuration of a zero-emissions vehicle, but some patterns were fairly plain. Most experts have agreed that the most feasible way to comply with the zero-emissions stipulation was to commercialize all-electric vehicles (which excludes all internal combustion technologies as well as hybrid vehicles—those powered by combinations of combustion and electric technologies). The configuration that seemed destined to be most aggressively commercialized in the near term (aimed at full legislative compliance, not market success or technological superiority) was a vehicle powered by storage batteries, requiring periodic recharging, just like camcorders, cellular phones, and the like. A very significant event was General Motors' (GM) introduction of the EV-1, marketed since the fall of 1996 through Saturn dealerships in California and Arizona.[5] The EV-1 is an extremely advanced design, but, ironically, is powered by an array of lead-acid storage batteries, the dominant design in stored automotive electric power. Because of its inherent electrochemical limitations, lead-acid technology is best viewed as a tactical choice. Lead-acid was the technology which, as of the mid-1990s, was probably the least risky candidate for achieving minimal compliance by 1998 or 2003.

There has also been an enormous, global and sustained effort made towards developing other promising battery technologies, such as nickel-cadmium, sodium-sulfur, and lithium-based variants.[6] Thousands of articles focusing on electric vehicle power sources have appeared in a wide variety of media channels and academic circles, and have presented an interesting public debate about which EV propulsion technologies are best, worst, and why. This debate is too complex and multidimensional for a fair assessment here, would be largely repetitive, and would be very rapidly dated considering the breakneck pace of developments. Also, and of much greater interest to some observers, it is known that in races for technological ascendancy, the 'best' technologies do not always 'win' in the marketplace.[7] One interesting reason seems to be that biased information campaigns precede or coincide with new product announcements, and can be quite effective.[8] A recent study investigated this possibility in the emergence of EV propulsion technologies and found evidence that data made available to the public, including academic researchers, may contain many important biases. The biases are almost impossible to assess because of the highly proprietary nature of the technologies, as well as the intentions and ploys of strategic managers. Thus, this article will not contribute to the debate on present and next-generation technical specifics, performance improvement patterns, cost/price obstacles, and so forth. Each battery technology has its own advantages and disadvantages, of course, but what seems fairly certain is that lead-acid technology will not maintain its lead for very long. Commercialization of batteries which deliver better EV range than lead-acid technology (about 100 miles in optimal conditions) will be essential if EVs are to ever capture more than a few small niche markets.[9]

While the California mandate has essentially forced the lion's share of EV R&D into the development of storage batteries, it is not yet certain that they represent the best long-term technological trajectory. Such inventions as zinc-air batteries (which are

essentially primary batteries because they cannot be recharged but can be refueled via the replacement of zinc cassettes) present an interesting alternative.[10] That is, such devices would require 'filling station' infrastructures, but would not be capable of home recharging. The subtle differences between primary and storage battery technologies, in the EV scenario, imply very different consumer patterns and socioeconomic impacts.

Fuel cells are also viable candidates for EV propulsion, though not in the very near term because their non-polluting status is arguable, because they are difficult to develop in small enough sizes, and because of other serious cost and production problems.[11] Ongoing efforts have been impressive, but not to the extent of radically altering most near-term strategies aimed at legislative compliance. Fuel cells and batteries operate very similarly in terms of their underlying scientific principles, in that they are all electrochemical devices. However, the basic consumer pattern that would be required by fuel cell EVs is more like that which would be required by primary batteries (and, for that matter, like that for ordinary internal combustion engine vehicles). That is, most kinds of fuel cells consume a hydrogen based fuel, and hence would require an infrastructure of filling stations to be commercially successful on any appreciable scale.

Flywheels also seem destined for incorporation into EVs as either primary or complementary power sources.[12] Flywheels, sometimes called mechanical batteries, are based on a principal entirely different from that of batteries and fuel cells. Flywheels deliver electricity through the conversion of stored kinetic energy, not stored electrochemical potential. Like storage batteries, they are rechargeable. Their energy storage potentials clearly outmatch electrochemistry, but manufacturability and cost problems make them seem infeasible for the short term (although advances in flywheels have also been rapid).

The point is that, by the mid-1990s, because of the head start and large number of firms pursuing storage battery innovations (compared with the number of firms developing primary batteries, fuel cells and flywheels), it seemed very feasible that the California mandate was forcing a path-dependency in storage battery powered EVs.[13] Common precedents in the histories of many technologies suggest that firms which were developing competencies and competitive advantages based on storage batteries would be unlikely to trigger voluntarily a subsequent change to anything else.[14] Thus, the possible global impact of Californian legislation should not be underestimated. The remainder of this article focuses on the prospects of EVs powered by storage batteries, but this focus should not be confused with a position of advocacy or opposition.

Another theoretical and empirically supported characteristic of emerging industries is strategic uncertainty.[15] Typically, early there is no 'right' or proven strategy, no clear basis for successful competition, no eminent and inevitable leader, and no rules of the game. This characteristic cannot be overemphasized, particularly the associated point that even in industries that are characterized by radical technological change, company/firm strategy is not the same thing as technology strategy. Firm strategy is a much more comprehensive concept. Concentrating on any single dimension of strategy severely risks suboptimization of overall firm interests and thus courts disaster.

For example, it is treacherous to assume that EV technologies can be pushed so forcefully that their technological parameters and specifications will automatically define market segments; that the EV industry value-added chain should (or even could) resemble the oligopolistic and hierarchical automotive establishment; that, even though the main bottlenecks are in product technologies, ultimate profitability will not be based on another competence, such as distribution and service; or that individualistic, classic entrepreneurship will be more successful and socioeconomically beneficial than collaboration, consortia and the planned sharing of economic rents. Patterns experienced during

the emergence of other industries might not apply to EVs, and conventional wisdom does not yet exist in terms of comprehensive and coherent strategic choices.

To illustrate, some events indicate that though EV technologies are emerging, the industry itself is converging. Very big firms with very deep pockets have been investing very significant sums of money in different arenas of the overall scenario, in apparent attempts to diversify their larger corporate interests and gain first-mover advantages. Examples include: a collaboration between Volkswagen and the Swiss marketing/merchandising company Swatch;[16] the subsidization of 3M by the US Advanced Battery Consortium (funded mostly by the US government and the Big Three US vehicle manufacturers) to develop thin-film electrolyte technology in lithium batteries;[17] significant strides made by the German electronics giant Asea Brown Boveri towards the development of sodium-sulfur battery technology for Ford;[18] the effort made by Fuji towards the introduction of fuel cells;[19] the establishment of Asian manufacturing and distribution rights of US Electricar's technologies by Japanese heavy industry giant Itochu;[20] and, of course, the mammoth investments being made by all the global automobile manufacturers, not just the US Big Three.[21]

Thus, it is very possible that the development of the EV industry, if it does develop, will be a unique phenomenon, the synthesis of an eclectic combination of both proven and advancing competencies of many types.[22] In contrast, the common prediction that the EV industry is poised to repeat the experience of the personal computer (PC) industry may, in retrospect, seem naive and, if so, perhaps for one underlying reason. Electric Vehicles will embody many new technologies, but, unlike PCs, EVs are clearly not new products. They do not deliver much new functionality in newly created markets. EVs might best be understood as substitute products For the most part, they deliver functionality already being delivered by existing products in developed niches.

Substitution Dynamics

An industry can be defined as a set of products that are close substitutes for each other in the marketplace, technological characteristics notwithstanding.[23] Substitute products (or radically new rival products) do not create new industries as much as they invade/restructure existing industries. From the retrofitting of internal combustion engine autos with electric powertrains to totally new, ground-up designs, most EVs exhibit impressive advances in technology, not only in powertrain devices, but also in specialty materials, aerodynamics, tires, systems integration, production, and more.[24] But from the consumer's point of view, most of the functions performed by EVs are not new. Other than appeasing a few psychological needs, such as environmental consciousness, there is little functionality that EVs deliver which internal combustion models do not. And in some important, tangible dimensions of vehicle performance, most EVs are not clearly superior, if they are superior at all. Therefore, it is appropriate to evaluate the EV movement in terms of the dynamics of product substitution. Theoretically, the determinants of the likelihood of substitution are relative value/price, switching costs, and the buyer's propensity to substitute.[25] Each will be discussed in turn.

Relative value/price is a straightforward concept, but its dynamics can be quite complex. Value/price, especially in such durable products as automobiles, refers to the value that a product is expected to return to the consumer, compared with the price of the product, where all monetary flows reflect changes in comparable products over a relevant timeframe, as well as the effect of discounts, rebates, free ancillary products and services, and so forth. Relative value/price, then, is the value/price of a substitute compared with the value/price of the good facing substitution. Improvements in relative

value/price derive from a perceived lowering of total costs to the buyer and/or improvements in valued dimensions of performance. Since consumer perception is the key, market signalling enters as a crucial dynamic in product substitution.

In free enterprise economies, price is known to be a powerful signal. In a world of perfect information (where all relevant decision-making information is available and information search is costless), prices should accurately reflect value. But the world is not characterized by perfect information—economic rationality is bounded,[26] information search is not free, and in plain terms, there is often an anxiety that a new product, especially one based on a new technology, might not be worth the price. So the acquisition of relevant information is pursued prior to purchase, and the results of information searches affect perceptions.

Consequently, the likelihood that value will be perceived is greater under some conditions than others. For example, it is enhanced when the improvements a product makes in overall consumer costs are immediate, rather than when they develop slowly over time.[27] Also, the perception of value is enhanced when a substitute's economic advantages are direct and focused on perceptibly valuable product functions. Here the near-term EV signals are still not good. Sticker prices of EVs are, and are expected to continue to be, much higher than the sticker prices of gasoline vehicles. Moreover, predictions of lifetime ownership costs vary wildly and suspiciously because of the many uncertainties involved, the different variables and conditions considered, and the confusion caused by mixing levels of analysis.[28]

Perception of value is also enhanced when performance improvements are immediate, rather than accrued over time.[29] The most acutely inferior dimension of EV performance, at least for the foreseeable future, will continue to be that they do not travel nearly as far on one electrical charge as internal combustion models travel on a tank of gas.[30] Therefore, the perceived value of total EV technical performance is not likely to be strong soon. Also, recall that the real issue is signalling. The signals being sent that EVs will underperform in the short run are being coupled with signals that the performance of foreseeable product upgrades will be significantly better.[31] The message being received by many consumers seems to be to wait.

Perception of value is also enhanced when the substitute does not force unwanted changes in consumer behavior.[31] A change in automobile consumption that relieves owners from ever having to visit filling stations is likely to be welcomed, but might be overwhelmed by the lifestyle constraints imposed by daily ranges of 100 miles or less. However, it must be admitted that technological performance is not always of paramount importance. Image is important to many people, and the automobile is part of the image. In some niches in which individuals value an image of social progressiveness, EVs no doubt have an appeal.[33] The ultimate issue, however, is whether EVs will sell in numbers that justify the risks being taken by investment communities, and in numbers that will have a cost effective impact on the natural environment and the depletion of energy resources.[34] Lingering uncertainties here injure the case for EVs.

Focusing on the cost issue, there is certainly more to EV ownership than sticker price. The following discussion is illustrative. Readers will note that some categories do not apply to the average automobile purchaser as much as they apply to managers of industrial fleets,[35] who often perform much more thorough and systematic cost analyses than individual consumers.

Delivered and Installed Cost

Any individual wishing to purchase a rechargeable EV will be made acutely aware of the

several thousand dollars also needed to modify household electrical systems, if advanced levels of performance are to be reached (in features such as recharging time).[36] Fleet managers will not overlook the expenses required to amend motor pool facilities.

Financing Cost

Because of the limited life and costliness of most kinds of rechargeable batteries, half the original price of many EVs must be re-incurred every two or three years through battery replacement alone.[37] This is such a significant problem that schemes such as 'buy the car, lease the battery pack' have already started to appear.

Availability of the Product and Variability in Price

Rapidly changing prices—ironically, even falling prices—suggest economic risk. Also, the long-term availability of a product is inversely related to the perception of the likelihood of consumer abandonment.[38] Producers of EVs should anticipate mass market reluctance until reasonably stable price plateaux and sales volumes are reached. Producers of EVs need to signal stable, even excess, capacity for the long-term. It is not yet certain that EV production, industry-wide, is anything more than a reluctant reaction to the California mandate. What is certain is that vehicle manufacturers have signalled extreme ambivalence about the EV movement, and have worked to change or eliminate the mandate.[39] Specific intentions of crafty mangers are difficult to deduce, and the intentions of managers can vary widely within any specific firm, but consider at face value the potential damage of signals embedded in statements such as the following:

> In a stark departure from the purple praise that usually accompanies the announcement of' a new product, the Chrysler Corporation said today that it would build a mini-van that customers would surely spurn ... While Chrysler executives called their mini-van 'state of the art' for electric vehicles, they declared that the art was miserable.[40]

> Even as Ford Motor Co. was delivering a fleet of polished new electric cars to utilities around the nation last week, the auto maker got in a dig about their cost ... To utility executives' considerable irritation, Ford officials told everyone within earshot that their Ecostars [were] being leased for $100 000 a crack. And even that, said the Ford people, didn't come close to the expense of making them.[41]

> General Motors is preparing to put its electric vehicle act on the road, and planning for a flop. With pride and pessimism, the company, furthest along of the Big Three in designing a mass-market electric car, says that ... it has done its best but that the vehicle comes up short. It will cost too much and will not go very far between lengthy visits to charging stations.[42]

Present Value of Indirect Costs of Use

When estimating value/price, non-obvious elements of cost need to be considered. Such categories of cost include: maintenance labor and ancillary equipment, consumables and spare parts, insurance, and salvage value or replacement, as well as the opportunity cost of performance limitations and breakdowns, and the opportunity cost of the alternative use of facility space and efforts to make quality improvements. In some of these

categories, EVs will almost certainly outperform gasoline vehicles. The inherent reliability of electronic and electrical equipment and the inherent maintainability of EVs are so superior to those of mechanical devices and gasoline vehicles that even rough calculations of total life cycle costs sometimes suggest their overall cost effectiveness.[43] However, the issue at hand is signalling, and the more radical the technological configuration of any EV configuration, the more likely a period of infant mortality and de-bugging will be experienced, and widely popularized by the movement's antagonists. In sum, relative value/price is not a simple calculation and comparison of ratios. Also, it is not entirely distinct from the second main dimension of the dynamics of substitution, switching costs. Switching costs are the one-time costs to a buyer of purchasing a substitute rather than maintaining or replacing an original product. They do not represent the price differential. The following discussion suggests that in the EV scenario, switching costs are likely to be most acutely relevant to fleet managers, though in some cases they will be significant to an individual EV purchaser as well.

Identifying and Qualifying Sources

Again, information search is not costless. The time, effort and tangible expenses that purchasers of EVs will incur just to make prudent purchasing decisions will not be zero.

Changing Role of the User

Overall trends in environmental consciousness probably favor a transition to EVs, though the debate about their overall environmental impact is still not settled.[44] It is quite possible that the average citizen is very aware of the direct impact that the internal combustion engine has had on the overall quality of life, and is less aware that a fully systematic analysis of EVs reveals serious problems, such as increased burdens on fossil-fueled electric utility infrastructures and the effects of disposing toxic battery materials. Fleet managers might gain from a switch to EVs in terms of overall public relations, but the precise economic value of goodwill is difficult to calculate, and some technology choices could still badly backfire, especially if the whole movement fails.

Risk of Failure and Switching Back Costs

Risk has an immediate economic impact, regardless of whether the feared phenomenon ever actually happens. The very risk that pessimists might be right, that political resolve might collapse, and/or that technologies might not evolve and synergize in expected ways, injects a real economic impact on the costs of switching. As any transition back to gasoline vehicles will in few cases be costless, one would surmise that many of the more prudent and patient potential EV purchasers will not rush towards an electric automotive paradigm. Buyers' technological orientations are also important to consider. Some types of buyers simply enjoy being technologically adventurous and are both capable and willing to perform, or at least participate in, new product introduction and de-bugging. Others simply are not.[45] To potential buyers who have an optimistic sense of technological evolution, past attempts to commercialize EVs might seem like a string of necessary experiments. Success might seem not only inevitable, but imminent. To more skeptical purchasers, even a dim acquaintance with society's century-long experience with underperforming EVs might be an impediment to substitution.[46] Premature commercialization of any new technology always incurs a significant risk of alienating those buyers who do

not view themselves as willing participants in someone else's costly and sometimes opportunistic experiment. Finally, and returning to a focus on industrial fleets, substitution will be partly a function of the nature of competition in the purchasers' industries. In industries where rivalry is intense, EVs might bear serious consideration in terms of how they might affect the overall value/price of the products/services firms themselves deliver. Where life cycle cost advantages are real, EVs will be attractive to managers in firms where cost-consciousness is important to long-term firm survival. Where social propriety is a basis for competition, EVs might help deliver an air of service differentiation. The nature of competition in each industry, as well as the strategic position and intent of each firm, bears examination.

Strategies for Substitution

From the above discussion, it would seem that improvements need to be made in each of the three main dimensions of substitution. Probably most important is the need to change the perceived and actual relative value/price of EVs. This should be done carefully, identifying and attacking the most important market niches first and in ways that lend themselves to the development of the next most important and/or likely niches.[47] At present, likely (though broadly defined) niches seem to be environmentally conscious, trendy, and wealthy individual consumers, owners of industrial, government, and quasi-government fleets, and the entrepreneurs and policy makers nurturing the development of emerging national infrastructures. It is likely that only a few precisely-defined niches can be successfully attacked at one time by any one firm, and development of any particular niche might take years. Therefore, it is essential that markets be carefully researched according to patterns of price elasticity and user functionality, and not simplistically defined by differences in technologies.

On the value side of the value/price equation, the most serious limitation is, and will continue to be, vehicle range. Most experts agree that nothing will help the EV movement more than relentless and consistent improvements in all technologies that affect range. However, concentration on one specific technological bottleneck runs the risk of losing sight of the ultimate socioeconomic objective. It is hoped that EVs will materially affect the quality of the natural environment and reduce dependence on imported oil. Consequently, it seems imperative that EV technologies evolve not only rapidly, but that they evolve faster than alternative technologies which deliver the same basic environmental and macroeconomic benefits.

On the price side of the equation, there are severe dilemmas. Opportunities for scale, learning and experience effects no doubt exist, but costs are likely to be so severe in the short term that industry profitability will be negative for a long time. This will impose severe strains on investment communities, so only patient capital should be pursued. Here, even US firms should consider non-US investors. This kind of financial strategy might not directly help restore the US automobile industry to global dominance, but prudent business people should not be expected to be agents of economic nationalism, especially when firm-specific outcomes suggest otherwise.

When, and if, industry profitability does develop, new entrants with second-mover advantages will likely appear, so the most successful early players might be those which have achieved unmatchable scale economies and uncatchable learning effects, have established proprietary positions in not only technologies but in any crucial value-adding competence, have assured low cost supplies of crucial resources (including the human kind), have clearly differentiated their products, and/or have secured favorable distribution channels (captured early, before their full economic values become appreciated).

Price and cost should not be tightly coupled. Survival, not profit, should be the immediate grand strategy.

Switching costs need to be lowered. Proactive signalling (through the active dissemination of information on technological advances, plant openings and expanded production capacities, corporate and investment community allocations of resources, cooperative interfirm developmental projects, etc.) will help improve perceptions of risk. More obviously, and despite their political ugliness, subsidies will be necessary to lower switching costs. Core groups, such as industrial, quasi-public and governmental fleets, are natural showcases and proving grounds for electric vehicles and their infrastructures, but many purchasers will need more powerful financial incentives than unproven life cycle cost estimates. Ancillary equipment can be supplied, support skill training can be freely given, and sophisticated business planning assistance can be offered aimed at bringing overall firm-level economic value out of EV ownership. Guarantees, warranties, and confidence in trade-in (or, hopefully, trade-up) values can be contractually established.

Product feature standardization sends strong signals that ameliorate perceived consumer risk, but efforts to do so will continue to create intense intrigue and in-fighting. That is, it is common for newly developing markets to experience periods of rapid growth once technological uncertainties become settled, when common interfaces and/or dominant designs have been established.[48] But though the establishment of any particular technological standard will be to the benefit of manufacturers prepared to deliver that standard, it will be equally to the detriment of proprietors of non-complementary technologies. Conflicts of interest will continue to make it difficult for all players to maintain one voice on all issues.

This point is vital because it would not be part of a wise long-term strategy to expect society to make more than one significant technological transition. It would be unwise for society to invest massive amounts of funds in what, in retrospect, might seem shortsighted and suboptimal. Thus, the optimal technological trajectory should be carefully identified as soon as possible, and developed in a coordinated but legal way. Perhaps it is naive to expect practicing managers to formulate strategy collectively and so far in advance, or to suggest that even the experts can identify the optimal trajectory in so complex a scenario. However, they must all realize that standardization signals are some of the most powerful they will ever send.

Other advisable efforts include total industry advertising. Without being too specific and especially without making unsupportable promises, the overall awareness of milestone accomplishments, as well as general progress, should be continuously elevated in target segments and across society as a whole, crafted to describe how EVs enhance overall lifestyles or improve overall business positions. Members of the new industry will need to police their population for those who are fraudulent or unduly opportunistic (as opposed to waiting for free market and social dynamics to cull them out), because the overall reputation of the movement is fragile and politically dependent. In sum, EV developers need to work continuously to elevate the image of quality in the entire industry, and must not compete too hard too soon.

In a similar vein, some collaborative research and product development will probably be essential for some time to come. It is clear that EVs require truly synergistic combinations of advanced technologies, so inter-industry spillovers will continue to be of great value. If the 'new' EV industry succeeds, it may not be dominated by firms which are at present small and entrepreneurial. The California mandate served fair and equal warning to all stakeholders, and it is not clear that nimble and innovative entrepreneurs will outwit or outmanage possessors of enormous technological, economic, marketing and political influence. Despite the current business climate, which encourages the small

entrepreneur, it must still be admitted that small and young firms fail at a faster pace than large and established firms.[49] Thus, the survival of the EV collective will be just as important as the survival of any individual firm. Strategies which favor the interests of specific players to the detriment of many others will be precarious. It may actually be wise to encourage entry by potential future competitors, if this means establishing consumer confidence that capacity is being established for the long term and that choices will be available.

EV developers must continue to invest in the political stability of institutional factors. California legislators have already blinked once, sending a severe chill throughout the EV world.[50] This tenuous condition must be guarded, nurtured and reinforced. Political collapse prior to the establishment of a relative value/price beachhead in at least one critical market niche will ruin large scale and long-term opportunities. Failure in California would have a dramatic effect on the overall global movement. In terms of improving buyers' propensity to switch, successes in early segments will encourage experimentation in subsequent segments where relative value/price calculations are not yet promising. In an important way, problems successfully solved by early segments will subsidize the experiences of subsequent segments. This pattern has been repeated in many industries and product life cycles, and is a fairly dependable dynamic.[51] The salient point that bears repeating is that mass market acceptance of EVs is unlikely until there have been years of success in small but key segments.

Producers of EVs should not expect their actions to go unnoticed and uncountered. They must realize that the fox is guarding the henhouse in the sense that the major vehicle manufacturers are already wielding their power in industry-shaping ways.[52] They may not have much to gain through a direct assault on the California legislature, for example, but do have much to gain through making rapid improvements in alternative automobile technologies that are environmentally benign for the most part.[53] Also, political camps in the EV scenario are not all dichotomously and diametrically positioned, and feasible compromises among odd coalitions of otherwise natural antagonists will be sure to transfer advances made in EV programs throughout entire automotive product lines, which will reduce some EV-specific appeal. In addition, while giant companies are not known for being particularly adventurous technologically,[54] their advertising and distribution advantages are certain. Existing automobile sales channels will be blocked to newcomers, unless they either strike alliances or open innovative channels of automobile distribution (such as selling EVs through joint ventures with distributors of other kinds of electric/electronic durables).[55]

Finally, it is no longer inappropriate for even small firms to think globally. Markets for EVs seem to be developing in parts of the world where users are not particularly concerned with vehicle range, and where fossil fuel prices are much higher than in the US.[56] In Europe, for example, prices of internal combustion engine fuels are typically twice those in the US, which is able to supply about half its own demand. The average trip driven in Europe is also much shorter, ameliorating the range problem; and mass transit is much more popular, relieving the need for countless long commutes by cars. Despite the fact that no Europe-based vehicle manufacturer sells enough cars in California to be held accountable to its mandate, BMW, Citroen, Mercedes, Peugeot, Volkswagen, and Volvo are developing EVs for the European market. The interesting question, and one that has been hinted at in this paper, is whether US politics has enough impact on the global scene to shape the EV technology paradigm towards a path-dependency in storage batteries, rather than allowing a fuller and more patient consideration of combinations of very promising and equally ingenious technologies.

Some of the basic conditions in Japan are similar to those in Europe. Gasoline prices

are typically at least three times those in the US, cities are extremely congested, and air pollution is a serious hazard. Traffic snarls are huge and long, ambivalently highlighting two specific EV features—they consume energy only when moving, but stop-and-go usage reduces range tremendously. At any rate, the Ministry of International Trade and Industry (MITI) has established a goal of fielding 200 000 EVs by the turn of the century. It would be unwise to dismiss this resolve as toothless or merely symbolic.

Finally, considering the continuing industrialization of other parts of the world, it seems certain that electrification will continue, and that a great portion of new power grid infrastructures will be built around relatively clean technologies, such as hydroelectric. Arguably, it might be wiser to plan emerging automotive infrastructures to be complements to emerging power grid infrastructures. Indeed, a main argument for EVs is that, since most recharging will be done at night, when electric generation facilities are greatly underutilized, an EV-based automotive paradigm would have a tremendous load-levelling effect on overall energy consumption. So the grand irony is that though the California mandate was devised to be a catalyst for improving local conditions, much of its effect could be felt in other corners of the world for decades to come.

Conclusions

The electric vehicle industry can be thought of as the politically driven and paradigmatically different development of a substitute for internal combustion engine automobiles. EVs represent new technologies, but in a full strategic sense are substitute products. They deliver few new functionalities to few unexploited market niches. Performance and price typically constitute an inferior combination relative to the products they are planned to replace. There are significant tangible and intangible costs to switching, and only small numbers of buyers have a high propensity to switch. But these are the conditions that the innovators of many substitute products have overcome. It has not been the purpose of this paper to denigrate the EV movement. The purpose has been to attempt a fair assessment from a specific strategic perspective of the challenges still faced, and to propose strategic choices which may help overcome them. Informed stakeholders in the EV movement will appreciate that most of the problems discussed here have already been widely recognized and are being aggressively addressed. Indeed, the movement is evolving so fast that great care has had to be taken in the construction of this article not to present biased data that would be dated by the time of publication. Considering the enormity of the undertaking, the EV movement has already achieved astonishing success, and its energy is not nearly spent.

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