Chevrolet VOLT
A Disruptive Innovation Bridge to Electrified Transportation[1]

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"Conceived by few and executed by many" was the key success factor of Chevrolet Volt development, recalled Jon Lauckner[2] at a December 2010 event celebrating the vehicle's market launch. It was a long and intricate path from that faithful afternoon discussion with Bob Lutz, General Motors Vice Chairman, in January 2006 when Jon drew the extended-range electric vehicle (E-REV) concept on a piece of paper. Bob Lutz had an "all-electric" dream to regain General Motors (GM) reputation for technological leadership lost to Toyota in part because of the successful Prius hybrid electric vehicle.

Jon's argument against a *pure* electric vehicle was convincing: GM needed to decouple technological development of an all-electric propulsion system from the development of complementary technologies such as low cost, high energy-density batteries and a ubiquitous public/private infrastructure for battery charging. GM needed a revolutionary electric vehicle design that could penetrate the mass market in the short term and bridge the way to realization of the technical potential of all-electric transportation in the long term. The proposed E-REV would be driven by an electric motor which was powered by a rechargeable battery with a 40-mile drive capacity - exceeding the daily commuting range of most American drivers. The propulsion system would also include a combustion engine and generator subsystem that seamlessly takes over when the battery was depleted to generate electricity for longer commutes to avoid "range anxiety" for the drivers.

Jon was encouraged that Bob Lutz had concurred with his concept and had asked him to initiate a project to develop an E-REV concept car, the genesis of Volt. Back in his office after the discussion with Bob Lutz, he contemplated the project plan. The dark winter clouds visible from his office window reminded him of the challenging road ahead. What is the most effective management approach for developing a disruptive technology in a large company? What is the right mix of skills for the project? What is the right product strategy integrating the business, technology, marketing and operational strategies for a *green* new-to-market vehicle concept? He was determined to develop a game changing product that surpassed the competition and laid the foundation for GM leadership in electric propulsion systems of the future.

1. General Motors Corporation and the Competitive Landscape in 2005

General Motors was founded on September 16, 1908. At its inception GM held only the Buick Motor Company, but in a matter of years would acquire more than 20 companies including Oldsmobile, Cadillac, and Oakland, which was renamed Pontiac. Currently, General Motors offers a comprehensive range of vehicles in more than 120 countries around the world. GM's top five markets by sales are China,

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[1] Professor Dariush Rafinejad prepared this case with generous support of General Motors Corporation as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation. Dr. Rafinejad is a core faculty at Presidio Graduate School and Consulting Associate Professor at Stanford University, Management Science and Engineering Department.

[2] Jon Lauckner is currently GM's CTO, VP of R&D and President of GM Ventures.

the United States, Brazil, the United Kingdom, and Germany. More than 70 percent of GM sales in 2012 came from outside the U.S.

Exhibit 1 describes GM's vision, technological focus, five guiding principles and its social/environmental commitment.

While GM had led the auto industry for most of the 20th century, overseas competition, particularly Japanese automakers, grew strong toward the turn of the millennium and threatened to upset GM's leadership position. GM's revenue history vs. Toyota Motors Corporation is depicted in Exhibits 2. The financial crisis of 2008 created a major recession in the U.S. economy and particularly in the auto industry. GM, running critically short of operating cash, went through a severe restructuring of its operations and emerged from bankruptcy in 2009 with strong support from the U.S. government.

In its tradition of technological leadership, GM was the first company to develop the modern all-electric vehicle, the EV-1. In response to a Zero Emission Regulation mandated by California Air Resources Board in 1996, GM invested an estimated $1B to develop and launch EV-1, a two-seater car with a range of 50 miles between charges. It used a lead-acid battery, which later was upgraded to use nickel-metal-hydride (NiMH) battery. Low demand, high production cost and reversal of the California mandate persuaded GM to discontinue the product in 2003. In addition, GM retrieved the EV-1s from all 1200 customers (to whom the car had been leased) and crushed all of them. The latter proved to be a public relations liability for the Company.

Toyota's response to EV-1 was the introduction of Prius in late 1997. Its hybrid electric technology achieved high fuel efficiency and demonstrated Toyota's technical prowess. Prius was a mid-sized sedan powered by a hybrid drive system with NiMH batteries that could store regenerative energy during deceleration and breaking and achieve 45 miles per gallon (mpg) performance. Although other auto makers including GM had also developed the hybrid technology, only Toyota and Honda had commercialized the technology in the late 1990s. Honda's hybrid car, Insight, had a limited success but Prius became a major success and propelled Toyota to a technological and commercial leadership position, surpassing GM for the first time. Toyota was also recognized for its environmental leadership because of Prius and its hybrid technology. Conversely, GM was positioned as lagging in technology because of slow adoption of the hybrid technology and as having a poor environmental record by marketing products like the Hummer or "killing" the electric car, EV-1. In 2007, Toyota replaced GM as the number one automobile manufacture in the world.

An additional challenge to GM's technological leadership came from an unlikely competitor, Tesla Motors. Tesla Motors was founded in 2003 in Silicon Valley to develop a high-performing sports electric vehicle targeted at the high end of the market. The Tesla Roadster, powered by lithium-ion batteries, was launched in early 2008. By the late 2000s, several other companies introduced all-electric, hybrid electric or plug-in hybrid electric (PHEV)[3] cars including: Nissan's all electric Leaf and Toyota's PHEV Prius. Chrysler introduced an extended-range electric vehicle (E-REV) *concept* at the 2009 Detroit Auto Show.

GM needed a game changer.

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[3] See Exhibit 3 for definitions of various technologies according to the Society of Automotive Engineers (SAE), International.

2. The Driving Force and Product Strategy

The strategic thrust for development of the Volt was the imperative competitive factors shaping the market in mid 2000s. The Volt program goals were: 1. Regain market and technology leadership by surpassing Prius; 2. Develop the building blocks of technology for comparative advantage in the growing electric transportation segment; 3. Respond to the underlying environmental sustainability and national security concerns of the dependence on oil.

CEO Rick Wagoner announced GM's strategic outlook in 2006 at Los Angeles International Auto Show and stated that: "Going forward, it is highly unlikely that oil alone is going to supply all of the world's rapidly growing automotive energy requirements. For the global auto industry, this means that we must – as a business necessity – develop alternate sources of propulsion. … The key as we see it at GM, is energy diversity. We believe that the best way to power the automobile in the years to come is to do so with many different sources of energy."

Since the introduction and rapid penetration of Prius in the U.S. market in early 2000s, the idea of developing a competing hybrid car had been raised several times at GM. But the idea had been rejected because the required $300 million R&D and $500 million production capital could not be justified (Ref. 3). Prius was deemed to be losing money at the prevailing market price of $22K and the estimated manufacturing cost of $24K. However, as Bob Lutz explained, "Toyota's investment criteria was different, they developed Prius and used it to position the company as ever attuned to the needs of the society rather than financial gain." And "... one marginally money-losing hybrid car, Prius, could suddenly prove to be the tide that floated all other Toyota boats."

In addition to the hybrid drive, General Motors R&D had developed other propulsion technologies such as hydrogen fuel cells, which were showcased at various auto shows. A significant design and manufacturing capability in electric propulsion technology had been developed through the EV-1 experience.

Bob Lutz[4]'s original idea for a new vehicle that would enable GM to gain competitive advantage over Toyota was a four-seat electric car with lithium-ion (LiOn) batteries. He proposed this idea at several meetings of the GM's Automotive Strategy Board (ASB) in 2005, but he could not win their approval to proceed. There were several arguments against a LiOn electric vehicle (EV) including: 1) The LiOn battery was not ready for automotive applications and was a high risk; 2) GM had to choose EV over other technologies, such as the fuel cell technology, which were competing for the R&D budget; 3) EV-1 experience had demonstrated that there was no viable market for an EV; and 4) GM (at that time) together with other car manufacturers was engaged in a lawsuit against the State of California's EV mandate.

[4] Bob Lutz was not new to automotive batteries. Before returning to GM in 2001, he had been chairman and CEO of automotive battery supplier Exide Technologies for three years. Prior to Exide, he had also been a Senior Executive at Opel, BMW, Ford and Chrysler.

The management decision timing was critical since Bob Lutz worried that Toyota might introduce an all-EV any day to extend the success created by Prius. The announcement by Tesla Motors that it was developing a LiOn battery-powered EV gave Bob Lutz the needed ammunition to mitigate concerns over LiOn batteries and to win ASB's approval to develop an EV *concept*[5] car. ***Volt was born***!

In subsequent brainstorming sessions, Jon Lauckner's idea which persuaded Bob Lutz that an all EV was not viable for the mass market (in spite of its attractive technological purity!) was further developed into an extended-range EV (E-REV) with a 16 kWh battery pack and a 1.4-liter internal combustion engine (ICE). The battery would power the vehicle for the first 40 miles[6] and the ICE would power an electric generator to drive the propulsion system for additional 300 miles (Exhibit 4).

In 2011, a year after Volt was introduced to the market, Bob Lutz reflected on the strategic impetus for its development (Ref.4): "*The Volt means a lot to GM and to the industry on a variety of levels. First of all, this is a solid technology that is going to be proven reliable. It's a practical way that we can electrify the automobile and drastically reduce our dependency on imported petroleum. It's also important to GM to help reinforce and continue its proud history of technological innovation, and to help restore the image of leadership that accompanied that history." "Volt is a shining testimonial to the company's vision and willingness to accept large risk. …Volt is the future."*

3. Disruptive Innovation in a Large Company

Jon Lauckner argued that the Extended Range EV (E-REV) concept had many benefits. On the one hand, it removed the range anxiety of a pure EV and on the other hand, it did not require excessive battery capacity for a 100-200 mile range which, at the current state of battery development, meant excessive weight and cost. Furthermore, the E-REV decouples the vehicle's success from availability of public infrastructure for charging the battery; the problem that EV-1 faced. And finally, E-REV was an optimal transitional concept to pure EV because the drive system was electric and the onboard IC engine was merely another source of generating electrical energy. The future roadmap for the vehicle could readily adopt a variety of engine technologies including alternate fuel engines (bio-ethanol, diesel, hydrogen or natural gas), fuel cells or no engine at all for a pure EV configuration.

Volt's extended range concept represents a disruptive technology that can transform the transportation industry and its infrastructure by creating a bridge to an all-electric system. Volt has also a disruptive potential for the society by enabling environmental sustainability through substitution of oil with electricity from renewable sources.[7] For the end users however, Volt is not a *disruptive technology* as defined by Clayton Christensen[8] - it does not create new markets or new users via affordable and accessible functions.

The E-REV concept was inspired by the innovation of *lead users*[9] at GM. A similar powertrain was used in 1994 during the EV-1 development. Andrew Farah (the Volt Chief Engineer and one of the EV-1 development engineers) recalled the *innovation* process when he and other EV-1 engineers converted EV-

[5] *Concept* car in the auto industry is often nothing more than an expression of intent for future vehicles and public demonstration of the company's technological and design prowess at trade shows.
[6] The 40 miles range was chosen (over the initial 10 miles estimate) based on a marketing study that showed the daily trips of 80% of American drivers were 40 miles or less.
[7] Volt is a *sustainable product* because it is an enabler in *sustainable development*.
[8] Clayton Christensen, "Innovators Dilemma", 1997.
[9] Von Hippel, E., "The Sources of Innovation", Oxford Univ. Press, 1998.

1 prototypes into an E-REV out of necessity[10]: "We were driving the EV-1 back and forth across the state on a regular basis. Because the engineers needed more miles to do their work than the batteries alone would provide, they devised small trailers equipped with gasoline-powered generators that their EV-1 test vehicles towed along behind. Push a button and it generated electricity, and as long as you were not driving faster than sixty miles per hour, you could keep driving until the gas ran out."

Developing a disruptive technology in a large company is a mixed blessing. While there exists superior capabilities in marketing, technology, operations, business processes and financial management[11], decision-making agility is often lacking and there is aversion to risk. This creates a unique environment that is both supportive and challenging for disruptive technologies to thrive and come to fruition. In contrast to a disruptive technology, sustaining technologies aim to continuously improve the existing products and hence are maintained by the status quo inertia. Sustaining technologies enjoy the support of the incumbents and are reinforced by existing business processes, which are robust and risk averse. The disruptive technology on the other hand requires a new strategy and business model whose outcome is uncertain.

Jon Lauckner could count on GM's deep knowledge of the auto industry, world-class design and manufacturing technology to lead the Volt project through all phases of the product development process including market launch. However, he had to navigate within a complex network of stakeholders with disparate experiences, interests, and strategic and tactical objectives. The stakeholders represented multiple vertical and lateral levels of the organization following entrenched business processes - from the CEO to functional managers and management review committees.

Even though the Volt champions, Bob Lutz and Jon Lauckner, held senior executive positions at GM, the complexity of the product development process in the large company and the forces of sustaining technologies abated their power and influence. But as Jon Lauckner pointed out, leaders must have the necessary skills to "*persevere*" through a courage of conviction, a strong will to overcome objections, and a profound knowledge of the product and technology. They must also be able to articulate the long-term benefits to the company, including the benefit of being first.

After the E-REV concept was communicated to the ASB (Automotive Strategy Board) and received its tacit approval to proceed, the "*institutional forces*" of sustaining technologies kicked in citing all kinds of problems. Many colorful discussions ensued between "them" and Bob and Jon who had to blunt the forces of the nay-sayers across the company who stated that "it cannot be done"! "*GM's culture creates defensive antibodies against development of radically new technologies like Volt! Antibodies attack innovations like Volt and argue that we cannot do that*", said Andrew Farah. However, the strong executive support from the beginning of the project provided the necessary shelter against the organizational *antibodies*.

Jon Lauckner, believing that successful innovations are "*conceived by few and executed by many*", was mindful of the People vs. Process tradeoffs. Individual initiatives are often under-valued when the *processes* take over and the company becomes "process-oriented" - believing that the best ideas come from well-oiled processes rather than individual ingenuity. Jon remained steadfast to the original E-REV

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[10] Reference 2 in this document.

[11] According to Scott Anthony, the advantages in a large company for innovation are: global infrastructure, strong brand reputation, partnership relationships, scientific knowledge, experience with regulators, and process excellence. Source: The New Corporate Garage", HBR R1209B, Sept 2012.

design concept (of an electric car with 40 miles electric battery range plus an engine for the extended range) throughout the program. When Bob and Jon faced political, management and technical challenges during the project execution, they did not waver nor did they compromise in bringing the initial vision to market. To win, the project leadership team had to make the *organization* accept the inherent risks and challenges (of the new technology and unconventional approach) and to execute the program successfully in solving the technology problems to maintain management support. To assure quick decision-making, Bob and Jon also decided to form a unique Leadership Board for the program, established a dedicated team in each product development area, and assigned project leadership roles to people with technical expertise and creative vision.

While the development of Volt - a disruptive technology in a large company - proved challenging, significant organizational learning ensued. Volt proved to GM what was possible and the importance of embracing inventions. Many members of the Volt team were promoted to higher levels and took their product development lessons to other parts of the organization.

4. The Project Team

The organizational structure of the Volt project is shown at three levels in Exhibits 5a, 5b and 5c: Executive Management, Concept Phase, and Production Vehicle Phase, respectively. The Executive Management structure was composed of two review boards: The Automotive Strategy Board (ASB) and Automotive Product Board (APB), whose membership included Rick Wagoner (CEO), Bob Lutz (Vice Chairman), Tom Stephens (Group Vice President of Global Powertrain), Ed Welburn (Vice President of Global Design), Jim Queen (Vice President of Global Engineering) and Jon Lauckner (Vice President of Global Program Management.) These Boards oversaw the strategic direction and execution of the program and made recommendations to the GM Board of Directors for funding R&D and strategic investments in supply-chain partnerships and production facilities.

GM's standard product development process also included reviews by the GM Global Product Development Council (GPDC). In the case of Volt, APB agreed with Jon Lauckner's recommendation to form a Leadership Board (LB) of Senior Executives to oversee the program in lieu of the GPDC. The LB had 12 high level U.S.-based executives including Bob Lutz, Tom Stevens and Jon Lauckner and met with the development team on a monthly basis; indicative of what Jon Lauckner observed as "more active involvement of the senior leadership in today's climate."

From the onset, the formation of the project team by Bob Lutz and Jon Lauckner was different from GM's traditional product development team and management structures. This was perhaps somewhat attributed to the program leaders themselves. Jon Lauckner noted that "Bob Lutz was *wired* differently than other executives; and so was he." Bob Lutz's choice for the program leadership was Jon Lauckner because he "was an engineer and a brilliant schemer" and could be counted on to produce results. Jon was the VP of global program management (for vehicle development) with a B.S. in mechanical engineering from the University of Michigan and an M.S. in Management from the Stanford Sloan Program. He had also attended the GM-Harvard Sr. Executive Program.

In taking a disruptive technology to a high volume vehicle for the mainstream mass market, "you need the right mix of *quant* and *poet* types of people", said Jon Lauckner. At the initiation of the concept and feasibility phase, Jon gathered a small team of unconventional thinkers to create technological breakthroughs that were both affordable in production and met global safety standards on an accelerated schedule. He knew who the likely candidates were and unofficially "recruited" them. Jon warned them that the project had many technological challenges and required a lot of hard work. The characteristics and sources of motivation among the team members varied. Many of them were passionate about the EV concept and knew a lot about the technology. EV-1 people knew its flaws too and wanted to fix them. Others had profound technological capability and experience in related technologies like the fuel cell and hybrid vehicles - they liked the technical challenges of Volt and wanted to work on the project (even part time).

The concept vehicle was named iCar and the team's charter during the concept development phase was to verify the feasibility and viability of the proposed E-REV concept. Tony Posawatz was assigned as the project manager to produce the concept car for the Detroit Auto show in January 2007 (Exhibit 5b). While initially he was the only full-time engineer assigned to this project, Tony was motivated by the innovation and technological challenges of the iCar and strived to develop it not just as a concept car for the show but with design capabilities necessary for volume production and commercialization.

Cristi Landy, who was a "Chevrolet person", was assigned to the project as the product marketing manager from the beginning during the iCar planning stage in 2006. This was unusual as GM concept cars are often created to stimulate thinking about future designs and technologies, and not to target commercialization. Cristi represented the Chevrolet marketing department and was responsible for knowing the customer requirements (voice-of-the-customer) and for working with the product design team to ensure compliance to maximum possible extent.

The battery development task was assigned to Denise Gray whom in summer of 2006 had been promoted to be GM's first global director of rechargeable energy storage systems responsible for all hybrid vehicles and future storage technologies.

After the 2007 Detroit Auto Show where the concept was unveiled, the initial Concept and Feasibility (C&F) team was folded into a larger, formal Volt Program team for development of the production car. This team comprised the best talent at GM, numbering several hundred (Exhibit 5c). The team leader was Frank Weber, who was brought in from Opel division in Europe in February, 2007. Weber's role and responsibilities as the Volt Program leader were different than the leaders of other vehicle development projects in the standard GM process. In the standard process, the product development (PD) organization was headed by two leaders: first, a *vehicle line executive* in charge of program management including schedule, budget and product commercialization; and second, a *chief engineer* responsible for delivering a vehicle that met all design and engineering requirements.

Volt's product development organization combined the above two functions into one position that was assigned to Frank Weber. Frank was a hands-on system engineer who liked to *create the future* and had the right mix of technical and business experience. He was technologically savvy and could navigate the unchartered territory of creating Volt's new technologies. He also had extensive product planning, production, marketing and project management experience at GM. Frank was motivated to take on the project because he cared about the environment and saw Volt as an opportunity to make a difference for society and to reduce the environmental footprint of transportation.

The other members of the production-vehicle-development team included several EV-1 veterans, fuel cell engineers (who brought the knowledge of power electronics and high voltage energy management system), hybrid engineers (with knowledge of regenerative breaking systems and electric motors), the gasoline engine team (representing a century of expertise in combustion engine vehicles), and many new engineering hires. The notable late additions were: Andrew Farah (the EV-1 chief engineer) who came from GM Europe in August of 2007 as the Chief Engineer for Volt, and Pam Fletcher[12] as the Global

[12] Pam Fletcher is currently the Executive Chief Engineer for all GM EV products.

Voltec and plug-in hybrid electric powertrain chief engineer. As Pam put it: "she was not one of the early team members but was brought on-board at the reality check-in time."

Several cross functional teams were created to carry out the development of critical subsystems of the product. For example, the cross functional team for development of the Rechargeable Energy Storage System (RESS) was responsible for systems engineering, controls, heat transfer, electronics, high voltage wiring, manufacturing, quality, purchasing, and project management. The RESS team was segmented into Product Development Teams (PDTs) who would design, manufacture, test, and validate prototypes of components and subassemblies of the RESS. The PDTs were coordinated by a RESS System Integration Team (SIT) and a RESS Integration Team (RIT). The SIT ensured RESS met the requirements for mass, cost, quality and manufacturability and the RIT managed the physical integration of the RESS and controlled the interface control documents (ICD.)

The other key subsystem managers were the *design director*, responsible for development of the Volt's appearance during both concept and production design phases; *interior and exterior design managers* to lead the development of the interior and exterior appearance themes; a *Human Machine Interface (HMI) manager* to design the controls and displays; and finally the *safety and crash managers.*

The project team members came from GM offices around the world including: Germany, UK, New York, Michigan and California. Some of the software was done in India. However, because subsystem integration was a critical task of the product development, most of the development engineers were co-located.

The Volt development team went through tough times including the financial meltdown (2008), GM bankruptcy (2009), government-funded resurgence, CEO turnover and even loss of a few key engineering executives. Some of the team members went to Germany to develop the European version of Volt, the Opel Ampera. In spite of the difficulties, the Volt management team under the leadership of Jon Lauckner maintained the project momentum and the focus on the original program objectives. Furthermore, the resources of the program were not reduced and the executive management support continued unabated.

5. Project Execution: Invention on the Critical Path

The Volt product development timeline including manufacturing milestones are depicted in Exhibit 6. The Vehicle Development Program Documents and Approval Gates to Production Release are also listed. The product development process is described in Exhibit 7.

In June 2008, 17 months after the concept car debut at the Auto Show, the GM Board of Directors approved a budget of several hundred million dollars for development of the Volt as a production vehicle. The precise engineering budget for the program has not been disclosed. GM's investment was over $800 million in Michigan alone including the Detroit-Hamtramck (DHAM) plant where Volt is assembled and $43 million in the Brownstown battery plant facility for manufacturing of the battery pack. In addition, as part of the U.S. Recovery Act, the Department of Energy awarded GM over $240 million for high volume assembly of the battery pack and electric motors and for testing of hundreds of (pre-production units.)[13] The initial Volt battery cell manufacturing plant was built in Holland, Michigan by the Compact Power Corporation, a subsidiary of LG Chem with $150 million (50% cost share) funding from the U.S. Government.

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[13] http://www.youtube.com/watch?v=OOsCpuWcV0g
http://www.foxnews.com/us/2012/10/08/lg-plant-that-got-150m-to-make-volt-batteries-in-michigan-puts-workers-on/

To keep the project team focused through the upheavals of the external environment, the leadership team established three guiding principles in managing the project and making choices among conflicting requirements: design for 40 miles of EV range; Volt is for all customers everywhere globally - operating in different climates and satisfying both early adopters and mainstream users; and start volume production in November of 2010. Pam Fletcher required her team members to sign up to three credos: “I cannot fail; I am responsible; No sacrifice is too big” - and this meant many long days, weeks and months!

Marketing was involved in the project from the beginning in 2006; however, customer research did not get into high gear until early 2007 after the concept car was unveiled at the Detroit Auto Show. During the concept car phase, the Product Manager, Cristi Landy developed the product “content” listing the unique features that had to be designed in the vehicle.

Marketing held focus groups with owners of various types of cars including midsize hybrids, EVs (including EV-1), and the Toyota RAV4 EV. These focus groups provided valuable information about what they liked and did not like about their cars and made suggestions for the Volt. A representative from GM’s Opel subsidiary in Germany assisted in defining the user interface requirements including the two seven-inch display screens with coordinated motion and sound. The focus groups also performed evaluative research on multiple design concepts and features including: four vs. five seats, manual or powered seat adjustment, 24/7 Internet connectivity, ease of plug-in and recharging, and design of the two display screens for navigation map and advanced electronics capabilities. Marketing pushed to maximize the standard features on the vehicle commensurate with its target price.

Engineers wrote the requirement specifications for all subsystems although many of the requirements, particularly those of the controls and software, evolved during the program. A significant challenge brought about by the newness of the E-REV technology was identifying the new and non-traditional stream of regulatory requirements by the Environmental Protection Agency (EPA), Underwriters Laboratory (UL), electric utilities (represented by the Electric Power Research Institute - EPRI) and various municipalities. For example, the standards for EPA certification that was necessary for product commercialization did not exist for Volt as a new class of vehicle. A dedicated Volt team helped the skeptical EPA regulators develop the new labeling method and test procedures for the vehicle while going along with the EPA timeline which was not always aligned with the project’s tight schedule. Exhibit 8 shows the EPA-DOT Fuel Economy and Environment label for a 2013 Volt. Another Volt team worked with the International Society of Automotive Engineers (SAE) to revise the J1772 standard for Volt’s plug-in charging equipment which also met UL safety requirements.

The standard GM vehicle development process required all technologies to be proven to the “readiness” point before adopting them in the product design. However, Volt development process deviated from this rule and consequently created a few process challenges in the GM system. Bob Lutz characterized the Volt process as “decoupled development” – decoupling the “most engineering-intense subsystems” from the development path of the rest of the vehicle. For example, the Rechargeable Energy Storage System (RESS) development followed a non-standard process practiced in advanced technology R&D. The RESS development cycle started with definition of the requirements and went through five pre-planned design and test iterations.

The tight project schedule placed the battery and propulsion system innovations on the critical path to production, requiring the managers to be knowledgeable about the details and available for timely decision making on a short notice. The project’s guiding principles helped prioritize alternate choices.

Volt's new and more stringent design requirements led the engineers to take a more cautionary design approach than was customary in the standard product development practice. For example, the team decided to over-engineer everything in vehicle electrification to ensure safety, arguing that future generations of the product would provide the opportunity to refine and optimize the design. State-of-the-art simulation and testing tools were also used extensively to accelerate the design optimization process and meet the time-to-market goal.

On September 16, 2008, the centennial of GM, a full-size mockup of the production-intent Volt based on the Chevy Cruz architecture was revealed to the public by Bob Lutz and Fritz Henderson, the GM CEO. Some Volt enthusiasts and journalists at the event were surprised and disappointed by the extent that the production vehicle's proportions had deviated from the original concept car's "daring" design as shown in Exhibit 9.

The first Integration Vehicle Engineering Release (IVER) prototype was built in summer of 2009. Eighty Volt prototypes were built and tested during the product development cycle at the Pre-Production Operation (PPO) facilities at the Tech Center in Warren Michigan.

The Volt team created a high performance E-REV on a tight schedule, but an important marketing challenge loomed as the product went to production in November of 2010: *How to communicate the technology and the car to mainstream customers?*

6. Volt Design Requirements and Features

"Volt must be an electric car for the masses, as the Chevrolet brand is. This above all means affordability", said the Product Manager, Cristi Landy. However, design-for-affordability became a significant challenge because of the extensive new technology content that had to be built into Volt to satisfy its performance requirements. In the traditional vehicle development process at GM, a cost target is set for the vehicle based on the marketing price target and vehicle business model. The cost target drives the design specifications and vehicle manufacturing process. For the Volt, the development team felt that "beating the competition" was the number one priority and business case was second. This change in the strategic outlook in vehicle development seemed to transcend Volt and extended across GM in the 2006 time frame.

In 2006, Toyota owned the hybrid market. The iCar had to go beyond. A ***whitepaper*** was given to the Volt team stating the requirements to leapfrog Prius (Exhibit 10): "*A vehicle that is more accessible, more environmentally acceptable and significantly cooler than Prius could ever be.*"

Although the association of the initial code name iCar with electronics products like iPod was intentional, it was later decided to change the name. An outside agency was hired in coming up with Volt as the name of the production car.

Marketing conducted user need research and updated the competitive landscape throughout the Volt development cycle. Exhibit 11 summarizes the user need characteristics, needs and wants; and Exhibit 12 depicts the Competitive Outlook in 2009.

Both market requirement specifications (MRS) and engineering requirement specifications (ERS) for Volt were influenced by the EV-1 experience. The Volt team wanted to overcome the limitations of EV-1 which contributed to its demise including the limited range, limited passenger and luggage space, and rapid battery depletion driving uphill.

The MRS for the EV range (in the battery-discharge mode) was 40 miles based on market information that 80% of American and European car owners commuted 40 miles or less in a day. The Battery power and energy capacity had to deliver the 40 miles performance for a compact sedan comfortably carrying four people with luggage through a wide range of road and weather conditions including extreme climate conditions from -40 to +40 ºC. Safety was also a major MRS item and drove the cell chemistry and manufacturing selection process since impurities in the cell manufacturing could result in cell overheating - a potential fire hazard. The battery energy capacity for powering the vehicle in the EV mode and also for powering all auxiliary energy consumption such as heating ventilation and air conditioning (HVAC) was calculated to be 16 kWh. The battery pack life and size were the next two critical specifications.

The MRS called for a 10-year warranty for the electric propulsion system including the batteries based on consumer expectations set by the competitive hybrid vehicles in the market. Therefore, the battery life had to be designed for 10 years and 150,000 miles, and individual battery cells had to be liquid cooled to control the cell temperature under all operating conditions. The battery pack size was established based on the overall vehicle dimensions, the size of other subsystems and the number of battery cells needed for the 16 kWh capacity.

Additional MRS and ERS requirements included vehicle acceleration of 0 to 60 miles per hour (mph) in 9 seconds or less. The top speed was set at 99 mph. While these specifications were the nominal performance requirements, the product design was often driven by the requirements in extreme conditions. For example, customers would expect to drive Volt at 70 mph speed on a 6% grade at high elevations. Andrew Farah estimated that 60 kW power was needed for this level of performance which he called "the lunatic fringe requirement."

The control system had to be designed for the vehicle response to be intuitive to the driver and seamless in both pure EV mode and the engine charging mode at all driving conditions (including steep roads, high and cold climates, and vehicle acceleration/deceleration.)

The product marketing strategy set by corporate executives established Volt's platform strategy and drove many aspects of its design. The length, width and wheelbase of the *Global Compact Car* architecture were felt to be the suitable design specifications for Volt. The leadership team argued that "starting from scratch with all-new chassis made no sense." A completely new vehicle architecture would have required significantly more production capital, engineering expense, and adversely impacted the product launch schedule. Rick Wagoner, GM's CEO, insisted that Volt must be a Chevy product rather than an entirely new brand. Sixty percent of GM business in mid-2000s was in Chevy sales (it was up to 70% in 2012.) However, Chevy was not a technology leader and Rick Wagoner wanted to strengthen its brand.

The platform choice and the required energy efficiency created a significant constraint on Volt's body design. The sleek design of the concept car which had received rave reviews could not be used. Using computational fluid dynamics (CFD) modeling and extensive wind tunnel testing, the body shape was redesigned to meet the target drag coefficient of 0.28.

The User interface and interior design requirements were mostly defined based on the Company's internal knowledge about the wants and preferences of mainstream customers. Customers were believed to want "an electric aesthetics" and an interior that reflected the Chevrolet brand character as represented by the latest models of Malibu or Camaro. Marketing believed that Volt buyers were tech savvy and comfortable with Xboxes and Twitter. However, different customers had different reasons to buy Volt –

as it would be: “the coolest thing on the block”; “powered by E-REV technology”; “getting the country off petroleum”; or, “a smart purchase because it saved money on gasoline consumption.”

A 9.3-gallon fuel tank was specified to achieve the 300-miles extended range. The vehicle was designed to use premium instead of regular unleaded fuel. Although this was contrary to the affordability requirement preferred by marketing, it was needed to achieve the desired miles-per-gallon performance. Another feature that was preferred by marketing was having a spare tire which was voted down based on engineering’s desire to reduce weight and packaging constraints.

Sustainability and environmental friendliness were not specifically called out as design requirements. However, Volt designers, cognizant of the positive environmental potential of an electric car, took special care to maximize the use of renewable and recycled materials in the product[14]although it was not easy to find materials that met automotive grade durability requirements.

Product design and manufacturing methodology and details are describe in Exhibit 13.

7. Key Suppliers

GE Plastics, Compact Power Inc. (CPI) and its Korean parent, LG Chem Ltd. were the key suppliers in the program. In early 2006, after the initial concept was born out of the brainstorming discussions among Bob Lutz and Jon Lauckner, Jon contacted GE Plastics (now part of SABIC[15]) to partner in creation of the concept car. GM would design the propulsion system and the vehicle design (shape), and GE would supply light-weight advanced composite plastics for the body and the interior. GE’s composite materials could also support exterior shapes that were hard to manufacture in metal and because they were lighter, they could further help the drive range.

Battery development had the biggest supplier involvement in the program. Immediately after the ASB approval following the introduction of the concept car in January, 2007, the battery development work got into high gear, including technology-360 and supplier/partner selection process. The battery supplier selection went through a three-phase process. In Phase one, 155 chemistries proposed by various makers and technologists were pre-screened. In Phase two, 60 potential candidates were evaluated during multiple workshops resulting in selection of 16 different suppliers. The battery proposals from these suppliers were assessed using a Pugh decision-matrix comprising multiple parameters including power, energy, abuse tolerance, packaging layout, temperature capability, software and control, life, technology maturity, mass and part count (representing complexity). In Phase three, two finalist suppliers were selected. The first supplier group was Compact Power Inc. (CPI) of Michigan who developed the battery pack and its parent company, LG Chem of Korea that supplied the battery cells. The second supplier group was A123 Systems of Massachusetts for cells and Continental Automotive Systems of Germany for the battery pack. The dual-supplier path development was chosen to mitigate risks in the critical battery system development. The finalists were thoroughly evaluated throughout 2008 before CPI was announced as the Volt battery production supplier of choice based on LG’s superior cell architecture and chemistry, and manufacturing readiness. The LG cell design is prismatic (flat package) using a carbon graphite anode and a Lithium-manganese-oxide cathode.

[14] Soy-based foam was used inside the seats.
[15] SABIC is a large petrochemicals manufacturer based in Riyadh, Saudi Arabia.

Another important supplier was dSPACE Inc. that provided rapid controls prototyping and hardware-in-the-loop systems for control software development and performance validation of various subsystems during vehicle dynamics, safety and integration testing.

8. Pricing Strategy

There was a disagreement in the company as where to set the list price. Marketing felt that early buyers were "technology adopters" and were willing to pay a modest premium for the new technology. The Company executives, on the other hand, felt the market didn't know the *right* price because Volt was a "game changer" and a new-to-market invention. In summer of 2010, the standard vehicle price was announced at approximately $40,000 dollars, or $350/month lease with a $2,500 down payment.[16] The retail price was believed to be too high by some automotive analysts, although the lease financing seemed competitive.

The pricing decision was not based on competitive reference pricing, particularly against Prius which was selling in $25K to $30K range[17]. Instead, the price was based on the Volt being a new class of product in the market that delivered benefits (40 mile EV capability) that Prius did not offer. Even at $40K price tag, the executives believed GM was demonstrating willingness to commercialize Volt at an initial loss[18] in order to establish technology leadership in the market. While the relatively high initial consumer price had been a deterrent to rapid market penetration, the rising gasoline prices and anticipated changes in greenhouse gas (GHG) emission regulations favored Volt and were believed to drive the future demand.

9. Product Launch and Market Penetration

When the iCar unveiled in Detroit Auto Show in January, 2007, Toyota responded by labeling it a public relations exercise and questioned the safety of lithium-ion batteries. Volt had been under the spotlight throughout its development. Newspaper headlines had created buzz around the technology and awareness about the product and this proved to be a blessing at the product launch in December of 2010.

Before a new product is released to market, GM gives the early units from manufacturing to employees to drive around and provide feedback to engineering and marketing. Because Volt was new to GM employees, it was decided to give it to a group of "EV-advocate" customers. Ten such customers were selected from target market regions near the service locations in New York, Los Angeles, and Washington, DC.

In the first year after launch, customers were "*fighting over the product"*, said Criti Landry. And customer satisfaction with Volt was highest based on a Consumer Reports analysis. The marketing team held monthly web-communications with selected group of buyers (10 to 12) to receive feedback. These

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[16] In August, 2013, GM announced a $5,000 price reduction on 2014 models of Volt to boost sales. With the reduced price starting at $35,000, the final price of a 2014 Volt would be as low as $27,500 after applying a $7,500 federal tax credit; and lower still after a $1,500 California State rebate.

[17] Leaf and Prius PHEV prices were in the $30K to $35Krange.

[18] EV technology was not yet in high-volume production and manufacturing costs of the battery pack and the drive units were high.

customers were treated as a trusted confidant focus group. Marketing prepared a "Market Launch Assessment" document six months after launch in October, 2011.

Beyond the initial momentum with the technology enthusiasts, selling the car at the desired rate became a challenge. Dealers did not know the product and its technology and feared that they might discourage customers who came to the showroom. To mitigate this risk, Marketing set up a dedicated "Volt Advisory Team" to help customers and educate them about the "optimal way of using Volt". Exhibit 14 shows the unit sales history of Volt from December 2010 to June 2013.

"Our challenge is how to communicate to the mass market the extended range of 300+ miles and the 40 EV miles", said Cristi Landy. The tag line in early TV commercials was: "more car than electric" and it did not make the people understand the car. The challenge was to clearly state "what is Volt? How to define it, how to differentiate it, how to justify its price?" The commentaries by investigating reporters and even by GM developers about the car were revealing of the underlying issues. Andrew Farah was pleased with Volt but "wondered if those who write about it will really understand just what the car is all about." Larry Edsall, the reporter and author of "Chevrolet Volt, Charging into future" (Ref. 2) concluded his experience with Volt as: "driving it is so unremarkable"! "Volt is not a different experience. It is simply a means to an end, a way to get from Point A to Point B, safely, comfortably, enjoyably, but without needing much, if any, imported petroleum. It is, after all, a car, just as it was meant to be."

Cristi thought that electrification of transportation was the driving force and paced the market penetration momentum.

10. Retrospect and Looking Forward

Two years after the product launch, the Volt team felt they had done a good job. The 40 EV-miles had been the right choice and it was market-tested[19]. Customer experience, and various consumer reports and EPA data were positive.

Volt has done many things for GM beyond being the first E-REV in the market and paving the way to electric transportation. Volt demonstrated the will and technical prowess of GM in the face of considerable risks: development of a revolutionary technology, a market that was not yet ready for Volt as a new class of electric vehicle, and the regulatory fuel economy labeling criteria. The investment in development of Volt created several building blocks of future success for GM, including: the design and manufacturing technologies for LiON batteries, high capacity traction electric motors and power electronics[20], and EV software and controls technology. The technology building blocks are being used in upcoming product lines such as Cadillac Converj coupe which was put on hold during the Company's financial crisis in 2008; and the new Chevy Spark all-electric car that shares a significant amount of its battery and propulsion system concept with Volt.

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[19] 40 miles is the upper-end of the EV range. According to Consumer Report, the EV range could be as low as 25 miles depending on the drive conditions at low ambient temperatures.

[20] GM is building a new electric motor plant in White Marsh, Md. – near Baltimore and it will be the first by a major U.S. automaker dedicated to making the critical components for vehicle electrification when the plant opens in 2013. http://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2011/May/0517_baltimore.html

As Marketing was focused on improving Volt's market share in 2012, GM's product planners were contemplating the strategy for development of the second-generation Volt. How should GM respond to the lessons learned in the first two years of Volt in the market and to the changes in the market conditions? Was it time to set an aggressive manufacturing cost target for the second generation product to enhance its pricing flexibility? Should the 40 mile EV range be increased to blunt the market momentum of pure-EV competitors like Nissan Leaf with 75 miles EV range? How should the battery cost ($/kWh), energy density (Wh/kg) and charging speed be significantly improved? Should GM participate in the development of the charge station infrastructure across the country?

Exhibit 1- General Motors Corporation

Excerpts from the Company Website http://www.gm.com/

At the new General Motors, we are passionate about designing, building and selling the world's best vehicles. This vision unites us as a team each and every day and is the hallmark of our customer-driven culture.

General Motors continues to develop innovative technologies to shape the future of the automotive industry. We are expanding our leadership in vehicle electrification with advancements in batteries, electric motors and power controls. The GM team is also working on a range of high-volume, fuel-saving technologies including direct injection, variable valve timing, turbo-charging, six-speed transmissions, diesel engines, and improved aerodynamic designs.

GM's Five Guiding Principles:

1. **Safety and Quality First:** Safety will always be a priority at GM. We continue to emphasize our safety-first culture in our facilities, and as we grow our business in new markets. Our safety philosophy is at the heart of the development of each vehicle. In addition to safety, delivering the highest quality vehicles is a major cornerstone of our promise to our customers. That is why our vehicles go through extreme testing procedures in the lab, on the road and in our production facilities prior to being offered to customers.
2. **Create Lifelong Customers:** We take nothing for granted in our efforts to earn the confidence and loyalty of our customers. We listen to customers to make sure we are meeting their needs, and are connecting with them on their terms. Through our relationship with customers, we strive to create passionate brand advocates who love their vehicle and freely tell others about their experience.
3. **Innovate:** We challenge ourselves to be creative and lead in everything we do. From implementing the smallest improvements to executing big ideas, we are constantly increasing our competitive advantage to delight and excite our customers.
4. **Deliver Long-Term Investment Value:** Our shareholders want to feel confident about their decision to invest in our company. By developing the world's best vehicles, building upon our strong financial foundation, growing our business and operating with the highest level of integrity, we will continue to deliver positive results.
5. **Make a Positive Difference:** We strive to make a difference in our world and in our workplace. Whether finding new ways to improve our business operations, achieving as part of a team or volunteering in the community, we know that our momentum is tied to positive change.

COMMITMENT

We believe in acting responsibly across the globe and focus our efforts in important areas, including the environment and education. The General Motors Foundation helps us achieve this goal by strengthening communities across the United States through investments in education, health and human services, environment and energy, community development and worldwide disaster relief efforts. Over the past ten years, the foundation, fully funded by a GM endowment in 2000, has donated more than $350 million to send students to college, keep teen drivers safe, educate parents on child passenger safety, promote diversity and support vital non-profit organizations.

Committed to reducing waste and pollutants, General Motors conserves resources and recycles materials at every stage of the vehicle lifecycle. We are proud to say that our best practices reduce the impact our vehicles and manufacturing operations have on the environment.

Our commitment to the earth will transcend the here and now through our work with students. We share our knowledge of sustainability with these future engineers, leaders and problem solvers to help ensure a better future for all.

Exhibit 2 - Revenue Growth History

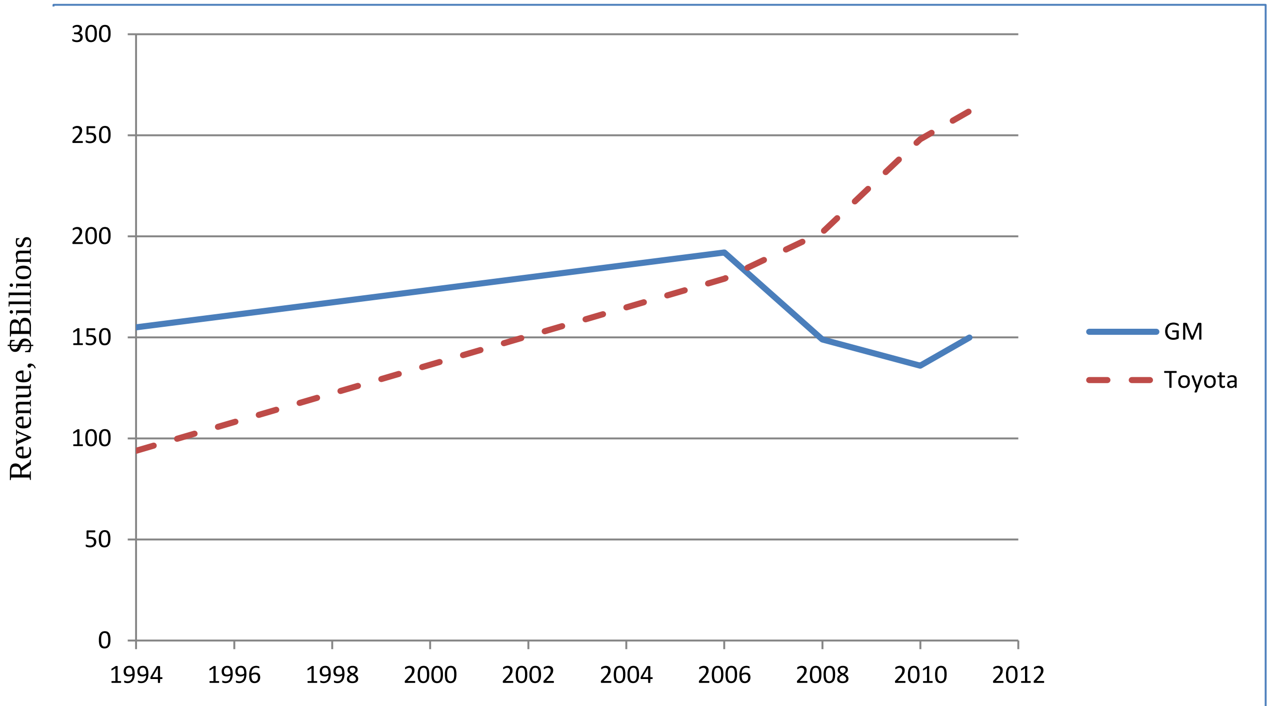

Exhibit 3 - SAE Definitions of Hybrid and Electric Vehicle Technologies

The Society of Automotive Engineers (SAE), International defines alternate vehicle technologies with electric power capability as follows:

1. Hybrid: A vehicle with two or more energy storage systems both of which must provide propulsion power – either together or independently. The two systems are internal combustion engine (ICE) and battery charged during breaking.
2. Plug-in Hybrid (PHEV): A hybrid vehicle with the ability to store and use an off-board electrical energy in the rechargeable energy storage system (RESS.)
3. E-REV; defined by GM as “A vehicle that functions as full-performance battery electric vehicle when energy is available from an onboard RESS and having an auxiliary energy supply that is only engaged when the RESS energy is not available.”

Exhibit 4 - Volt Powertrain

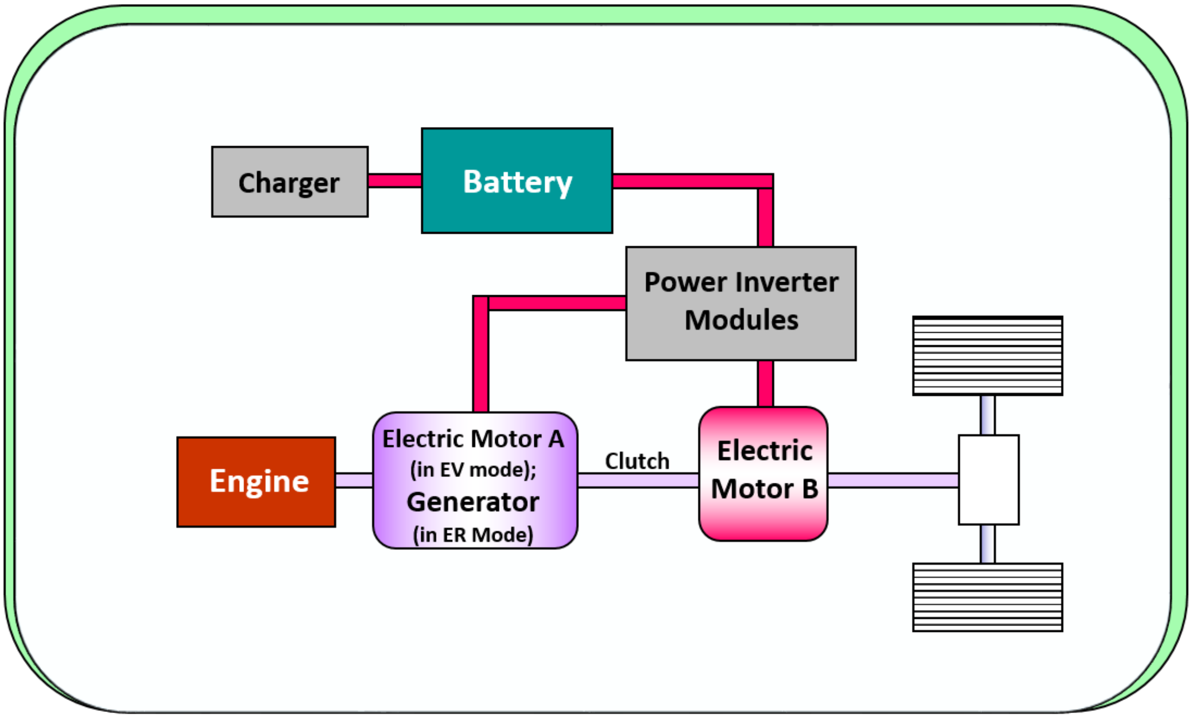

Exhibit 5a Program Organization – Executive Management

Source: case writer

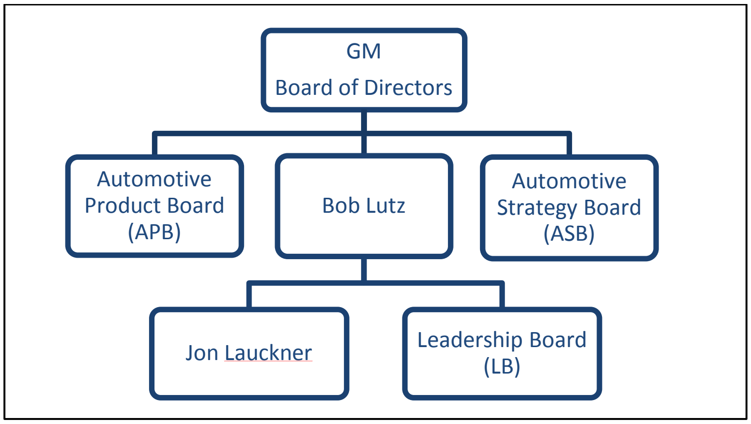

Exhibit 5b Program Organization – Concept Phase

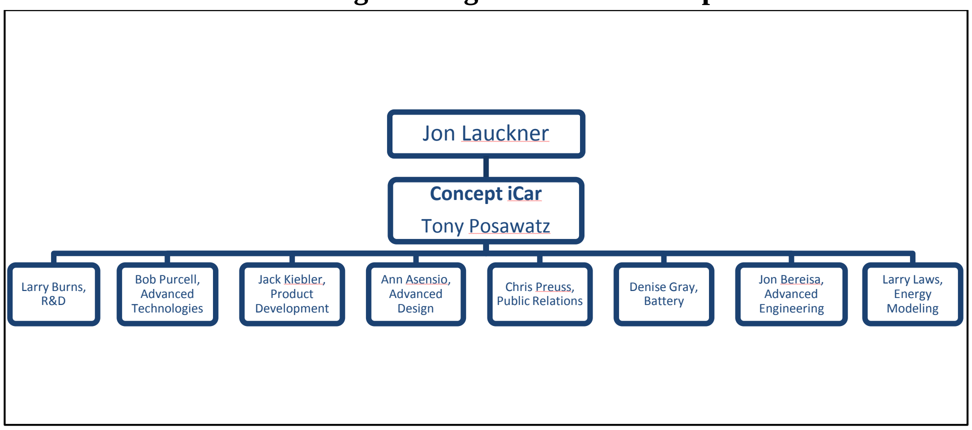

Exhibit 5c Program Organization - Production Vehicle Phase

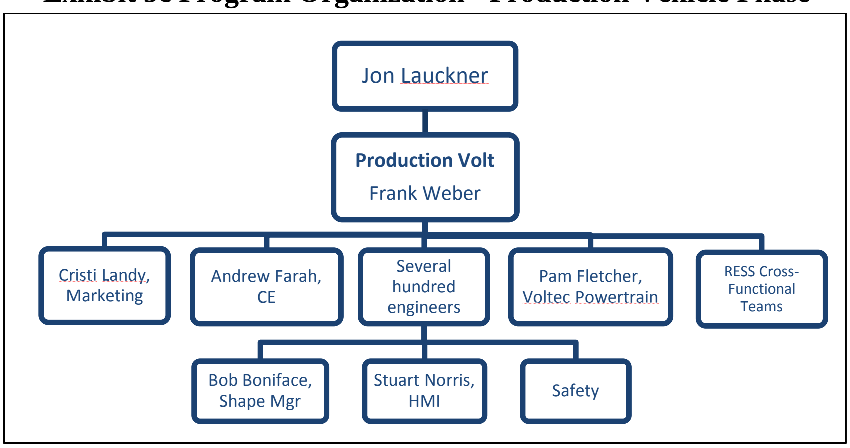

Exhibit 6 - Volt Development Timeline

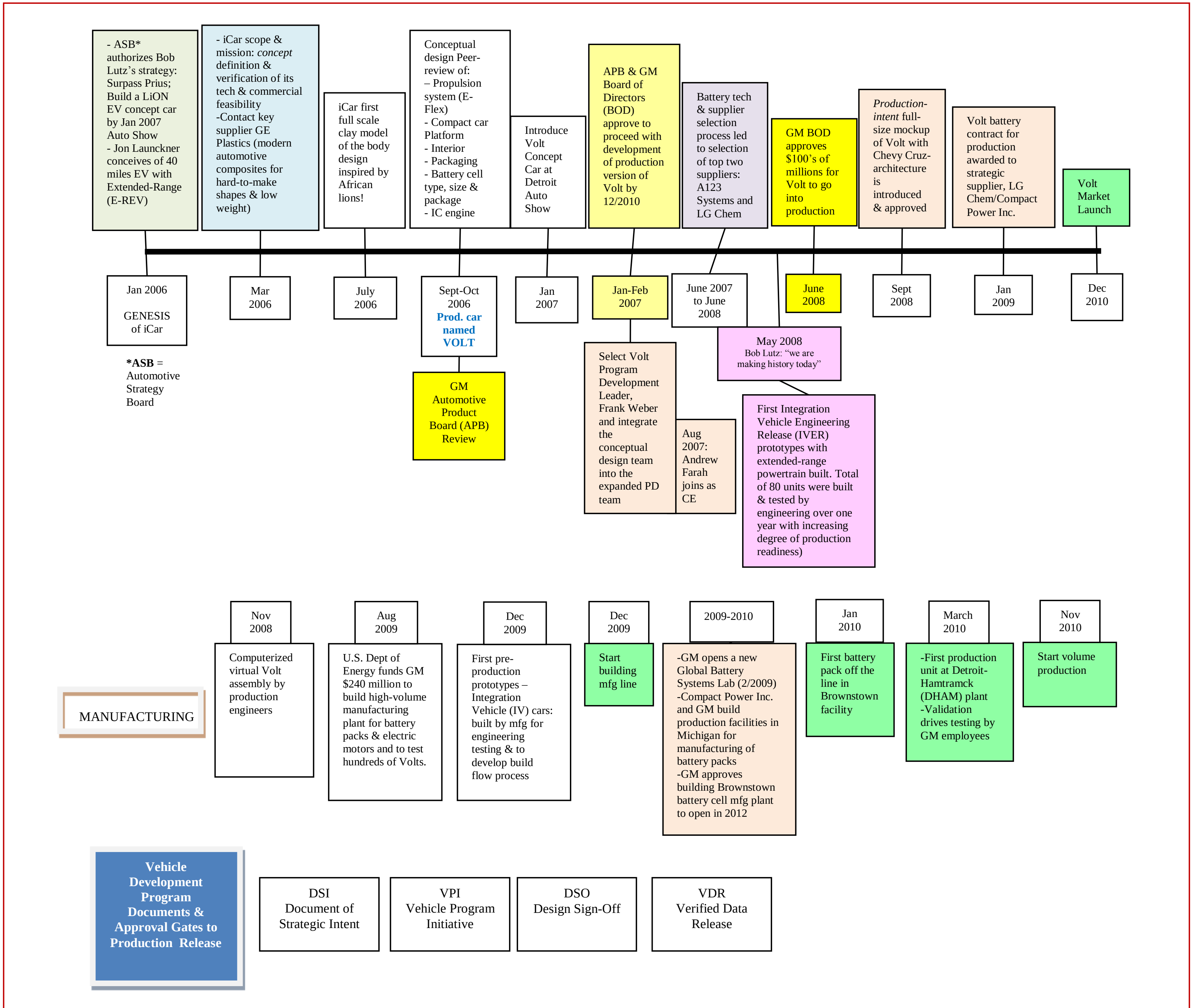

Exhibit 7 - Product Development Process

GM's standard product development process has gone through many revisions over the years to improve efficiency and to respond to the competitive market needs. For example, in July 2012 the GM News reported that a new product program structure was adopted at GM consolidating the leadership of each program under one executive chief engineer who would be totally responsible for her/his vehicles from inception to production. These changes removed a layer of management and approximately 20 executive positions globally.

The Volt project was under the spotlight from the beginning because of the internal politics in the company and an extensive media exposure. Therefore, the leadership team decided to have an "open" product development process with ample reviews. The Volt product development cycle went through five phases:

- **Phase 0** (January 2006) - Strategic approach and E-REV vehicle concept definition.
- **Phase 1** (January to March, 2006) - Concept viability and feasibility verification by the initial working group: Extensive simulation modeling was used in this phase.
- **Phase 2** (March to December, 2006) - Concept car development: The early tasks of this phase were development of the body exterior design and evaluation of alternate power train (propulsion system) concepts that met the 40 miles EV performance. In this phase, the team followed the Company's Peer Review Process to make sure that proposed technical concepts and associated risk assessment approach were sound. Design reviews were conducted by the experts from across the Company. For example, a peer review by the Power Train experts validated the propulsion system modeling and integration approach. Several other peer reviews were held at various stages of the design throughout 2006 concluding the technical feasibility of the iCar's propulsion system in meeting the performance targets. Several executive review meetings were also held in this phase. Jon Lauckner presented the iCar's concept design to the Automotive Product Board and underscored the extendability of its platform and powertrain designs to future pure-electric and fuel-cell-powered vehicles. Phase 2 was concluded with the detail design and manufacturing of the concept car for the Detroit auto show in January 2007.
- **Phase 3** (January 2007 to December 2010) - Production Volt development: This phase went through several Go/No-go gates at critical milestones before the first full-scale prototype (IVER) could be built and driven on the test tracks. These milestones and associated sign off documents - as defined by GM's standard vehicle development process, are listed in Exhibit 6 and include: DSI - Document of Strategic Intent; VPI - Vehicle Program Initiative; DSO - Design Sign-Off; and VDR – Verified Data Release. The road testing milestones in this phase were designated as "x-Percent Drive Tests", indicating that the test vehicles were at the x-percent *production readiness* state. The drive tests were carried out with prototypes that were at increasing levels of production readiness from 65% to 100%.
- **Phase 4** (January 2011 to 2013) – Market launch and early market surveillance.

Exhibit 8 – EPA-DOT Label

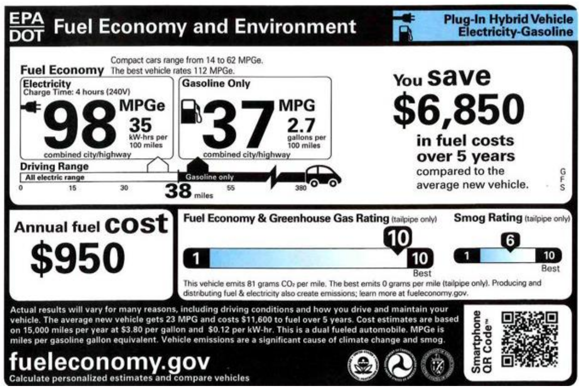

Exhibit 9 - Volt Concept and Production Designs

Concept iCar

Production Volt

Exhibit 10 - iCar Vision, 2006

Source: Chris Preuss, Advanced Technology Public Relations, GM

iCar is:

- A global vehicle that will launch a paradigm shift for GM
- A vehicle based on the same marketing ethic that makes iPod so popular – style fashion, practicality, and freedom – making the car a seamless part of one's personal lifestyle and technology portfolio.
- An electric vehicle with plug-in hybrid (E85 and bio-diesel) and pure electric (battery and fuel cell) capability.
- An affordable four-place vehicle with high sales volume potential.
- A lightweight, highly styled and highly functional vehicle about the size of an Astra/Cruz.
- A vehicle that is more accessible, more environmentally acceptable and significantly "cooler" than Prius could ever be.
- A vehicle that is efficient in terms of energy, space, and time.
- A vehicle that is fun to own and use with no worries and no excuses.
- A vehicle that is a platform for passion, fashion, driving, riding, connecting, communicating, socializing, and powering.
- A vehicle for the 21st century that redefines mobility for mass markets, being "connected" to everything and transcending transportation.
- A vehicle wherein traditional comfort features are exchanged for high utility and functionality, low cost, and "fun to drive." (This does not mean an unrefined vehicle – it means rethinking aspects of the vehicle that have become commonplace with respect to creature comforts and occupant interfaces.)
- A vehicle with elegant simplicity providing meaningful value and avoiding extraneous technology that adds complexity and confusion.
- A vehicle marketed to high influencers globally.
- A vehicle that prompts the response: "Why didn't I think of that?"

Exhibit 11 - User Characteristics and Needs/Wants Analysis in 2009

Source: Cristi Landy, GM

	Mid car	Hybrid	EVs
Psychographics	**Conservative** **Risk Averse** **Very Practical** Worried about battery charging time & where to plug in	**Draw attention to me**	Early Adopters Want **Motivated by TECHNOLOGY and the environment;** We are special – “enter the bubble of the EV world”; Use Solar panels on their homes
	Concerned about global warming, the environment (clean-air – asthma, animal health), future generations Recycle, change light bulbs, walk rather than drive …		
Wants	**Reduce their dependence on petroleum** **Environmentally friendly materials** **To do the right thing**		Doubt Hydrogen – **EV is the answer – Want an all EV vehicle** PHEV most immediate promise in furthering technology – solution for society Politically Correct materials
Willing to Pay	**Did the math and the price of the hybrid is not better than paying for the gas;** **Price deterred me;** **When it is the same price as gas, I will buy**	**I didn’t do any calculation…** **I just assumed it would be worth it**	**Willing to pay the most**
Purchase Mindset	**Rational / Calculated** Other things can help the environment just as much (walking, recycling, conserving energy)	**Emotional** Not just about saving $ - more about the environment	**Obsessive** Energy conservation is always on their mind, part of their identity; Society is not ready to go all electric – I am ahead of the curve
Other	My car is an appliance – I want the one that do the best job for me	Love the attention I get from driving a hybrid; My car makes a statement about me – I am proud	My car is part of my identity Obsessive desire to appear green and have the latest

Exhibit 12 - Competitive Outlook in 2009

The circle size represents the market potential; Prius is 100k/mo

Source: Cristi Landy, GM

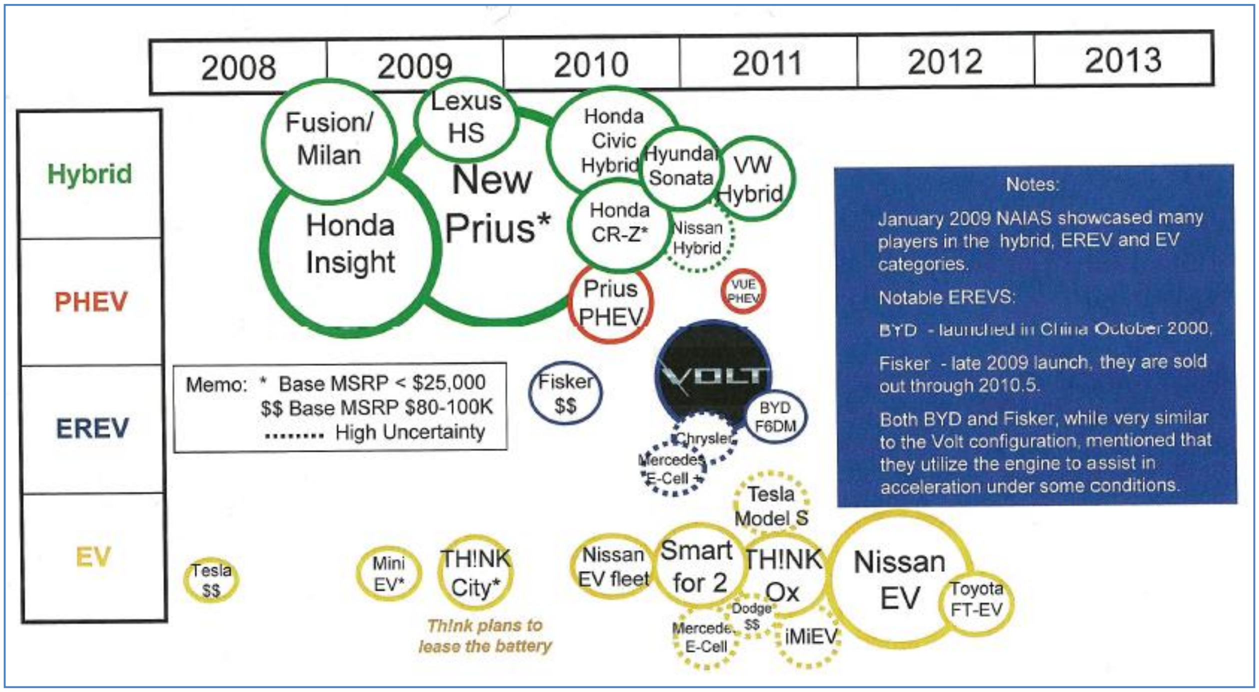

Exhibit 13 - Product Design and Manufacturing

Powertrain

Volt design benefitted greatly from GM's core expertise in automotive design and manufacturing. The EV-1 experience helped Volt engineers in the development of the electric power train, software and controls system even though the EV-1 design was a one-motor single-speed drive which could not meet the E-REV requirements of Volt.

The Volt propulsion system, known by the acronym E-REV, was formally re-named Voltec (Exhibit 4) and was designed to enable Volt's operation over the entire range of speed and acceleration. The Voltec powertrain has two operational modes: first the electric-vehicle or charge-depletion mode which runs 40 miles on the battery and second, an extended-range or charge-sustaining mode powered by the ICE. Voltec's electric transaxle enables the patented operation of two motors and one generator during all operational modes of the vehicle. Voltec designers reused many components and tooling that had been previously developed for GM's front wheel drive hybrid electric vehicles to improve product reliability, and to reduce the development schedule and manufacturing cost. Volt was also designed with an off-the-shelf 1.4L gasoline-powered ICE. Although a more efficient and customized engine[21] or an unconventional power unit could have been designed, the task was deferred to the next generation product for cost and schedule reasons.

Three modes of operational control were designed for the vehicle which the driver could select by a switch mounted on the center console: 1) Normal mode; 2) Sport mode for more spirited driving; and 3) Mountain mode when the IC engine is turned on sooner to ensure there is adequate battery charge for maintaining the cruise speed while climbing up a steep road or at high elevations.

Battery Pack

The 16 kWh LiOn battery pack comprises 288 cells that must work flawlessly because failure of one cell can cause failure of the entire pack. A large design-of-experiments study was carried out to gather data for battery management calibration and to develop a battery life model.

The battery cell temperature is actively controlled by a liquid cooling/heating system which is integrated in the battery pack with the thermal management and power control subsystem. The 5.5-feet long, 140 dm^3 (~1/2 meter cube) battery pack weighs 198.1 kg and supplies energy to the 111 kW (149 hp) electric drive unit. The T-shaped housing of the battery pack serves as a semi-structural member of the car and is secured properly to eliminate any movement of the batteries during shock, vibration and impact.

The LiOn battery cells, liquid thermal management and battery pack assembly posed the biggest technical risks of the program and presented many R&D and manufacturing challenges including cell chemistry stability (for safety and efficiency) and cost. When the program started, there was extensive battery research at leading universities and companies in Japan, U.S., France, Germany, Korea and China. Taking advantage of these research activities, GM's battery team conducted an exhaustive analysis of two dozen battery cell chemistries and suppliers and selected the Korean company LG Chem for its advanced technology, responsiveness and manufacturing capabilities. LG Chem battery cell electrolyte used nano-phosphate, a benign and ultra stable compound instead of cobalt that was used in LiOn batteries of computers and portable devices. Compact Power, Inc. (CPI), a U.S. subsidiary of LG Chem was contracted to build the battery pack and thermal management system.

The development of battery cells by Korean engineers and design of the battery pack by CPI and GM engineers were tightly integrated. They worked very hard to overcome the technology and integration issues on the tight project schedule. The initial manufacturing cost of the batteries was estimated to be $10,000 and it was expected to go down to $5,000 (or $312/kWh) at 40,000 cumulative production units.

The battery charging equipment was designed according to UL and SAE J1772 standards which were developed with active participation of Volt engineers[22]. The EV-1 experience provided valuable information about customer expectations and the technical issues. For example, EV-1 charging was inductive which proved to be a mistake. Volt batteries can be charged at the regular household power outlets at 120 volts although it takes roughly 10-16 hours to fully charge the batteries from a depleted state. With a 240 volt power supply, the charge time is reduced to 4 hours. Charge stations with 240 volt supply are increasing at public locations across the country and many businesses are installing charge stations in employee parking lots.

[21] Because ICE is decoupled from the drive wheels, it can be designed around a narrow set of operating parameters to fulfill its sole function of powering a generator.

[22] Charging levels are defined as: Level 1 - 120 V AC, 16 A (= 1.92 kW); Level 2 - 208-240 V AC, 12 A - 80 A (= 2.5 - 19.2 kW); Level 3 - high voltages (300-600 V DC), high currents (hundreds of Amperes).

Software and Controls

Volt software (SW) has 10 million lines of code to operate 100 electronic controllers. In contrast, a Boeing 787 has 6.5 million lines of code[23] and an average GM car in 1990 used one million lines of code (Ref. 2.) Developing defect-free software was a challenging undertaking. In SW development, it is the rule of thumb that there will be 0.1 to 1 software defects per 1,000 lines of code (not counting comments) and the cost of fixing bugs rises exponentially in subsequent phases of product development.

Volt's rapid product development was enabled by deploying a model-based design approach and automatic code generation. Nearly 100 percent of software was generated automatically which is believed to have improved SW engineers' efficiency by 30%. In the model based design approach engineers model the system dynamics and control algorithm, including diagnostics, while the hardware is being developed, instead of waiting for completion of the hardware design and prototyping of new components and technologies.

The OnStar team at GM developed several features and remote *apps* for Volt. They also partnered with Volt engineers to work with utility companies and government agencies in the development of "smart-grid technology" to program Volt SW for charging at lowest possible electric rates and to guide drivers to public charging stations. The OnStar team also helped in the product development by designing diagnostics and monitoring electronics for testing Volt prototypes.

The Body

The body (exterior) design was one of the first tasks of the vehicle design during the concept development phase. Multiple design sketches and sub-scale models were proposed by GM's design studios around the world in Warren, Michigan; London, England and North Hollywood, California. The proposed designs were reviewed in April, 2006 by the project leadership team including Bob Lutz, Jon Lauckner, and Ed Welburn who was the global design Vice President. The selected concept was conceived by the exterior designer, Jelani Aliyu.

During the production vehicle development phase, the product exterior (shape) and interior deviated substantially from the concept car design. Through 500 hours of wind tunnel testing on one-third-scale and full-scale models and analytical computational fluid dynamics (CFD) modeling the final body design was developed. The production Volt body shape achieved a coefficient-of-drag (Cd) of 0.28, in contrast with EV-1 and Prius that had a Cd of 0.19 and 0.30, respectively.

Another design criterion for the body was crash safety of the high-voltage electrical system. This was new to the safety experts at GM and needed special attention. Volt crash safety was evaluated by both computer simulation and testing of full-scale prototypes.

Interior Design

A rich mix of state-of-art technologies from GM and GE were used for cool, affordable, light, strong and recyclable interior design. A state-of-art graphical-user-interface (GUI) was designed to display the battery storage level, fuel level, propulsion system data and other standard vehicle information. The instrument panel displays were tested in a GM driving simulator to make sure that the high-tech displays would not distract drivers.

Manufacturing

Volt was intended to be made-in-Michigan to the maximum extent possible – turning Detroit into an "Electric Motor City". The final assembly began at GM's Detroit Hamtramck Assembly Plant (DHAM) concurrently with other GM vehicles like Cadillac DTS and Buick Lucerne. DHAM workers were trained in building Volt and its unique electric propulsion system through involvement with the prototype manufacturing team and assembling the prototypes in the Pre-Production

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[23] Norris Guy, Wagner, Mark, "Boeing 787 Dreamliner", Zenith Press, 2009.

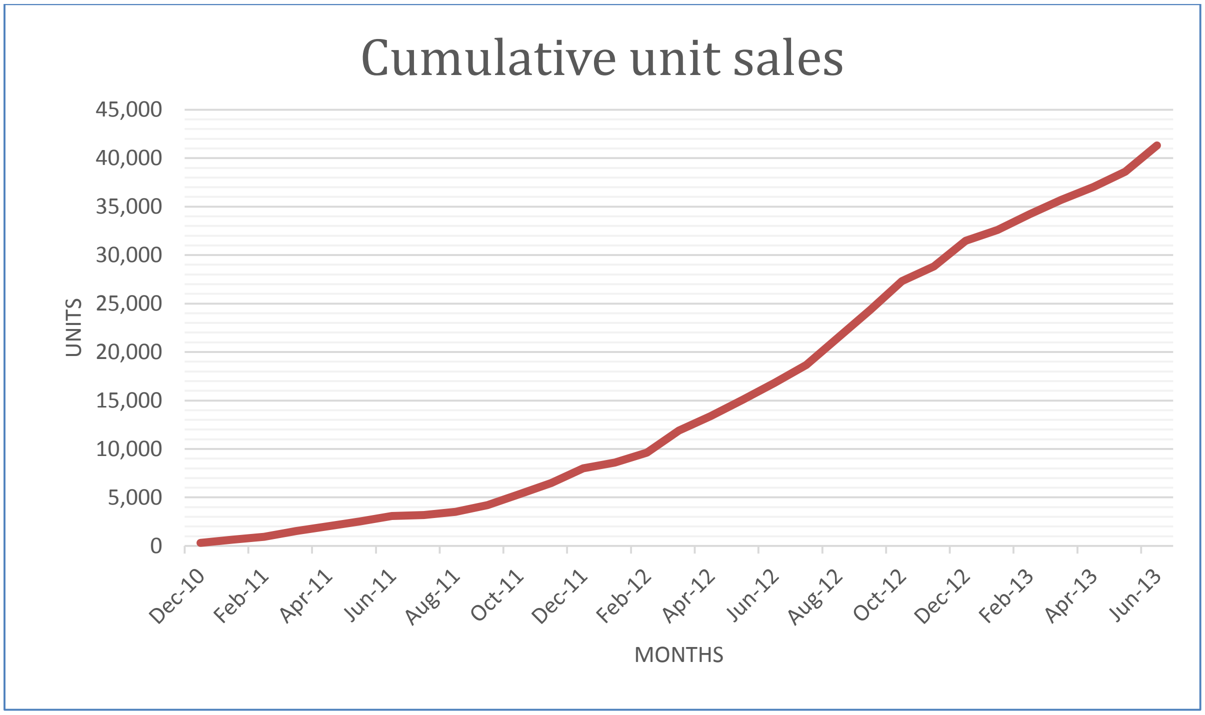
Operations (PPO) shop at GM Tech center in Warren. In turn, the manufacturing involvement in the prototype phase helped the design engineers improve manufacturability of the product and its manufacturing process flow. GM production engineers started to develop a computer model of the vehicle assembly process as early as November of 2008 and started to build the assembly line at the DHAM plant in late 2009, one year before Volt went into production.

Originally, GM planned to have CPI manufacture the battery pack assembly with cells coming from LG in Korea. That strategy changed later in the program and GM decided to manufacture the battery pack assembly in Brownstown's new lithium-ion battery pack manufacturing facility that went online in 2012. This change in the manufacturing strategy was motivated by the desire to control the system integration and battery pack design IP. Furthermore, GM wanted to use Volt's power train design in other vehicles lines too.

A new high-speed battery pack assembly process was developed to achieve the desired precision and throughput. The takt-time of the battery pack assembly process was 60 seconds. The process was a combination of conventional car assembly techniques and manufacturing processes of medical and electrical products.

Exhibit 14 - Volt Sales History

Source: Argonne National Lab, US DOE



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3. Bob Lutz: "Car Guys vs. Bean Counters: The Battle for the Soul of American Business, Portfolio/Penguin, 2011"