

Hawaii Renewable Energy Development Venture  
Technology Assessment  
**Electric & Plug-in Hybrid Electric Vehicles**

**1. Overview - Issues and Enabling Technology Needs**

Electric and plug-in hybrid vehicles (EV and PHEV) represent an emerging trend in transportation technology that can substantially support and enhance renewable energy deployment with improved energy efficiency. To promote the acceptance of EV and PHEV, substantial investment in infrastructure is necessary, from battery technology, to charging infrastructure, and to grid integration. The status on the availability of EV and PHEV for market deployment and the infrastructure development will be reported in this section. Figure 1 illustrates a typical EV drivetrain configuration, describing major components and their topology in the vehicle system.<sup>1</sup>

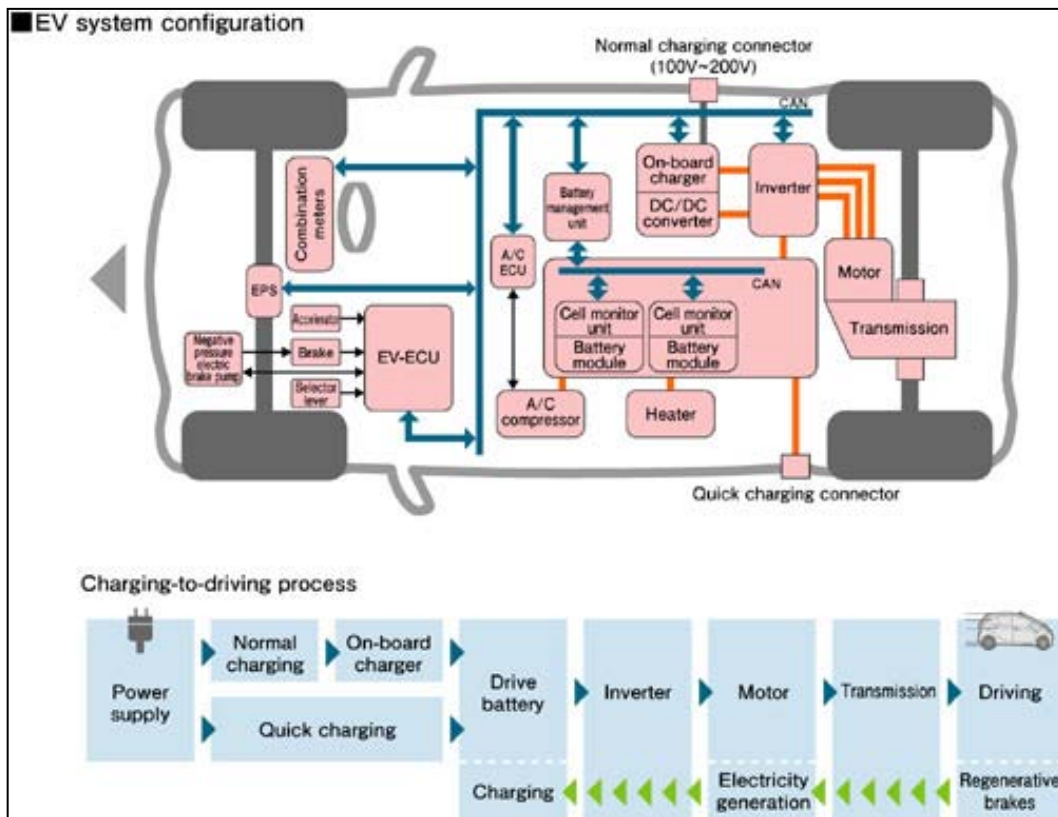


Figure 1: EV Drivetrain Configuration

<sup>1</sup> Courtesy: Mitsubishi Motors Corporation, 2009

## 2. Status of Commercial Readiness

Several major vehicle manufacturers have announced the introduction of EV or PHEV into marketplace as early as 2009. Some of the major announcements are noted below:

### Fuji Heavy Industries Ltd. (FHI)

Tokyo — Fuji Heavy Industries Ltd. (FHI), the maker of Subaru automobiles, on June 4, 2009, announced the launch of its Subaru Plug-in STELLA electric vehicle (EV), which is equipped with a high-performance lithium-ion battery. The model will be sold in Japan directly through FHI. Delivery will start from late July and around 170 units of delivery in total will be planned in this fiscal year (by the end of March 2010). After-sales services will be provided through some Subaru dealerships designated by FHI.



#### Major specifications:

Length × Width × Height	3,395 × 1,475 × 1,660 mm
Curb weight	1,010 kg
Passenger seating	4
Max. speed	100 km/h
Per-charge driving distance	90 km (10-15 mode)
Electric motor	Permanent magnet synchronous system
Max. power output	47 kW
Max. torque	170 N·m
Drive-train	Front-wheel drive
Battery type	Lithium-ion batteries
Total voltage	346 V
Total energy	9 kWh

### Mitsubishi Motors Corporation

Tokyo, — Mitsubishi Motors Corporation on June 5, 2009, the World Environment Day, unveiled the production version of the i-MiEV <sup>\*1 \*2</sup> new-generation electric vehicle (EV), describing it as “the pioneer that will open the door to the next 100 years of our automobile society.” The i-MiEV will go on sale on the Japanese market in late

July of 2009 to corporate, governmental and local authority users. Sales to individuals will start in April 2010.

**i-MiEV**



**Smart ForTwo**

### **Daimler AG**

By late 2010, Daimler plans to release about 400 electric versions of its Smart commuter car in several pilot programs worldwide. Daimler AG also acquired an equity stake of nearly 10% of Tesla Motors Inc. in May 2009. The two companies have already been working closely to integrate Tesla's lithium-ion battery packs and charging electronics into the first 1,000 units of Daimler's electric smart car. Since 2007, Daimler has been operating a battery-powered test fleet comprising 100 Smart ForTwo electric drive vehicles in London. Mercedes-Benz is launching its first passenger car model equipped with a hybrid drive system in summer 2009 - the S 400 BlueHYBRID. The new Mercedes-Benz S 400 BlueHYBRID is based on the S 350, and features an extensively modified drive train. This encompasses a further development of the 3.5-litre V6 petrol engine, an additional magneto-electric motor, the 7G-TRONIC seven-speed automatic transmission specially configured for the hybrid module, the necessary operating and control electronics, the transformer and a high-voltage lithium-ion battery.

## BMW

According to BMW, the Mini E will be powered by a 150 kW (204 horse power) electric motor fed by a high-performance rechargeable lithium-ion battery. Also, the Mini E's drive will be transferred to its front wheels via a single-stage helical gearbox, making the car almost completely silent and entirely free of emissions. In terms of single-charge distance coverage, BMW claims the Mini E's battery technology will give the car a maximum operational range in excess of 240

kilometers, which is the equivalent of around 150 miles. BMW's Mini division has announced that they would be launching a

test fleet of 500 electric Mini (Mini E) cars in 2009. The cars will be produced in 2008, and vehicles will be available for lease to "select" private and corporate customers in NY, NJ, and CA. Apparently the one-year lease will be about \$850 per month, and could be renewable.



**BMW Mini E**

## Th!nk

Think delivered the first THINK city EVs to ElmoNet in February, and will continue to deliver vehicles



**Th!nk City**



according to the MOU in 2009. With the Dutch Parliament calling for the quick introduction of EVs (electric vehicles), the Ministry of Transport earlier this year announced a fund of 10 million Euros to be made available to support the large scale, early introduction of electric mobility. On March 12, 2009, Norway's pioneering electric car maker, Th!nk, plans to open a new manufacturing plant and

technical center in the United States. The company is currently in discussions with eight states, including Michigan, hoping to host the facility, which will initially employ about 300 workers with a starting capacity of 16,000 cars per year. The technical center will provide jobs for another 70 engineers and electric drive specialists. Plans ultimately call for up to 900 employees and a capacity of 60,000 electric vehicles per year.



## GM

General Motors outlines its roadmap for cities to plug into the Chevrolet Volt EV on February 3, 2009. GM considers “plug-in-ready” communities key to commercializing electric vehicles. Next phase of getting the

Volt ready for market will include communities such as Washington, D.C., San Francisco and other early-adopter markets. GM and a broad group of utilities are working together to establish infrastructure and accelerate the commercialization of plug-in electric vehicles.

GM is making great strides toward bringing the Volt from concept to the showroom. More than 30 prototype vehicles powered by lithium-ion battery packs are undergoing rigorous testing at GM's Proving Ground in Milford, Mich. In addition, last month at the North American International Auto Show in Detroit, GM announced it will manufacture the Volt battery packs in the United States. Several recent positive developments in this regard include:

- October 2008, the federal government approved a \$7,500 tax incentive for consumers of plug-in electric vehicles such as the Chevy Volt.
- In November 2008, the California cities of San Francisco, San Jose and Oakland announced a plan for plug-in vehicle infrastructure, incentives and enablers.
- A new Michigan law expedites the development of advanced battery manufacturing and research capabilities in the state.

GM is also helping to pave the way to plug-in commercialization on several other fronts, including:

- Working with the Electric Power Research Institute (EPRI) and a coalition of more than 40 utilities to solve challenges and accelerate the commercialization of plug-in electric vehicles.

- Playing a lead role in helping to create Society of Automotive Engineers (SAE) standards for the vehicle charging interface.

In June 2009, GM opened its latest battery testing laboratory in Michigan. As GM is walking out of its bankruptcy, maybe there will be some more details of its plan to roll out the Volt in the future.

## Toyota

According to Japan's Nikkei news agency, Toyota has decided to start series production of a plug-in version of the Prius hybrid in 2012. At launch, the

automaker plans to

build about 20,000-30,000 units a year of the plug-in hybrid. The report indicates that the model will be priced comparably to the Mitsubishi i-MiEV at about \$48,000. That's a pretty steep price and quite a bit higher than the \$40,000 pricetag expected to be applied to the

Chevrolet Volt when it arrives late next year, and it also puts the PHEV Prius at about twice the price of a conventional model.



Toyota has recently begun on-road testing of its first-generation prototype plug-in hybrid Prius. These 500 early-development prototypes are being used to gain insight into real-world customer use and acceptance, as well as to measure the well-to-wheel emissions impacts. Toyota has on-road test programs in the United States, Japan, and France. Toyota's plug-in hybrid system is designed to operate in a similar manner to the current Prius, switching from pure-electric mode, to gas-engine mode to a blended gas-electric mode. With the addition of a second nickel-metal hydride battery pack, the plug-in Prius can store greater levels of electricity and its battery is charged by plugging into a standard household electrical outlet. With more electric power in reserve, the vehicle is capable of operating in pure-electric mode

for longer periods of time and at much higher speeds than the current Prius. The pure-electric range is 10 miles.

Toyota Motor Sales (TMS), U.S.A., Inc. on January 10, 2009, announced that it will display the Toyota FT-EV concept on opening Media Day at the North American International Auto Show (NAIAS), confirming its plan to launch an urban commuter battery-electric vehicle (BEV) by 2012.



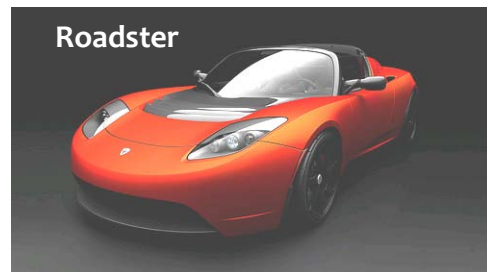
PROTOTYPE SPECIFICATIONS			
<b>Model</b>	Name	Toyota Prius Plug-in HV	Prius
	Length/Width/Height	4,445/1,725/1,490 mm	←
	Weight	1,360 kg	1,260 kg/2,832 lbs.
	Passengers	5 persons	←
<b>EV Performance</b>	EV driving range	Approximately 7 miles, full charge (US LA #4 mode), driving speed and style dependent	Brief periods, occasionally up to a few minutes at very low speeds. No EV-only mode.
	EV mode maximum speed	About 62	About 20 mph under a very light throttle
<b>Engine</b>	Capacity	1,496 cc	←
	Maximum Power	56 kW(76 PS) /5,000 rpm	←
	Maximum Torque	110 N·m(11.2 kg·m) /4000 rpm	←
<b>Motor</b>	Type	Alternating current dynamo	←
	Maximum Power	50 kW(68 PS)/1,200 ~ 1,540 rpm	←
	Maximum Torque	400 N·m(40.8 kg·m) /0 ~ 1200 rpm	←
<b>Secondary Battery</b>	Type	Nickel-metal hydride	←
	Capacity	6.5 Ah×2 (13 Ah)	6.5 Ah
	Regular Voltage	202 V	←
<b>System</b>	Maximum Power	100 kW(136 PS)	81 kW(110 hp)
	System Voltage	202 ~ 500 V	←
<b>Battery Charge</b>	Power Supply	Household electrical energy	-

	Charging Time	1 ~ 1.5 hours (200 V) 3 ~ 4 hours (100 V)	-
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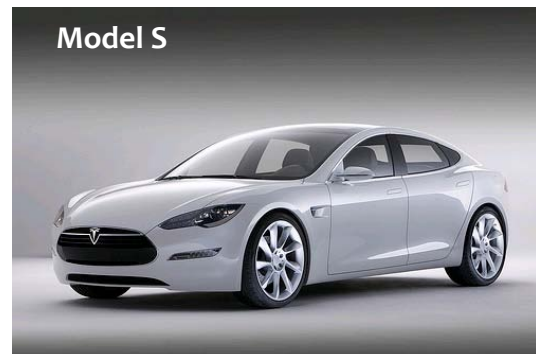
## Tesla Motors

On its June 23, 2009 press release, Tesla Motors announced that it has received approval for about \$465 million in low-interest loans from the US Department of Energy to accelerate the production of affordable, fuel-efficient electric vehicles.

Tesla will use \$365 million for production engineering and assembly of the Model S, an all-electric family sedan that carries seven people and travels up to 300 miles per charge.



The Model S has an anticipated base price of \$49,900 after a \$7,500 US federal tax credit. It has lifetime ownership costs equivalent to a conventional car with a sticker price of \$35,000, thanks to the lower cost of electricity vs. gasoline and a relative lack of service and maintenance. Tesla expects to start Model S production in late 2011 in a state-of-the-art assembly plant employing about 1,000 workers.



Tesla will use \$100 million for a powertrain manufacturing plant. The facility will supply all-electric powertrain solutions to other automakers, greatly accelerating the availability of mass-market EVs. The new facility will employ about 650 people. Tesla is in the final stages of negotiation for facilities in California.

## Fisker Automotive, Inc.

Fisker Automotive, Inc., the new American manufacturer of premium green automobiles, unveiled its first production car -- the 2010 Fisker Karma -- at



the 2009 North American International Auto Show (NAIAS) in Detroit on January 12, 2009. With a starting price of \$87,900, 1,000 orders for the 100 mile-per-gallon luxury plug-in hybrid have been received since the prototype debuted at the 2008 NAIAS. Karma deliveries are scheduled to begin in the fourth quarter of 2009 through the Fisker Automotive Retail network.

The four-door, four-seat Karma fuses the traditional and timeless styling of veteran auto designer and Fisker Automotive CEO Henrik Fisker, with Quantum Technologies' clean Q-DRIVE® plug-in hybrid powertrain to become the world's first luxury plug-in hybrid car. The system is comprised of two 201 hp electric motors powered by an advanced lithium-ion technology battery pack. A generator attached to a turbocharged 2.0-liter Ecotec® direct injection (D1) gasoline engine provides extended range capabilities.

Q-DRIVE® features two operating modes: Stealth Mode and Sport Mode. In electric-only Stealth Mode, drivers can travel emission free for up to 50 miles on a full charge from any 110-, 220- or 240-volt electric outlet. A total range of up to 300 miles is estimated in Sport Mode, which utilizes the efficient Ecotec® gasoline engine to turn a generator that powers two electric motors on the rear differential. With over 60% of the public driving less than 50 miles per day, a fully charged Karma can achieve an annual average of more than 100 miles per gallon. With a top speed of 125 mph and a 0-60 mph time of 5.8 seconds, the Karma is the world's first true premium plug-in hybrid sports sedan. The Karma's low center of gravity and performance oriented, A-arm suspension system offer a world class driving experience. Tall, wide tires deliver immense lateral grip while electrohydraulic disc brakes provide effortless stopping power.

### **Phoenix Motorcars**

Phoenix Motorcars, which is based in Ontario, CA, manufactures zero-emission, freeway-speed, all-electric vehicles. It uses the revolutionary lithium titanate battery pack that eliminates noise and toxic vehicle emissions that contribute to air pollution. It is an early leader in the



mass production of full-function, green electric trucks and sport utility vehicles (SUVs) for commercial fleet and consumer use. Phoenix Motorcars targets fleet operators in the State of California, particularly electric utility companies, universities, and municipal and state fleet operators. Fleet sales facilitate vehicle and parts distribution; service is performed in a controlled environment and allows the opportunity for vehicle data acquisition and ensures a controlled range of all electric vehicle models.

### **Aptera**

Aptera in Vista, CA, produces three-wheeled two-seater 2009 Aptera 2e EV. With a 13 kWh lithium iron phosphate battery pack, 336 V DC motor, and light weight frame made of composite resins, it can travel up to 100 miles per charge. Aptera is committed to putting 100,000 Apteras on the road by 2015



### **BYD**

BYD is one of China's largest battery makers, and that gives them an edge over most automakers when it comes to electric cars (the battery's always the big challenge). The E6 electric car was introduced at the 2008 Beijing International Auto Show. We don't know yet when the company will start selling it, but its F6DM plug-in hybrid is scheduled for 2010 (probably to be followed by the F3DM plug-in hybrid). Range for the E6 should be 300 km (186 miles). Photo: BYD F3DM PHEV.



### **Miles Automotive Group**

Miles Automotive Group in Santa Monica, CA, featured recently at CNN Money, is



promising the \$30,000 Miles XS 500 to reach a top speed of 80 miles per hour and a range of 120 miles at 60 miles per hour; six hours of charging in a normal wall socket will top the batteries off. Founder Miles "Per Gallon" Rubin says he'll have 6 prototypes of the XS 500 by the fall 2009, but they still need tinkering to get safety approval from U.S. regulators, plus do additional battery testing. The XS500 should have an all-electric range of about 120 miles.

### **CT&T Company, Ltd.**

CT&T Company, Ltd., a global leader in Electric Vehicle (EV) technology, announced plans today for e-Zone and c-Zone electric vehicle production in the United States with plans to employ 2,600, including production workers and managers, over the next five years.

CT&T United, the U.S. subsidiary of CT&T Korea, Ltd. is investing significantly to maintain its global position in the move towards consumer use of electric vehicles by establishing its North American headquarters, a research and development center and several manufacturing facilities to produce and market an entire product line of EVs and batteries. Company officials are considering potential sites in South Carolina, Georgia, North Carolina, Alabama and California.



CT&T United will produce and market City Drive Electrical Vehicles (EVs), Mid-speed Electric Vehicles, High-speed Electric Vehicles, Utility Electric Vehicles, as well as batteries in the Lead Acid, Advanced Lead Acid, Lithium Polymer and Lithium Ion categories for domestic and export markets.

By the fourth quarter of 2009, the company expects to begin selling c-Zone utility EVs for commercial and government applications as well the e-Zone City Drive EVs. Vehicles will range in price from \$8,000 US dollars to \$16,000 fully equipped.

CT&T United recently submitted proposals to work with the Department of Energy to accelerate the implementation of battery,

electric motor drive and electric vehicle technologies. DOE is expected to announce their plans regarding these proposals later this summer.

CT&T works in four battery platforms by co-operatively manufacturing with Korean partners SK Energy, Sebang, EIG Corporation, LG Chemical Corporation, FCP, and Samsung. Specifically, the company works in Lead Acid, Lithium Polymer, Fuel Cell (FCP) and Lithium-ion battery systems.

The company has also announced a joint venture with PUES Corporation of Tokyo Japan for the development and production of inverters and new technology In-Wheel Motors.

### **Competition among the big players**

Toyota's plans to move forward with mass production of its plug-in hybrid vehicle within the next few years — at a price comparable to Mitsubishi's planned electric vehicle, according to the Nikkei's sources — represents another major milestone for a technology that's widely seen as the future of electric car batteries. The timeline also offers a glimpse of the competition coming down the pipeline for plug-in hybrid makers like General Motors with its Chevy Volt, and to some extent Fisker Automotive and Hyundai with their plug-in hybrid sports cars, as well as Honda if it eventually ends up pursuing plug-in hybrid tech. (Honda President Takeo Fukui described it as an option under consideration earlier this year.)

For comparison, former Volt frontman Bob Lutz has said GM is supposed to roll out 10,000 units of the model in 2011, and have as many as 60,000 of them in showrooms in 2012. On the upside for GM, the Volt looks like its \$40,000 price tag will be significantly lower than the price Toyota is aiming for. (Mitsubishi plans to offer its EV to fleet customers in Japan for around 4.59 million yen, or \$47,800.)

But GM won't necessarily be able to afford to compete on cost in the plug-in hybrid market (or trim prices the way Toyota has with the Prius in response to the new Honda Insight) over the long term. Aside from being fresh from bankruptcy, GM doesn't expect to profit on the Volt until well after the first generation of the model, which is intended for the mass market but priced on the high end (which could hinder sales).

Battery makers also may face a changing competitive landscape as a result of Toyota's plug-in hybrid ambitions. The plug-in hybrid lease program announced in June marked the first time that Toyota is using lithium-ion batteries (as opposed to nickel-metal hydride) for propulsion in one of its vehicles. Mass deployment of lithium-ion batteries (developed and manufactured by Toyota's joint venture with Panasonic, Reuters reports) in the upcoming plug-in model — and in the all-electric Toyota FT-EV subcompact also slated to launch by 2012 — could mean a massive competitor, but potentially also new opportunities.

Those opportunities could result from Toyota's lithium-ion and plug-in plays increasing pressure on competing automakers to turn to startups. The idea would be to secure a quick fix for technology in an attempt to speed plug-in models to market (something Daimler described as part of the reasoning for its investment in Tesla Motors). On the other hand, with mass-scale production, ramped-up battery production from Toyota's joint ventures with both Panasonic and Matsushita Electric Industrial Co. (which now makes the nickel-metal hydride batteries for the regular hybrid Prius and aims to start out capacity for lithium-ion batteries this year) could present tough competition for smaller startups without the same manufacturing capacity or resources.