# PLUGGED IN, POWERED UP, AND SERVED CHILLED

## The Chevrolet Volt's breakthrough powertrain is confirmed Arizona-summer-ready

By Joe Sage

Range anxiety is the buzz-phrase we've all been hearing when it comes to electric vehicles. What if the power runs out before we get where we're going, or far from home? Doesn't matter with the Chevy Volt, at least not much. After all, they're the ones who got the term out in front of the public, so they could be sure to preempt the discussion with their extensive reassurances. Doesn't matter to us much this day, either, as we take the Volt on its maiden launch drive through the hills of Southern California. We know they've planned a challenging route, to demonstrate both the car's ability and its range, but we know someone will be at hand, if need be, if the juice runs out. Of course it never does.

When GM's Bob Lutz first pushed for an electric car, it was in response to the wicked-fast Tesla Roadster, a two-seat sports car with incredible acceleration, power and range—truly a game-changer for the developing mindset of the time, concerning alternative powertrains and electric cars in particular. The Volt Concept was introduced on the show circuit in 2007, and it had major wow factor. Low and lean, it resembled a yet-to-be-seen new Camaro at halfway-to-Corvette dimensions. We were disappointed when the production Volt first came to Phoenix for a visit a couple of years ago, as it had morphed into a much more ordinary form. However, this makes sense when you think of it in terms of the anxiety range issue: not only could a four-door sedan appeal to a broader audience, but the more normal the car seemed, well, the more normal the car would seem. And GM has been determined to develop alternative drivetrains without scaring their customer base. All in all, this is probably wise. But we look foward to that coupe one day.

### HYBRID OR ELECTRIC?

Chevrolet presents the Volt as a range-extended electric vehicle. The onboard gasoline engine does not power the drivetrain directly. Some sources refer to this setup as a plus-in hybrid, others as a series hybrid (or both), as opposed to the Toyota Prius, for example, which is a parallel hybrid, in which both a gasoline engine and an electric motor are connected to the drivetrain, with excess gasoline power and regenerative braking energy providing additional charge to the electric motor, which assists in drive to varying degrees throughout the process. GM avoids the hybrid moniker for the Volt, and we can't blame them. Electric is the big news. And if you drive your Volt in certain usage, for instance just to work each day, then back to the plug, you can live a 100 percent electric-vehicle life with it. In most conventional hybrids, this would be good for about a mile, and/or at speeds under maybe 10-15 mph.

If you drive more than the estimated 40-mile range of electric-only power, then the supremely frugal (yet more than adequately powerful) gasoline engine kicks in. Again, this is not to drive the car, but rather to act as a generator, providing additional juice to the electric system. (See drivetrain highlights in the sidebar on the previous page.) Chevrolet lays out four scenarios:

**SINGLE-MOTOR EV DRIVING:** In this mode, the primary traction motor provides all propulsion at lower speeds and hard accelerations, drawing all energy from the battery. The ring gear is locked, and the generator/motor is decoupled from the engine and gear-set. The traction motor can use up to 111 kW of power and deliver 273 lb-ft of torque for quick and strong acceleration.

**TWO-MOTOR EV DRIVING:** As speed increases, the ring gear is unlocked and coupled to the generator/motor. This allows the two electric motors to work in tandem to provide blended electric power output with higher efficiency. This let the engineers extract up to two extra miles of pure electric highway range.

**SINGLE-MOTOR EXTENDED-RANGE DRIVING:** Once the battery has reached its minimum state of charge, the 1.4-liter gasoline engine is coupled to the motor/generator via the third clutch. At lower speeds and hard accelerations, the Volt is propelled by the traction motor alone, with the ring gear locked. The engine-driven generator and battery provides electricity to the traction motor via the inverter. Since the most efficient way to charge the Volt's battery is to plug it in, the generator is only used to maintain minimum battery state of charge. If the battery is drawn down below the minimum level during acceleration or when mountain mode is engaged below about 45 percent charge, the generator will charge the battery up to its minimum state of charge and then maintain it there.

**TWO-MOTOR EXTENDED-RANGE COMBINED DRIVING:** The blended two-motor electric propulsion strategy for higher-speed EV driving has been adapted for extended-range driving. The clutches that connect the generator/motor to the engine and ring gear are engaged, com-

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## CHEVROLET VOLT POWERTRAIN

At the core of the Chevrolet Volt's engineering is its battery pack, a lithium-ion assembly that powers the vehicle solo for up to about 40 miles. A small onboard gasoline engine does not power the wheels, but rather can power the battery pack when and if available, or when necessary after that 40± miles, providing a combined extended range of up to 350 miles. The 16 kilowatt-hour (kWh) rechargeable energy storage system is enclosed in a 5.5-foot-long T-shaped module that sits atop the frame, built from a grass-filled polyester composite structure with aluminum thermal radiation shielding and steel case. Total weight of the module is 435 pounds.

**LITHIUM ION BATTERY PACK.** Developed by GM with LG Chem and built at a new $300-million plant in Holland, Michigan, this is one of the first lithium-ion packs engineered into a high-volume production vehicle. The Volt battery features an 8-year/100,000 mile warranty. The pack is positioned in the center tunnel of the Volt, protected by ultra-high-strength steel, and is part of the body structure. It comprises nine linked modules containing 288 prismatic Li-ion cells, each the size of a 5x7-inch photo frame, less than 1/4 inch thick and weighing about a pound. Li-ion packs 2-3 times as much power as nickel metal hydride (NiMH), in a much smaller package.

**THERMAL MANAGEMENT.** Because batteries can be sensitive to temperature changes, the Volt pack is climate-controlled via an exclusive active liquid control system that continually monitors and maintains battery pack temperature for optimum performance and durability. Circulating liquid (coolant and distilled water) passes through a series of internal heat exchangers in the battery modules. This is designed to provide reliable operation, when plugged in, at temperatures as low as -25º C (-13º F) and as high as 50º C (122º F). In cold weather, the battery is preheated during charging to provide full power capability. In hot weather—the most challenging environment for any battery—the Volt's battery is chilled during charging. (See sidebar, next page, for more on this in Arizona's heat.)

**DIAGNOSTICS.** The Volt's battery management system continuously monitors safety and performance in real time. More than 500 diagnostics run 10 times per second, keeping track of the pack. 85 percent of the diagnostics ensure the battery pack is operating safely, while the remaining 15 percent track battery performance and life.

**THE MOTORS AND ENGINE.** Unlike most battery electric vehicles, which use a single motor with a fixed reduction gear that steps down the motor speed to synchronize with the wheel speed, the Chevrolet Volt uses a unique electric drive unit to boost efficiency. The efficiency of any electric motor always drops off as it approaches its maximum rotational speed. The Volt drive has two motors, three clutches and a planetary gear-set that improve efficiency by reducing combined rotational speed of the electric motors. This reduces battery drain at highway speeds, adding up to two miles of additional EV range.

The Volt's motors and gear-set are mounted in-line with the industry's first range-extending internal combustion engine. Two of the clutches are used to either lock the ring gear of the planetary gear-set or connect it to the generator/motor, depending on the mode. The third clutch connects the internal combustion engine to the generator/motor to provide range extension capability. ■

## CHEVROLET VOLT AND ARIZONA SUMMERS

So what about us? Is this daring new technology up to the challenges of an Arizona August afternoon? To find out, we talked to William J Wallace, Director of Global Battery Systems for the General Motors Vehicle Engineering Center in Warren, Michigan, who joined us for lunch in the California foothills and our drive back to Santa Monica. We'd been told the refrigerants used to maintain a range of vehicle operating temperatures had an engineered cap of 90º F, so we wanted to know how it would work in a Valley of the Sun summer, where nighttime lows may not drop below the mid-90s and garage temperatures climb extremely high. Everything that goes to market of course gets tested not only here but in Death Valley, where temperatures of 50º C (122º F) are routine. We're curious how long the whole apparatus can remain cool.

Wallace tells us the strategy begins with thoroughly insulating the whole package, with the key being to keep out daytime energy peaks. As BTUs will constantly transfer between any two items of differing temperatures, Wallace agrees the refrigerant's ability to remain cool will last "not forever, but you look at one day's temperature profile—up, down and back—you look at the mean temperature, and we can hold the battery at that average, so the key is how to get rid of the peaks, off that." He reminds us that the battery is designed to last for the lifetime of the car, so this is an endeavor the team takes very seriously.

"We realize the insulation system can't do it all on its own—that's a fact," Wallace continues. "But we have active cooling. Primarily, we cool it while you're charging. In the hot climates, if you look at our documentation, it recommends that especially in hot climates, you leave the car plugged in even if the charge is complete. The system will continue to condition the temperature of the battery even after that point, pulling the temp down below 32º C (90º F), so once the car is unplugged, we can get through the heat of the day without rising above our target."

Is there a practical minimum to cool the refrigerant down to, in a climate like ours? "Well," says Wallace, "practical is not to use more than energy than necessary, but a limit might be 25º C (77º F)."

So, we ask, if your refrigerant is at 25º C (77º F) and ambient temperature is 45-50º C (113-122º F), it depends on load and how long you run it, but…? "Yes, we've run those tests," Wallace confirms. "Just sitting, it takes 10-12 hours to rise to its limit. The charger is very closely monitored and shuts off, but the refrigerant system is all electric, so the engine doesn't have to run to do any of it. The car runs all that equipment off the grid, so all is available while you're driving, while you're plugged in, and we even have a mode for when the car is sitting for a long period of time in a very hot climate. In this case, it will actually draw energy out of the battery, run the refrigerant system and cool the battery while it's sitting." They call this the "Sky Harbor Airport mode," as in how long could you park your Volt at the airport, not plugged in? "Indefinitely," says Wallace. Will it do undo damage at some point? or fail to start at some point? "No," says Wallace, "it will always start." Well, sooner or later, if your battery core gets to be 130º or something? we ask. Wallace assures us the battery will work and the car will start, but it's a question of life over time. The longer you expose the battery to extremely high temps, the faster it wears out just sitting there. Actually, though, heat is a benefit. "At high temperature, it has very high power, and it's simple to start the car," Wallace explains. "We really don't want people parking at the airport all summer for ten years, that would not be a good thing."

So are they ready for Arizona's challenges? Will they stock showrooms in Phoenix like everywhere else? "Oh yeah, we want to sell them there," he confirms. "We developed a test case called Phoenix Abuse. We took normal driving in Phoenix, then invented a test cycle that represented what might not be bad for a human, but bad for a battery, then basically designed the system around that scenario to make sure we could achieve our warranties. And everybody else benefits from it. Everything's stronger and better. "In a temperate climate, our battery will last 25 years—way longer than you'd ever keep the car."

We mention the early-adopter conundrum: that so many new ideas will be in play by the time that 25-year span is ever used up. "Yes," says Wallace, "that's where residual value of the battery becomes important. When you buy the Volt, you own the battery. We don't own it; you do. By the end of the Volt's life, you hopefully can sell that battery for money, that's our goal. If we can create a viable market for post-vehicle batteries, that drops the cost of ownership."

The Chevrolet Volt is ready for Arizona. Bring it on.



bining the engine and both motors to drive the Volt via the planetary gear-set. All propulsion energy is seamlessly blended via the planetary gear and sent to the final drive.

Regardless of which mode is in play, the Volt's drivetrain is always propelled by electric power from the traction motor. The engine cannot propel the Volt unless the traction motor is also running. In order for a planetary gear-set to transmit torque, at least one of the three main elements (ring gear, sun gear, or planet carrier) must be able to be locked or held. There is no clutch to lock the sun gear, so the traction motor is required to provide reaction torque for propulsion.

This unique propulsion architecture allows the Volt to achieve 10-15 percent better efficiency at highway speeds than would have been possible by using only the single traction motor. At the same time, the Volt always delivers a solid electric driving experience, even in extended range driving, utilizing the large battery for full electric launches even during brisk accelerations.

### . MORNING TECH TOUR

We started out with a tour of the Volt's drivetrain (see sidebar on first spread), where Chevy's representative said it was the biggest collection of Volts he had ever seen. Us, too, having never seen more than one at once. Battery engineer Bill Wallace (see Arizona summer sidebar) has been living with one for personal use for some time now, and he tells us it has changed his whole perspective on driving. (He also emphasizes once again that this is a 4-person electric vehicle with extended range, or EREV—*not* a plug-in hybrid.) His personal best has been 379 miles. Wallace reminds us that the Volt "can run forever on no fuel, or can run forever on only fuel," though it will have "generator-like behavior most of the time." Any hybrid, he points out, can be converted to create a plug-in hybrid; but the Volt is a new concept from the ground up. As he continues his tech presentation, he stresses that "everything I'm showing you here, I hope you don't even notice when driving; it should be basically invisible to the driver." And that's the key.

We're brought up to speed on Normal (best economy), Sport (more torque with less pedal deflection), Mountain and Low settings. We'll be headed up the coast through Malibu, then into the hills, where the Mountain mode can keep more capacity in the battery, due to the lack of weight of a big engine. High speed and mountains will be our biggest challenges. "Anyone building any blended engine will have this challenge," Wallace points out. If our battery becomes depleted—and it will, as our course is well more than 40 miles even before our mountaintop lunch turnaround spot—the gasoline engine is enabled. "Battery leads, engine follows," he reaffirms. The battery delivers full kWH even at low charge, then as the engine comes into play, it backcharges the battery. This approach makes the Volt *feel* like an electric car even when recharging from the gasoline motor.

GM reps point out the Volt's other attributes, "tech beyond the battery," which include touchscreen interfaces, Bose sound system, airbags galore and much

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## VOLT TRAVEL SCRAPBOOK


Santa Monica is one of our SoCal favorites, from the pier to the palm-lined volleyball beaches to a very pedestrian-friendly core. We flew to LAX on US Air, had clear views of Catalina Island and snow-capped peaks, stayed at the Fairmont Miramar Hotel, ocean-front, and walked through the evening's street entertainment to Zengo, a fun and tasty restaurant we'd revisit in a heartbeat.

more. The Volt has been carefully developed to be a normal 4-door sedan—with a great trick up its sleeve.

Recharging the Volt takes about 10 hours from a 120v circuit (more when very hot or very cold), and only about 4 hours from 240v (a recommended upgrade at just $490 or so, installed). The cost? About $1.50 to recharge.

EPA mileage? This is completely new territory, and the full explanation could fill a page, but the EPA's methodology has anointed the Volt with a "93 MPG equivalent" rating (or 37 MPG gas-only city/highway combined). Expect some debate and further evolution as additional innovations come into play, but for now, the Chevy Volt has displaced the Prius as numero uno.

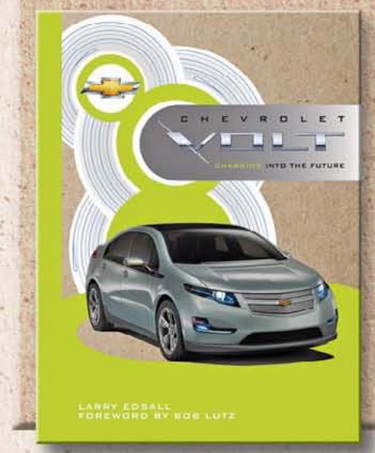
### . COAST TO HILLS AND BACK

From our hotel base in Santa Monica, we headed north on the Pacific Coast Highway through Malibu, where the Volt had to hold its own with such clichés as a trophy bride piloting a three-ton Bentley up the wrong side (and the right side, intermittently) of the road at about 70 in a 45. No problem. Power, brakes and control were all superb. On our climb through the mountain park highways of Los Angeles and Ventura Counties, we had to make a point of noting when our electric-only propulsion was depleted (an assignment we all had), as performance was indeed seamless at that point. We had driven normally, which means relatively aggressively, and had achieved somewhere between 35-40, a great and pretty common result among the group. We dutifully tried the Mountain setting on the upper twisties, though we weren't able to A-B that against others as readily as we'd like for an in-depth comparison. Suffice it to say that it served its purpose and was a clever inclusion.

### . POWER IN PERSPECTIVE

- The 16-kWh Chevrolet Volt battery could power an iPod nano for 112 years of nonstop music.
- Fully charging the Chevrolet Volt battery five days a week for a year will use about 2730 kWh—less than a quarter of an average household's annual total.
- To travel 1776 miles from Austin TX to New York City in a Volt would take 28 hours of constant driving and stops to refuel. The same trip would take 10 days of constant driving and recharging in a battery electric vehicle with 100-mile range and 12-hour recharge.

Alternative drivetrains will continue to develop, including extended-range EVs such as the Chevy Volt. The crystal ball does not reveal how it will all shake out, but on a playing field of quicksilver, GM is to be commended for this enormous effort to advance the ball. The car they've produced is worth a serious look for its technical prowess, but will be a seamless modern experience for most owners—with bragging rights included. ■




### CHEVROLET VOLT: THE BOOK

Even before the new Chevrolet Volt started rolling into dealerships, Larry Edsall's book, *Chevrolet Volt: Charging into the Future* was rolling off the printing presses. Chevrolet Volt, the book, was officially licensed by GM, giving Edsall unprecedented access to the people who made the Volt happen, from Bob Lutz to the designers, engineers and even assembly line workers. In 144 pages, with 236 color photos, Edsall takes the reader on an adventure through the creation of one of the most revolutionary new cars in recent history. For your copy ($30) go www.motorbooks.com, amazon.com or bookstores nationwide.

*—Bill and Barbara Schaffer*