The Automotive Industry Development Process for Major Radically New Technologies, Inception to Production: A Study of Electric and Hybrid Electric Vehicles.

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ABSTRACT

The automobile has been around since the early 1900's, and the internal combustion engine has been the main source of power. In order to stay competitive and produce top quality vehicles, the automotive industry introduces new products to meet customer's needs, comply with government regulations and introduce new technology. However, conventional automobiles have been known to release large amounts of carbon monoxide that produces air pollution and other environmental concerns. Government regulations are forcing automotive manufacturers to develop vehicles that are cleaner and more energy efficient. There are several potentially attractive major new radical automotive technologies such as electric vehicles, hybrid electric vehicles and fuel cells. This thesis presents a methodology that will use the General Motors 4 Phase Vehicle Development Process Template (4∅VDP) and VDP process that was utilize for the EV1. The goal of this methodology is to highlight vehicle development bottlenecks and make recommendations on the best practices. The intent is to layout a vehicle development process that will focus on the major development of new technology in hopes of minimizing costly changes. The methodology developed in this thesis starts with literature review, which provides a historical perspective of the technology and discusses the advantages and disadvantages of electric and hybrid electric vehicles. Environmental issues and concerns will be explored as well. The capital cost of developing this new technology, and assembly plant issues to accommodate this technology will be discussed.

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In Memoriam

This thesis is dedicated to the memory of my father, Mr. Charles Henry Dobson, who departed this life on August 5, 1988 in Jackson, Mississippi. Daddy, so many years have passed since you been gone; and it only seems as though you were here for just a little while. You were a positive force in my life and inspired me to excel to the highest level. I learned so much from you and wish you were here.

Psalms 55:16-18, 22

16: *As for me, I will call upon God; and the lord shall save me.*
17: *Evening, and morning, and at noon, will I pray, and cry aloud: and he shall hear my voice.*
18: *He hath delivered my soul in peace from the battle that was against me: for there were many with me.*
22: *Cast thy burden upon the Lord, and he shall sustain thee: he shall never suffer the righteous to be move.*

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1.1 Background of the Electric Vehicle

Electric Cars: Unlike conventional cars that are powered by heat energy produced during the combustion of gasoline, electric cars are powered by electricity. The electricity is generated by chemical reactions that take place in batteries. Rechargeable lead-acid batteries (similar to those used for starting the engine in conventional cars) are commonly used. The main advantage of electric cars is that there are no tailpipe emissions; indeed, they are the only zero-emission vehicles. Polluting emissions do result from power plants that produce the electricity needed for recharging the batteries, however, emission control is easier at a single stationary plant than for the comparable number of motor vehicles. Including pollution from recharging its batteries, electric cars generate only one-tenth the pollution of conventional cars (Wouk, 1997).

Electric vehicles are radically different from today's gasoline powered vehicle. Instead of storing gasoline, the electric vehicle stores electric energy in a large, rechargeable battery. A vehicle system controller sends this power to the electric drive motor whenever the driver pushes down on the accelerator pedal. Refueling is accomplished by plugging the vehicle's charge plug into a 240-volt charge receptacle specifically designed for an electric vehicle. We prefer 240 volts because the vehicle charges faster - recharging at 120 volts can take up to 24 hours.

Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) are the latest technologies that the automotive industry is pursuing. Electric cars have been around since the beginning of the automobile. However, the internal combustion engine (ICE) was chosen because it turned out to be the best power system. Modern cars have much lower emissions than their predecessors, but still are not clean enough [Riezenman, 1998].

As easily recoverable petroleum deposits dwindle, automobile populations soar, and cities become choked with combustion by-products, ICE is increasingly becoming the victim of its own success [Riley, 1997]. Automobiles must become cleaner and more energy efficient. Nearly after ten decades, the electric vehicle and hybrid electric vehicle may actually prevail. In order to assess the potential benefits of various technologies, it is critical to understand how vehicles are used [Nercor, Inc, Reuyl, Schuurmans 1996].

Technological research and development have shown that electric vehicles can make a difference in reducing the emission standards. The use of electricity as an energy transporter makes it possible for conservation of environmental quality. Further technology development in the field on energy and drive systems must take place in order to find the proper vehicle process. No one really knows if there is a market for electric vehicles, and how successful they will be? Many automotive manufacturers are developing and implementing EV and HEV. General Motors and Toyota have both release vehicles in 1998, GM EV1 and Toyota Prius Hybrid. Ford, Daimler-Chrysler, Honda, and others are also developing this technology as well.

1.2 Purpose of the Thesis

The research conducted in this thesis reviews two new technologies, Electric Vehicles (EV), and Hybrid Electric Vehicles (HEV). Determining the vehicle development process of radically new technology in the automobile industry is not widely understood. Automobile manufacturers use many different product development practices to produce vehicles. There is little consensus on the right approach to design the most efficient and effective electric vehicle.

Program timing in the American Automotive Industry may be subject to different approaches than foreign Automotive Industry. The goal of this thesis is to explain the vehicle development process for radically new technology used in the auto industry, and those employed in the industry that could be applied to EV and HEV technology. This thesis presents a methodology that will use the General Motors 4 Phase Vehicle Development Process Template (4∅VDP).

The methodology will also utilize the General Motors vehicle development process for the EV1 and compare it to the 4∅VDP. The goal of this methodology is to highlight vehicle development bottlenecks and make recommendations on the best practices. The intent is to layout a vehicle development process that will focus on the major development of new technology in hopes of minimizing costly changes

1.3 Outline of Thesis

The purpose of this thesis is to determine the development process differences between conventional automobiles and radically new technology vehicles. The ultimate goal of this thesis is to explain the practices used by the automotive industry, and those employed that could be applied to development of electric vehicles.

Chapter 1 starts with some background and motivation to the development of electric vehicles. **Chapter 2** deals with the History and State of the Art of EV Development. A historical perspective of electric vehicles and hybrid (Series/Parallel) electric vehicle, advantages & disadvantages of EV's, EV energy efficiency and Environmental benefits. In addition, Chapter 2 will discuss current EV development and team collaboration by companies who are developing EV technology. **Chapter 3** deals with the story of the General Motors EV1, and the 4∅VDP. A comparison of the vehicle development process between a conventional vehicle and the GM EV1 will be discussed. **Chapter 4** will discuss some components from BIW, Electrical, and Exterior/Interior of the EV1 and a conventional vehicle. In addition, the problems that were found during this process, and what decisions were made to overcome these bottlenecks. Finally, **Chapter 5** provides a conclusion of this research and recommendations for future work. Appendix A presents a glossary of terms frequently used in this thesis; Appendix B is a list of abbreviations & acronyms; Appendix C is an overview of the Federal Motor Vehicle Safety Standards for EV's; Appendix D is a list of changes that current EV owners will like to see on the next EV1 model.

Chapter 2 History and State of the Art in EV Development

2.1 Introduction

This chapter gives the first steps in understanding the history of electric and hybrid electric vehicles. The EV and HEV power source, advantages of the technology, EV& HEV energy efficiency and environmental benefits will be discussed in this chapter.

2.2 History of Electric Vehicles

Electric Vehicles appeared shortly after 1830 when Joseph Henry invented the first dc-powered motor. Thomas Davenport is credited with building the first practical EV in 1834. In 1847, Moses Farmer built a two-passenger electric car in 1851; Charles Page invented a 20-mph electric car. Gaston Plante paved the way for early electric vehicles when he built a "rechargeable" battery in 1859. In 1899 EV's captured world attention when Camille Jenatzy's "Jamais Contente" set the first land speed record of 66 mph in a streamlined vehicle powered by two 12-volt motors. The first distance record was set in 1900 when the BGS Company's electric car was driven 180 miles on a single charge.

By 1912 there were 34,000 electric cars registered in the U.S. and almost 50 companies producing electric vehicles from 1895 to 1920. Popular models of the time were the Baker and the Detroit Electric Car. Women liked the electric cars because they did not require cranking and doctors preferred them for their reliability. Although the early gasoline-powered cars were noisy and often broke down, their range was better than that of electric cars. The demise of the electric cars came in 1912 when Charles Kettering invented the electric starter. The Model T revolutionized mass production and gasoline was plentiful. The Golden Age of the gasoline-powered car had begun.

The Golden Age lasted for almost 50 years into the 1960s, however it produced a golden haze in the sky, which raised concerns about air pollution. GM began work on their Electrovair, a converted Corvair, and Ford began development of their sodium-sulfur battery. However, the manufacturers could not financially justify the costs to push the technology especially when Americans were interested in muscle cars. Visionaries and hobbyists continued where the manufacturers left off and converted their own individual cars. In 1967 the Electric Auto Association was formed. The oil crisis of the 1970's caused another wave of interest in EVs. Ford continued development of their sodium-sulfur battery and Chrysler teamed with GE to work on the ETV-1 program. GM began work on their Electrovette, based on the Chevette. At the same time, many independent EV companies began to appear such as Sebring/Vanguard. This small start-up company produced 2000 CitiCars and was at one time the 5th largest automaker in the United States where many CitiCars still exist.

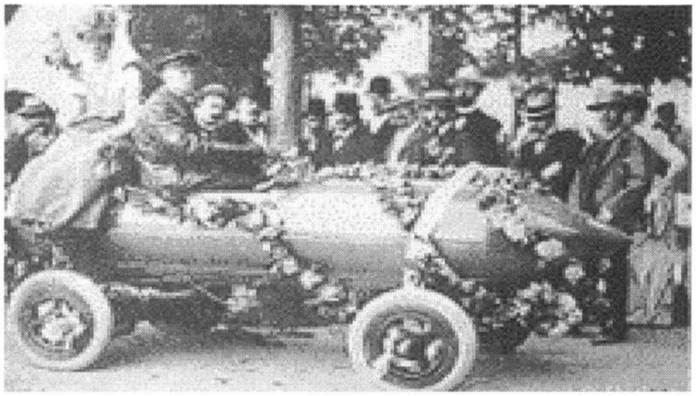
EV activity slowed phenomenally during the 1980's as oil supplies were plentiful and gas prices remained close to early 1970's levels. Cars were more fuel efficient and equipped with anti-pollution devices. However, EV components continued to improve with the development of solid-state control devices and motors that are more advanced. Although cars were equipped with pollution devices, people were driving more, especially in California where the car is considered a necessity.

Air quality continued to deteriorate so California introduced legislation that would require a small percentage of the vehicles sold in the state to be electric by 1998. By the year 2003, an additional percentage increase would be electric. It was not a surprise that the mandate met with intense opposition from the automakers and the oil companies, particularly Mobil, who claimed the technology, was not ready. After an intensive lobbying effort, the mandate was overturned and finally EVs were going to the market.

In the fall of 1996, GM will release the EV1 to customers from Saturn dealerships in California and Arizona. The electric vehicle has been utilized since the early 1900s in many different applications. Many vehicles were used in the industrial plants, on the golf courses, worksites, and college campuses. The first known electric car was a small model built by Professor Stratingh in the Dutch town of Gröningen in 1835. But the first practical electric road vehicle was probably made either by Thomas Davenport in the United States or by Robert Davidson in Edinburgh in 1842 [Nieuwenhuis, Cope and Armstrong, 1993].

Non-rechargeable electric cells were used as a source of power. The storage battery came along during 1865 and was developed by Frenchmen Gaston Plante and Camille Faure, and improved in 1881. The performance of "La Jamais Conte" in 1899 brought the potential of the electric car to the attention of an enthralled world. This was the name for the unique streamlined racing car in which the Belgian Camille Jenatzy broke the world land speed record in France, the first car to go faster than 100kph (62mph) [Nieuwenhuis, Cope and Armstrong, 1993].

Figure 1 shows the La Jamais Conte Electric Vehicle in 1899.



The electric vehicle was used in small applications, but the Internal Combustion Engine (ICE) was considered the best power system for cars. The electric vehicle powertrain was much more superior in many respects, but as a source of energy, the battery wasn't built for high-energy content, comfort of handling, and did not supply cheap and abundant supplies of petroleum motor fuel like ICE.

Today, nearly a century after the electric vehicle (EV) was forced into near exhaustion the automotive industry is considering EV and HEV as potential future vehicles. As easily recoverable petroleum deposits dwindle, automobile populations soar, and cities become choked with combustion by-products, the ICE is increasingly becoming the victim of its own success. If personal transportation continues to be a vital link in the economic chain of modern societies, the private automobile appears to be the system of choice. However, automobiles must become cleaner and more energy efficient. Electric vehicles are divided into two general categories: battery-electric vehicles and hybrid-electric vehicles, which represent the design orientation of the vehicles' power system. Electric vehicles use secondary batteries (rechargeable batteries, normally called storage batteries) as their only source of energy.

2.3 Brief History of Hybrid Electric Vehicles

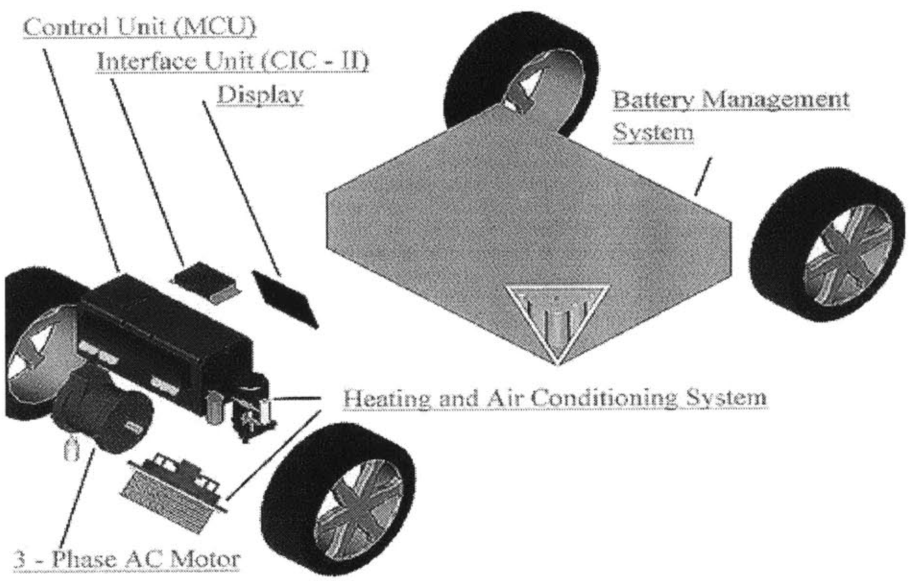
The HEV concept goes back to 1905. On November 23 of that year, American engineer H. Piper filed for a patent on a hybrid vehicle. Piper's design called for an electric motor to augment a gasoline engine to let the vehicle accelerate to a rip-roaring 40 kilometers (25 miles) per hour in a mere 10 seconds, instead of the usual 30. But by the time the patent was issued, three and a half years later, engines had become powerful enough to achieve this kind of performance on their own. Nevertheless, a few hybrids were built during this period; there is one from around 1912, for example, in the Ford Museum in Dearborn, Michigan.

The more powerful gasoline engines, along with equipment that allowed them to be started without cranks, contributed to the decline of the electric vehicle and of the nascent HEV between 1910 and 1920. In the early to mid-1970s, though, a brief flurry of interest and funding, prompted by the oil crisis, led to the construction of several experimental HEVs in the U.S. and abroad.

2.4 Electric Vehicle Power Source

Battery EVs use high-energy-density batteries as their sole power source. Most EVs currently on the market use lead-acid batteries, with direct-current motors driving the wheels. Battery types under development include lithium-iron disulfide, nickel-metal hydride and lithium polymer, as well as lead-acid batteries employing new materials and advanced designs that enhance energy density and durability.

Figure 2 shows complete drive system solutions for electrical vehicle.

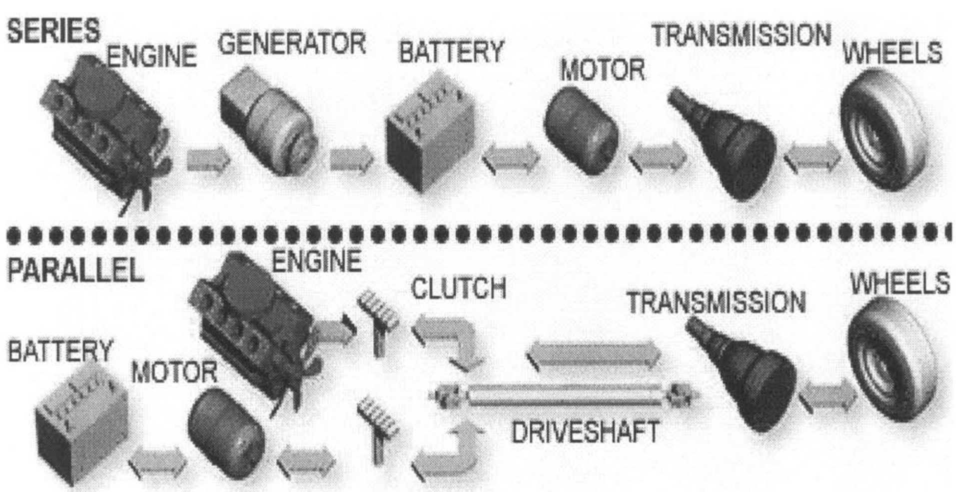


Source: AV Electric Vehicles, LTD.

2.3 Hybrid Electric Vehicle Power Source

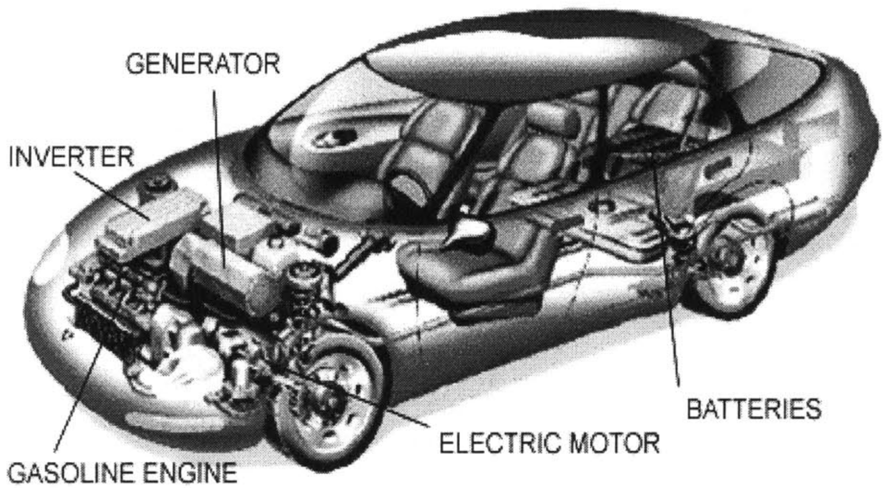
Hybrid vehicles (Series and Parallel) combine two power sources, a high-energy-density battery or an ultracapacitor, and a small internal combustion engine as a generator or, in the case of some designs, to drive the rear wheels. An ultracapacitor is simply an energy storage device that stores electricity and releases it on demand. Batteries convert power into chemical energy and reconvert it on demand. A hybrid-electric vehicle, or HEV, combines an electrical energy storage system with an onboard means of generating electricity, normally through the consumption of some type of fuel. Each type of EV has its own operating characteristics and preferred design practices, as well as advantages and disadvantages.

Figure 3. In the series type, a gasoline engine drives a generator that charges the batteries that power the electric motor, which turns the wheels. Only this motor can turn the wheels. In the parallel scheme, the gasoline engine or the electric motor--or both--can turn the wheels.



Source: Slim Films

Figure 4 shows the baseline design of a hybrid electrical vehicle



Source: George Retseck

An HEV with a series configuration uses the heat engine with a generator to supply electricity for the battery pack and electric motor. Series HEVs have no mechanical connection between the hybrid power unit (HPU) and the wheels; therefore, all motive power is transferred electrically to an electric motor that drives the wheels. The benefits of a series configuration over a parallel configuration are:

- The engine never idles, which reduces vehicle emissions
- The engine drives a generator to run at optimum performance
- Allows a variety of options when mounting the engine and vehicle components
- Some series hybrids do not need a transmission

2.4 Parallel Hybrid Electric Vehicle Power Source

An HEV with a parallel configuration has a direct mechanical connection between the hybrid power unit (HPU) and the wheels as in a conventional vehicle, but has an electric motor driving the wheels as well. For example, a parallel vehicle could use the power created from an internal combustion engine for highway driving and the power from the electric motor for accelerating. Some benefits of a parallel configuration versus a series configuration include: the vehicle has more power because both the engine and the motor supply power simultaneously. Most parallel vehicles do not need a generator and the power is directly coupled to the road, thus, it can be more efficient.

Figure 5 shows a baseline design for a parallel vehicle.

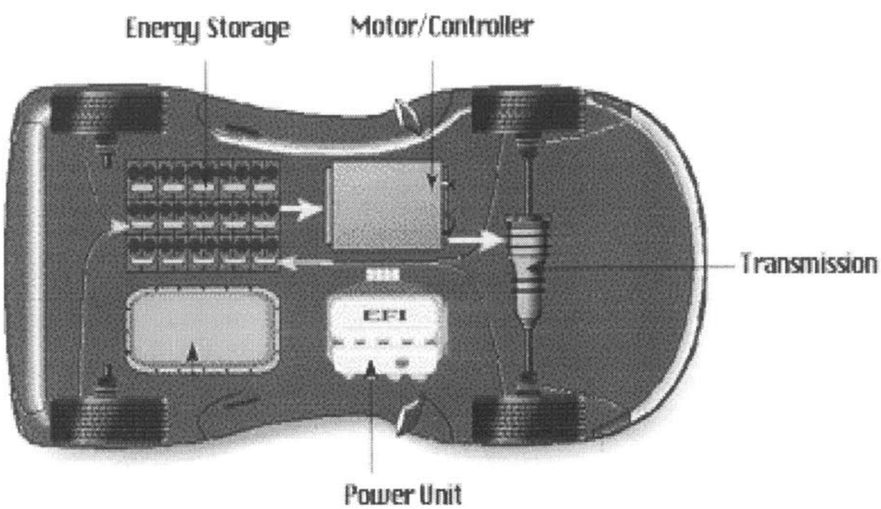
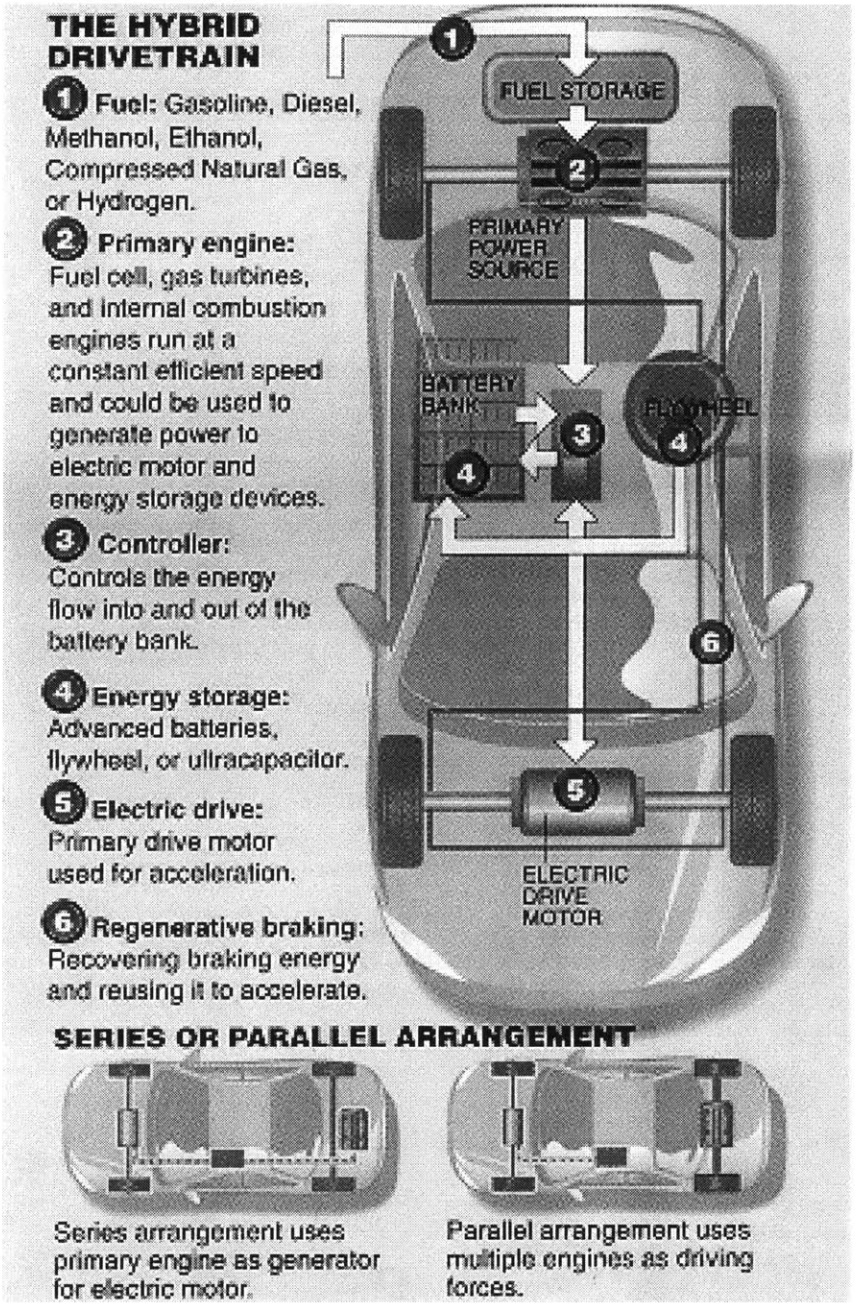


Figure 6 Illustrates the Drivetrain of a Hybrid Electric Vehicle



Source: USCAR

2.5 Advantages of Electric Vehicles

A primary technical advantage with EVs of either category is the inherent bi-directionality of their energy/work loop. An EV powertrain can convert energy stored into vehicle motion, just like a conventional vehicle, and it can also reverse direction and convert vehicle motion back into energy stored through regenerative braking. In contrast, internal combustion engine vehicles cannot reverse the direction of the onboard energy flow and convert vehicle motion back into fuel. The significance of regeneration becomes apparent when one considers that approximately 60% of the total energy spent in urban driving goes to overcoming the effects of inertia, and ideally, up to half of this energy can be reclaimed on deceleration [Riley, 1997].

Other technical advantages center on the superiority of the EV's electro-mechanical powertrain. In comparison to the internal combustion engine, an electric motor is a relatively simple and far more efficient machine. Moving parts consist primarily of the armature (dc motors) or rotor (ac motors) and bearings, and motoring efficiency is typical on the order of 70% to 85% [Riley, 1997]. In addition, electric motor torque characteristics are much more suited to the torque demand curve of a vehicle. A vehicle needs high torque at low speeds for acceleration, then demands less torque as cruising speed is approached. An electric motor develops maximum torque at low rpm, and then torque declines with speed, mostly in step with a vehicle's natural demand.

ICE develops very little torque at low rpm, and must accelerate through nearly three-quarters of its rpm band before it can deliver maximum torque. A multi-ratio transmission is therefore necessary in order to correctly match ICE output characteristics to the vehicle demand curve.

Due to the more favorable output curve of the electric motor, an EV drive train usually does not require more than two gear ratios, and often needs only one. A reverse gear is unnecessary because reversing the electrical input polarity can reverse the rotational direction of the motor itself simply. These advantages lead to a far less complex and more efficient powertrain, at least on a mechanical level.

2.6 Disadvantages of Electric Vehicles

There are many disadvantages to an electric car. Although electrical energy costs are low, initial vehicle cost is high. Its batteries are heavy and take up a lot of room -- the whole trunk area and more. The amount of battery power limits its' driving range to only 80 miles (130km) (Wouk, 1997). In addition, its' acceleration is poor. Furthermore, there are generally no recharging facilities along the roads, and recharging at home takes eight hours or more. The use of fuel cells could eliminate the need for such large batteries in the future. In the meantime, electric power is best suited for vehicles that can be recharged overnight, such as small commuter cars, fleets of delivery vehicles, and rental cars in individual public transport systems.

2.7 Electric Vehicles Energy Efficiency

Most researchers agree that a switch to EVs would reduce the total primary energy consumed for personal transportation. However, many do not agree on the precise amount of energy that might be saved. The divergence in estimations is mainly due to the fact that energy use comparisons between battery-electric vehicles (BEVs), hybrid-electric vehicles (HEVs), and conventional vehicles (CVs) are affected by a number of variables and necessary assumptions. Vehicle mass, performance, range requirements, system configuration, operating schedule, and the upstream losses of converting source fuels into useable energy and delivering it to the end user all affect system wide energy use.

A realistic baseline EV performance profile is difficult to define, primarily because the technology is relatively undeveloped and rapidly changing. Electric Vehicles are far more energy efficient than conventional automobiles. In order to determine system wide energy efficiency, the upstream losses of refining and delivering motor fuel and the losses of generating and delivering electricity must be factored in. The losses of converting source fuels into electrical energy and delivering the energy to a local electrical outlet are far greater than the losses of extracting, refining, and delivering petroleum motor fuel.

However, petroleum fuel chain efficiency does not include conversion losses, as does the electrical energy chain. Conversion of liquid motor fuel into useable power takes place in the vehicle and is therefore considered a component of CV energy efficiency. According to research, large percentage of the energy contained in crude oil arrives at the service station as gasoline, whereas only a small percentage of the primary energy used to generate electricity (depending on the source fuel and conversion efficiency) arrives at the electrical outlet ready to charge EV batteries. Studies generally conclude that battery-electric cars are more energy efficient than conventional gasoline cars, depending on the particular assumptions of vehicle energy use and energy chain efficiency.

2.8 Hybrid Electric Vehicle Energy Efficiency

Comparisons between HEVs and Conventional Vehicles are more diverse because of the many design variables of the hybrid power system. HEVs are generally considered slightly more efficient to significantly more efficient than CVs - again, depending on the assumptions used in the comparison. Due to the variables and the significant differences between electric and conventionally powered vehicles, precise energy use comparisons are difficult to achieve, and conclusions are often open to debate.

Comparisons may not fully account for the differences in engineering and performance between baseline EVs and CVs. For example, comparison EVs may be better engineered or more poorly engineered than their gasoline-fueled counterparts. And studies often include an indirect energy penalty for EVs in the form of greater vehicle mass.

The power of a hybrid's internal-combustion engine generally ranges from one tenth to one quarter that of a conventional automobile's. This engine can run continuously and efficiently, so although an HEV, when its internal-combustion engine is running, emits more pollutants than a pure electric, it is much cleaner than a conventional car. In fact, a hybrid can be made almost as "clean" as a pure electric.

When pollution from the generating sources that charge its batteries is taken into account, an electric vehicle is about one tenth as "dirty" as a conventional car with a well-tuned engine. An HEV, in comparison, can be about one eighth as polluting. With good design, moreover, HEVs can achieve several times the fuel efficiency of a gasoline-powered vehicle. Thus, if HEVs ever do become a success in the U.S., there could be benefits both for the environment and for the balance of trade: imported petroleum now accounts for almost half of the country's consumption [Wouk, 1995].

Significant improvement in battery technology and hybrid vehicle systems will minimize the obstacles that are prevalent today with this new radically form of automotive technology. Development of new technology will improve over time as it evolves. BEVs are the ultimate alternative fuel vehicles because their energy comes from the source fuels used to generate electricity. In the U.S., which gets 55% of its electrical energy from coal, battery-electric cars are predominately coal powered cars. About a third of the energy used by EVs in the U.S. would come from clean-burning natural gas [Riley, 1997].

In addition, EVs make it possible to meet transportation energy needs with other sources of technology such as solar, wind, and geothermal energy. Hybrid Power Systems of a small internal combustion engine can continually charge the battery of an EV. Hybrid vehicles have the ability of energy efficiency much more significant percentage wise, than gasoline engines in normal driving conditions. The recovery of braking system can reduce energy consumption by a small percentage in city driving.

2.9 Environmental Benefits of Electric Vehicles

Electric Vehicles produces zero vehicular emissions. However, emissions are produced at the generation site when the source fuel is converted into electrical power. The emissions of electric cars therefore depend on the emissions profile of regional generating plants. Some researchers conclude that, in regions serviced by coal-fired plants, a switch to EVs may actually increase emissions of sulfur oxide (SOx) and particulate matter (PM), and perhaps increase emissions of carbon dioxide (CO2). Conclusions, however, are usually based on the existing mix of coal-fired plants, and often, they do not consider the effect of newer and cleaner plant designs. Studies generally conclude that emissions of SOx, PM, and CO2 are reduced in regions that rely on natural gas, and virtually eliminated in regions supplied by hydroelectric and nuclear power [Riley, 1997].

EV's reduced exposure to gasoline fumes; cancer-causing fumes from gasoline refueling are avoided. EV's save time for the consumer and not having to hassle with tune-ups, smog checks, or oil changes. With an electric motor and virtually very little moving parts, electric vehicles have the ability to last a long time.

EV's are much more silent than conventional automobiles; noise levels are reduce significantly. The fact that they don't have any mufflers and quiet when idling is the main reason. Air emissions are reduced by large percent even after considering emissions from power plants that produce the needed electricity. EV's also play a major role in the reduction of global warming gases such as carbon dioxide depending on the utility fuel mix.

The table below provides energy efficiency an emissions comparison between electric vehicles and ICE vehicles running on a variety of fuels.

Figure 7 Energy Efficiency and Emissions for Mid-size Automobile

Vehicle Type/Fuel		Efficency Over Fuel Chain(%)		Net Emissions Over Chain (1)in g/mi (2)				
			SO2	Nox	CO	HC	CO2	
ICE Engine Vehicle								
		10.2	0.2	0.63	3.43	0.35	444	
Gasoline		8.5		0.86	1.71	0.35	408	
Methanol		8.1		0.52	1.9	0.13	44(3)	
Ethanol		10.8	0.04	0.4	1.7	0.16	337	
CNG		9.4		0.61	0.02	0.75	388(4)	
Hydrogen								
BEV by Source Fuel								
		16.5	1.73	0.81	0.07	0.01	485	
Coal		15.1		0.52	0.09	0.01	302	
Natural Gas		14.6	0.93	0.52	0.08	0.02	459	
Petroleum		14.4	0.1	0.05			25	
Nuclear		20		0.36	0.2	0.07	229	
Adv. NG								
Fuel Cell Vehicles								
Methanol		17.6		0.27	0.01		236	
Ethanol		15.1	0.02	0.08	0.13	0.02	28	
Natural Gas		21.7					196	
Hydrogen		21		0.11			197	

(1) From primary resource extraction through vehicle end-use, except for SO2, NOx, CO2, and HC emissions, which are estimated for fuel/electricity production and vehicle tailpipe only.

(2) G/mile x 0.621 = g/km.

(3) Assumes ethanol-derived farm and conversion energy, and a zero netCO2 release from biomass conversion due to the carbon content of the biomass having been adsorbed from the environment during crop growing.

(4) Assumes hydrogen from natural gas, which releases CO2 during reforming.

2.10 Environmental Benefits of Hybrid Electric Vehicles

The environmental benefits of a hybrid-electric vehicle depend on the design of the hybrid power system. Some studies show that optimized hybrid vehicles may be nearly as clean as battery-electric vehicles. Designs using a combustion engine for onboard electrical generation and an operating schedule that is heavily biased toward the engine/generator system (genset) produce the greatest amount of harmful emissions. Even in this worst-case scenario, emission levels are lower than those of a typical CV. This is due to the fact that a hybrid vehicle genset is either switched off, and therefore producing zero emissions, or it is operating at predetermine output where it produces the fewest emissions and achieves the best fuel economy per unit of output.

Typically, a hybrid genset is not throttled for variable output, as is the engine in a conventional vehicle. This leads to more effective emission controls because it is technically easier to control combustion-engine emissions when the engine runs continuously and at a constant output. When the hybrid-operating schedule is biased more toward the energy storage system, and emission levels become more like those of an Electric Vehicles, and with fuel-cell hybrids, vehicular emissions are virtually eliminated.

2.11 Current Companies in EV Development

2.12 General Motors and Boston Edison

General Motors and Boston Edison utility-company are joining forces to develop a comprehensive marketing initiative for electric vehicles (EVs), inductive EV chargers and EV infrastructure for Massachusetts and the Northeast. The two organizations are partnering to market Chevrolet S-10 electric pickup trucks and Delco Electronics Magne Charge inductive chargers primarily to fleets, and to collaborate on establishing EV incentives and infrastructure. Boston Edison is already an authorized distributor for GM's charging equipment for nine Northeast states. The two are also developing a business plan for an EV service center in Boston that will service EVs and chargers and provide GM training for EV technicians [Calstart News, 1996].

2.13 Nissan Motor, Sony Corporation

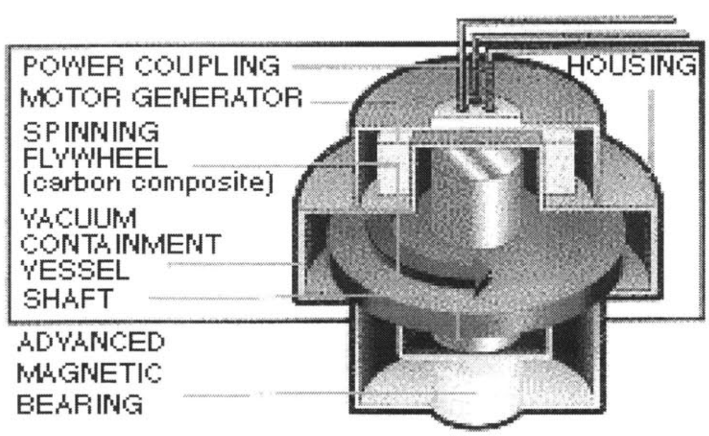
Nissan Motor Co. says it will introduce a "newly developed" electric vehicle (EV) for use in California fleets in early 1998. This follows the announcement that it will begin marketing an EV called the "Prairie Joy EV" in Japan in early 1997. The new, California-model EV, powered by lithium-ion batteries, will be part of the Advanced Battery Demonstration Program that automakers agreed to as part of a deal with the California Air Resources Board to delay its zero-emission vehicle market introductions until 2003. California testing of the California-model EV is slated for early 1997. Nissan says the lithium-ion batteries jointly developed with Sony Corp. offer about triple the energy storage capacity of lead-acid batteries and about 1.5 times that of nickel-metal hydride (NiMH) batteries [Calstart News, 1996].

Nissan will introduce an electric vehicle in Japan's retail market early next year, and later in 1998 it will bring the Altra EV compact van to the U.S. fleet market. The vehicles will run on lithium-ion batteries developed by Sony. Corbin-Pacific, Castroville, Calif., is marketing the three-wheel, one-passenger Sparrow, powered by a lead-acid battery. The car was designed for commuters and inner city driving. The company notes that the vehicle can use car-pool lanes because it can be registered as a motorcycle and carries large percent of passenger capacity when driving alone.

2.14 Daimler-Chrysler, Flywheel Technology

Energy losses in the electric generator, storage device, and motor can more than offset the powerplant energy efficiency advantages relative to conventional Internal Combustion engine. Also, current batteries cannot be recharged fast enough to take full advantage of the current generated by the small motors or through braking. The application of flywheel technology will allow fuller realization of the energy efficiency potential of hybrid powertrains. This technology is expected to become commercially feasible between 2005 and 2025. Daimler-Chrysler has developed the Patriot experimental car powered by a flywheel-based electromechanical battery. American Flywheel Systems has built a non-running show car that it claims will accelerate from 0 to 100 km/h in the 7-second range and run 560 km. between recharges. It further claims that the vehicle will accept a high-voltage recharge in 20 minute or less.

Figure 8 Flywheel (Source: PNGV 1994)



2.15 Southern Coalition for Advanced Transportation (SCAT)

The Southern Coalition for Advanced Transportation (SCAT) announced $3.2 million in new electric vehicle (EV) and hybrid EV projects. The Southern states consortium is working with the Advanced Research Projects Agency to develop and demonstrate electric and hybrid EV technologies. These projects include flywheel battery safety systems, conversion of a military “Humvee” to hybrid electric power, and development of a variable field alternator. Nearly $1.7 million comes from SCAT’s participating companies and organizations, which total 70. SCAT’s agreement with ARPA links universities, government research centers and large and small business in its development efforts [Calstart News, 1996].

2.16 Allied Signal

The commercial feasibility of hybrids also may be advanced by the development of the turbo-generator. Turbo-generators consist of a permanent-magnet generator driven by a small turbine engine. Turbo-generators are used as auxiliary power units in aircraft, tanks and other military vehicles. Work is underway by Allied-Signal Aerospace Division of Dearborn, Michigan and others to adapt turbo-generators for automotive use.

Allied Signal plans to install a 22 kW turbo-generator, in a small (8.8 meter) hybrid city bus for demonstration. In this application, the 22 kW units are considered a "range extender". They will begin testing in what it terms a late 50 kW turbo-generator. A 50 kW unit will allow for continuous, unlimited-range operation of a full-size car. Allied Signal has "kicked around" a target price of $US 2,000 for a 50 kW turbo-generator. The actual cost of an automotive unit remains vague, however, since development of turbo-generators for automotive applications is in the early stages.

Allied Signal is projecting lower fuel consumption and lower VOC, CO and NOx emissions for the 50 kW units than a piston engine. The fuel economy goal for Allied Signal's 50 kW turbo-generator is in the range between the Department of Energy Hybrid Propulsion Program goal and the Partnership for a New generation of vehicle's goal The target date for commercialization is "some time after the year 2000". Nine of the first 81 Ford Ecostars produced will be hybrids. Volkswagen is also planning a hybrid small car based on the Golf.

2.17 Toyota

Toyota offers the RAV4-EV sport-utility vehicle in Japan (and for 1998 fleet models in the U.S.) and Honda is marketing the EV Plus, both of which run on NiMH batteries developed by Matsushita. Toyota also markets an electric bus in Japan that runs on lead-acid batteries.

2.18 Ford Motor Company

Ford's compact pickup truck, the Ranger, will debut with a valve-regulated, maintenance-free, 2,000-lb lead-acid battery in the 1998 model year. Ford will use the NiMH battery in its 1999 Ranger EV vehicles. Initial target customers include utilities and fleets. Chrysler's Dodge Caravan and Plymouth Voyager EPIC (Electric Powered Interurban Commuter) minivans will come out with advanced lead-acid batteries in 1998 for California fleets. The company is also working with SAFT on NiMH for the minivan. SAFT's nickel-cadmium batteries are being used in cars such as the electric Peugeot 106 and Renault Clio in Europe.

Chapter 3

General Motors EV1 Case Study

3.1 Introduction

This chapter discusses the very first electric vehicle in GM history, the story of the General Motors EV1, the EV1 design team and a graphical 4∅VDP. The GM 4∅VDP as it relates to the conventional vehicle will be discussed.

3.2 General Motors EV1 Story

General Motors has been trying to develop an Electric Vehicle for quite some time. The EV1 isn't the first vehicle GM has pursued. The Electrovette was a converted Chevette that used zinc nickel oxide batteries with a DC motor. The use of zinc would give the Chevette greater energy density than lead. A process was developed to keep the zinc from deteriorating after a few recharges. It was a great plan, except that the batteries cost far more than lead acid, and more range still meant at most 100 miles. This was also before the new age of automotive electronics; the car had a mechanical-electrical control system that made for lots of arcing, energy loss, and unreliability. When the oil prices dropped, the Electrovette died a quiet death at the demo stage [Shnayerson, 1996].

General Motors started gaining interest in developing another electric vehicle. Project Santana was the name being used for this new vehicle concept. The major issue that concerned GM was the type of battery that will be used. Lead acid batteries were the first choice due to the cost of producing them, and the vehicle speed that could be generated. Another power that was being considered was the recombinant battery. This was still another lead acid battery but the electrolyte was absorbed into a sponge like glass with fiber mats between the plates. The battery was unique because it didn't require any space above the plates for the gas to vent and the liquid electrolytes to form. The importance of this process allowed for the batteries to be more densely packed.

In July 1988, a presentation was being made to GM executives about funding to Project Santana. Robert Smith of the chairman's office wasn't supportive of the project and insisted that management not pursue this radically new automotive technology. Robert Stemple and Vice Chairman Don Atwood spent long hours conversing with Smith about the project. Finally in September 1988, Smith awarded $3 million dollars and a fifteen-month deadline to produce the EV1. Eventually, GM invested over $350 million in the EV1 program. The manufacturing plant is located in Lansing Craft Centre, Lansing, Michigan, and is approximately 100,000 sq. ft.

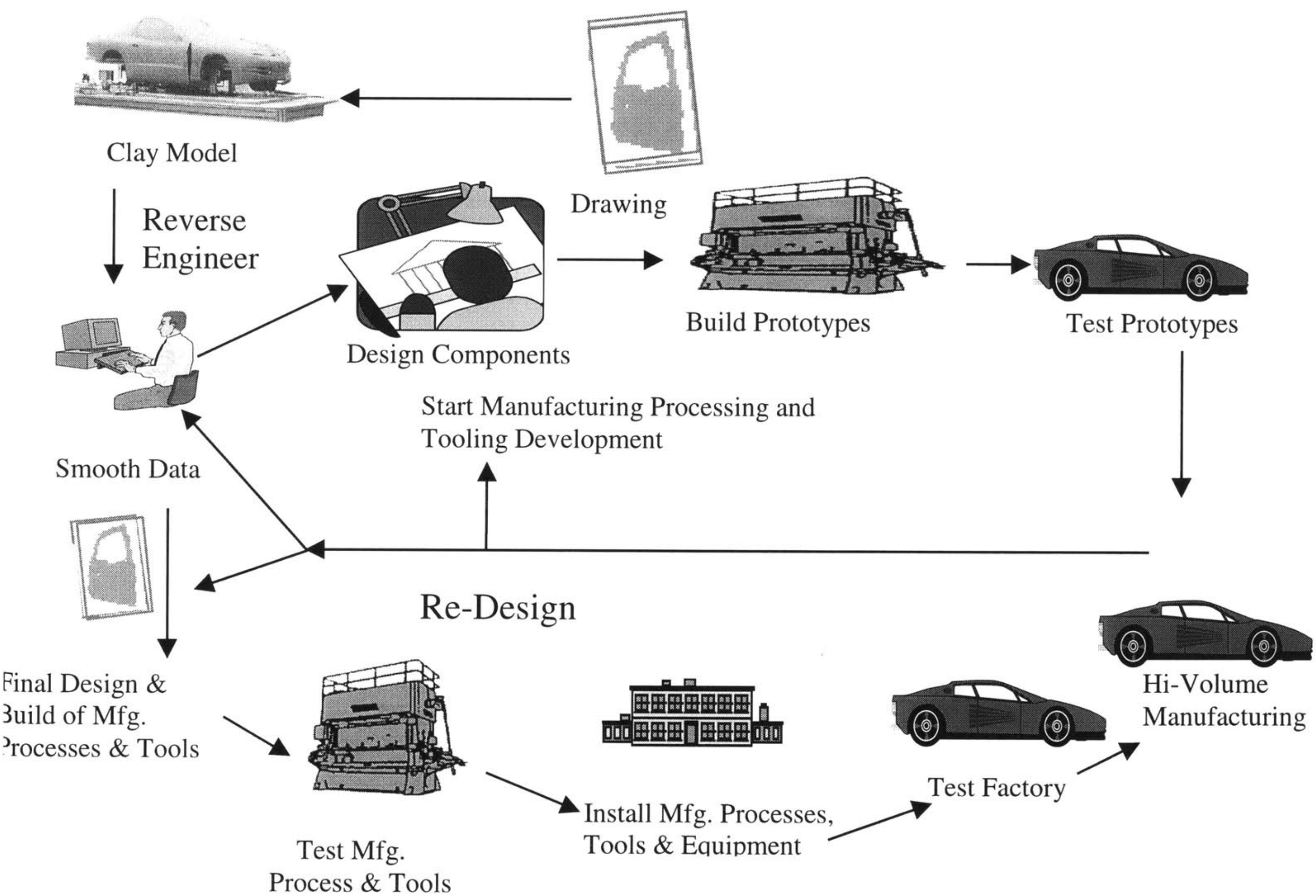
3.3 EV1 Design Team

Alex Cocconi would design the vehicle inverter, Aero Vironment Team was developing the vehicle body, Delco Remy was creating the batteries, and General Motors Advanced Concepts Center (ACC) will design the EV1 body. Conflict developed between G.M. ACC and Aero Vironment on who will design the vehicle design. Don Runkle (Program Manager) was forced to fly out to California to clear up the misunderstanding between the two design teams. Fortunately, both sides agreed to create one design.

3.4 General Motors Past Vehicle Development Process

The Vehicle Development Process for a GM vehicle was 48 months, which included concept initiation to prototype development, and final production. This process is broken up into 4 phases of development. During this long rigorous process of automotive development several requirements for the product are required. Vehicle requirements for the Body-in-White, Interior Ornamentation, & Exterior Ornamentation are all generated during this stage of the automobile.

Figure 9 General Motors Graphical Past Vehicle Development Process



General Motors Generic 4∅VDP

The following framework depicts what takes place for all new vehicles. Starting with the pre-bubble up initiation (BI) stage and then followed by the implementation of Phase 0, 1,2, & 3.

Phase 0

- Brand Theme Dev. & Select
- Continue Prod. & Mfg. Req. Dev.
- Continue Prod. &
- BOM/BOP
- Mfg. Criteria Dev.
- Product & Mfg. Design
- Initial Product & Process Development
- Critical Commodities Sourced for Alpha
- First Alpha Build
- Major Commodities Sourced for Beta
- Consensus Criteria agreed

Phase 1

- Mfg. Processes, Tools, & Equipment Development
- Product Development & Validation
- Sales, Service, & Marketing Development
- Beta Build
- Sourced for Prototype
- Prototype Build

Phase 2

- Market
- Production
- Product Launch
- Mfg. System Validation

Phase 3

- System Fill
- Production
- Sales
- Accelerate Production

3.5 Introduction to General Motors 4∅VDP

The 4∅VDP hierarchies is the multilevel framework that connects GM's Common Vehicle Development Process to the organization it supports. The hierarchy has three focus areas: Corporate focus, program focus, and functional focus [GM 4∅VDP, 1998].

3.6 Pre – Bubble up Initiation (BI)

These areas consist of the market & customer, program scope & requirements, business case, program timing and charter issues.

3.7 Marketing and Customer

When new products are being considered, the marketing group collects data from the voice of the customer. This information is taking into consideration in hopes of creating a product that meets the needs of the customer. In addition, strategies and market performance requirements are generated as well. Marketing determines where the product is going to be manufactured and what position this product will take in the GM product portfolio. For example: the Cadillac is manufactured in Hamtrack, Michigan and has a yearly volume of about 250, 000 vehicles; six different styles are made; an average vehicle costs about $40,000. In the case of the EV1, management chose the Lansing, Michigan assembly plant to manufacture the EV1; a yearly estimated volume of 20,000 cars for four years; a cost of $30,000.

3.8 Program Scope & Requirements

This area is very critical to the success of new product development. The following areas are just a few of the areas that take place during the development stage of a conventional vehicle and EV:

Bill of Design for a Conventional Vehicle

This is the area where the body and the components are developed. Several subsystems are put into place. The following components are created during this phase:

BIW (Body in White Lower)	**BIW (Body in White Upper)**	**Interior/Exterior**
Vehicle Structure	Structure & Crashworthiness	HVAC Controls
Body - Side lower	Steering Column/Wheel	Fascias/Lamps
Underbody Structure	Body - Side Upper	I/P Trim
Interior Crash	Exterior Panels	Console
Instrument Panel (I/P)	Interior Crash	Seats
Underbody Chassis	Doors	

Chassis Systems

Engine	Radiator
Suspension	Water Pump
Shock Absorbers	Windshield Wiper Module
Struts	Engine Coolant
Wheels	Gas Tank
Wheel Bearings	Oil Pan
Tires	Transmission Fluid
Oil Stick	Transmission
Brakes	Rotors
Brake Fluid	Calipers

Bill of Design for an Electric Vehicle

With an EV, this is where the system design occurs; exterior, interior, chassis, weight of the vehicle, aerodynamics, and batteries are all design here.

Structure (Space Frame)	**Exterior (Composite)**	**Interior**
Welded Alloy &	Doors	Heat Pump
Bonded Aluminum Frame	Hood	Heat Exchanger
Chassis Springs	Deck-lid	Solar Control Glass
Shock Absorbers	Roof	Dual Air Bags
	Front & Rear Fascia	Front & Rear Seats
	Front Fenders	Instrument Panel (I/P)
	Rear Quarter Panels	Center Console
	Rocker Panels	Climate System
	Rear Wheel Skirts	
	Belly-pan	
	Front & Rear Headlights	
	Daytime Running Lamps	
	Electronic Keypad Entry	

Chassis System

Batteries
Power Steering Pump
Front Suspension (which includes a Short-long arm with coil spring-over-shock absorber)
Rear Suspension (which includes a multi-link and Panhard rod located aluminum beam)
Rack & Pinion
Shock Absorbers
Coil Springs
Tie Rods
Electric Motor
Front Wheel Drive
Regenerative Braking
Wheels
Tires

Bill of Process for Conventional Vehicle (BOP)

The Bill of Process describes the common GM manufacturing and assembly processes, product design requirements, and equipment/tooling/facilities guidelines. The Bill of Process will enable the Flex Strategy, support Competitive Manufacturing Strategies, and provide consistent direction to engineers. Its scope covers Dies, Stamping, Body Structures, Body Closures, Paint, General Assembly, and other manufacturing functions. The Bill of Process is developed for global application across GM.

Bill of Process for Electric Vehicle (BOP)

The Bill of Process for an EV was very similar to the conventional vehicle process. The design requirements, tooling & equipment development followed the same guidelines. What made the EV BOP unique from the conventional vehicle were the various aluminum materials for the spaceframe (Body). Manufacturing considerations simplified parts, improved consolidation, and reduction. This process helped integrate 24 separate sheet metal parts into just four castings for the attachment of the chassis springs and shock absorbers to the spaceframe. The spaceframe has a total of 165-formed parts. Conventional stampings were used for 50% of the part count. In addition, composite materials for the body panels, the solar windshield, and a heat pump that was used to help generate the air conditioning. This BOP method was quite unique compared to the conventional vehicle.

How is the Bill of Process Developed?

With so many different requirements, several groups have to come together in order to make BOP a success. GM Metal Fabricating Division & Worldwide Facilities; Quality, Reliability & Competitive Operations Implementation; GMNA Body & Exterior Center; and the General Assembly Center -- networked with Vehicle Centers & Plant Contacts. BOP is linked to many other activities. Here are a few examples:

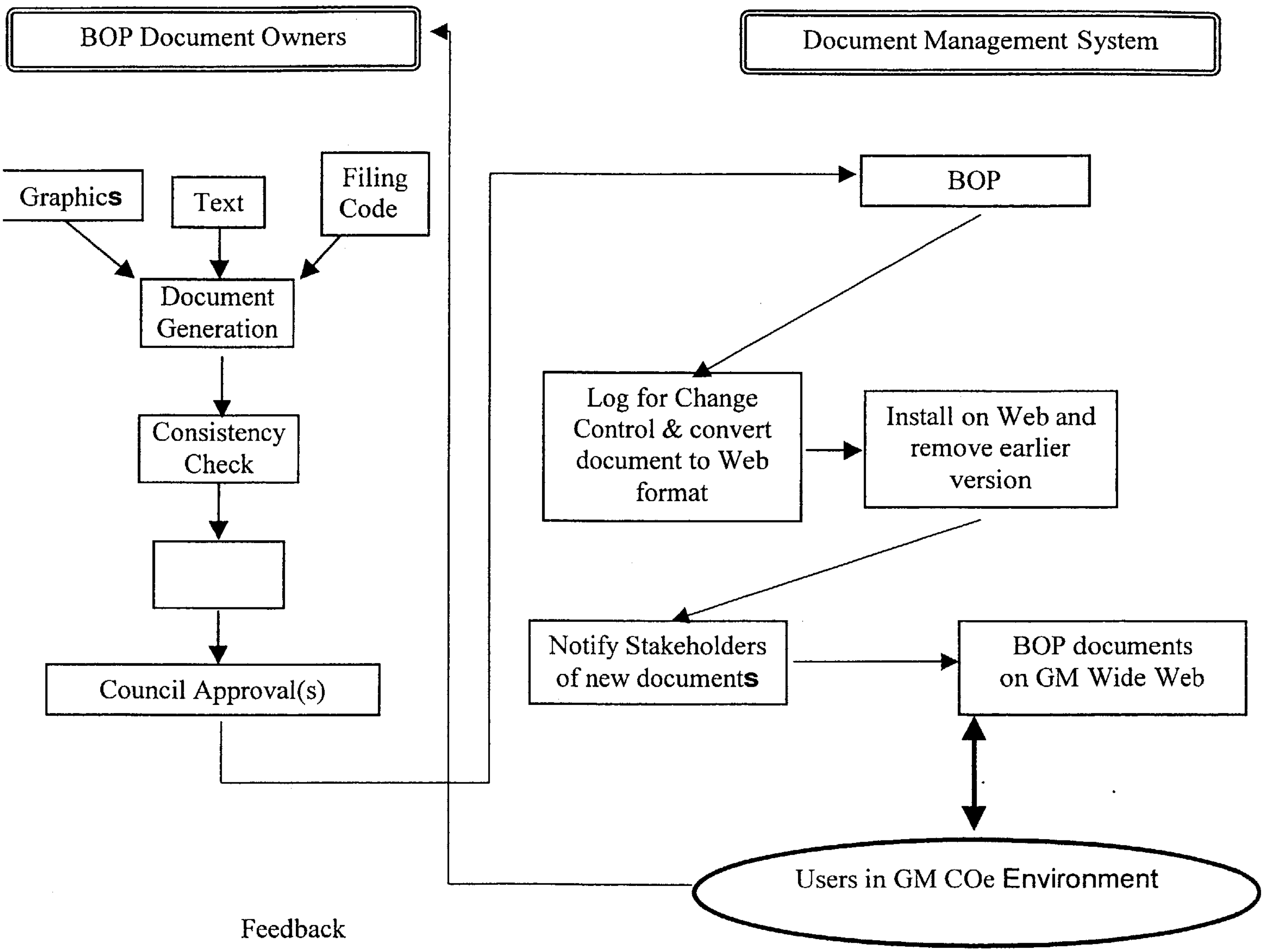
Vehicle Engineering Centers

DFM	Bill of Design
Implementation	Bill of Material
Compliance	Coordination w/Product Plan
Feedback	Marketing

Manufacturing Engineering Operations & Integration

Manufacturing Technical Specifications
Vehicle Technical Specifications
Stamping/Dies
Body/Paint
General Assembly

Figure 10 BOP Document Process Template
Document Development and Distribution of BOP



Source: GMU Knowledge Center, June 1999

3.73 Phase 0 of the 4∅VDP

During this stage of the development process, many sub – phases are generated. The conventional vehicle and the EV have similar categories with some areas slightly different. A side-by-side comparison has been made to show these differences. Product Engineering, Manufacturing Engineering, and Purchasing requirements move into action. The very first Alpha vehicle is released during this phase. The different categories will be listed only and not explained specifically. The following sub – phases are created and implemented:

Conventional Vehicle

Sub – Phase A
Preliminary Interior Hard Trim
Math Data

Sub – Phase B
Interior/Exterior Styling Theme

Sub – Phase C
Interior/Exterior Surfaces Frozen
Tooling and Equipment Design
Die & Stamping Design
Process Control Design
BIW Sub – Assembly Process Design

Sub – Phase D
Product Engineering:
Alpha Design for Engine
Alpha Design for Chassis Systems
Product Sub – system requirements
Vehicle Design & Subsystem/Components
Alpha Design Development for BIW
Alpha Design Development for G/A
Engineering Drawings Being Created
Alpha Design for Chassis System

Manufacturing Engineering
BIW Component Assembly Process
G/A Component Assembly Process
Alpha Part Fabrication: BIW
Alpha BIW Assembly

Electric Vehicle

Sub – Phase A
Preliminary Interior Hard Trim
Math Data

Sub – Phase B
Interior/Exterior Styling Theme

Sub – Phase C
Interior/Exterior Surfaces Frozen
Tooling and Equipment Design
Die & Stamping Design
Process Control Design
Spaceframe Sub – Assembly Process Design

Sub – Phase D
Product Engineering:
Alpha Design for Batteries
Alpha Design for Electrical System
Product Sub – system requirements
Vehicle Design & Subsystem/Components
Alpha Design Development for Spaceframe
Alpha Design Development for EXT/INT
Process Assembly Documents Creation
Alpha Design for Chassis System

Manufacturing Engineering
Spaceframe Component Assembly Process
EXT/INT Assembly Process
Alpha Part Fabrication: Spaceframe
Alpha Spaceframe Assembly

Alpha General Assembly
Tooling & Equipment Specifications

Alpha EXT/INT Assembly Process
Tooling & Equipment Specifications

Conventional Vehicle

Purchasing
Alpha Parts & Tools purchased

Sub – Phase E
Product Engineering
Product Design Testing– Analytical
Product Design Evaluations –
Match Checking Process
Production Design & Development: BIW
Production Design & Development: GA
Production Design Revisions: BIW

Manufacturing Engineering
Alpha BIW Assembly
Alpha GA Assembly

Electric Vehicle

Purchasing
Alpha Parts & Tools purchased

Sub – Phase E
Product Engineering
Product Design Testing – Finite Element Analysis
Product Design Evaluations – Vehicle Checking
Production Design & Development: Spaceframe
Production Design & Development: EXT/INT
Production Design Revisions: Spaceframe

Manufacturing Engineering
Alpha Spaceframe Assembly
Alpha EXT/INT Assembly

After comparing the conventional vehicle Phase 0 sub-phases to the EV1 sub-phases, the only differences that take place occur in the sub-phases D & E. In sub-phase D, the conventional vehicle starts the Alpha Design for an Engine and Chassis, while the EV design is for the Battery and Electrical System. In sub-phase E, the conventional vehicle product design testing is analytical while the EV uses finite Element Analysis for product design testing. These are the only differences and the rest of the process is similar.

3.74 Phase 1 of the 4∅VDP

At this stage of the vehicle development process, validation of components is completed and the beginning of building long lead tools. Vehicle integration and subsystem evaluation, lessons learned from previous production designs are updated, prototype build readiness, and preparation for vehicle launching at the assembly plants. The conventional vehicle and EV once again have similar categories. The following categories are also being implemented and developed as well:

Conventional Vehicle
Manufacturing Processes
Tools & Equipment Development
Product Development and Validation
Beta Build of Vehicle
Vehicle Prototype Build
Vehicle Production Tools Installed and Validated
Vehicle Production Tools Installed Validated
Beta Build of Vehicle

Electric Vehicle
Manufacturing Processes -
Castings, Extrusions, Formed Sheets,
Structural Adhesive, Spot Welds,
Finite Element Analysis
Tooling & Equipment Development
Product Development and Validation
Vehicle Prototype Build

In Phase 2 of the VDP, The EV manufacturing processes were completely different than the conventional vehicle. Castings, extrusions, formed sheets, structural adhesives, and spot welds were all used in manufacturing the spaceframe of the EV1. In addition, finite-element analysis was used. Finite-element analysis allowed GM engineers to select a material that was appropriate for the space frame, and to determine a design that would suit the amount of stress at each point in the structure. This allowed them to achieve the lightest and stiffest possible design

3.75 Phase 2 of the 4∅VDP

This the level where vehicle level validation and complete tool and equipment validation starts. Program Managers, manufacturing engineers, process engineers, product engineers, and several other engineering disciplines spend numerous hours in assembly plants launching new vehicles. The conventional vehicle and the EV followed the exact same procedure.

Conventional Vehicle
Pre – Pilot
Vehicle Validation
Production Launch
Manufacturing System Validation
Sales
Services
Marketing Product

Electric Vehicle
Pre – Pilot
Vehicle Validation
Production Launch
Manufacturing System Validation
Sales
Services
Marketing Product

In phase 2, the conventional and the EV have been completed. This phase of the vehicles go through the exact same process. Pre-Pilot of both vehicles is implemented and validated.

3.76 Phase 3 of the 4∅VDP (Final Stage)

After completing Phase 0, 1, 2: Phase 3 is the beginning of building the actual vehicle. Several months have gone by and many iterations of the vehicle have taken place. This the moment where all of the planning, prototype development, vehicle validation, personnel training, tooling design and development are put to the test. The conventional vehicle and the EV did not do anything different in this final stage of the vehicle. This was a common process no matter how different the two technologies are.

Conventional Vehicle & Electric Vehicle

Engineering – post validation audits

Marketing – develops pricing for new vehicles

Quality – sends quality requirements to assembly plants and dealerships

Manufacturing Engineering – final integration of the vehicle and manufacturing system completed and confirmed.

Manufacturing – acceleration of the production system, proper vehicle identification, shipping of new vehicles and filling the system with vehicles.

This final stage of the VDP applies to both vehicles. There is difference between the two.

Chapter 4 Differences Between Conventional and Radically New Development Process

5.1 Introduction

There is no difference between a conventional vehicle and a radically new vehicle development process. The EV 1 followed the same 4∅VDP just like a GM conventional vehicle. This chapter will focus on components from BIW, Electrical, and Exterior/Interior of the EV1. In addition, the problems that were found during this process, and what decisions were made to overcome these bottlenecks will be highlighted. While conventional and radically new technologies follow the same process, radically new technology development is different in that there is additional diversity of concepts, materials, and choices that must be made.

5.2 Conventional Vehicle & EV1 Goals

The car goals are: What would the vehicle do? What would it cost? What would it be? These goals happened to apply to the conventional vehicle and the EV. General Motors develops vehicles that would meet the following vehicle technical specifications (VTS):

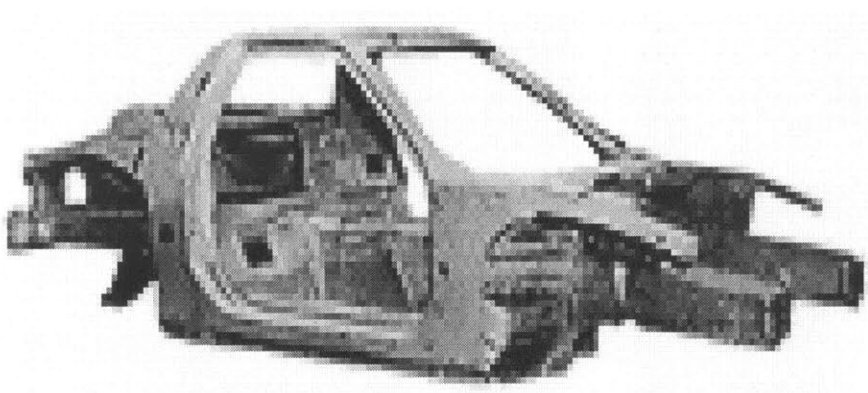
Conventional Vehicle Goals
Engine 4L, 6L, 8L (HP)
2 Door Coupe or 4 Door Sedan
How many color schemes?
Manual or Automatic Drive
Front or Rear Wheel Drive
Size & Weight

Electric Vehicle Goals
Acceleration speed of 0 – 60mi/hr in 8 seconds
Battery weight ≤ 1000lbs
Battery that could provide a range no less than a 100 miles
1 large motor instead of two
Drag coefficient of 0.19

5.2 The Structure Process of the EV1

Structural engineers designed a weld-bonded aluminum space frame for the EV1. This was done to minimize mass and create a solid structure that would comply with government and GM standards. Conventional vehicles use steel, too much weight for the EV. The engineers had to consider a much more diverse set of materials and configurations such as: aluminum, composite materials, framed pieces, uni-body, etc. A significant amount of weight savings was achieved using this type of material instead of steel. In the conventional development process, a steel design, usually have the structure accounts for about 20% of the car curb weight, or 600 pounds in a 3000-pound car. With the space frame, this is at least a 50%reduction.

Figure 11 EV1 Body Structure



The EV1 structural team had to consider many more options such as: several different types of aluminum materials for the space frame that includes, castings, extrusions, and formed steel. Individual pieces are joined by a combination of spot welds, rivets and structural adhesive. The success of this frame was the result of added finite-element analysis not typical of a conventional development process. Conventional vehicles use a match checking process known as functional evaluation.

The process where several components are hung on the body of the vehicle and measurements are taken to see if the parts meet the specifications. This process was insufficient for the EV1, so models were used instead. Finite-element analysis allowed GM engineers to select materials that were appropriate for the space frame, and to determine a design that would suit the amount of stress at each point in the structure. This allowed them to achieve the lightest and stiffest possible design: with a natural frequency of 25 Hz.

In the first bending mode, and a static torsion stiffness of 15,000 N-m/degree, the EV1 achieves a high level of structural stiffness. That permits suspension elements to be tuned for optimal ride handling without compromising to compensate for structural limitations [Saturn Corporation, 1996]. While the tools, systems, and material used in phase two different for the EV1, nevertheless the engineers did develop the spaceframe in the same part of the 4∅VDP.

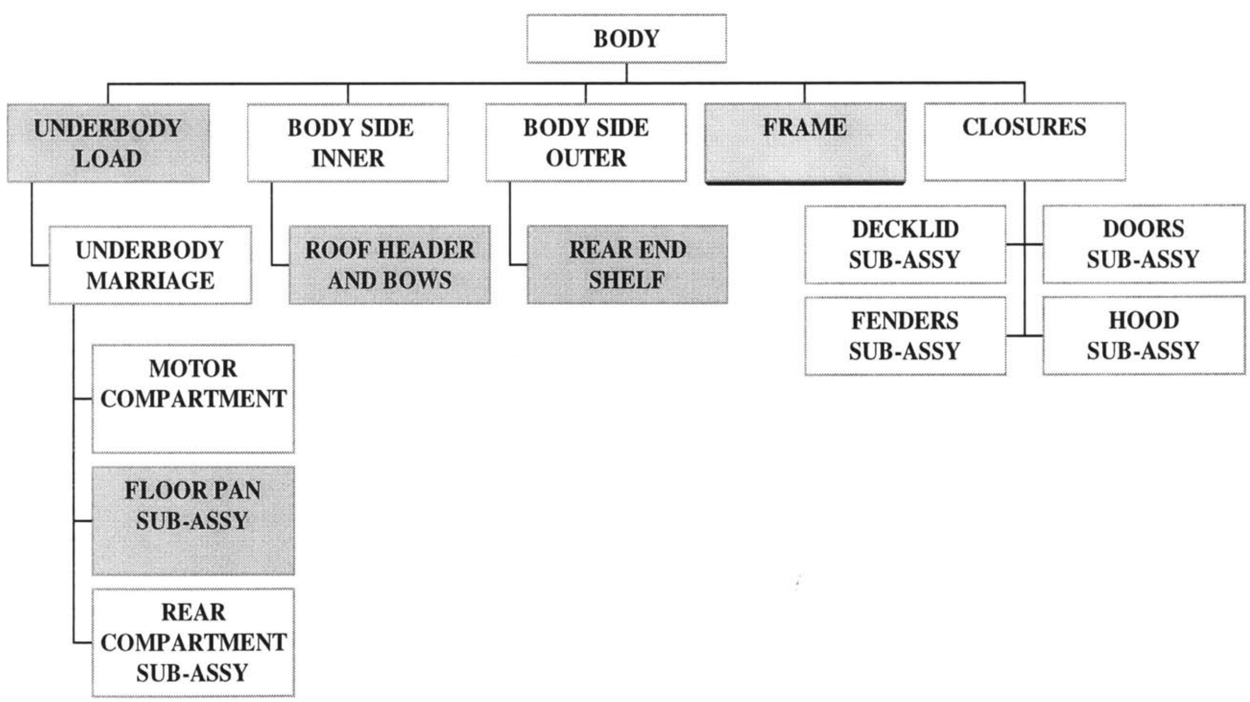
5.3 The Body Process of the EV1

In 4∅VDP, the body comes next. Conventional development uses a clay model to develop the body. The EV1, on the other hand, required a more faster body prototypes to achieve the lowing objective. A new laser gun that fed the model measurements to a computer, where it appeared, and it was finally calibrated in 100 mm squares on the screen. Using coordinates, a computer operated milling machine cut a full-scale model from a block of foam. Once the model was complete, molds were taken from the foam car. This process was done to form body panels.

Conventional vehicles used steel for the body. Steel was extremely heavy for the EV, so the EV1 engineers had to consider a broader range. Composite materials were considered and explored for the EV body. Engineers at GM like the idea that this material made the EV light, sleek, and functionally efficient. This material reduced the amount of mass on the vehicle. Comparing it to a steel body, which is much heavier, this was more feasible. Composites also helped to create the aerodynamic shape that was required for maximum efficiency; and helps prevent corrosion and dent resistance to the exterior of the vehicle.

Figure 12 shows the component breakdown differences for the EV1 as compared to a conventional vehicle, showing that the EV1 team had to consider many alternative breakdowns of the body, where as it is always the same for a conventional steel car.

EV BODY CHART



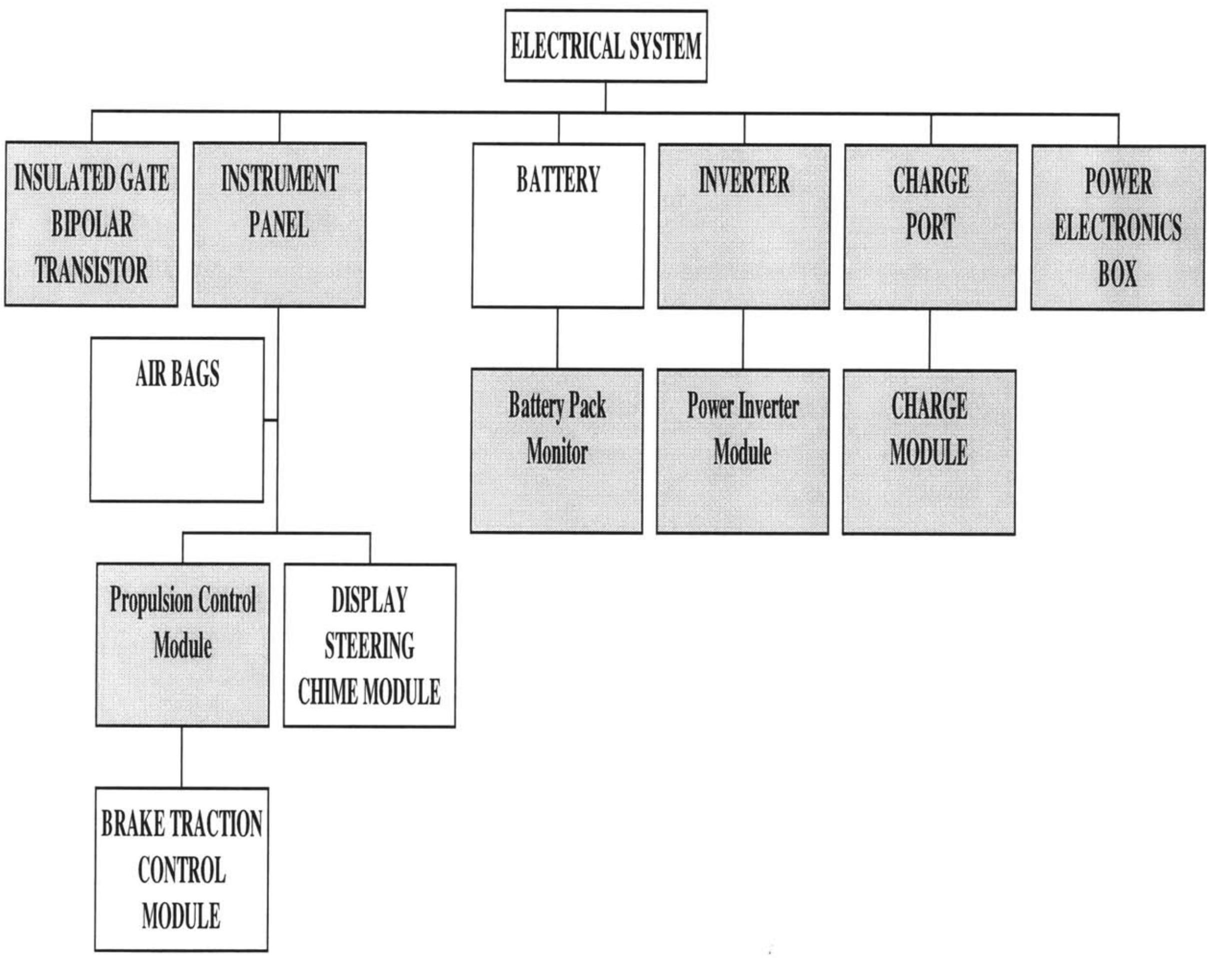
5.4 EV1 Electrical System

After the body and structure, the electrical system is developed in GM 4ØVDP. The electrical system is the area that was very challenging for General Motors EV1 team. Trying to find the right battery caused several problems. The EV1 is propelled by electrical energy and regulated by advanced electronic controls. More than a dozen harnesses congregate wires ranging from 22 gauges at the small end to 2-gauge cables carrying from 5 to 400 colts. The harnesses connect 26 batteries to the propulsion motor, and they also connect to seven Delco Electronics microprocessor-based controllers in the car.

Given that it was so challenging, it is now apparent that the EV1 division should not have followed the 4ØVDP, but instead the power system should have been developed first and the rest of the vehicle should have been built around it. The EV1 Braking and suspension systems, thermal management systems, braking systems, interior & lighting systems, electro-hydraulic steering, and chassis systems did not have too many difficulties during the developing stages of the EV1. The battery and inverter were considered the major problems of the EV1. Clearly, conventional cars have no such problems. The engine and fuel systems are well defined because GM has several years of experience of developing this technology. The EV1 had numerous amounts of decisions surrounding the batteries and the inverter.

Figure 13 shows the component breakdown differences for the EV1 electrical system as compared to a conventional vehicle, showing that the EV1 team had to consider many alternative breakdowns of the electrical system, where as it is always the same for a conventional steel car.

EV ELECTRICAL SYSTEM



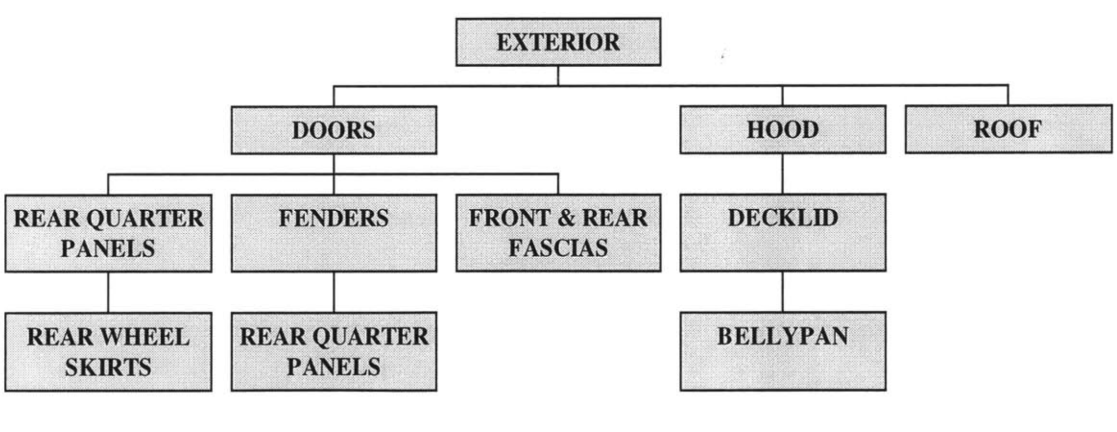
5.5 Exterior

In the Exterior of the conventional cars the process is always the same due to the years of experience GM has in this process of the vehicle. The EV1 utilize new materials that made the process different. For example, when GM decided that a composite body design was best for the EV1, three different types of materials to suit its specific needs were going to be used.

SMC (fiberglass-reinforced-resin sheet molding compound) is used for the hood, doors, roof, and the car decklid. RIM (reaction-injection-molded polyurethane) was selected for the front and rear fascias, front fenders, rear quarter panels, rocker panels, and rear wheel skirts. The EV1 bellypans are molded in SRIM (structural reaction-injection-molded polyurethane). Dealing with light delegate materials was new for the engineers and the employees. The Corvette is the only other vehicle, which has fiberglass components that require some special machinery.

Figure 14 shows the component breakdown differences for the EV1 Exterior as compared to a conventional vehicle, showing that the EV1 team had to consider many alternative breakdowns of the exterior system considering the vehicle new composite materials.

EXTERIOR

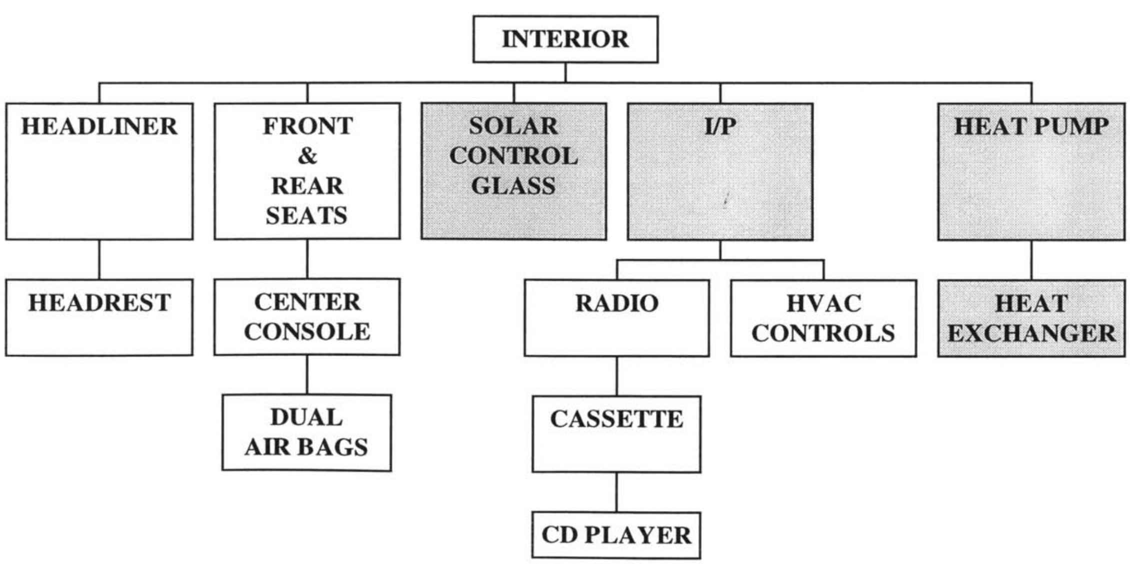


5.6 Interior

The Interior process for conventional vehicle and the EV1 followed the same process. The EV1 had some different materials and obvious control mechanisms different from a conventional vehicle. The air conditioning unit key components are similar to a conventional vehicle cooling system. A heating pump and a heat exchanger along with a compressor under the hood of the vehicle are the controlling mechanisms for the AC. The compressor circulates R134A refrigerant in the car and the driver can pick from five blower speeds and three power settings. The compressor is driven by an integral computer-controlled three phases AC motor instead of the EV1 propulsion system. Installation of seats, carpet, headliners, dual air bags, etc. follows the same process as the conventional vehicle.

Figure 15 shows the component breakdown differences for the EV1 Interior as compared to a conventional vehicle, showing that the EV1 team had to consider many alternative breakdowns of the interior system considering the vehicle new fiberglass-reinforced urethane materials.

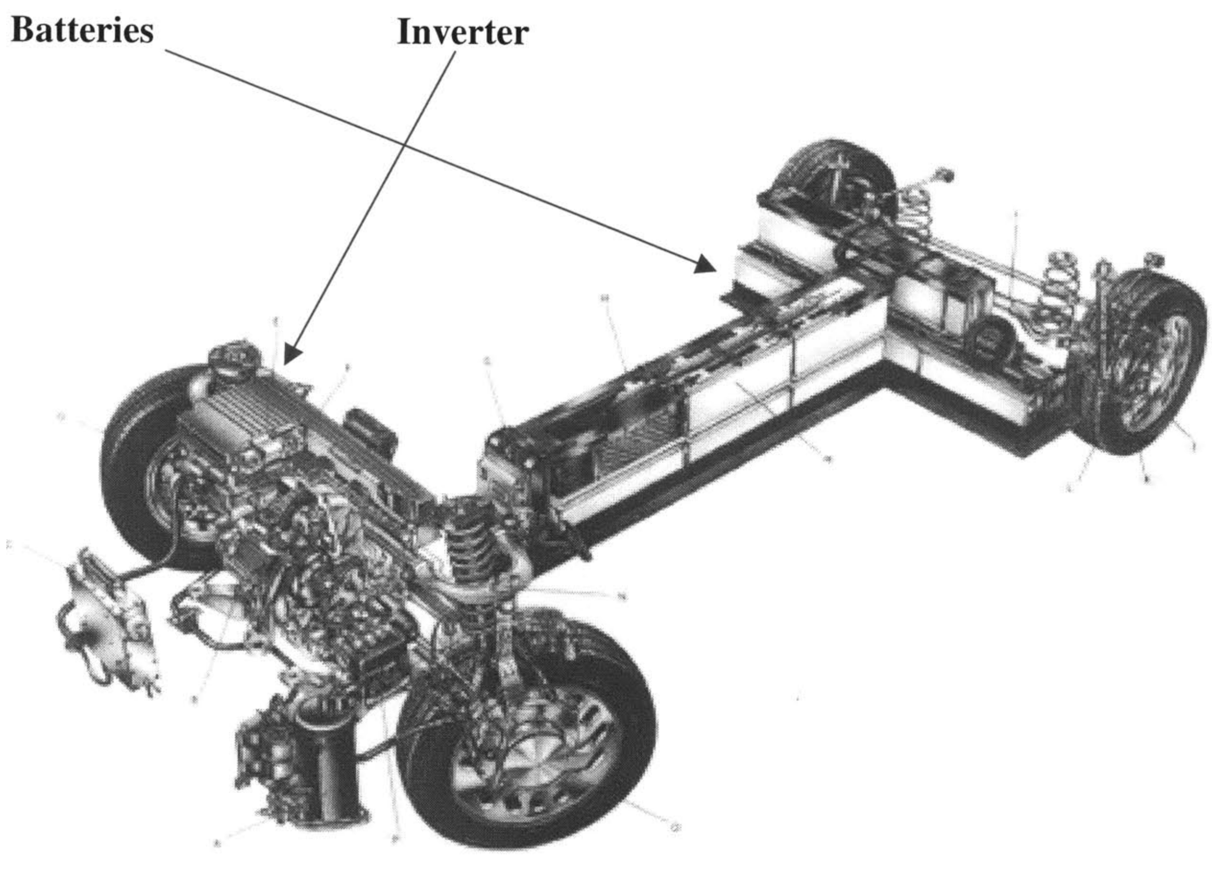
INTERIOR



5.7 Chassis System Development

The chassis system for a conventional vehicle and EV1 was slightly different. The EV1 suspension system is comprised of aluminum and composite materials to minimize mass; where steel is the main material for a conventional vehicle. The EV1 has a Short/Long Arm front suspension system that has features forged aluminum upper and lower control arms. An electric motor drives the power steering pump and it is only programmed to run only as required; in a conventional vehicle the engine provides the power. This reduces a significant energy demand compared to a conventional hydraulic system.

Figure 16 shows the drivetrain unit for the EV1.



Source: EV World

5.6 EV1 Inverter

General Motors was experiencing several problems with the EV1 inverter. Hughes was developing the inverter; the inverters were coming to the plant dead. Hughes was not following the vehicle systems engineering requirements [Shnayerson, 1996]. The inverter was interfering with other electric modules in the vehicle and causing the radio or the AC on the EV1 to malfunction at anytime. If you were driving down the street, the malfunction could cause car garages to open up when you passed by the house. GM decided to find another designer for the inverter.

The inverter was being design and developed by Alex Cocconi. An Inverter is a device that converts AC electricity in DC electricity. Electric cars that have DC motors do not need an inverter; EV's using AC motors need the inverter to change the DC electricity from the batteries into AC for the motor. Inverters are not easy to design to specific applications. Cocconi was able to develop an inverter for the EV1 that weighed 61 lbs. To achieve this goal, he used these methods:

- Identify a method of mounting the power devices that will improve thermal performance
- Develop a transient thermal model for an integrated motor and inverter power stage
- Design a partitioned inverter power stage and controller with fiber optic interfaces
- Design a sensorless control algorithm for a high-speed AC induction motor
- Construct a test-bed hardware system to demonstrate the concept

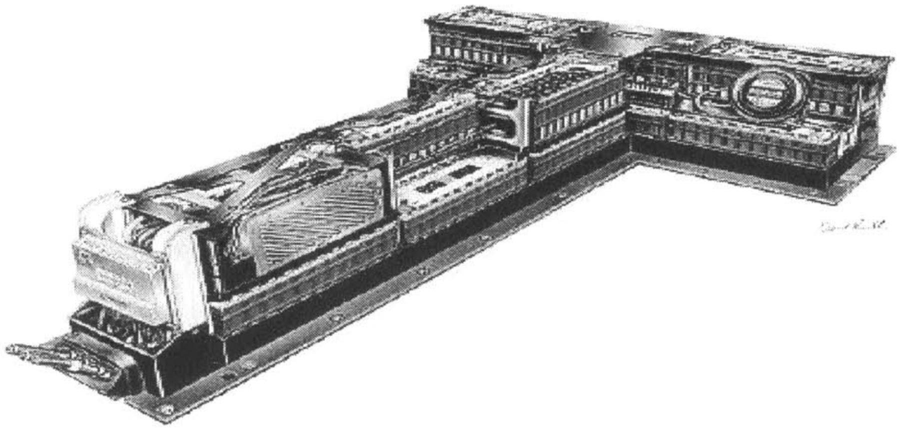
The most important success of the inverter was also achieved because the systems engineering data was used.

5.6 EV1 Batteries

The EV1 team was trying to develop a battery pack that had the power to propel a life-sized electric vehicle as fast or faster than a gas-powered car, as well as the energy to make it go more than 100 miles. In addition, the battery had to strong enough to accommodate power windows, steering, radio, and one that could generate enough current.

Another issue of concern was what type of batteries would be used? How many batteries? There was lead acid, nickel metal hydride, sulfur oxide, etc. The major concern for the batteries was the cost. How much would each battery weight? Delphi Energy System Engineers developed the Valve Regulated Lead Acid (VRLA) batteries for the EV1. These batteries will give customers the ability to use at 85% of the battery pack's charge on a daily basis without damaging the batteries or decreasing the life of the battery. Again, the batteries demonstrated a typical example of new technology development. Many more options and decisions than a conventional car, but nevertheless, the 4∅VDP was used.

Figure 17 Shows the EV1 Battery Pack



GM engineers were able to fit 26 batteries into the EV1 without any problems. Once the technology was confirmed, the design was easy to install. The batteries fit within a longitudinal cavity and across a rear shaped compartment in the EV1. Each battery weighs approximately 41.4lbs (18.8kg) and stores 664 Watt-hours of energy at a 20-amp discharge rate. A T-shape pack of 26 batteries (figure 14) weighs 1175 lbs. (533kg) including all mounting and wiring components.

Chapter 5

Conclusions and Recommendations

The research conducted in this thesis reviewed two new technologies, Electric Vehicles (EV), and Hybrid Electric Vehicles (HEV). Determining the vehicle development process of radically new technology in the automobile industry is not widely understood. Automobile manufacturers use many different product development practices to produce vehicles. There is little consensus on the right approach to design the most efficient and effective electric and hybrid electric vehicle. The main advantage of electric cars is that there are no tailpipe emissions; indeed, they are the only zero-emission vehicles. Chapter 2 of this thesis discussed the advantages of EV's as well as environmental concerns.

When developing new technology your unfamiliar with, an enormous amount of work must take place before implementing the product. I would recommend the General Motors 4ØVDP to develop new Automotive Technology, which is presented in Chapter 3 of this thesis. This has been a successful process for years and GM has improved the process over time. Emphasis would be placed on the components or technology my organization has no prior knowledge. GM should have put more time into creating the electronics of the vehicle. This was one of the major issues on the development of the vehicle.

Research on the new technology would allow you an opportunity to review data that would illustrate some of the adversities and uncertainties that can or may occur during the project. When developing unfamiliar technology, I would recommend the following:

- First, determine what will be the most difficult part of the technology.
- What are the major systems that are least understood?
- Starts working on major systems that need clarification.
- Establish wide latitudes on all other systems accounting for the results of the different systems.
- Set up a model 4∅VDP where the difficult systems are developed first and various systems built around it. This will cause the design of the difficult systems by removing unnecessary constraints of the other systems.

In conclusion, if companies are interested in developing new technology, and have no prior knowledge: some guidelines should be established from the very beginning which is listed in the previous paragraph. In hopes of proper preparation, this could minimize many major problems that may occur with technology. I do recommend future research in the area of the batteries. Long range EV's will be the key to attracting more customers. Many other batteries exist and I don't think enough thorough research on battery technology was conducted during the development of the very first EV1. Overall, EV's are making significant improvement and GM has just release another EV, which has a different battery and more features.

APPENDIX A: GLOSSARY

Adapted from General Motors EV1 web: http://www.gmev.com/specs/specs.htm and Volvo web: http://www.environment.volvocars.com/app-b0.htm.

ALBS Anti-lock Braking System

Eliminates brake lock-up during panic or emergency stops.

AC Alternating Current

An electric current that periodically reverses its direction of current. This reversal usually takes place 60 times (60 cycles) per second in household current in the U.S.

ACSP Authorized Charger Service Provider

Provides the infrastructure and equipment to install and service EV1's inductive chargers. In California, Edison EV is the ACSP. In Arizona, it is EV Power.

APM Accessory Power Module

Contains a power supply which interfaces with the auxiliary battery to energize various accessory systems in the EV1. (Housed in PEB).

Battery Pack

An interconnected group of cells or batteries treated as a single unit. EV1's battery pack contains 26 modules.

BPM Battery Pack Monitor

Monitors state of charge, temperature and other vital battery readings. Communicates with charger to facilitate charging. (Attached to front of battery pack).

BTCM Brake and Traction Control Module

Controls the braking, ABS, traction control, tire pressure monitoring system, and regenerative braking features of the vehicle. (Housed in PEB).

CCM Convenience Charge Module

The 110-volt charger provided in the trunk of the lead acid EV1.

Carbon dioxide (CO2)

a toxic gas consisting of one carbon atom and one oxygen atom. Carbon monoxide generated by human activities is mainly produced by the transportation industry during the incomplete combustion of gasoline and diesel fuel.

CP Charge Port

Located at the nose of EV1, it is where the paddle is inserted to commence inductive charging.

Curb Weight

The empty weight of a vehicle, including batteries but excluding occupants and cargo.

DC Direct Current

Electricity that flows in only one direction; this is the type of current that flows from a storage battery

DSCM Display, Steering & Chime Module

Instrument cluster that presents information on state of charge, range remaining, speed, odometer, instantaneous energy consumption and provides intelligence to the power steering system (EHPS) and also communicates with the RSA.

EHPS Electro-Hydraulic Power Steering

Motor-driven, variable assist power steering system that provides more assistance at lower speeds, and less at higher speeds. The system includes a unique energy-saving feature, meaning it is programmed to only run as required, reducing energy by as much as 65% compared to a conventional hydraulic system. (Housed in PEB).

EV Electric Vehicle

Typically, a vehicle powered by batteries and electric motor(s), qualified as a zero-emission vehicle.

EVS EV Specialist

EV1 marketing area specialists that coordinate the leasing of EV1's working with customers, Saturn retailers, and the local ACSP.

HVAC Heating, Ventilating and Air Conditioning

In EV1, this is controlled by the HTCM and heating or cooling is provided by the electric heat pump system.

Hybrid electric vehicle (HEV)

a car that has a battery pack and an electric motor like an electric car, but also has a small gasoline or alternative-fuel engine. The engine can be used when extra power is needed for accelerating or for recharging the car's batteries for driving long distances.

ICE

Internal Combustion Engine.

IGBT Insulated Gate Bipolar Transistor

Converts DC voltage into 3-phase AC voltage to power EV1's motor. (Housed in PEB).

Inverter

A device that converts AC electricity in DC electricity. Electric cars that have DC motors do not need an inverter; EV's using AC motors need the inverter to change the DC electricity from the batteries into AC for the motor. (Also see PIM, IGBT).

Liquefied Petroleum Gas (LPG)

Methane, carbon dioxide and other gases generated by the biological decomposition of organic matter.

Nitrogen oxides (NOx)

Gases composed of nitrogen and oxygen, which are produced mainly by stationary fuel combustion sources and motor vehicles. They can cause breathing problems and respiratory illness. They also react with volatile organic compounds to form smog-producing gases, and contribute to the formation of acid rain.

PCM Propulsion Control Module

Controls the energy flow to the motor during propulsion and regenerative braking. Works with APM, BTCM, PIM, and IGBT. (Housed in PEB).

PEB Power Electronics Bay

Houses major electronics such as PIM, APM, PCM, and IGBT. (The big box under the hood).

PIM Power Inverter Module

Controls the conversion of AC power to DC power and back again, working with IGBT and PCM. (Housed in PEB).

Regenerative Braking

A means to recover energy when slowing or stopping an electric vehicle. On cars equipped with such a system, when the brake pedal is pressed, the electric motor acts as a generator and sends a small amount of electricity back into the batteries.

relating to human activities.

RRIM Reinforced Reaction-Injection Molded

Compound utilized for front and rear fascias, front fenders, rear quarter panels, rocker panels and rear wheel skirts.

SCM Standard Charge Module

220 volt floor and wall mount chargers.

SDM (Supplemental Inflatable Restraint Control Module)

Monitors sudden changes in acceleration and other factors necessary to trigger air bag inflation.

SIR Supplemental Inflatable Restraint

Air bag system.

SMC Sheet Molding Compound

Fiberglass-reinforced-resin sheet molding compound that make up the hood, doors, roof and decklid.

SOC State of Charge (of battery pack)

solid or liquid materials like soot, dust and pollen that are small enough to be released into the atmosphere and stay suspended there as they are moved about by air currents. They are also referred to as particulates or total suspended solids (TSS).

SRIM Structural Reaction-Injection Molded

Polyurethane compound that makes up the belly pan.

Sulfur dioxide

a gas, produced mainly by burning coal that contributes to acid rain and smog.

Volt

A unit of electromotive force. One volt equals 1 watt per ampere.

VRLA Batteries (Valve-Regulated Lead-Acid)

The valve-regulated designation refers to a one-way/pressure valve, which permits small quantities of gas to escape from the battery during the vehicle's operation. These gasses are collected and vented safely under EV1's hood.

APPENDIX B: LIST OF ABBREVIATIONS AND ACRONYMS

4∅VDP	4 Phase Vehicle Development Process
AC	Alternating Current
BEV	Battery Electric Vehicle
BIW	Body In White
BOD	Bill of Design
BOM	Bill of Material
BOP	Bill of Process
CNG	Compressed Natural Gas
CO2	Carbon Dioxide
CV	Conventional Vehicle
DC	Direct Current
DFA	Design For Assembly
DFM	Design For Manufacturability
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
HPU	Hybrid Power Unit
ICE	Internal Combustion Engine
IP	Instrument Panel
LPG	Liquefied Petroleum Gas
MFG	Manufacturing
Nimh	Nickel Metal Hybrid
Nox	Nitride Oxide
PHEV	Parallel Hybrid Electric Vehicle
PM	Particle Matter
SHEV	Series Hybrid Electric Vehicle
Sox	Sulfur Oxide
VOC	Voice of the Customer
VTS	Vehicle Technical Specifications

APPENDIX C: An Overview of The Federal Motor Vehicle Safety Standards for Electric Vehicle Developers

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Introduction

In September of 1966, the National Traffic and Motor Vehicle Safety Act were signed into law. This law directs the Secretary of Transportation to issue Federal motor vehicle safety standards (FMVSS) to which motor vehicle manufacturers must conform. The National Highway Traffic Safety Administration {NHTSA) has been mandated to develop and enforce these standards.

This document is intended to provide an overview of the safety considerations, which must be addressed, by the developers and manufacturers of ground-up design and conversion electric vehicles (EVs) under the Advanced Research Projects Agency (ARPA) EV and HEV Development Program. The issues covered are summarized under the sections listed below:

1. **Federal Motor Vehicle Safety Standards** - The FMVSS most likely to pose financial and/or technical difficulties concerning proof of compliance.

2. **Certification** - The self-certification process, for original equipment manufacturers (OEMs) and vehicle converters.

3. **Exemptions from Standards** - Petitioning for a temporary exemption from the FMVSS.

4. **Resources** - Contacts and resources that can provide information concerning the issues listed above, as well as test data, procedures, and compliance testing capabilities.

Appendix A - A summary prepared by the Office of Vehicle Compliance (OVSC) of their test program. Includes information on manufacturers' responsibility, OVSC mission, test procedure development, test specimen procurement and non-compliance investigations. Also includes a table of the Compliance Test Program for FY 1994 and 1995.

Appendix B - Notices published in the Federal Register from December1991 through present, which pertain to electric vehicle safety rule making activities.

This summary is intended, as a supplement to the Federal Motor Vehicle Safety Standards published in the Code of Federal Regulations (CFR) Title 49.Manufacturers must consult the complete set of standards to ensure compliance.

Section 1 - Federal Motor Vehicle Safety Standards

This summary highlights those standards for which a vehicle's compliance may be affected by either conversion to electric power (in the case of conversions of existing internal combustion engine (ICE) vehicles), or by the low mass, or stiff composites used in ground up design vehicles.

FMVSS No. 102; Transmission shift lever sequence. starter interlock. and transmission braking effect. This standard requires that the transmission shift lever sequences have the neutral position placed between forward and reverse drive positions. Its purpose is to reduce the likelihood of driver error in shifting. Also required is an interlock to prevent starting the vehicle in reverse and forward drive positions and an engine braking effect in one of the lower gears at vehicle speeds below 25 miles per hour.

FMVSS No. 103: Windshield defrosting and defogging systems. This standard references SAE Recommended Practice SAE J920, which specifies the performance requirements and testing procedures for vehicle defrosting and defogging systems. With the absence of excess heat, previously provided by the vehicle's engine, an EV defrost/defog system will require another source of heat to enable the system to perform as specified. The Agency published a final rule on March 9, 1994(Docket No. 91-49; Notice 4) amending the standard on windshield defrosting and defogging systems making it more appropriate for electric vehicles. The notice is included in this document as part of Appendix B. EV Related Federal Register Notices.

FMVSS No. 104: Windshield wiping and washing systems. This standard specifies the windshield area to be wiped and requires high-performance washers with two or more speeds. Any conversion vehicles, which use components different from the original vehicle's equipment, must comply with this standard.

FMVSS No. 105: Hydraulic brake systems. This standard specifies the requirements for hydraulic service brakes and the parking brake. It outlines performance requirements for braking distances and specifies the test procedures for measuring the performance of the braking system. In some EV conversions, the Gross Vehicle Weight Rating (GVWR) may be higher than that of the original vehicle or the location of the conversion vehicle's center of gravity (CG) may differ from the original. Depending on how much the weight of the vehicle is increased or how much the CG is moved, the converted vehicle's braking performance could be affected. The Agency published a supplemental notice of proposed rule making (SNPRM) on January 15, 1993 (Docket No. 85-6; Notice 7) that recommends amending proposed Standard No. 135, Passenger car brake systems, so that it incorporates requirements for electric vehicles. The notice is included in this document as part of Appendix B. EV Related Federal Register Notices.

FMVSS No. 108: Lamps, reflective devices. and associated equipment. This standard specifies requirements for original and replacement lamps, reflective devices, and associated equipment. Any conversion vehicles, which use components different from the original vehicle's equipment, must comply with this standard.

FMVSS No. 204; Steering control rearward displacement. This standard specifies requirements limiting the rearward displacement of the steering control into the passenger compartment to reduce the likelihood of chest, neck or head injury. It requires that the steering column not move more that 5 inches in a horizontal rearward direction parallel to the longitudinal axis of the vehicle. In crashes of some conversion vehicles, the steering control may be displaced due to the added weight or positioning of the new EV components. For example, the weight of a battery pack placed in the front of the vehicle may cause the steering wheel to be displaced in a head-on crash. Vehicle converters must determine whether the placement of any added components or the added weight of the vehicle would cause displacement of the steering control beyond the limit specified in the standard.

FMVSS 208-occupant crash protection. This standard specifies performance requirements for automatic crash protection of vehicle occupants in a 30-mile per hour barrier crash test. Congress has mandated that all passenger cars, light trucks and vans be equipped with air bags by model year 1999. Table 1.1 shows the phase-in schedule for air bags.

APPENDIX D: Customers EV1 Wish List

The following is a list of features or options that some EV1 customers would like to see changed or added to the EV1, based on over 7000 miles of driving and 6 months experience.

State of charge and range

Digital readouts of battery charge (%), both for the pack and for the individual modules- Currently this information is available only for the entire pack and is only available from the 220V wall charger.

Digital readout for the auxiliary battery state.

Digital readouts of power use (e.g. amps) vs. 11-bar nonlinear display. This would help our awareness of power use by the different car systems and allow us to train ourselves in optimal driving techniques.

An explanation of how the state of charge is calculated - In addition, perhaps a "min" and "max" range envelope display would allow us to get a better estimate of how much further we could go based on our knowledge of what is ahead (e.g. freeway vs. surface streets).

Cruise control modifications to allow the EV1 to automatically maintain constant power instead of speed (to be used in very light traffic on freeways).

Braking

An indicator showing when regenerative and friction braking is being used - This would allow us to train ourselves to brake efficiently as well as make it unnecessary to use the coast-down feature when it would be safer to indicate to drivers behind the car that the car is slowing down.

Controls and switches

- Move some of the controls on the central console elsewhere to make it unnecessary to look down at the console when selecting a control. For example, the window controls could be put in the more traditional place (on the respective doors).
- Replace the shift lever with a button select to improve the driver's access to the controls currently blocked by the shift lever. Note: I was told that the shift lever was actually ADDED based on feedback during the GM Preview program, but apparently this is NOT correct. The shift lever actually engages a pawl, which locks the front axle when in "Park" so it may not be so easy to implement this suggestion.

Charger

Convenience charger redesign - Move this into the car under the hood so that charging from 110V just requires plugging an extension cord into the car. A male 3-prong outlet could be built into the car to allow a standard power extension cord to be used as is done for electrical tools such as hedge trimmers. This would eliminate the following problems:

- Charger power cord is too short for most situations.
- The charger needs an extra cable lock because it can be easily unplugged and stolen.
- Extra work is required to remove and stow the charger.
- The charger takes up extra room in the trunk.

- The fan noise of the charger would probably be less obvious if it were buried under the hood.

HVAC

- "Precondition now" feature to allow manual turn-on of the preconditioning cycle regardless of state of charge and the time of day previously set for preconditioning (for those of us with irregular schedules).
- Related to the above point, a suggestion from a couple of EV1 club members- remote control to turn on preconditioning from inside your office or home!
- Better internal (ventilation) airflow.
- As noted earlier, we would like some indication of how much power is being used by these systems.

Displays, Indicators & Warnings

- Momentary override for warning tones , e.g. door ajar (but also for reversing). Also, the door ajar warning need not be constantly sounding if the car is not in motion or is in the "park" setting.
- Alphanumeric display- Ideally a generic CRT-type (or LCD) display could present more information to the driver and lend itself to incorporating electronic maps for the future.
- Security code- Provision should be made for optionally accepting a longer code. Placing the security keypad in a less visible location is also very desirable for more privacy while keying in the access code.

Windshield Wipers

- The windshield fluid spray pattern needs to be improved. The lower part of the windshield does not get cleaned, especially when the car is in motion and the airflow is carrying the spray to the top of the windshield.
- The way the windshield wipers tuck away under the lip of the hood makes it difficult to wash the exterior windshield. A "cleaning" wiper switch position, which moves the wiper arms out fully, would be handy.

Miscellaneous

- Internal storage- a glove box or shallow lockable storage hatches where the shelf behind the seats is currently located (look at the Honda Del Sol for an example).
- Creep feature- replace or augment this with a mode which holds the car motionless no matter what kind of slope the car is stopped on (e.g. uphill or downhill traffic lights).

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