
Making an Impact at General Motors

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INTRODUCTION

On January 23, 1995, an article in *Business Week* [1] read:

The Impact, General Motors Corp's on-again, off-again electric car, seems to be on again... Until now, auto manufacturers have vigorously fought tough new environmental laws, such as California's standards for pollution-free cars. Their gripe: consumers won't pay the extra cost the technology will require.

These new developments could undermine Detroit's claims that it can't meet California's tough emissions standards ... Carmakers may have to start selling [ultra-low emissions vehicles] in California as early as 1997, while Zero Emission vehicles, which currently means electrics, will be required starting in 1998...

The Impact's price tag will be ... as much as \$40,000 for early versions. But GM decided to go ahead with the car, sources say, because consumers in three cities who test-drove Impact prototypes were entranced with it... "The biggest problem we've had is getting people to give back the car," says Kenneth R. Baker, [recently-promoted] vice-president of GM's Research and Development Center. GM officials are cagey about their plans for producing the Impact. "We have not made a final decision on production", says Robert Purcell, the car's program manager [and successor to Baker]. But, he adds, "We are very serious about making a business out of this technology..."

Still, even if the automaker sells thousands of Impacts at premium prices, the company probably won't make any money. GM spent in excess of \$250 million developing the vehicle. "I'll be in my grave before they recover all those costs," says one former GM executive.

WHAT 'GOES ROUND COMES ROUND'

The quality of breathable air became a major social issue in the United States in the 1960s [2-4]. Automobile emissions, in particular, had been causing an unacceptable increase in the risk of cer-

tain kinds of cancer, respiratory ailments, and birth defects. While the problem had become acute in many areas around the world, conditions in California were particularly noxious — or at least, particularly unacceptable to its citizenry. As a result, that state's legislature mandated the development of emissions control technologies for automobiles, laws that were vociferously resisted by the automobile manufacturers. Nevertheless, and despite protestations that automobile technologies could not be advanced far and/or economically enough to meet California's requirements, the automakers complied.

By the 1990s, harmful automobile emissions (per auto per mile driven) in California had dropped to a small fraction of what they had been several decades earlier. Unfortunately, the total number of miles driven in the state had grown at such a rate that the total pollution situation had not changed nearly as much as was originally hoped. Also, trends indicated that the overall volume of pollutants would grow another 40% by the year 2010. Such predictions, coupled with the unproven but dire possibility of global warming, compelled the California state legislature to act again. In 1990, it enacted a body of air quality laws that mandated, in part, that starting in 1998, all automakers that sold significant volumes of automobiles in the state must make available for sale completely non-polluting automobiles in numbers that accounted for 2% of likely auto sales. In effect, this meant that General Motors, Ford, Chrysler, Toyota, Honda, Nissan, and Mazda would have to offer electric vehicles (EVs) for sale in California, or suffer a \$5,000 fine for every gasoline vehicle sold in California, or exit the California market entirely — 15% of the U.S. market. Accomplishing this goal would have an arguable effect on the state's short-term pollution profile, but the grander idea was to begin a permanent transition to a non-polluting automotive paradigm. Again the automakers howled at the impossibility of developing roadworthy, commercially feasible zero-

emissions vehicles on such short notice, but inspired by their previous successes at "mandating" technological innovation, legislators remained steadfast.

While the political movement in California was the most focused and advanced (Exhibit 3 provides an example of state-supported incentive programs [5]), conditions elsewhere might have been more naturally inviting of an electric vehicle paradigm. For example, in Europe the price of gasoline was usually about twice the price in the United States because of Europe's much higher dependence on imported oil. Since early calculations of EV ownership indicated that their total costs were favorable only in an environment where gasoline cost at least \$3.52 per gallon, Europeans seemed more likely to accept a transition. Attitudes in Europe were also more amenable to highly subsidized transportation infrastructures, and Europeans had a more utilitarian relationship with the automobile than Americans. Average vehicle trips were also shorter than those in the United States, which made modest EV range limitations less of a marketability problem. (The "range" of any vehicle is how many miles it can travel on a single "fill-up".)

Similarly, in Japan gasoline cost about \$4 per gallon, and there, cities were even more congested and polluted than in either the United States or Europe. Average driving distances were also shorter, though commuting times were not necessarily shorter because of huge, ubiquitous traffic snarls. Japan's Ministry of International Trade and Industry (MITI) reacted to the situation by stipulating an industry "goal" of fielding 200,000 electric vehicles by the year 2000. MITI also became busy courting relationships among the Japanese automobile, electric utility, electronics, and financial sectors. Arguments were not limited to environmental concerns. The addiction of advanced economies to imported oil had long been appreciated as one of their major vulnerabilities. Every day in the United States, for example, three million barrels of oil were consumed by automo-

biles, light trucks, and vans alone. More generally, transportation industries drank two-thirds of all petroleum consumed, accounting for \$40 billion annually in the U.S. trade deficit. Meanwhile, the electric utility industry had massive unused nighttime capacity — utility grids were designed to serve peak loads, which occur during the day. Officials asserted that as many as 20 million electric vehicles could be recharged each night before any additional power grid capacity would be needed. (In the early 1990s it took as long as eight hours to fully recharge an EV, so the foreseeable usage pattern was to use them during the day and recharge them at night. By the mid-1990s advancements in recharging techniques and technologies had reduced recharging times greatly — to in some cases under an hour — but recharging any EV still took longer than buying a tank full of gasoline.)

Then there was the tinderbox of displaced employment. Part of the reason why the electric vehicle movement was welcomed by many Californians was because it was hoped to bring partial relief to the serious recession that had been plaguing the state at the turn of the decade, particularly in the post-cold-war defense/aerospace industry. Electric vehicle advocates felt sure that a California-based EV industry would create tens of thousands of new jobs, even in the short run [5]. Of course, residents of other parts of the country, especially Michigan, claimed that the phenomenon would not represent job creation as much as job displacement.

At the consumer level, studies about the feasibility of EV ownership costs (Exhibit 4 show a few idiosyncratic trials [6,7]) were not universally accepted without intense debate. Because of the exorbitant unit costs of producing small volumes of very exotic batteries, the sticker prices of EVs were expected to be about double those of their gasoline-powered cousins [7]. Worse, EV batteries were expected to need complete replacement every two or three years. As such, subsidies were felt to be necessary in order to sell EVs in appreciable volumes (Exhibit 5 outlines some of the more acute problems and proposed solutions [9]). Of course, subsidies would prove to be unpopular amongst those bearing the externalities. For example, it was expected that

the major automakers would need to raise the price of every gasoline-powered model by two or three thousand dollars in order to price EVs attractively, even to wealthy and environmentally-conscious trend setters. Ironically, one possible effect of raising prices by these amounts was to price non-affluent owners of old, gas-guzzling automobiles — those autos that were known to cause the majority of air pollution — right out of the market for new cars. In other words it was possible that EV subsidies could retard overall improvements in both the quality of air and the consumption of oil.

All arguments, pro and con, had articulate backers. But it was funding that could very well decide the outcome, and money flowed in a number of ways [2]. Environmentalist groups and the electric utility industry plainly favored EVs, and waged transparent information campaigns. “Big Oil” did not generally favor EVs, and waged well funded but more subtle campaigns in opposition. The Department of Energy (DOE) was in favor of cleaner air in principle, and together with the Big Three U.S. auto manufacturers, the Electric Power Research Institute, and several government research laboratories, formed a \$260 million effort called the United States Advanced Battery Consortium (USABC) to specifically develop promising EV battery technologies (Exhibit 6 outlines main consortium goals and programs [10-12]).

On legislative fronts, in 1990 the Clean Air Act was amended by the U.S. Congress to practically mandate a phase-in of clean-air vehicles in state-owned fleets. In a similar spirit the National Vehicle Act of 1991 created tax incentives for the private or commercial purchase of EVs. But the most active and controversial political entity was and continued to be the California Air Resources Board (CARB), which not only was the main impetus behind the 1990 California mandate, but as a model, inspired political movements elsewhere, most notably among twelve northeastern states spearheaded by New York and Massachusetts (Exhibit 7 outlines Northeast states’ version of the California mandate [13]). CARB had been the force behind California’s automotive technology policies since the 1960s and if its resolve collapsed, EV movements elsewhere could

fall like dominoes.

1990: KEN BAKER’S CHALLENGE

Amidst the blizzard of Electric Vehicle activities that were to begin with the passage of the California mandate in 1990, Ken Baker was asked to resurrect the electric vehicle concept at General Motors [14.] Baker was a successful engineer and mid-level manager in the Chevrolet and Pontiac divisions, but was not a novice to EV projects. He had been in charge of GM’s Electrovette program, a knee-jerk response to the oil panics of the 1970s that failed miserably. Naturally this left him ambivalent about taking the Impact program assignment, much preferring not to be again associated with a failure like the Electrovette.

Baker’s ambivalence went beyond first-hand experience with the intimidating technological hurdles he knew lay ahead. He felt that a part of the reason for the failure of EVs at GM in the past was the less-than-ringing endorsement of GM’s brass, management, and culture of 750,000 people very much devoted to the internal combustion engine, a tradition steeped in decades of experience and billions of dollars of invested funds [15.] To illustrate, at an auto show and news conference held in Los Angeles on January 3, CEO Roger Smith was photographed sitting proudly behind the wheel of a prototype electric vehicle with the word “Impact” embossed on its side. Though the car was nowhere near ready for production, the CEO was obviously proud of GM’s apparent vision. Yet towards the end of the news conference, he was heard to ask a CARB official, “You guys aren’t going to make us build that car, are you?” [15] In retrospect, this should have seemed to be a strong hint of some of the internal and external dynamics that were to come.

The internal combustion paradigm was about more than just an engine type, of course. “Big Auto” had long become interdependent with “Big Oil” and “Big Steel”, legendary juggernauts that fueled American economic growth for many years. Big Steel, Oil, and Auto were about mass production, economies of scale, huge centralized facilities, and hierarchical and oligopolistic industry structures.

Baker's program would therefore experiment with much more than auto technologies; it would experiment with new ways of getting things done, new arrangements of value-adding linkages that many industrialists would find both threatening and exciting. Some visionaries, for example, wondered if EVs weren't more like personal computers than automobiles, and foresaw entirely new value-added chains [17]. Ostensibly, since EVs would basically be electronics packaged in lightweight cases, the marriage to Big Oil and Big Steel could weaken; perhaps even dissolve. Production of EV components could be done anywhere and assembled on a relatively fragmented, regional basis. Thus capital investments in scale-intensive facilities could be largely reduced, and break-even points on individual EVs could be reached much sooner than in the present manufacturing environment.

Baker recognized, however, that the realities of his task frustrated a full commitment to such a vision [14, 18, 19]. He simply hoped to operate within the industry's present way of doing things, establishing brand-name recognition as the technology leader in a new market. He could not afford to try to be the sole GM agent of a rapid, traumatic, industry-wide transformation, but the Impact program could help lead the way in a corporation-wide transition to mass-customization, flexible manufacturing, focused factories, limited production runs, systems engineering, small independent development programs, and in particular, technological convergence with the electronics industry and GM's new subsidiary Hughes Electronics, a former military-electronics powerhouse.

But at the heart of it all, the most basic challenges involved difficult matchups of unproven technologies and equally unproven markets. To lead the industry in EVs, Baker's program needed to be first to market with a commercializable vehicle, which was a complete re-invention of the automobile from the ground up, not just the engine. Ironically, the reason such an effort was necessary was because the state of the art of electrochemical power sources, such as space age fuel cells and storage batteries, was still primitive relative to vehicle requirements (Exhibit 8 outlines advances made

in critical parameters of the most viable technologies [10-12]). In short, batteries capable of EV ranges of much more than 100 miles were still in early stages of development. As of 1990 and for years thereafter, there was little doubt that the most feasible way to meet the California mandate by 1998 was to base an electric vehicle on the venerable, low-risk, least-costly, but under-performing lead-acid battery technology (Exhibit 9 outlines the major global developments publicly admitted by respective firms [20]). At best, improved lead-acid batteries might yield a vehicle capable of traveling 100 miles under ideal conditions — flat terrain, warm temperatures, infrequent stops — but only if the rest of the car embodied technologies that had been pushed beyond the present state-of-the-art, in areas such as aerodynamics, materials weight/strength, and rolling resistance.

And, of course, the car had to be much more than just an engineering miracle — it needed to be safe, stylish, reliable, and in a word, marketable. In several market surveys, even the responses from potential "early adopters" indicated that they would not pay more than a \$5,000 premium for an EV [14, 21, 22]. Finally, despite the fact that most trips in automobiles were taken by a driver, alone, to commute to work, for an average daily usage of under 50 miles, there was a clear market perception that two-door, two-seat cars with ranges of under 100 miles were impractical even at good prices.

On the other hand, if Baker could achieve success, it would probably result in a promotion to Vice-President [13, 32, 24]. So, after being given the opportunity to consider the assignment, plus the promise of complete backing from corporate management, Baker accepted. He hand-picked a team of experts to begin work in a physically/administratively-removed setting in GM's "Tech Center" in Warren, Michigan, and hung a sign on a wall that read "Whatever you vividly imagine, ardently desire, sincerely believe in and enthusiastically act upon, must inevitably come to pass" [14.]

1991: DEJA VU ALL OVER AGAIN

Despite the fact that not a single component had been designed yet, and that

some of the necessary electrical, electrochemical, and electronic components would require completely original designs, by Christmas of 1990 Baker laid plans to begin production in March of 1993 [14, 25, 26]. To do so, he estimated that the development program would consume \$12 million each month, or about \$150 million each year; about \$300 million by the time the first production Impact would be rolled out. Volume was planned to be 20,000 cars in each of the first four years of production, at a production cost of about \$16,500 per car, for a total four-year investment of about \$1.5 billion. Considering the fact that even a significant re-styling effort of an existing design could cost \$1 billion, and that the new Saturn division cost about \$3 billion to start up, these figures did not sound unreasonable. But an interpretation from Finance was that break-even would not occur until at least the tenth year, and that a positive return on investment was nowhere on the foreseeable horizon. All, including Baker, surmised that profitability would not occur until a second or third generation EV — after the market was proven, infrastructure was developed, batteries were improved, and prices had come down — assuming as much.

In May of 1991, GM announced quarterly losses of over \$4 billion, the third quarter in a row of serious losses [13, 27]. The unthinkable had become thinkable — General Motors might go out of business if the crisis went unattended. Baker became pressured to delay production for a year. While this would cut R&D expenses from \$150 million to \$120 million, in the longer term the extra year would cost \$150 million. While Baker understood where the Impact program stood in the overall corporate portfolio, he also felt that any delay longer than six months would jeopardize the whole EV effort at GM.

By the fall of 1991, the situation had not changed much. It looked as if losses for the year would amount to about \$4.45 billion — the largest recorded loss in U.S. corporate history. GM's war chest was down to about \$3.5 billion, or about half its normal level. A stock offering issued in April raised \$1 billion but just paid some operating expenses. Standard and Poor's reacted by lowering GM's credit rating. On December 11, GM's CEO an-

nounced that 21 plants and factories would be closed, and that the payroll would be trimmed by 74,000 jobs.

On the other hand, battery R&D had been making progress [14, 28, 29]. So far, the USABC had proceeded relatively swiftly, unencumbered by anti-trust concerns because most of the work was being done almost at the level of pure science. Splitting up the rights to the consortium's progress was a concern for the (hopefully near) future. Nevertheless, each of the Big Three was mostly betting on a different corner of the consortium's effort. Ford was betting on Sodium-Sulfur technology, to which it had held proprietary rights with the pan-European electronics giant Asea-Brown Boveri since the 1960s. Chrysler was playing it safe by hedging its attention across a number of modestly promising nickel variants such as Nickel-Cadmium (the long-time norm in devices such as flashlights), and the rugged Nickel-Iron technology that had been commercialized long ago by Thomas Edison. GM was betting on one company called Electronic Conversion Devices (ECD), and one man named Stanford Ovshinsky. Ovshinsky was largely responsible for significant strides made in Nickel-Metal Hydride (NiMH) technology, one so complex that the word "Ovonic" was to be created to describe the science involved. NiMH inherently possessed twice the energy per unit weight as lead-acid technology, and in the prototype stage was almost achieving the USABC's mid-term performance goals for advanced EV batteries. Ovshinsky claimed that an EV powered by NiMH batteries could have a range of between two-and-three hundred miles [14, 30]. But many battery developers had made unsubstantiated claims in the past.

1992: THE BUSINESS CONCEPT BECOMES CLEARER, BUT ... BETTER?

The year 1992 was supposed to be the "tooling up" year for the Impact program, budgeted to cost \$179 million [14]. But because of the corporate situation, \$44 million of this was deferred until 1993. A year was now too long a time to plan for the development of the first hand-built Impact prototype. Baker felt the need to show material progress very quickly. So

he and his lieutenants decided to launch a "fast build" effort, a concentrated push to produce a drivable Impact that GM's brass could physically experience. The program's vehicle architect calculated that crashing the project would increase costs by \$2 million; a lot of money when capital is scarce. So the chief engineer "called in all his chips" with corporate finance and secured this amount.

By May, a concept car had been built. After taking a spin, even the CEO was impressed and showed rejuvenated enthusiasm. The next decision was whether or not to transition from Phase Zero to Phase One — from building the concept car to building sixteen proofs of concept cars. The proof of concept cars would be much closer to the eventual final design, but their real purpose was to demonstrate manufacturability. After all, it would be impossible to hand-build 20,000 Impacts every year. The risk, of course, was that management would be attempting to prove the manufacturability of a design that still needed many small changes — at an estimated \$450,000 per vehicle. Aware that the present design was too heavy and too costly, and pulling rank on his program chiefs who wanted to make the transition, Baker postponed it for thirty more days of intense effort.

During that thirty-day period, much was re-calculated as well as improved. Baker calculated that the best overall balance of costs would be reached at a production rate of 9,000 a year. But at that rate, price per vehicle would probably need to be around \$35,000. Also, GM would still need to invest \$500 million before the program's overall net cash flow stopped going further into the red, and there was no realistic hope left that the first-generation Impact program would ever be profitable.

By the end of the thirty days, Baker's team had come remarkably close to achieving all of its targets. The vehicle's mass was projected to be 1,319.8 kg, under target; investment was down to \$150,450,000, .5% over target; piece cost was down to \$15,982.24, 3.7% over target [14]. But it was not clear that enough progress had been made to avert program cancellation.

On August 11, 1992, a GM management committee convened to focus on the fate of the Impact program. The car was

probably one of the best that GM had ever developed, but its business case still seemed weak. Baker was instructed to develop a short list of feasible alternatives. On October 12th, the following alternatives were presented to the committee [14]:

Plan A: Stay the course, but view the Impact program as an investment, not a self-sustaining program per se. Build the Impact knowing that it would lose a lot of money, but commit to developing a follow-up vehicle that might result in a return on the total EV investment by as early as 2002. Seek to mitigate losses through alliances with, and subsidies from, the electric utility industry. Work hard to transfer advanced vehicle technologies throughout the GM product line, and take advantage of the improvement that taking a true technological lead would bring to the lackluster corporate image.

Plan B: Continue the development program, but delay mass-production for two years, knowing that a delay this long would actually kill the likelihood of mass-production altogether. The production "delay" would save \$200 to \$270 million, but continued development would still allow much progress along the learning curve. Hope for and work towards a collapse of California's political resolve and the mandate, but maintain the capability to comply. Produce 50-to-100 Impacts, but tool-up only for the production of EV components. (Despite a great deal of internal bickering and territoriality, GM's subsidiaries Hughes and Delco had managed to develop very advanced EV componentry.) Pursue a joint venture with Ford and Chrysler and promote it as Team USA, as if the main threat was losing another technology war to non-U.S. firms.

Plan C: Abandon the existing program except for the propulsion-system team; plan to sell EV propulsion systems and electronic/electrical components.

Plan D: Walk away from all sunk costs; do nothing else except minimal compliance with the law. Even without the Impact, GM still had several options. For example, and borrowing the idea from California entrepreneurs, GM could deliver an electric version of its popular Chevrolet S-10 pick-up truck. It was unlikely that old-plus-new technologies

could synergize into being a widely marketable electric S-10, but doing so would comply with the law, which, after all, mandated supply, not demand. Similarly, GM could sell engine-less S-10's or other "gliders" to any of several start-up firms willing to install EV propulsion systems, and then re-resell them. GM would still get the political credit for each EV.

The committee chose Plan B, and sent it to the Board of Directors for ratification during their November meeting. Soon thereafter Baker was offered his vice-presidency — Vice President of Research and Development. The Impact program would be administratively moved to being an R&D program, still under Baker. He had aspired to a much more visible, operational position, but accepted the job.

1993: A YEAR OF COLLABORATION

In January of 1993, executives from Chrysler, Ford, and GM met to begin talks on the Team USA concept. In an unprecedented act of mutual trust, each showed the others the material results of their EV programs. Chrysler was in the advanced stages of working on a converted Voyager mini-van, powered by Nickel-Cadmium batteries. Ford was developing a version of its smallish, European delivery van to be called EcoStar, powered by Sodium-Sulfur batteries. GM's Impact, powered by Lead-Acid batteries, was otherwise the superior vehicle [31-36].

The team started developing feasible options for a joint undertaking. The EcoStar seemed to be the most practical EV concept; a joint production effort and first year's run of 10,000 cars was calculated to cost about \$100 million. The more traditionally-sized but very heavy Chrysler TEVan would cost \$145 million. Impact would cost \$275 million, and a four-door follow-on would cost \$335 million. If, together, Team USA decided to abandon new designs and collaborate instead to deliver conversions of existing models, between 1993 and 2000 it would cost from \$375 to \$500 million. A wholly new design would cost \$575 to \$775 million. A compromise of options might cost \$725 to \$953 million.

To complicate matters, soon Chrysler technically won the race for being first-

to-market. The hand-built Voyager conversions were priced at \$120,000, and had a range of well under 100 miles, and few would probably be sold. But Chrysler's managers reasoned that this accomplishment, together with the reputation for innovation they had already established in vans, could synergize into overall, long-term leadership in EVs. This prompted them to work half-heartedly at Team USA. Before long Chrysler's program chief admitted, "I just don't think we'll be able to make this work," to which Baker responded, "Well, then, we're going to be tough competitors, won't we?" [14].

The relationship with Ford became strained as well. Baker and GM felt that Ford contributed little to a partnership, and offered to split future expenses and revenues 2:1. Ford's program executives were incensed by this suggestion, that the value of their intellectual EV property was about equal to the value of the Impact, and demanded a 50/50 split. Team USA collapsed, but GM and Baker held to the plan of building 50 Impacts, and to the public assault on the mandate.

By late 1993, Ovshinsky (the father of Ovonic battery technology) had made more strides with his NiMH batteries. So much so, that GM now felt compelled to deal directly with him, its regard for the spirit of the USABC now faded. Agreeing to a 60/40 partnership, GM and ECD (respectively) began a program of test-drives at GM's proving grounds in Mesa, Arizona. Though conditions were rigged for optimal battery performance, a special EV (i.e., not an Impact) went 201 miles on its first try on one pack of fully charged NiMH batteries. A city range of 135 miles was soon demonstrated. The technology was not yet ready for commercialization, but the results were astonishing, widely publicized, and therefore at face value, "proved" to CARB that EVs were feasible [37].

1994: CONFLICTING SIGNALS AND MIXED MESSAGES

On January 28, 1994, a remarkable article titled "Expecting a Fizzle, GM puts electric car to test" appeared in *The Wall Street Journal* [38], and in part read as follows:

General Motors is preparing to put its electric vehicle act on the road, and planning for a flop...

[GM] hopes that lawmakers and regulators will agree with it and postpone or scrap the deadline.

Hoping to prove its point, in April the nation's no. 1 automaker will roll out 50 electric cars... in two-week loans to 1,000 households around the country.

GM says its goal is to study customer reaction. But to the horrors of regulators and other electric-car promoters, GM appears to be counting on the test to demonstrate that nobody really wants a car that will cost considerably more than a gasoline-powered vehicle and will only go about 100 miles or more before it needs to be plugged in for several hours... Despite GM's qualms, initial interest in taking the Impact for a buzz has been overwhelming. The loaner program is being run through local utilities, which put fliers into their bills late last year asking for volunteers. In Los Angeles, GM expected 4,000 responses and received 9,300; in New York, the company expected fewer than 5,000 but got 14,000 and stopped recruiting a month earlier than planned...

A GM spokesman said ... "Clearly, the consumer is going to decide what the future of Impact is. It is not going to help if we build X number of units to satisfy the mandate, and then don't sell them."

"Their position is unbelievably curious," [said a New York environmental official] ... The real reason, he contends, is that the automakers do not want to make obsolete their multi-billion-dollar investment in technology for the internal-combustion engine.

The previous October, Impacts had started coming off an assembly line that simulated low-volume production. In parts and labor, each car cost \$340,000. The PrEView test drive program was budgeted to cost \$32 million.

Reviews were fast to follow PrEView. Of the lead-acid Impact, *Motor Trend* said: "The Impact is precisely one of those occasions where GM proves beyond doubt that it knows how to build fantastic automobiles. This is the world's only electric vehicle that drives like a real car" [39]. *Popular Mechanics* largely concurred: "Electric cars may have had their share of jokes, but no one is laughing at

GM's Impact — the first real-world, practical electric-powered passenger car for the twenty-first century ... If the Impact had but a 200-mile range, by God, she'd be a car" [34].

Such reactions were enough to revive Plan A among GM's executives and program managers, but only tentatively, under a thick veil of secrecy, and with a budget reduced from \$300 million to \$235 million. The PrEView test drive program would be continued, but it would serve as a ploy. Officially, General Motors would still have no plans to mass-produce the Impact, but would still want to use the prototypes to conduct market studies and to serve as technology-development test beds. The main objective now would be to wait as long as possible for an unveiling of production plans, hoping to trump Chrysler, Ford, and all the European and Japanese carmakers.

The tentative decision to switch secretly back to Plan A was essentially made on March 7, 1994, at which time Bob Purcell, the new Impact program manager, calculated that Impacts needed to begin rolling off a mass-production assembly line in eighteen months. As Ken Baker's immediate replacement upon his move to R&D, Purcell was obviously a different kind of manager. Most notably, he was not an engineer, not a "car guy." He had come up the ladder through Finance and Planning. Shortly after his arrival on the Impact program, and upon ratification of Plan A, he bluntly challenged his people; "We're on a ninety-day window to get back to the board of directors with a world-class business case. And by that I mean we have to demonstrate that no one in the world can do this car better than we can" [14].

On August 6, 1994, the New York Times reported [41]:

In one of the strongest statements yet about its plans for electric cars, the General Motors Corporation said on Friday that it had no plans to build an all-new electric vehicle to meet 1998 California emissions standards...

Speaking to reporters at the University of Michigan auto conference here, Kenneth Baker ... said GM was 'candidly looking' at all other options but would not try to build an all-new electric vehicle capable of meeting emissions laws. Among the options under consideration

are productions of G.M.'s current electric test vehicle, the Impact; retrofitting the Geo Storm, Geo Prizm or Chevrolet Cavalier with 'electric engines' or offering an electric-powered van or commercial vehicle.

Mr. Baker said the first round of Impact consumer test programs in California had generated a favorable response. But he said it remained to be seen whether consumers would pay more to drive electric vehicles.

'The one thing we're finding is that people love to drive a car for free,' he said.

In the mid-term November elections of 1994, in a dramatic reversal of mood from the 1992 Presidential campaign, Republicans gained control of both houses of Congress. It was the first time the more conservative of the two parties had controlled both houses in decades. It looked as if Newt Gingrich's "Contract with America" might reverse, or at least put a moratorium on, a quarter-century of environmental legislation. Republican Pete Wilson was re-elected the governor of California, and in New York Republican George Pataki ousted three-term Democratic governor Mario Cuomo. On cue, Big Oil with gusto bolstered the anti-EV camp with millions more dollars spent on blatantly negative information campaigns, powerful enough to quell much of the utility industry's commitment to subsidizing the development of EV infrastructure. The utility industry in California revised its plan to raise \$640 million through rate surcharges, to \$160 million. Beyond rumors — and the EV scenario was constantly peppered by many bad rumors — no one outside the Impact program knew that Plan A was back in effect. All options were back on the table.

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Exhibit 2. Photo of Impact Car



Exhibit 3. California EV Incentive Program, as of 1993 [5].

Purchase Incentives — Existing Programs

1. \$1,000 state income tax credit
2. Exemption from sales tax on incremental cost of EVs.
3. Special off-peak recharge rates from municipalities.
4. \$1,000 from regional air districts for EV purchase.

Purchase Incentives — Proposed Programs

1. \$1,500 direct rebate per EV from utilities (1995-2000)
2. Sales tax exemption for EV purchase (\$1,500 maximum.)
3. Special EV recharge rates from major investor-owned utilities.
4. Rebates from other regional air districts.
5. EV consumer information program.
6. DRIVE+ legislation creates \$3,000 rebate for EVs.
7. Grants/loans for EV projects.

8. Credits for special use EVs.

Infrastructure Development — Existing programs

1. Standardizing re-charging connectors and equipment.
2. Install charge stations at lots, malls, airport, etc.
3. City of Los Angeles 10-point readiness program:
 - a.) EV-ready wiring in new residential single family homes
 - b.) EV-ready wiring in 17% of new parking structures.
 - c.) EV-ready parking by employers of 100 or more.
 - d.) EV-ready at airports, plus airport EV shuttles.
 - e.) Encouragement for EV ridesharing and car rental.
 - f.) Preferred parking
 - g.) EV-ready park-and-ride lots.
 - h.) Encouragement for EV charging at rest stops.

- i.) Re-charge facilities for city employees.
 - j.) Re-charge for city fleet EV purchase equipment
4. California Energy Commission developed Ainfrastructure master plan.
 5. Utilities currently installing electrical transmission and distribution up grades.
 6. Utilities conducting technology research with automakers.

Infrastructure Development — Proposed Programs:

1. Utilities pay for charging equipment at customer's home.
2. Preferred parking, special lane access.
3. Credit businesses for installing EV-re-charging and educated parking.
4. Develop model code for EV-ready residential and non-residential construction.
5. Develop instructional material for accidents and emergencies.
6. Train law enforcement and health and safety personnel.

Exhibit 4. Early Studies of Electric Vehicles [6,7].

<u>Assumptions</u>	<u>EV Truck</u>	<u>EV Van</u>	<u>Gasoline Van</u>
Purchase price	\$12,000	\$60,000	\$18,000
Salvage value	10%	10%	20%
Battery cost	\$1,520	\$4,700	n/a
Years per battery pack	2.5	4.0	n/a
Miles per battery pack	20,000	32,000	n/a
Fuel cost	\$.05/KW-Hr	\$.05/Kw-hr	\$1.30/gallon
Fuel efficiency	.4Kw-hr/mile	1.1Kw-hr/mile	10 mpg
Labor per 1,000 miles	.3 hours	.4 hours	1 hour
Parts per 1,000 miles	\$30	\$30	\$60
Vehicle life	40,000 miles	64,000 miles	64,000 miles
Vehicle costs (cents per mile)	27.0	84.4	22.4
Battery cost (cents per mile)	7.6	14.0	—
Fuel Cost (cents per mile)	2.0	5.6	13.0
Maintenance (cents per mile)	4.2	4.6	45.5

	<u>EV</u>	<u>Internal Combustion</u>
Batteries (\$45 ea.)	3,500	135
Brakes (@50,000 miles)	200	200
Tires (@ 5,000 miles)	200	200
Fuel	3333	3143
Acquisition Cost	6,000	7,100
Maintenance	150	1077
Resale	1,500	1,500
Insurance	1,800	7,200
Total	13,683	17,555
Cost per mile (cents)	13.7	17.6

Conditions/Assumptions: 1980 Volkswagen Rabbit and converted 1975 Rabbit (purchased for \$2,500 and converted for \$3,500); 10,000 miles remaining life span.

	<u>EV</u>	<u>Internal Combustion</u>
Vehicle Cost	9.3	18.5
Conversion Cost	11.1	—
Batteries	4.3	—
Maintenance	3.1	5.0
Fuel	3.1	31.5
Total	30.9	31.5

Conditions/Assumptions: Two 1975 Honda wagons; EV conversion accomplished for \$3,845, both vehicles originally acquired for 5,000. Range 65 miles. 54,000 miles were logged.

Exhibit 5. “How to Jump-Start Electric Cars” [9].

Electric vehicles (EVs) won't match gasoline vehicles in performance or price by California's 1998 deadline. But here's how carmakers hope to narrow the gap:

Cost

PROBLEM: Low volumes will boost prices of early electric vehicles.

SOLUTION: Most carmakers will start by making electric versions of high-volume gas models. The cost of electronic components should fall quickly as volumes increase. Subsidies from carmakers and utilities, plus tax breaks, will help keep sticker prices competitive.

Range

PROBLEM: A 50-to-70 mile range per 7-hour charge could turn off consumers used to going up to 400 miles per tank and refueling in five minutes.

SOLUTION: Improved lead-acid batteries boost range. Utilities may install quick-charge stations that recharge batteries in 15 minutes.

Battery Life

PROBLEM: Expensive EV battery packs can burn out in as little as two years and cost thousands to replace.

SOLUTION: New charging techniques using rapid battery pulses may double or triple battery life. Utilities may lease batteries to consumers, spreading the cost and shouldering the risk of early failure.

Recharging

PROBLEM: Many potential customers lack proper outlets for recharging.

SOLUTION: Some utilities are seeking temporary rate hikes to subsidize installation of recharging stations.

Marketing

PROBLEM: mainstream consumers will likely shy away from EVs until they have a track record.

SOLUTION: Carmakers will initially focus on fleet buyers, such as utilities, so they can work out bugs before tackling the tougher consumer market.

Exhibit 6. USABC Activity Profile [10-12].

Performance Parameter	Mid-Term USABC Goals	Long-term USABC Goals
Specific Energy, Wh/Kg	80	200
Specific power, W/Kg	150	400
Price, \$/Kilowatt-hour	\$150	\$100

Battery Type	Contracts Awarded (,000)	Contractor(s)
Nickel-Metal Hydride	\$18,800	ECD
Sodium-Sulfur	\$12,400	Silent Power GmbH
Lithium-Polymer	\$33,000	3M/Hydro-Quebec/Argonne Labs
Lithium-Vanadium	\$14,500	Valence Technology, Delco Remy
Lithium Iron DiSulfide	\$17,300	SAFT America, Argonne labs
Lithium-Carbon	\$24,500	WR Grace, Johnson Controls, SRI, SAFT America, Delco Remy

Exhibit 7. “Making it Clear: Plans for Clean Air” [13].

The 12 Northeastern states that make up the Ozone Transport Commission asked the Environmental Protection Agency for permission to adopt California’s emissions standards. These are the possible outcomes:

Adopting California’s Standards:

Car manufacturers would produce five kinds of cars, from the most to least polluting. A carmaker could sell any combination of five models as long as the exhaust produced by all the cars it still meets a standard for volatile organic compounds, which is tightened every year.

When the new models replace the cars now on the road, the commission predicts that volatile organic compounds will have been cut by 63%, nitrogen oxides by 39% and carbon monoxide by 33%.

The automakers have threatened to sue if this option is chosen, arguing that the commission itself is unconstitutional. Some state legislatures oppose being forced to adopt rules by other states.

Additional Measures Beyond the Clean Air Act of 1990

The Tier I Motor Vehicle Control program requires that all vehicles comply with a single set of tailpipe emission standards for volatile organic compounds, carbon monoxide and nitrogen oxides. Current law allows the EPA to cut those standards in half should air quality decline.

Under this option, individual states would still be allowed to choose standards like California’s, as New York and Massachusetts have already done.

The Auto Makers’ Proposal

The carmakers have offered a compromise: a 49-state car. They have said they will voluntarily build and sell a car nationwide that would be almost as clean as the low-emission vehicle now required in California. In return, the states would drop demands for electric cars or ultra-low emissions cars.

Several states have rejected this proposal, saying it would be too little, too late.

Exhibit 8. Electric Vehicle Battery Characteristics [10-12].

Battery	Upper Limit Wh/Kg	1993-1995 Wh/Kg	Peak Power W/Kg	Cost	Stage
Lead-Acid	175.7	25-40	70-90	Low	Commercial
NiMH	185.9	50-80	150-200	Moderate	Module
Nickel-Cadmium	219.0	50-60	175	High	Commercial
Nickel-Iron	268.3	50-60	100	Moderate	Prototype
Zinc-Bromine	429.8	80	80	Moderate	Prototype
Lithium-Polymer	548.5	100-200	100-400	Moderate	Cell
Lithium DiSulfide	652.0	130-200	200-250	Moderate	Stack
Sodium-Sulfur	763.6	75-80	100-250	Moderate	Prototype
Sodium-Chloride	795.6	80-100	50-100	High	Prototype
Zinc-Air	1316.1	75-100	25-65	Moderate	Prototype

Legend:

Battery: Described by the chemically reactive substances that are the sources of electrochemical energy.

Upper Limit, Wh/kg: The theoretical upper limit of the prolonged amount of energy available from the chemically reactive substances in the battery, measured in watt-hours per kilogram. This crucial figure ultimately defines the absolute limit of the range of a vehicle.

1993-1995 Wh/kg: The state of the art amount of energy actually being extracted as of 1993-1995. These figures represent data reported by participants in the USABC, and do not necessarily reflect other proprietary efforts.

Peak Power, W/kg: The amount of energy available at any point in time, not over a prolonged period. This figure determines vehicle acceleration.

Cost: Estimated cost of each type of battery, relative to lead-acid. Reasons for high costs vary, from expensive raw materials to difficult production techniques.

Stage: Relative stage of development of USABC projects as of 1993-1995. From the most primitive stage to the most advanced, terms are cell, stack, module, prototype, and commercial.

Exhibit 9. Profile of EV programs, 1993 [21].

<u>Firm</u>	<u>Vehicle Type</u>	<u>Battery</u>	<u>Range</u>	<u>Target</u>
Chrysler	Conversion Van	Nickel-Cadmium	80 miles	Utilities
Daihatsu	Conversion Van	Lead-Acid	81	Governments Utilities
Fiat	Conversion Car	Lead-Acid and Nickel-Cadmium	62 93	Utilities Governments
Ford	Conversion Van	Sodium-Sulfur	100	Utilities Governments
Honda	Ground-Up Design	Lead-Acid	n/a	n/a
Isuzu	Lead-Acid	Lead-Acid	56	Citizen Groups Delivery Firms
Mazda	Conversion Car	Nickel-Cadmium	112	Utility
Mitsubishi	Conversion Van	Lead-Acid Nickel-Cadmium	102 155	n/a
Nissan	Conversion Car	Lead-Acid	75	Governments Corporations
Peugot/ Citroen	Conversion Van	Lead-Acid	43	Municipalities
Renault	Conversion Van	Lead-Acid Nickel-Cadmium	n/a	Municipalities Corporations
Suzuki	Conversion Van	Lead-Acid	80	Governments
Toyota	Conversion Van	Nickel-Cadmium	99	Governments Municipalities
Volkswagen	Conversion Car	Lead-Acid	75	n/a

Internal Combustion Engine

Drive System
 transmission
 drive seals
 differential
 brakes
 wheels/tires
 steering
 fluids
 Fueling and Ignition System
 carburetor
 fuel injectors
 fuel pump
 fuel
 lines and hoses
 gas tank
 fuel filter
 air filter
 distributor points
 caps and rotors
 ignition coil
 spark plugs
 Cooling System
 radiator
 water pump

Electric Vehicle

Drive System
 transmission
 drive seals
 differential
 brakes
 wheels/tires
 steering
 fluids
 Fueling and Electrical System
 Batteries
 Charger
 Electric motor
 Electric controller

 No similar cooling system

cooling hoses	
thermostat	
Exhaust System	No similar exhaust system
exhaust pipes	
manifolds	
muffler	
catalytic converter	
Mechanical System	No similar mechanical System
block/heads	
crankcase	
oil pump	
pistons/rings	
gears/chains	
shafts/rods	
gaskets/belts	
alternator/starter	

Figure 8. Comparison of Vehicle Propulsion Systems [13].

Body Type: two passenger, two-door coupe

Drive System: front engine, front drive

Drivetrain: computer-controlled, liquid-cooled 137-horsepower three-phase induction motor and propulsion inverter module.

Power source: 1,150-pound battery pack of twenty-seven 16.8 Kilowatt-hour, maintenance free, recombinant lead-acid batteries

Battery life: 25,000-30,000 miles; EPA range estimates: 70 miles city, 90 miles highway

Charging system: inductively coupled Hughes magnetic-field charger. Using standard 220-volt, 30-amp current, the Hughes home charger can recharge the battery pack in three hours. A remote-location charger is provided as standard vehicle equipment; on 110-volt, 12-amp system, it can recharge the vehicle in 8-10 hours.

Charging cost: about \$1.90 for a "complete" charge (85% of actual battery capacity)

Cost of Home Recharger: \$2,000.

Acceleration: 0-60 mph in 8.5 seconds; Top Speed: governed to 80 mph

Length: 169.8 inches; Height: 50.5 inches; Width: 69.3 inches; Wheelbase: 98.9 inches.

Curb weight: 2,970 pounds; Drag coefficient: 0.19

Energy-Efficient features:

rigid welded and bonded aluminum alloy body structure

polymer body panels

electric-motor-driven heat pump

electrohydraulic braking system with blended regenerative braking

low-inflation tire monitor; high-voltage isolation assurance

self-sealing, low-rolling resistance Michelin tires and aluminum wheels

Standard features

double wishbone front suspension

bucket seats

AM-FM-CD-cadette audio system

electric clear windshield and solar glass

dual power outside mirrors

side door defogger

daytime running lamps

cruise control

power door locks

power windows

keypad door and keypad vehicle activation (no keys required)

remote trunk release

Safety features

dual air bags and seat belts

four-wheel anti-lock brakes

traction control

Figure 11. Impact specifications, as planned for production [5].

Teacher's Note

Making an *Impact* at General Motors

Case Summary

Management at General Motors finds itself forced to respond to rapidly changing external political, economic, and ecological conditions with respect to the extant automotive technology paradigm. The California legislature has passed a mandate that essentially forces major carmakers to develop electric vehicles by the end of the decade. Ken Baker, a successful GM engineer and mid-level manager, is given the highly visible project of developing GM's first mass-production, passenger electric vehicle in many years. But neither internal nor external stakeholders are unified in their advocacy of such an idea, and Baker must manage internal resistance as well as external political and competitive pressures. From the most pessimistic point of view, he has been tasked to commercialize very costly, under-performing and unproven technologies, in a vehicle for which there is an enthusiastic but small market, for a corporation where radical change is culturally anathemic, because of a political stance in one state that sometimes is on the verge of collapse, in an overall climate where information needs to be held suspect because of its politically-charged nature. Despite these obstacles, Baker and his project team managed to develop (arguably) the most technologically advanced auto that GM has ever produced. But signs developing by the end of the case imply, paradoxically, that either (a) complete project cancellation or (b) a to-

tal commitment to electric vehicles might be strategically successful.

Discussion Questions

1. What issues in the case apply most acutely to engineers?

Successful engineers will be expected to exercise leadership skills sooner or later; and the better the engineer, the sooner the likelihood. Also, gone are the days where engineers work in isolation, both in time and in place. In a scenario such as that depicted in this case, the implied engineering solutions must be highly integrated. Relatively straightforward design engineering decisions, for example, must be integrated with value engineering considerations. Concurrent engineering philosophies also demand that engineers learn to grasp marketing and other business issues. While the case is not very rich in the kind of detail that engineers crave, it encourages engineers and potential engineering leaders to develop some of the softer skills and boundary management abilities needed even for engineers to be successful in a world of "bounded rationality" (Simon, 1977.)

Ken Baker, for example, is an engineer in a highly visible but otherwise typical role of project manager. The engineering challenges should not be divorced from cost and/or schedule, and in the classic view of project management, there are usually trade-offs among these three parameters. While all information needed

for a thorough analysis is not available, a rudimentary examination and fruitful discussion can be made about how techniques such as Gantt Charts, Program Evaluation and Review Techniques, and the Critical Path Method could help Baker.

Of course, the main objective of the project is the development of a new product, and engineers are typically (but not always) in charge of such a situation. The case helps bring out some important but generally underemphasized engineering issues. For example, there is enough rudimentary information in the figures to examine the importance of reliability to the success of this product. EV designs are apparently much more elegant than combustion-engine autos and in the long run, this inherent characteristic, and the way it is managed, may mean success or failure. Yet maintainability may be the soft underbelly of this product. Not only is there no logistic support infrastructure for EVs – the knowledge to develop one doesn't even exist. It is a classic engineering failing, or a failure of engineering leaders, to overlook maintainability as a feature of product design. It is an engineering responsibility, for example, to make sure that batteries can be swapped out quickly, that the skills needed to diagnose sophisticated problems exist in the field, that proprietary electronics are designed to match for their warranty arrangements, and so forth. Moreover, there is enough information throughout the case to exercise a Quality Function Deployment (i.e., House of Quality) approach to integrating the perception of the consumer of the product, with the perception of the engineer. This is an important engineering skill. On a more general level, a long discussion can be made of how each of the quality "gurus" would view the Impact situation, and the choices that are likely to ensue from each of those views. Common quality control tools can be addressed to help illustrate this discussion.

As well, engineers need to understand the importance of design-for-manufacturability, though information

Case Objectives

This case is most appropriate to an undergraduate or graduate Strategic Management (Technology Strategy and/or Government-Industry Relations) or Management of Technology and Innovation, and can also be used to illustrate top-level Project Management and Production Management (Product Development) principles. It is also appropriate for Engineering Management courses at upper levels, that address the

views and interests of engineers in leadership roles and in search of fully-integrated solutions. Specific objectives include problems managing:

- 1. Internal corporate venturing;**
- 2. Engineering at the project/program level;**
- 3. Technology cycles and emerging industries;**

systems are rapidly institutionalizing this responsibility. Not so obvious, perhaps, is that as a product matures, manufacturing philosophies must evolve. Fixed-position layouts, for example, must give way to cellular layouts and other more efficient means of mass-customization. The point is to acknowledge the vested interest that many walks of engineering have in the Impact project and thereby to acknowledge the critical nature of leading their integration.

2. *What is the key decision to be made at the end of the case? Whose decision is it? Who are the most relevant stakeholders?*

The key decision to be made at the end of the case is whether to stick to Plan B, switch to another plan previously considered, or do something else. The dilemma is that while reviewers and PrEViewers of the Impact are astonishingly positive about it (indicating that the latent demand for such a car is stronger than anticipated), institutional and political winds seem to be changing and abandonment of the Impact also looks feasible.

Decision-making at GM is a bit complicated and bureaucratic. While Ken Baker is the main focus of the case, it would be simplistic to say that the decision is his. The decision involves Baker (Vice-President of R&D,) Bob Purcell (new program manager) and other Impact project managers, GM brass up through the CEO, and the Board of Directors. Asserting one's will amongst the implied coalitions takes much more than a decisive mind and entrepreneurial attitude; it takes political skill. Most project team members are probably "car guys", engineers like Baker whose main values and goals lie in technology development. The dominant logic above program-level, however, is classically corporate, viewing the Impact program in terms of the viability of its business case in an overall investment portfolio in troubled times.

Relevant internal stakeholders include all named persons in the case, all Impact team members, key divisions such as R&D, Delco and Hughes, union members, and to varying degrees all GM employees. External stakeholders include employee families and local communities, ECD, members of the USABC and

other consortia, organizations and persons investing in the EV movement, organizations and persons bearing the externalities of EV subsidies, environmentalists and people who breathe polluted air, Big Oil, Big Steel, Big Auto, and the electric utility industry.

3. *What are the risks (not to be confused with unpleasant certainties) and potential rewards of each plan? What are the key uncertainties that must be managed?*

Plan A: The main risk is financial; Impact is a cash drain but the amount is indeterminable, as is the "return" on this "investment." Secondly, if the mandate collapses, GM may be stuck with quite a white elephant. Many stakeholders will be continuously wary about this. The reward is improved corporate image at grass roots and institutional levels, and the long-term, corporate-wide benefits of R&D. Regulators and environmentalists will be happy. The main uncertainties were, as of the time of the case, technological and marketing. The "dominant design" was still anyone's guess and breakthroughs as well as significant incremental progress were both needed in several technologies. Market signals about niche sizes, propensities to purchase, price elasticities, etc., were also uncertain.

Plan B: The main risks are political and social; Plan B might be interpreted as a calculated plan to sabotage the whole EV movement; at best, it is non-committal. Regulators might interpret this as foot-dragging, and take action. The main rewards are cost-effective legal compliance, continued technology development, and technology diffusion throughout GM's product line. Some stockholders will view this as value-maximizing. The main uncertainty lies in the continued difficulties "spinning" the execution of the plan in ways that portray GM as being the voice of sanity among radicals.

Plan C: The main risk is losing technological leadership, especially in EV system engineering. GM seems to be leading the world in EV technology but maybe not by much, in strategic terms.

The main reward is financial, in the sense that the decision seems to rationalize-out all efforts except (arguably) the most value-adding. Revenues achieved through this plan might be relatively modest but it might result in the best profit margin; in fact, it might be the only profitable plan. The main uncertainty is technological progress. Key breakthroughs that are managed well should bring significant windfalls to whoever makes them. Failure to make breakthroughs will "prove" that the conservative auto establishment was right about EVs all along.

Plan D: This plan virtually abandons most benefits of the Impact program along with sunk costs. It proposes to do what anyone could do — subcontract all value-adding elements of EV development. Perhaps the main risk, then, is the loss of corporate credibility in a political environment that demands change. This option might only be "rewarding" to the most conservative of decision-makers, as it seems to be the most risk-averse. But it will advance no internal competencies; bring no real financial gain, etc. Perhaps the main uncertainties lie in the vehicle programs going on at rivals and potential new entrants. For this plan to really work, GM must look, in retrospect, to understand that viable EVs were bad ideas and that technological innovation cannot be mandated. This is a highly controversial position to take.

4. *What strategically-relevant information can be gleaned from the figures?*

Exhibit 3 (California EV Incentive Programs) indicates that California legislators are quite serious and imaginative about making EVs work and that they plan on participating in the solution to pollution as well as enforcing limitations on others. They also seem to have a fair grasp of the magnitude of the undertaking, and to know that massive and costly changes need to be made to infrastructures in order not to too dramatically affect lifestyles. Given such successes in their own backyards, legislators may accept little less from industrialists.

Exhibit 4 (Early Studies of Electric Vehicles) illustrates some of the techno-

logical uncertainty underlying the EV movement. A few spotty and idiosyncratic “studies” undertaken by very biased EV advocates and technology enthusiasts is insufficient data to predict results of an undertaking like Impact. On the other hand, since all of the vehicles presented in the data are relatively amateurish vehicle conversions, one might surmise only better performance from ground-up designs.

Exhibit 5 (“How to Jump Start Electric Cars”) helps in the understanding of general industry-wide conditions. In a sense the figure is an amalgam of EV-industry obstacles and overall strategic responses. It seems as if the industry at large is taking a conservative, minimal-compliance tack, and that relative to most others, GM may actually be one of the most pro-active and risky participants. It seems that the Impact is the most technologically advanced EV, except for GM’s choice of batteries. But since Impact might be the first of several generations of GM EVs, the trajectory it represents may become a blanket solution to most problems presented, and become a de facto dominant design.

Exhibit 6 (USABC Activity Profile) provides a glimpse of the most influential consortium in the case. It is interesting that the USABC is interested in so many Lithium variants, and that only ECD has been awarded a contract to develop NiMH batteries. Interpretations of this can vary. GM’s choice of contractually capturing ECD early and committing to NiMH technology is a high-risk, potentially high-return one.

Exhibit 7 (“Making it Clear: Plans for Clean Air”) does make clear that California legislators are not the only ones officially interested in EVs. More importantly, it helps illustrate how treacherous the political landscape is. GM cannot possibly accommodate every region’s approach to solving emission problems, and the characteristics of each region are different and a unified policy is unlikely. GM cannot afford to remain politically passive and be torn apart by disparate political directions and their likely regulatory results.

Exhibit 8 (Electric Vehicle Battery

Characteristics) illustrates the most popular battery ideas being pursued in the 1990s. Lead-Acid batteries have the lowest potential of all options. They are the most feasible choice because of their low cost, availability (established production and reclamation infrastructures), and remaining potential for incremental improvements. What may be a surprise to some is that NiMH is hardly better than Lead-Acid in its potential, but its characteristics are already allowing scientists to get much better performance. All other options have much higher potential than either lead-acid or NiMH but scientists did not yet know how to tap deeply into those potentials, even during laboratory stages.

Exhibit 9 (Profile of EV Programs, 1993) profiles a thumbnail sketch of the activities at virtually all-notable auto manufacturers worldwide. The global level of effort seems relatively consistent; virtually all firms have a low-production program in effect; almost none were working on ground-up designs, and virtually no other firms were yet targeting the individual consumer — as far as *public* information indicates! This is an important observation.

5. *Given the novelty of the EV industry, the uncertain path of radical innovations, and general trends with respect to the emergence of dominant designs, why did GM specifically pick one contractor (ECD) to develop their battery?*

The motives for “locking” in ECD probably vary and can be controversial. Some probably include:

(a.) ECD had established political and institutional legitimacy as a leader within the USABC. It is often true that political and market factors play more important roles in “choosing” a technological trajectory, than do more “rational” economic and engineering factors.

(b.) GM needed to commit to one technology or another just to meet the mandate. Choice of battery technology held tremendous importance to overall system engineering. Battery technologies could not easily be “swapped out.” Co-opting ECD dur-

ing the time of the case would reduce its bargaining power as a more independent entity later.

(c.) Even if Ovonics proved to be not the best technology in the long run, GM had the power to force it into the marketplace and reap short-term and mid-term gains.

(d.) If Ovonics did prove to be the best, or one of the best, overall solutions to EV propulsion, ECD was certainly undervalued at the time of the case and GM could “pick it up for a song.” Licensing the technology to others for significant profit later held some important promise.

In sum, the choice to commit to Ovonics technology and ECD was probably a calculated risk, based on both hard and soft data available in the mid-1990s, made with respect to possible economic returns to a proprietary position.

6. *Do a SWOT analysis of GM’s situation in the automobile industry.*

A thorough SWOT analysis should draw from an examination of the macroenvironment, the industry environment, and the firm-specific internal environment.

MACROENVIRONMENT

Political/Legal Factors

The California EV mandate and regulatory climate; 15% of the US market

Similar movements elsewhere in the U.S. and Washington D.C., many agencies involved

Similar movements in Asia/Japan and Europe

Shift to Republican control of both the House and the Senate

Some economic nationalism in key/nationally strategic industries

Longstanding unions, including internationals; “Jobs, jobs, jobs,” industry regionalism

Sociocultural Factors

The importance of automobiles in U.S. lifestyles

Environmentalism; Fears of global warming

Diminishing resources of many kinds
Surprisingly positive acceptance of
EV technologies but not their costs
Baby boomers moving into their most
prosperous years
Conflicting social goals (medical, na-
tional debt, social security, etc.)

Technological Factors

EV technologies in a “period of un-
certainty;” immature but with large
potential
Internal Combustion Engine para-
digm clearly in “incremental” phase
Proprietary property climate in US is
healthy
Favorable investment climate for
technological innovations
History of governmental impact on
automotive technological trajecto-
ries
Strong university and other R&D in-
frastructures

Economic Factors

Resurgence of US automobile indus-
try; collapse of aerospace
Hierarchical industry supply chains
being transformed into networks
Uncertain oil industry; especially im-
portant outside the US
US economy stabilizing and becom-
ing robust
Consumer confidence
Emergence of new giants: China, Bra-
zil, India, perhaps Russia

Global Factors

Fluid technology transfer internation-
ally
Emerging economies; different rela-
tionships with autos in different cul-
tures
Underdeveloped transportation and
communication infrastructures
Automobile industry a key to global-
ization dynamics
End of Cold War opening up vast ho-
rizons
Increasing political acceptance of
market-based economies

INDUSTRY ANALYSIS

Electric vehicles represent revolution-
ary technological advancements but in a
strategic sense might best be thought of
as substitutes for gasoline-engine automo-
biles. That is, EVs perform few truly

original functionalities in unexploited
market niches, and the relationship of
performance and price will largely deter-
mine their chances of success. Also, there
are significant tangible and intangible
costs of switching, and presently only a
few buyers in small niches would have a
high propensity to switch.

Strategies exist to induce product sub-
stitution (Porter, 1980.) In the EV sce-
nario, probably most important is the need
to change both the *perceived* and the ac-
tual value of EVs. This should be done
carefully, identifying and attacking the
most important market niches first, in
ways that lend them naturally to moving
on to the next, most opportune niche. At
the time of the case, the most likely niches
are (a) environmentally conscious, trendy,
and wealthy individual consumers, and
(b) owner/operators of industrial fleets,
especially those organizations that have
much to gain from the success of EVs,
such as electric utility companies. Of
course, due to the design of the Impact,
industrial fleets are not likely targets. And
it is difficult to conclude with confidence
from the PrEView test drive program that
individuals who like the Impact, even
those who say they *want* to buy one, even-
tually *will* buy one. The market for the
Impact is small and uncertain. It will take
time for market niches for all EVs to fully
develop, so patience and patient capital
will be required. Here, GM has an ad-
vantage over many small start-ups that are
driven by venture capitalists that do not
have the staying power of GM. But man-
agers at GM must appreciate this as a
strength and use it, and not lapse into
shortsightedness. Also, and present finan-
cial crises notwithstanding, GM is not the
only incumbent firm with deep pockets.

Assuming the “new” industry does
eventually become profitable, GM might
try to pre-empt new entrants early. New
entrants will come not only in the form
of the major auto manufacturers but also
the smaller ones, and in the 1990s entirely
new EV manufacturers were starting to
appear. In this light, the case implies that
scale economies might not be as impor-
tant (or even possible) to achieve in EVs
as they have traditionally been in conven-
tional auto programs, but learning effects
should not be overlooked. Achieving sig-
nificant learning effects in such a com-
plex technology-market scenario has the

potential to be the source of sustainable
competitive advantage. For the long run,
GM should continue to take great pains
protecting the proprietariness of not just
their technologies per se, but also their
organizational techniques (manufactur-
ing, assembly, systems engineering etc.)
As a summary rule of thumb, in many
new industries and revolutionary tech-
nologies, it is wise to forego early profit-
taking for the sake of investing in long-
term positioning and survival.

Yet, and thinking towards these same
main goals, one might argue that GM
should encourage, not pre-empt, entry. If
management at GM truly wants EVs to
be successful, they should probably pro-
mote the basic product concept, not just
the Impact. They should help publicly
champion milestone technical accom-
plishments made at consortia, for ex-
ample. Doing so would help legitimize
the whole “new industry” and create op-
portunities for all early players. On the
other hand, and again — if GM manag-
ers want EVs to be successful — they
should work to eliminate opportunistic
entrants who could tarnish the new
industry’s image. At the very least, GM
should continue to be active in forming
industry groups and lobbying regulatory
agencies and work towards establishing
standards of quality only a few firms like
itself can achieve.

Either way, finding ways to lower
switching costs will facilitate the substi-
tution of EVs for gasoline-powered cars.
For example, pro-active signaling of ca-
pacity commitments, announcements of
plant openings, irreversible financial
commitments, etc., will help mitigate con-
sumer risk. It also seems certain that sub-
sidies will be needed, and the character
of subsidies is, for practical purposes, lim-
ited only by the imagination. For ex-
ample, ancillary recharging equipment
can be given away, maintenance training
can be funded, and guarantees/warranties
can be established. As well, costs borne
by early adopters essentially subsidize de-
bugging in subsequent target markets.
The case text and exhibits only hint at
some of the possible forms of subsidiza-
tion and externalities.

Technologically, product standardiza-
tion at all levels sends strong signals that
lower risk and switching costs. Here, it
is not absolutely certain that batteries will

become the heart of the eventual dominant EV design. It is only certain that battery-powered vehicles are the most feasible path to complying with the mandate. If the mandate collapses, a less urgent path taken towards the development of electric vehicles may follow an entirely different trajectory, such as exists in the superior but longer-term potentials that exist in fuel cells, flywheels, and hydrogen. On the other hand, politically-induced, large early commitments made in battery technologies might be creating an irreversible path-dependence in them, regardless of their inherent limitations relative to other electric and ultra-low emissions technologies. In short, unambiguous standardization signals are probably not coming in the near future, but GM is in an opportune position to begin writing the technology rules in its favor.

Yet, management at GM would be wise not to assume too quickly that all required competencies are possessed in-house. The case indicates, for example, that marketing EVs might need some significant innovation; perhaps traditional automobile dealerships are not the best channel for marketing a product that some feel is basically electronic, not automotive. Mass merchandisers of electronics, for example, might be viable distribution infrastructures.

Finally, opportunities in other nations seem more naturally amenable to successful EV commercialization. GM already enjoys a global presence and if it is serious about electric vehicles, should probably be taking a global view. If all GM chooses to do is comply politically, then building a "California car" demurs some of its global/technological leadership opportunities

INTERNAL (VALUE-CHAIN) ANALYSIS OF GM AS A WHOLE

Management and Organization

- Professional, experienced management
- Classical corporate bureaucracy, divisional structure
- Climate is politically charged and adverse to competence-destroying change
- Vast financial power, "deep pockets"

- and ability to incur huge losses
- Fluctuating periods of large gains and losses; not a Wall Street darling
- Mix of strategic and financial goal-setting (e.g., market share v. ROI)
- Significant overhead hurts overall cost of capital
- Extensive information capabilities
- Significant political power even at very high levels
- Investors show impatience and stress short-term returns (stock prices)
- Lackluster image for technological innovation
- Public perception of new-technology sabotage to maintain the status quo
- Strong supportive subsidiaries such as Hughes and Delco
- Weak relationships with Ford and Chrysler; somewhat better overseas

Human Resources

- Strong training program
- Relations with organized labor can be strained
- Relationships have a tendency to degenerate into hostility and threats
- Career tracks favor "car guys"

Technology Development

- Impact prototype established; much of it accomplished internally
- Ability to transfer Impact technology to large-scale production still very unproven
- The EV unit is still able to operate independently and entrepreneurially
- Large 'impact' on the direction of the USABC
- Strong relationship with Ovonic (practically proprietary)
- Generally methodical and by-the-book
- Long product-to-market cycles compared to industry benchmarks
- Huge sunk and fixed costs
- Costs pressure off-the-shelf solutions and product standardization
- Driven by specifications and standards
- Many diverse engineering disciplines, Design-to-Goals

Procurement

- Generally adversarial
- Huge bargaining clout
- Some strong partnerships but "arm's length" culture apparent

Quality of inputs vital to the value of outputs

Inbound and Outbound Logistics

- Keys to inventory (JIT) management
- Strong physical distribution

Production

- Geared to Tayloristic mass production, "produce to inventory" instead of demand
- Capital intensive and becoming "smarter" all the time
- Scale, scope, and learning economies dominate decisions
- Capacity utilization is a key
- Control of costs is key
- GM culture is union-bound
- Continuous improvement of processes is key

Marketing and Sales

- GMAC
- Enormous brand capital
- Excellent resources for market intelligence; Impact test drive program
- Ability to command "free publicity" through press releases
- Generally an 800-pound gorilla; does what it wants with impunity

Product Support

- Very strong network of dealers, parts suppliers, trained/skilled people in all areas
- Many thousands of independent companies provide strong network
- No EV support anywhere: facilities, materials, training, technical data
- Reverse logistics mature

SUMMARY OF STRENGTHS, WEAKNESSES, OPPORTUNITIES, AND THREATS (SWOT)

Strengths

- Financial power
- Marketing power
- Political power
- Systems engineering
- Integration of R&D through field support and service

Weaknesses

- Inertia of "old" technology development and production paradigms in almost all areas

Product development cycles
Fluctuating R&D commitments
Negative climate for truly revolutionary product and process innovation
Tyrannized by short-termism despite long-term strengths

Opportunities

Political leadership, national agenda-setting (including Contract With America)
De facto and formal dominant designs still “anybody’s guess”
Agenda setting in publicly-financed R&D
Many new and inevitable start-ups starved for cash
Market leadership, view of EVs by a huge and wealthy demographic (baby boomers)

Threats

Public and political image
The California mandate and hostility towards the internal combustion engine
Visibility to, and demands from, Wall Street
Unions ensconced in the status quo
Lessons from history regarding competence-enhancing and competence-destroying innovations

Epilogue (Schnayerson, *The Car That Could*, 1996)

1996

Management decided to stick to Plan B. Development continued on a production version of the Impact, while the PrEView test drive program maintained a reasonable veil of secrecy, or at least strategic ambiguity.

A variety of normal, sometimes unforeseeable technical problems continued to erupt, and were solved one-by-one. Morale was difficult to sustain, though, as the program had experienced so many near-death experiences and rumors continued to sap individual will. Public as well as internal signals sent by GM (and other industry) brass continued to sound fork-tongued, and few people were ever really sure about the future of the Impact one way or the other. Then, in the 4th quarter of 1995 GM profits were \$1.87

billion, and profits for the year were a record \$6.88 billion. Such a turnaround eliminated much of the internal threat to the program.

The early hoopla surrounding developments in NiMH technology were to become appreciated as optimistic, as normal prototyping bugs slowed down progress. For instance, interface problems between battery packs and EVs caused overheating problems, on which GM and ECD engineers both blamed each other. Also, scaling-up the prototype version to mass-production turned out to be difficult, and costs did not come down very rapidly. But its overall, mid-to-long-term technical promise remained encouraging.

Regulators and policy-makers continued to monitor battery developments very closely, not only of NiMH and other USABC projects, but dozens of other projects going on around the world as well. Based on extrapolations of likely progress, in late 1995 the California legislature rolled back the mandate. Under the new mandate, 10% of new vehicles sold by 2003 must be zero-emitting, not 2% by 1998. Some felt that this decision was a covert compromise among Big Three and CARB officials, but such rumors were denied. At any rate, the change was generally interpreted as a major shift in California’s resolve.

Media battles continued to rage, and sometimes became sensational. For example, a severe chill was sent through the emerging EV industry when environmentalists themselves released a report addressing the worrisome effect of so many more lead-based batteries being produced. On this and other suspicions and forecasts, point was followed by counterpoint almost endlessly in virtually all major media venues. The truth was forever hard to pin down.

In the summer of 1996, GM publicly announced that it would mass-produce the Impact and begin retail/dealership sales in the fall. In the fall, lead-acid battery Impacts began to be sold through Saturn dealerships in California and Arizona. However, not just anyone could buy an Impact, and not only because the price tag was \$35,000. GM’s policy mandated that prospective purchasers had to fill out questionnaires about their lifestyles and driving habits before they could buy an

Impact; this was to make sure that the vehicles were not sold outside their very limited niche, hence develop poor reputations, and “poison the well” for subsequent GM EVs. Also, Impacts could only be leased, not purchased outright — for nearly \$400 each month. The first-edition Impacts had a range of 70-90 miles, and it was no secret that subsequent models would be powered by NiMH technology. GM also announced that in 1997 an electric S-10 pick-up truck would be available; orders were quickly accepted for about 1,000, to be sold mostly as industrial fleet vehicles, for about \$22,000 apiece after subsidies.

Baker continued as Vice President for Research and Development.

1998 and forward:

As the century ended, GM was still committed to the EV-I, the name chosen for the vehicle instead of *Impact*. On June 15, 1998, Bill Moore, GM VP and Chief Environmental Officer, was interviewed in evworld.com/reports/env98-minano.html. He said ““Back when we started the electric vehicle, we decided to look at it not as a novelty or a way to fill demand by government authority, but as a business opportunity. We believed and we know now that people care about the environment and want to minimize their impact on it, but they also value their mobility. Marrying these two concepts in environmentally friendly modes of transportation is not only smart, it is essential.”

The article continued, “He pointed out that GM has invested \$350 million dollars to build the EV1 [sic] ... However, after some 18 months the company has leased only 400 vehicles ... consumers wanted more room and more range from their EVs, but above all they want fast, convenient charging facilities, lots of them. As a result, GM learned three very important lessons: (1.) Neither government nor industry can dictate consumer behavior; (2.) Without a proper infrastructure, alternative propulsion vehicles will fail to move from niche market popularity to the preferred mode of transportation; (3.) Beyond innovation, success requires cooperation and collaboration by all the stakeholders from manufacturers to regulators to environmentalists to utilities.”

Six points were stressed as a framework for eventual success. "Innovation, not regulation, should guide everyone in the industry ... Standardization is required to help cut costs, drive market development, remove market uncertainties, and alleviate consumer anxiety ... Incentives by both [sic [state, local and federal agencies are needed ... Infrastructure in the form of large scale deployments of public recharging stations are needed ... [and] Involvement by electric utilities [is needed.]"

Events continued at a rapid pace, and interested observers are highly encouraged to visit two excellent websites:

evworld.com and **gmev.com**

The former website provides a wealth of information concerning all kinds of EV developments worldwide; the latter is an extensive archive of information concerning the EV-I and more to the point, "Generation II." Photos, drawings, and extensive technical information are provided. The following specification data is extracted directly from gmev.com/specs_specs_top.htm:

Propulsion/Electronics

- Configuration: transverse-mounted, front-wheel drive
- Motor Type: three-phase, alternating current induction, electric
- Power Rating: 102 kw (137 hp) @ 7,000 rpm
- Motor Torque: 150 Nm (110 lb-ft) @ 0-7,000 rpm
- Transaxle: single speed with dual reduction gears
- Drive ratio: 10:946:1
- Power Management System: insulated gate bipolar transistor power inverter
- Battery Packs:
 - Standard: High-Capacity lead-acid battery pack - 1319 ponds
 - Optional: NiMH battery pack - 1147 ponds
- Chargers and Charge Port: listed by Underwriters Labs
- Battery Pack, Charging System and Vehicles: classified by Underwriters Labs for indoors charging

Body/Chassis: 2-passenger coups
 Body Type: aluminum alloy structure joined with welds, rivets

Dent/Corrosion Resistant Composite Exterior Panels: hood, doors and trunklid (sheet molding composite); front fenders, rear quarter panels, rocker panels, rear-wheel skirts, aerodynamic bellypan (reinforced reaction injection molding polyurethane)
 Body panels 100% recyclable and lightweight

Suspension:

Front. Aluminum short/long arm with coil spring over shock absorber with stabilizer bar.
 Rear. Multi-link aluminum beam with Penhard rod.

Steering:

Type: Electro-hydraulic, power rack-and-pinion (speed sensitive, variable effort)
 Steering ratio: 16.5:1
 Turning Diameter: 32.5 ft
 Steering wheel turns: 3.0

Braking:

System: Electro-hydraulic, power-assisted front and electric rear with blended regenerative and anti-lock features
 Front: 9.65 in. solid disks with aluminum calipers
 Rear: 8.9 in. metal-matrix composite drums with electric actuation
 Parking: electric actuation with gear selection or push button

Wheels: 14-in aluminum alloy

Tires: Michelin, all-season radial with self-sealing, puncture-resistant feature

Safety Features

- Anti-lock brakes
- Traction control
- Check tire pressure system
- Air Bias and three-point shoulder/flap seatbelts
- Projector lowbeam/reflector optic highbeam headlights
- Daytime running lamps
- Keypad entry
- Electric windshield and rear window defogger

Comfort Features

- Power windows, door locks and outside mirrors
- Cruise control
- Sound system
- Center-mounted vacuum fluorescent instrumentation
- Interior courtesy lights
- Solar reflective/absorptive glass
- Intermittent windshield wipers and washer
- Remote hood and trunk releases
- Four-way adjustable bucket seats, lightweight aluminum alloy frames
- Carpeted floor mats
- Carpeted cargo area with net

Performance

- 0-60 mph in less than 9 seconds
- Electronically regulated top speed of 80 mph
- 0.19 drag coefficient (25% lower than any other production car)
- Range:
 - Standard Batteries: 55 to 80 miles per charge
 - NiMH: 75 to 135 miles per charge
- Energy Consumption:
 - Standard: 26 city / 26 highway kW/

	GenI Delphi Lead	GenII Panasonic Lead	GenII NiMH
Number of Modules	26	26	26
Battery Pack Weight	1,177 pounds	1,310	1,147
Nominal Voltage	312 v.	321 v.	343 v.
Regulated pack Capacity	48 ah	60 ah	77 ah

hr per 100 miles

NiMH: 34 city / 30 highway

Recharging at 70 degrees and standard conditions

Standard: 5.5 to 6 hours @ 220 volts

22 to 24 hours @ 110 volts

NiMH: 6 to 8 hours @ 220 volts

Pricing (tax, title, license, registration not included)

Gen II Lead-Acid Batteries for California:

MSRP: \$33,995

Lease: \$424 to \$574 per month

Charger installation: extra

Charger: included

Mileage charge: \$0.35 per mile over 36,000 miles

Gen II NiMH for California:

MSRP: \$43,995

Lease: \$499

Charger installation: extra

Charger: included

Mileage Charge: \$0.50 per mile over 36,000 miles