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Turning Over a New Leaf: The start of an electric vehicle revolution, Symposium Report S-09-08

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Turning over a New Leaf: The Start of an Electric Vehicle Revolution



MTI Report S-09-08



MINETA TRANSPORTATION INSTITUTE

The Norman Y. Mineta International Institute for Surface Transportation Policy Studies (MTI) was established by Congress as part of the Intermodal Surface Transportation Efficiency Act of 1991. Reauthorized in 1998, MTI was selected by the U.S. Department of Transportation through a competitive process in 2002 as a national “Center of Excellence.” The Institute is funded by Congress through the United States Department of Transportation’s Research and Innovative Technology Administration, the California Legislature through the Department of Transportation (Caltrans), and by private grants and donations.

The Institute receives oversight from an internationally respected Board of Trustees whose members represent all major surface transportation modes. MTI’s focus on policy and management resulted from a Board assessment of the industry’s unmet needs and led directly to the choice of the San José State University College of Business as the Institute’s home. The Board provides policy direction, assists with needs assessment, and connects the Institute and its programs with the international transportation community.

MTI’s transportation policy work is centered on three primary responsibilities:

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MTI works to provide policy-oriented research for all levels of government and the private sector to foster the development of optimum surface transportation systems. Research areas include: transportation security; planning and policy development; interrelationships among transportation, land use, and the environment; transportation finance; and collaborative labor-management relations. Certified Research Associates conduct the research. Certification requires an advanced degree, generally a Ph.D., a record of academic publications, and professional references. Research projects culminate in a peer-reviewed publication, available both in hardcopy and on TransWeb, the MTI website (<http://transweb.sjsu.edu>).

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The educational goal of the Institute is to provide graduate-level education to students seeking a career in the development and operation of surface transportation programs. MTI, through San José State University, offers an AACSB-accredited Master of Science in Transportation Management and a graduate Certificate in Transportation Management that serve to prepare the nation’s transportation managers for the 21st century. The master’s degree is the highest conferred by the California State University system. With the active assistance of the California Department

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MTI REPORT S-09-08

**TURNING OVER A NEW LEAF: THE START
OF AN ELECTRIC VEHICLE REVOLUTION
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Sponsors include The Commonwealth Club of California, the United States Department of Transportation, Caltrans and the Bay Area Metropolitan Transportation Commission (MTC). Co-sponsor is AAA of Northern California, Nevada, Utah.

This program, addressing the technology, infrastructure and future possibilities for electric vehicles, was moderated by Kerry Curtis, chair of The Commonwealth Club Environment & Natural Resources member-led forum and member of The Commonwealth Club Board of Governors. Panelists included Mark Duvall, Director of Electric Transportation, Electric Power Research Institute; Tony Posawatz, Vehicle Line Director, Chevy Volt, General Motors; Jit Bhattacharya, CEO, Mission Motors; and Richard Lowenthal, CEO, Coulomb Technologies, Inc. The program was recorded and later broadcast on National Public Radio (NPR).

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CONTENTS

FOREWORD	1
EXECUTIVE SUMMARY	3
TURNING OVER A NEW LEAF: THE START OF AN ELECTRIC VEHICLE REVOLUTION	7
SPEAKER BIOGRAPHIES	31

LIST OF FIGURES

1. Expert panel discusses electric vehicles at The Commonwealth Club in San Francisco, May 18, 2010. Left to right: Kerry Curtis (moderator); Mark Duvall, Electric Power Research Institute (EPRI); Tony Posawatz, General Motors; Jit Bhattacharya, Mission Motors; and Richard Lowenthal, Coulomb Technologies.
2. Mark Duvall, director of electric transportation, Electric Power Research Institute (EPRI).
3. Jit Bhattacharya, CEO, Mission Motors.

FOREWORD

With hybrid and natural gas vehicles having achieved mainstream success, manufacturers are in a race to introduce vehicles powered entirely, or almost entirely, by electricity. But, while these vehicles can provide “cleaner” transportation, the question of whether they can also provide consumers with the convenience, mobility and affordability they require remains unanswered. Can technology and marketing overcome the real and perceived limitations of electric vehicles? Will the infrastructure be sufficient to attract a critical mass of early adopters?

On May 18, 2010, the Mineta Transportation Institute (MTI), hosted an expert panel at The Commonwealth Club in San Francisco to facilitate discussion of these important issues. The panel addressed the environmental impact, engineering, market acceptance, and other issues surrounding electric vehicles, and the infrastructure necessary to keep them viable.

Moderated by Kerry Curtis, chair of The Commonwealth Club Environment & Natural Resources member-led forum and member of The Commonwealth Club Board of Governors, the panel included experts Mark Duvall, Director of Electric Transportation, Electric Power Research Institute; Tony Posawatz, Vehicle Line Director, Chevy Volt, General Motors; Jit Bhattacharya, CEO, Mission Motors; and Richard Lowenthal, CEO, Coulomb Technologies, Inc.

Sponsors included The Commonwealth Club of California, the United States Department of Transportation, Caltrans, and the Bay Area Metropolitan Transportation Commission (MTC). AAA of Northern California, Nevada, Utah, was co-sponsor.

The program was recorded for broadcast on National Public Radio (NPR). This e-book is an edited version of the proceedings.



Rod Diridon, Sr.

Executive Director, MTI

EXECUTIVE SUMMARY

Demands for mobility are increasing at the same time climate change and legislation require cleaner vehicles. Electric vehicles hold promise for satisfying both needs, but current models pose limitations. Can electric vehicles overcome their current shortcomings? Do the advantages outweigh the drawbacks? What is the industry doing to help overcome public resistance?

On May 18, 2010, at The Commonwealth Club of California in San Francisco, the Mineta Transportation Institute (MTI) hosted a panel of experts to address the environmental impact, engineering, and market acceptance of electric vehicles, and the infrastructure needed to keep them viable.

Sponsored by the U.S. Department of Transportation, Caltrans, and the Bay Area Metropolitan Transportation Commission (MTC), and co-sponsored by AAA of Northern California, Nevada, Utah, the panel was moderated by Kerry Curtis, chair of The Commonwealth Club Environment & Natural Resources member-led forum. The event was recorded for future broadcast on National Public Radio.

Discussion centered around four issues: the capacity of the power grid to meet the increased demands of electric vehicles, electric vehicles' ability to meet consumer needs, the short- and long-term costs of electric vehicles, and the environmental sustainability of battery-powered transportation.

Mark Duvall, director of electric transportation at the Electric Power Research Institute (EPRI), acknowledged that electric vehicles place a strain on the power grid and cited strategies to reduce the stress, including a "smart grid" that allows intelligent appliances and electric meters to communicate and automatically shift loads to off-peak hours as needed.

Richard Lowenthal, founder and CEO of Coulomb Technologies, Inc., said his company's charging stations can be programmed to take advantage of the lowest rates. Tony Posawatz, vehicle line director for the Chevy Volt, cited OnStar technology built into the Volt that potentially could receive and execute requests from a utility to temporarily suspend charging due to unusually high demand.

Jit Bhattacharya, CEO of Mission Motors, said the key to mass acceptance of electric vehicles is the widespread availability of charging stations. Mr. Lowenthal said his company aims to place charging stations at key locations where vehicles sit idle, such as residences, workplaces, and travel stops. He said several Silicon Valley companies have installed charging stations for employees, and stations also are currently being installed at hotels and McDonalds restaurants. He said most of these businesses plan to provide the service for free as a customer incentive.

Mr. Lowenthal acknowledged a fully depleted battery can take eight or nine hours to charge but said charging can take place when owners are sleeping or working. Mr. Duvall mentioned growing interest in "fast charging" stations—large stations that direct-charge batteries in as

little as 30 minutes. Mr. Posawatz said the Chevy Volt doesn't require a charging station and can be charged overnight from a standard 120V outlet.

To the issue of sustainability, Mr. Duvall acknowledged that, although electric vehicles don't produce greenhouse gases, the electricity that powers them is generated primarily by fossil fuels, which do. His agency participated in research that found if renewable resources were used to generate that power, electric cars could reduce CO₂ emissions by 50 to 60 percent. Even with renewable and fossil fuel resources combined, the net result is a reduction of emissions.

Mr. Bhattacharya said research is underway to find secondary uses for lithium-ion batteries when they have exhausted their usefulness in cars. Mr. Posawatz explained that an electric vehicle battery still retains 70 percent of its capacity at the end of its useful life. General Motors expects the battery pack on the Chevy Volt to last for a minimum of ten years, or 150,000 miles, after which he believes it may be possible to recapture the lithium. Mr. Bhattacharya and Mr. Lowenthal also discussed the benefits of electric vehicles beyond environmental advantages, including fast acceleration without shifting, a unique, stimulating driving experience, and reduced cost of operation.

Addressing the cost issue, Mr. Posawatz said when the industry achieves an economy of scale in its production, the purchase price of all-electric vehicles will likely drop below that of gasoline-powered vehicles. Mr. Duvall said consumers should consider the lifetime costs of a vehicle to appreciate the cost savings of electric vehicles. Mr. Lowenthal said electric cars cost approximately two cents per mile to operate versus approximately 14 cents per mile for gasoline-fueled cars.

TURNING OVER A NEW LEAF: THE START OF AN ELECTRIC VEHICLE REVOLUTION

KERRY CURTIS

Today's program is being underwritten by the Mineta Transportation Institute.

Our focus today is on electric vehicles. Even as the demands of climate change compel manufacturers to innovate with cleaner vehicles, the world's demand for mobility is increasing. We appear to be on the cusp of an unprecedented rise to prosperity of billions of people, most of whom will want the same benefits that we in this country have enjoyed for decades—most notably, automobiles. So, how well can electric cars help to meet the combined challenge of plentiful vehicles while also reducing greenhouse gases? Can the advantages of electric vehicles outweigh their shortcomings, and will they eventually become the vehicles of choice?

Today, we are fortunate to have a panel of experts who will discuss not only the environmental aspects, but also the engineering, market acceptance and other issues regarding electric cars and motorcycles possibly becoming the vehicles of the future:

Mark Duvall is director of electric transportation at the Electric Power Research Institute, also known as EPRI. EPRI is an independent, nonprofit center for public interest in energy and environmental collaborative research. EPRI does receive funding from its member organizations, many of which are electric power companies. Dr. Duvall is responsible for EPRI's research and development program for electric transportation, including electric plug-in hybrid and fuel-cell vehicle programs, and related advanced infrastructure. He oversees a number of partnerships and collaborations between EPRI and electric utilities, automotive companies, local and federal state agencies, national laboratories, and academic research institutions. Mark's work currently is focused on plug-in hybrid electric vehicle research, development and demonstrations in collaboration with major automotive manufacturers, such as the EPRI Daimler-Chrysler PHEV Sprinter Van Program—advanced battery system development and testing, electric charging infrastructure, and environmental analysis of air quality and greenhouse gas emissions and characteristics of plug-in hybrids and other electric transportation technologies.

Prior to joining EPRI, Dr. Duvall held the position of principal development engineer at the Hybrid Electric Vehicle Center of the University of California at Davis. He holds B.S. and M.S. degrees in mechanical engineering from the University of California at Davis and a Ph.D. in mechanical engineering from Purdue.

Tony Posawatz is vehicle line director of General Motors new Chevy Volt. Mr. Posawatz has led the development of the much-anticipated Volt and continues to help lead the development of the 2011 production vehicle. He says that this morning, he drove one, so it actually exists. He has served as a GM vehicle line director for the past 11 years. In this capacity, Tony and his product development teams have compiled an impressive record of successful, award-winning and innovative products. Mr. Posawatz's teams have amassed seven *General Motors Chairman's Honors Awards* for excellence and have

overseen the development of cars and trucks, from concept initiation to production and market launch, in four different countries. Mr. Posawatz is also co-chairman of the Electric Drive Transportation Association.

Jit Bhattacharya is CEO of Mission Motors, whose new Mission One motorcycle is being promoted as the fastest production electric motorcycle in the world. Mr. Bhattacharya started as COO of the company in 2008. (For those of you who aren't into corporate-speak, that means chief operating officer.) He has an engineering background including experience from the product design firm Ideo and he also holds an MBA from my alma mater, the Haas School of Business at UC Berkeley. Mr. Bhattacharya has been involved with energy and clean tech for over five years, most recently as co-president of the Berkeley Energy and Resources Collaborative, where he helped lead the launch of UC Berkeley's new Center for Energy and Environmental Innovation. He is taking on the leadership role at Mission Motors at a pivotal moment in the company's history as it prepares to bring the Mission One to market and looks to announce new products in its pipeline.

Richard Lowenthal is the founder and CEO of Coulomb Technologies, Inc., widely acknowledged as a leader in electric vehicle charging station infrastructure worldwide. Mr. Lowenthal started the company in 2007. From 1998 until 2007, he was instrumental in starting several companies, including Lightera, Pipal Systems and Procket Networks. From 1996 to 1997, Mr. Lowenthal was vice president and general manager of Cisco Wide Area Network Access Products division. Prior to that, Mr. Lowenthal worked in the computer industry. He was co-founder and vice president of engineering for Stardent Computers and served as vice president of engineering for Conversion Technologies. Mr. Lowenthal is also a former mayor of Cupertino and has been heavily involved in the nonprofit world. He holds a B.S. degree in electrical engineering from UC Berkeley.

My first question is for Mark Duvall of the Electric Power Research Institute. Looking ahead for ten or 15 or 20 years, as electric cars become much more common, will the demands that they make on the electrical grid be something that we can cope with?

MARK DUVALL

The quick answer is yes. Electric vehicles do place stress on the grid. A typical home in San Francisco in the summertime draws about three kilowatts, and if you take that home and you put it in Arizona, it could be seven or eight kilowatts. Well, that's right around the charging range of electric vehicles. However, the industry and the electric utilities have an obligation to serve reliable, safe electricity to homes and businesses and it's their job to overcome that; it's their job to deal with it.

On the positive side, almost complete electrification of the light-duty passenger car fleet in the United States, however long it might take, would really amount to maybe less than ten percent of the electricity that we use in the United States. So, on a system level, it's really a very small amount. There are a number of things that you can do that can dramatically reduce that, such as charging vehicles off-peak, timing when they charge, and giving utilities the option to work with vehicle owners to turn vehicles off during times of really high stress in the afternoon on really hot summer days. So the overall effect is really not something that anyone who wants to go buy an electric vehicle should be

concerned about.. The utilities have coped with residential air-conditioning, plasma screen TVs, computers in every home. All of these things place stress on the grid, and they deal with it, but the goal here with electric vehicles is to integrate them into the system to a level where it's a much smoother transition, where we don't see any stress and where the investment required to provide electricity to the vehicles is really very small.

KERRY CURTIS

Thanks, Mark. And my question for Tony Posawatz is, I've been hearing about the Chevy Volt for—it seems like my whole life. Maybe not, but for a *long* time. And so the question is, does it really exist and when will it be available for sale? And I was told not to ask him how much it will cost.



Figure 1 Expert panel discusses electric vehicles at The Commonwealth Club in San Francisco, May 18, 2010. Left to right: Kerry Curtis (moderator); Mark Duvall, Electric Power Research Institute (EPRI); Tony Posawatz, General Motors; Jit Bhattacharya, Mission Motors; and Richard Lowenthal, Coulomb Technologies.

TONY POSAWATZ

I won't answer that question. First, thanks very much for joining us today and having us here with you. I do see some familiar faces in the audience, because this morning a few people in your audience actually drove the Chevy Volt. It was an engineering test vehicle, probably a vehicle that was developed at the end of last year, that was something we used to make sure that we can validate this product, to bring this electrified car to the market. Your real question is, "Are electric vehicles coming?" The answer is the Chevy Volt will be in California in a retail environment for sale before the end of this calendar year. We are finishing the final testing and preparation to build said cars in quantities of thousands of vehicles the first model year, beginning in 2011, in November, and by the middle of calendar year 2011 for the 2012 model year. We'd like to be in a position to build tens of thousands of electrically driven vehicles and really introduce the first mass-market electrically driven vehicle to the United States and hopefully export this leading-edge technology abroad, as well.

KERRY CURTIS

Thank you, Tony. Jit, you're the motorcycle guy on the panel, and when I think about electric vehicles, I just think about cars. Your company is developing an electric motorcycle. What's the potential for electric motorcycles compared to the potential for electric cars?

JIT BHATTACHARYA

Well, thanks. Yeah, I am the motorcycle guy, and I think what's really compelling about an electric motorcycle is that there are a number of benefits to electric drive beyond the fact that it doesn't produce any emissions at the tailpipe. These are benefits such as instantaneous torque, the ability to drive to incredible speeds and accelerate so quickly without needing to shift. These are tangible benefits that a motorcycle rider understands in a very visceral way. What we're doing here at Mission Motors in trying to create the fastest production electric motorcycle in the world is take those benefits, package it into a vehicle that riders can get on, that they can actually buy, that is reliable, that they can take to the track and enjoy, because a motorcycle, especially here in America, is really a recreational vehicle. It's one that you have to connect to the riding experience in order to justify the purchase. At Mission, what we're trying to do is create a new riding experience unlike anything you can get on gasoline.

KERRY CURTIS

And Richard, you're the charging-station guy. Tell us how that works and why you need a network of charging stations.

RICHARD LOWENTHAL

You're going to need a new way to fuel your vehicle when you buy one of Tony's or maybe one of Jit's vehicles, and that's our role. We want to be sure that when you're in the showroom and you're considering buying electric or buying gas, you don't worry about the need to charge your car; we'll take care of that for you. These vehicles are a little different. The first ones coming out will take hours to charge, and the way that works is that you park them 23 hours a day. Generally speaking, when you're sleeping and when you're working, the car is sitting for long periods of time and you need one of our stations there. We provide charging stations for those environments.

Our company is a little different from what you might expect. Most of our engineers are software engineers because we spend our time doing business software for our charging station infrastructure. These are things to replace what is familiar at a gas station but for example, some of the owners of our stations want the drivers to pay for charging their vehicles, so we have a billing system that our station owners can use and we have applications. For example, when I came up here today, I used an application on my Blackberry, also available on the iPhone, where you put in an address and it will navigate you to the closest station to your destination that is not currently in use so you have a place to charge your vehicle when you're visiting here at the Commonwealth Club. Mostly what we do is try to provide you the tools so that you're comfortable buying electric vehicles.

KERRY CURTIS

Thanks. The big thing that I hear about the concern about electric vehicles is what you touched on, Richard, which is the anxiety about running out of electricity. You can run out of gas, obviously, but there are gas stations all over the place. What do you do when your Tesla is out of electricity in Buttonwillow, California? What is the outlook for actually being able to address that anxiety on the part of electric vehicle drivers?

RICHARD LOWENTHAL

It's a very good question. We have several answers for that. There are two different kinds of situations. One is the commute. I commute in a BMW MINI electric vehicle, and my commute is about 15 miles. The car has a range of about 100 miles, so I charge in my home garage or at work and I never have any issue at all. But there is that time when you want to go farther than the battery will carry you, and then there are a number of solutions.

There's one that Chevy has, with the Chevy Volt, which is called an extended-range electric vehicle that, once the battery is depleted, it has a generator that keeps the car going for hundreds of miles. So, it's something familiar to all of you, and basically what happens is you switch from my infrastructure to the gasoline infrastructure for the extended road trip. The Tesla Roadster is another model; their approach is to put a big battery in there—a battery big enough so that the car will go farther than you want to go in a day—and have one of our stations where you sleep at night, and have one of our stations at hotels, and you're done, because you only need to charge that vehicle when you're sleeping.

So there are a few different answers for that problem, but rest assured, we work on it all the time. One of the situations that we have that's a little different is the one here in San Francisco where there are six times as many cars as garages, so most residents here in San Francisco won't have the ability to charge in the home garage. Instead, you'll see our stations, for instance, down at City Hall, at the Civic Plaza, so you can charge while you're working. Primarily, people living in this urban environment will charge in an apartment lot, or a condominium lot, or while they're working, so we have answers for all the situations you may encounter with your electric vehicle.

TONY POSAWATZ

Richard's spot-on relative to the data that exists how often you really are driving your car and how often the car is sitting. Typically we'd like to charge the car or any electric vehicle overnight when you're sleeping, take advantage of when the grid usage is low. As a matter of fact, the utilities love us to use that capacity; the rates are usually very low. The interesting opportunity is rather than necessarily putting in more and more battery in the car, which is expensive, increases charge time, increases mass, and increases associated packaging issues with the car, to instead provide a secondary charging opportunity when one is at work—for some of us that's 12 hours, and for others it's less than that. So that's another one of the challenges we collectively can work on together when we think about Mark representing the utilities, Richard with the charging stations, and Jit and I as the vehicle providers. I think that's a very, very elegant solution and then with appropriate grid management, it's something that could again take this technology and begin to usher in

this new era of electrified transportation.

KERRY CURTIS

Thank you, Tony. The big benefit of electric vehicles is in reducing the emission of greenhouse gases, at least in my view, and so if you look down the road 10, 20, 30 years, you can envision an electrical grid that's powered by renewable sources, wind, solar, and so forth, primarily that electricity is brought to your home where you charge your electric car and then you drive that during the day, and so the greenhouse gas contribution of your driving is really close to zero. But in today's real world, the electricity is generated in the U.S. largely through fossil fuels. So my question for Mark Duvall of the Electric Power Research Institute is, in today's world, what is the real benefit of powering a vehicle with electricity instead of fuel?

MARK DUVALL

Well, I spent about two years of my life trying to answer this question, and obviously



Figure 2 Mark Duvall, director of electric transportation, Electric Power Research Institute (EPRI).

we do work for the electric utility industry. Our partner with this was the Natural Resources Defense Council, which is just downtown in San Francisco, to represent the environmental community. We kept each other honest, and one of the things that we found during this is that yes, renewable energy is a very good transportation source, and would result in CO₂ emissions of a plug-in vehicle being as much as 50 or 60 percent lower than even the best hybrid vehicle—very low. However, taken as a whole, even with all of the coal and natural gas and other sources of electricity, there are still some plants that burn oil as a fuel source to create electricity—not very many, but there are a few. If you take all of that in total, along with the wind and the solar and all the other sources of energy, it's a significant reduction in CO₂ emissions, regardless. So we don't have to sit here and think we have to do this vast modernization to the grid. That's actually already taking place independent of whether electric vehicles

are here or not. The grid will get cleaner, that electricity will get cleaner, but today, as the first vehicles roll out at the end of this year and plug in, they're going to be significantly cleaner than either hybrid, gasoline, or diesel vehicles.

RICHARD LOWENTHAL

Kerry, I'd like to give a little counterpoint if I could. Besides the environmental benefits, there are a lot of other reasons people want these vehicles, and I'm going to let Jit talk about the fun of driving an electric vehicle, because he knows all about that, but there are still people who don't believe in the carbon equation and what it means to us and the vehicle's role in that, even. But if nothing else, the importation of oil into the United States is a problem. Last year was a half-a-trillion dollar trade deficit that we imported so much oil, so EVs help there too. They're also considerably lower cost to fuel. Driving on electricity costs you about two cents a mile, and driving on gasoline's more like 14 cents a mile, so it's got a consumer benefit. But the real reason, if you drive one—I drive an EV and if you drive Tony's car, or especially if you drive Jit's vehicle—is that they're tremendously fun to drive. You want one of these things. This is not a compromise situation. You're not doing this necessarily to save the planet. You like it, and I'll let Jit take it from there.

JIT BHATTACHARYA

Thanks, Richard. For those of you who ride motorcycles, the Mission motorcycle will be the most fun vehicle you have ever driven, but I will actually add one other point to this, and that's a perspective from another country: China. Mission Motors is right now exploring a partnership with one of the largest manufacturers of gasoline motorcycles in China. This is a manufacturer that makes a million motorcycles a year, and many more millions of gasoline engines every single year, so why are they interested in electric? Well, we're here in the U.S. talking about the coming electric revolution. In reality, the electric revolution began a while ago. It began on two wheels in China. There are over 100 million e-bikes—electric powered, electric-assist bicycles—on the road in China. There are over 20 million electric scooters already on the road in China. Cities all over the country are banning the use of gasoline motorcycles and scooters because these two-stroke engines are so polluting, and now we're talking about air pollutants that cause smog in the air, that cause asthma. This is a very real environmental concern today, so the need for electric is more than just reducing greenhouse gases or reducing dependence on foreign oil. It actually helps, in China, solve a very real environmental problem. If we all remember the concerns that were launched during the Olympics, I think it was two years ago now.

KERRY CURTIS

Yes, 2008. It's interesting that your company, Mission Motors, has chosen to enter the electric motorcycle market at the very high end, much like Tesla did with their high-end, \$100,000 sports car, rather than coming in at the low end. But in other countries, it seems like the electric motorcycle is much more of a mass-market phenomenon. What's it going to take for the electric motorcycle business to get hot in the U.S.?

JIT BHATTACHARYA

That's a very good question, and it goes a lot to what Tony was talking about: Are electric vehicles coming? Are they here? Where do we really stand in this industry? We've been talking about it for so long. I look at the battery pack and the electric power train, which

is really what Mission Motors is focused on. I look at that power train, and I compare it to where we were 15 years ago. The battery pack in the Mission One Motorcycle, which is actually very similar to the one in the Chevy Volt, would have cost over \$25,000 back in 1995. We're not even talking about packaging or anything else, just looking at the cell technology. Now we can do it for under \$6,000 with technology that exists. That battery pack in 1995 would've taken up 15 gallons worth of space. Today, it takes less than six. That battery pack would've weighed over 270 pounds, and now, it weighs less than 140. That's at the cell level, just talking about the batteries.

The technology is improving every single day. Basically, what we see when looking at that comparison to 1995 is the electric motorcycle that we're building was not possible a decade ago. It could not exist and still be realistically called a motorcycle. But, that being said, in actual answer to your question, Kerry, we still have a long way to go. The cost is still too high, and the focus of our business is, how do we take that leading-edge technology, the supply chain that we're working with, and continuously optimize the performance of these vehicles, improve the range, get more value out of every dollar that is going into the vehicle and improve the performance for the driver or the rider?

KERRY CURTIS

Thank you, Jit. Here's a question that's directly relevant to that point from one of our audience members who says, "I rode here on an electric bicycle, less than one cent a mile, parked right outside, and I made BART's inadequate network usable." A little editorial comment there from someone about BART. Why aren't we also talking about electric bicycles? Of the five of us, you're probably the one that knows the most about electric bicycles. Is that a feasible concept and how do I get one?

JIT BHATTACHARYA

It is very much a feasible concept, and there are companies here in the Bay Area that are producing some really fun-to-ride, very functional, will-get-you-to-work-and-back electric bicycles. And for those people who are interested, I highly recommend them. They're a lot of fun to ride. I think what we have to do is appreciate the reality of the American driver context. Once again, our focus as a motorcycle company is the riding experience. We want to create a riding experience that is different from everybody else, but to solve the problem as a whole we need what Tony is doing. We need what Richard is doing in terms of the infrastructure, in terms of producing that mass-market car that everybody can drive and not just to work and back, but also on the weekends—that can actually begin to displace the gasoline vehicles on the road. So here what I think you're going to see: you'll see more adoption of things like electric scooters and e-bikes. They are here and they are present—they're available—but in terms of solving the problem in the United States as a country, we do need to solve the problem of the car.

TONY POSAWATZ

If I could just piggyback a little bit on one of Jit's comments, and this concerns taking the technology to scale, so you get cycles of learning, more competition, more commercial money, more venture capital, more innovation. This is where I think the industries play

together. Jit said it very well: The cell technology and the way that batteries are constructed are not too different. Certainly the duty cycles are a little different— environmental conditions, some of the regulations and standards are different.

One of the things that the Chevrolet Volt is designed to do is to find a solution with its extended-range capability to make this a mass-market car. I did some calculations, and I can't quote the exact value number, but it's not too far off of where our target is, where General Motors could literally be the single largest procurer or purchaser of active lithium-ion materials, exceeding all the PC companies, and the like. It gets back to Jit's comment as to the different levels of costs as we're seeing them come down. So I think there's a tremendous synergistic effect if we look at this technology, as Richard stated. You know, there's really some interesting energy diversity in the security aspects of it. So I think, if you may pardon the pun, that we on this panel are quite charged up to see it happen, and we've seen the future—driven the future a little bit—and we think it's very, very possible. Very possible.

RICHARD LOWENTHAL

One more word to that, which is the infrastructure that we're putting in—the charging stations in downtown San Francisco, for instance: All have provisions for lower-speed vehicles. Every one of ours has two different ports on it, one for the vehicle connector, and another one that is basically the household connector for the electric motor scooter, the low-speed vehicles, and the electric bike. So we are putting this infrastructure in. We expect our stations to stay in the ground for 25 years because we know this is going to evolve. And, yes, at the leading edge are some high-end products like Jit and Tony have, but this will be a pervasive change in transportation.

KERRY CURTIS

One of the things that I keep hearing about electric vehicles is that they are inherently simpler and should be cheaper to manufacture, and yet what I've noticed is that the electric cars seem to have a price premium on them. So my question for Tony Posawatz is, when will the electric vehicle cost equation drop below that of the internal combustion engine, and how cheap could it get, really?

TONY POSAWATZ

That's one of the million-dollar questions, obviously. I think one of my previous comments related to when we have some scale—when there's commercial activity, when some of the brightest and smartest individuals from research institutions, companies and R&D departments focus on this, we think you'll see some significant improvement. For example, let's focus just on the battery technology: Many of the white papers have quoted the going rate is about a thousand dollars per kilowatt-hour (the energy unit of a lithium ion battery). I know, and many of my other manufacturing brethren who are introducing vehicles know, that rate has already been bested by a significant factor—by almost a factor of two. Technology in general—whether you use the examples of memory storage for computers, cellular phone technology, etc.—usually takes a couple of generations to drive down. With a Chevy Volt, because we still have an ongoing extended-range feature—a generator set on board—the

absolute cost of that type of vehicle probably won't get below a conventional vehicle, but, as stated before by Jit, Richard, and others, the benefits, we think, far outweigh the costs. But I think we'll see a lot of interesting inventions. I think by GEM e2, you'll see an ability for manufacturers to break even on this technology, and not too far after that you'll see us making money, and then a lot of good things will happen relative to future innovations and cost reductions.

MARK DUVALL

I'd like to add something to that. This is something that has to happen in the mind of the vehicle purchaser before electric vehicles can truly be successful, and that is if you go out and buy any mid-size car today and you keep it over its reasonably useful life, you're probably going to buy a minimum of \$15,000 in gasoline for that vehicle. That factors into the price.

In many cases, you could literally pay for the car again in gasoline, and we really have to understand when we go to make those kinds of purchases that you're weighing a little bit more expensive vehicle, and I would dispute that electric vehicles are simpler. All modern vehicles are incredibly technologically sophisticated, so just because you don't have a gasoline engine, or you have a smaller gasoline engine, doesn't mean that your vehicle is simpler, it just means that it has some extra things and doesn't have a few other things. So I think, ultimately, you can't really understand what the vehicles are going to cost until they're made at high volumes—minimum of about 50,000 to 100,000 vehicles per manufacturer in a calendar year. We're a ways out from understanding that, so in the mid-term, what we need is rapid adoption of the vehicles that are available, and then everyone try and really understand what all of the benefits are, not just cost. Leather seats and DVD players for the kids in the back row, those things don't pay back over time either, but we get them because we want them. So really understanding what the benefits are, the technology, is extremely important. There's probably, as an individual, few decisions you can make more fundamental than what car you purchase in terms of environmental impact, so if you switch from a gasoline vehicle to an electric vehicle or a plug-in hybrid vehicle, it really can have a very strong impact on your own environmental signature.

KERRY CURTIS

Here's a question from the audience that I'll direct to Tony Posawatz. Which technology will be the mainstream for the future vehicle: the plug-in hybrid or the pure electric?

TONY POSAWATZ

I think the future will be blended, in that it will be good for all of us to see these competing technologies. One comment I'd like to make in reference to our discussion about where the energy comes from to fuel the electric grid: the beauty of the electric grid is there are so many different pathways, from renewable sources, natural gas, nuclear, geothermal, water, etc., and this creates some interesting competitive situations.

The Chevy Volt was constructed in a manner to help people make that leap to a mass-market electrically driven vehicle. We've called it an extended-range electric vehicle, or

electric vehicle with extended-range capabilities. It is quite modular in the respect that if technology in battery cells improves—in other words, if power and energy density improves or costs come down and we can get more and more range, and we can make this car more and more affordable—it's quite conceivable that the Volt could morph into a battery-only vehicle. Or the modularity associated with how big the battery is, what size gas tank, and what liquid fuels you use to support your extended-range feature, allows the model to evolve. In the future, the Volt will also have an extended-range capability to use biofuels and flex fuels, so it's hard to say which one will win. I think allowing them all to compete and doing enabling technologies like General Motors is doing—we are building our own battery packs—will give us some very specific knowledge and expertise, to hopefully someday do another battery electrical vehicle. We think the Volt, for the near-term, to drive a mass-market revolution, is a vehicle that it is not only for the enthusiasts, it is not only for the early adopters, we think it is a car that everyone could grow to love.

KERRY CURTIS

Thank you. A follow-up question for you from the audience, Tony: Do you envision a future where the car itself, via advanced photovoltaic materials, charges its battery from solar power?

TONY POSAWATZ

Very good question. Full disclosure: We studied that in the Volt, did a very, very detailed study. And there are a few manufacturers that have an optional photovoltaic roof on the car. We came to the conclusion, based on the prevailing technology—the alleged high cost of the car, which we didn't want to increase any further—that the best place for capturing solar would be in a position like a home or another installation that would be able to get solar all the time. I'm not sure how much solar we'd get when the car is garaged, I'm not sure how much solar we'd get when the car is under a shady tree, and, again, the extra cost in mass. We are absolutely in favor of, and supportive of, and taking a lot of initiatives on, to make certain that the charging that will help facilitate driving electrically in a Volt will come from green electricity and there's a bunch of initiatives we can talk about at a future date, but we really think that the best position of photovoltaics is to be part of a larger installation, whether a home installation or some other more significant installation, and the Volt will gladly capture and store in its battery that green electricity.

KERRY CURTIS

Thank you.

RICHARD LOWENTHAL

If I could just add a little bit to that. We have stations in Chicago that are all solar powered, and basically there are solar panels out there all day. There's a battery underground that's being charged off those panels, and when it comes time to charge a vehicle, we discharge those batteries into the vehicle. Similarly, in Hawaii we have stations that are completely wind-powered, that have no grid tie at all, because they have such consistent wind power

there, so we do still have ways of getting entirely locally generated clean energy into the vehicles.

MARK DUVALL

I would like to add quickly to that is that those are really two separate issues. The roof of a car is really small, so unless someone comes up with a really, really good solar panel, it only collects so much sunlight—there's only so much surface area there to capture it—so it's really too small. But a lot of folks who have electric vehicles today power them with solar panels, and that's great, but those are two individual choices: If you decide you want a solar panel, you buy a solar panel; if you decide you want a car, you buy a car. You shouldn't predicate buying an electric car, saying, "No, I've got to go get my renewable energy from somewhere." California has an amazingly aggressive and ambitious renewable portfolio standard for the electric utilities in California, so the utilities here are doing everything they can to get more and more renewables into the grid as fast, or faster, than they can reasonably do, so the renewables are a lot different than just buying the car. You should be able to buy the car without feeling you have to go out and do this other thing. If you want to do that, that's great.

KERRY CURTIS

At one point, I was thinking of buying an electric motorcycle. I was in the process of having photovoltaic panels put on my roof, and my vision was photovoltaic panels on the roof that are going to charge my electric motorcycle which I can ride to BART. But then I studied the math: I applied my MBA skills and discovered that I was a lot better off selling that peak-time energy to PG&E at the top-tier rate than I was using it to charge my bike. So I wound up with the solar panels but not the bike.

JIT BHATTACHARYA

The bike would've been more fun than the solar panels.

KERRY CURTIS

You're right. I never even see those things. A question for Richard Lowenthal of Coulomb Technologies—this is from the audience, and I know you've answered some aspects of this already: What does the infrastructure look like today across the country for recharging e-vehicles? Where would I go today to recharge if I were in Denver, for example? How would I recharge my e-vehicle?

RICHARD LOWENTHAL

It's interesting; the early adopters we think will probably be the type who want to hide their car away in the home garage, and so most of the charging I think for the early adopter will be in the home garage. I'm kind of an exception, I primarily do my charging at work, and my landlord has two charging stations in our lot; they're becoming a normal piece of parking lot furniture. Several of the high-tech companies in Silicon Valley are putting in

charging stations as a normal course of business, and Dell Computer made a big splash by putting in both solar panels and charging stations together to encourage their employees and visitors to use clean transportation, but we see it throughout the valley now in the high-tech firms.

We see hotels have them, McDonalds restaurants have our stations, so they're beginning to spring up. The federal government is trying to get this kick-started by using stimulus money this way. They've already awarded about \$130 million in the last six months to help get this started, the reason being that, in a place like San Francisco where there are so few home garages, you might not think you have the opportunity to buy the Chevy Volt and use it. So they want to get it kick-started here because, without any of Tony's cars, people won't put in the infrastructure, and without the infrastructure, you can't buy his car, so we are getting a little boost from the federal government. Fortunately, when you buy a charging station, it puts three people to work for a day, so the federal government is interested in using stimulus money in that way.

KERRY CURTIS

Thanks, Richard. I'd like to address this audience question to Jit. You have spoken of the technological advances in batteries, in terms of cost, weight, and so forth. Can you speak to the recyclability and the toxicity of the batteries, as they get more and more powerful?

JIT BHATTACHARYA

Sure, and this is a really important question, because it's speaking to the broader issue of sustainability. When we talk about renewable energy, when we talk about vehicle electrification, we need to start thinking about the entire cycle, the full system, what's going to happen to these batteries at their end of life. There's going to be a lot of batteries if the electric vehicle revolution takes off the way that all of us are talking about. The one thing about lithium-ion that is a benefit, compared to the incumbent technology which is really nickel-metal-hydride—that's the style of battery that you see in the Toyota Prius—is that lithium-ion is less toxic. It is easier to recycle. That being said, large-scale recycling of lithium-ion batteries is still something that is in development. Now, there is a lot of research going on—and a lot of this is happening through the government labs I know about, but then you also have companies



Figure 3 Jit Bhattacharya, CEO, Mission Motors.

that are starting to look into it—as to whether we can take these batteries at the end of their life and potentially use them in other applications. Can we use them to do renewables firming for the grid? Can we use them as ancillary services for the grid, and what are the possibilities around that? There are a lot of hurdles, a lot of challenges, but it's an interesting opportunity for how we can actually take the lithium-ion batteries at the end of their life, when they're no longer useful for the car, and still get a lot more value for them down the road. It will help for renewable energy at the grid level. It will also help reduce the up-front cost of the batteries for the car.

TONY POSAWATZ

As I stated earlier, General Motors also is manufacturing and assembling battery packs, so we too have pondered this very important topic that Jit raises. One of the expectations we have with the Chevy Volt is that the battery will be in the car ten-plus years, 150,000-plus miles. What that indicates is, in order to have a sustainable system for this new technology, you want to make its life in its primary application as long as possible and then take care of that product, that battery, so that it does have a secondary use as Jit indicated.

The interesting point of note: the end-of-life for a battery in a vehicular application is when it reaches 70 percent of its capacity. Well, that's kind of interesting; there are very few things that I throw away when I still have 70 percent of its use available. In the case of the Chevy Volt, I've liquid-cooled the battery to temperatures that people like—I condition it to the degree that we condition people in a passenger compartment, if you will, so I think that supports the point that Jit raised; I think it's something that we have to collaborate on, look at those secondary uses, work with Mark and the team at EPRI, and then, obviously, as the costs and the weight come down, and the applications come down, I think the basic fundamental science and physics around the way the battery packs are comprised make them quite good candidates for recycling, for recapturing the lithium. Lithium is quite easy to recapture: It's generally in the form of a lithium carbonate, so it can be separated. But to Jit's point also, there aren't a lot of commercial applications because there are not a lot of batteries that are at the point that they need to be recycled. We are working on it, along with Jit and others and the battery manufacturers; I think you'll see more on that in the future. But I think the key point is the longer you can extend the life of the battery and ready it for a secondary use, the recycling issue becomes very much pushed out into the future and planned for.

KERRY CURTIS

Thanks, Tony. A question from the audience about the smart grid—I'm going to address this to Mark Duvall, because that seems to be more of an EPRI question: In 25 words or less, what is the smart grid and how does it relate to electric cars?

MARK DUVALL

If I could say that in 25 words or less they would promote me.

KERRY CURTIS

I'll give you 50.

MARK DUVALL

The smart grid looks exactly like the electric grid serving your home or your business now, except that it consists of a bunch of devices that can talk to each other, and when I mean talk to each other that doesn't mean measure what's going on and feed it back to a central computer. It means that they talk to each other. It means that the meter at your house knows the cost of electricity. It can talk to your refrigerator, talk to your dryer, it can send you messages on your iPhone, it can help you manage your electricity.

A trivial fact about electricity and not the smart grid—so it doesn't count against my words—is that electricity as a commodity has gotten cheaper every year since the inception of the electric industry, until last year. Last year it went up for the first time. And that is because we have a lot more investment needed to modernize the grid, to meet new environmental requirements, to plan for a future where carbon emissions are limited. Electricity will get gradually more expensive, not like we're used to seeing with gasoline and oil prices spiking up and down, so it will be key for the users to be able to manage their electricity, and the smart grid helps you do that, and it helps the electric utilities run a much more efficient system. And the more efficiently they operate, the lower all our rates are, so that's something very important to note about it.

RICHARD LOWENTHAL

Could I just relate smart grid to just this application, because I think it's vivid to see how it can affect cars? In most of the utilities we have in the U.S., there's some time where there's a peak load of energy that drives the size of the generation and the capacity that the grid has. California is one of the best examples of that: we all turn our air conditioners and pool pumps on in the afternoon in the summer when it's hot, and we nearly run out of electricity. So what the utilities will do is to inspire all electric vehicle drivers to charge their car at night when they have plenty of capacity. They'll have a differentiated rate, so it will be cheaper to charge your vehicle at night than either using smart features in Tony's car or using our infrastructure. You can tell the vehicle or the charging station, "Get me the cheapest energy; I just need the car at 7:00 in the morning, get me the cheapest energy," and then I'll take care of it, or Tony will take care of it, and it'll save the driver as much as \$800 a year in energy costs. It's just incentive pricing provided by the utilities because they want us to charge off-peak.

KERRY CURTIS

Thank you, Richard. Here's a sort-of-related question from the audience, related to the challenge a homeowner would have in getting a charging station put into his home: "How is the permitting system changing to allow for suitable charging units in the home?"

RICHARD LOWENTHAL

There's a lot of work to be done, and I think Tony or Mark will weigh on this too, but the situation now is not so good. When I bought my Mini, it took a month for me to get a charging station in the home, but we see how to get it done in four days in a pretty straightforward fashion, and we're working on getting that down to one day. The situation now is you need to get a site inspection to see how difficult your home might be, then you need to get a building permit, then you need the station put in place, and then you need an inspection, but those things can really be all done in one day, and we're working hard. It's one of the issues we need to solve so that the day after you buy your car you'll get a call from one of our installers saying when can we put a station in your home and then they can do it on one visit, so that's the goal. We're far from it today, but we can get there.

MARK DUVALL

It's important not to be too afraid of installing the charge station. It's an appliance; it's like a clothes dryer or like a spa. Some homes it will go in easily, because you have space in your electrical power and you have a conveniently located garage – modern homes, generally, new homes. Some houses, older houses, you have to do a lot more work and so the expense can vary considerably, and it's important. Cars are parked at home two-thirds of the time, so this whole industry depends on mastering residential charging.

TONY POSAWATZ

It's interesting, and one of the reasons why the Chevy Volt will come standard with a 120V cord set for what we call an EVSC, electric vehicle supply equipment unit, is so you can in fact take advantage of the grid as it stands today, the size of the Volt battery, and the smarts we have in the car. So literally when you take a Volt home, you can plug it in and charge it, overnight, eight, nine hours, using 120V, because you have the range extender.

To Richard's point, we're working together, because if we can solve the delicacies and detail associated with developing lithium manganese cell chemistry and packaging it up into a battery that started one day as a cell phone power cell, if we can make that work in a harsh environment like an automobile where there are temperature changes, humidity, dust, debris—it's really a violent environment. If we can make that work, I think we can work on the permitting, too.

KERRY CURTIS

One of the things that's been talked about, the upside potential for electric cars in the homes and everywhere, is the idea of supplying electricity from the vehicles to the grid through this so-called smart grid and so forth. So the question is how far away are we from that and each of you can take a crack at that. Is it reasonable anytime in the future to expect that a homeowner could wind up getting paid for supplying power to PG&E overnight or during the day if his car's sitting there?

RICHARD LOWENTHAL

Everyone's probably going to want to say something about this. Our charging stations will do that. We design our stations so they're bidirectional; every one of ours has a meter in it, so we'll know if you put energy into the grid or take it out. So all those things you can do with a solar panel about measuring and doing net metering and seeing whether you're providing energy to the grid or vice versa, you can do with our stations. But the real question is, do you want to use that asset—the battery in your car—that way? Because there is some life left in it. Tony talked about what happens in ten years or 150,000 miles or so, when the battery doesn't have the capacity it used to have. The question for the homeowner is, what's that worth? Is it worth enough to use your battery in that way? I think we're a ways off from that and we really want to use that battery to fuel the vehicle and get you to work and back. So let's look at that a little bit later.

JIT BHATTACHARYA

I'll speak about this a little bit more from the technology side of things. Richard really touched on the question, do you want to be using your battery in that way? As a vehicle manufacturer, when we're looking at these electric vehicles, knowing that these batteries have a finite cycle life, that's a big question we're trying to answer, and it's going to take a lot more data, a lot more understanding. More than anything else, it's going to take vehicles in the field, and that's something that a lot of manufacturers are working toward. The one thing that goes without saying: The more data that we have—the more intelligence we have around these systems—the more we are going to be able to optimize, and create that bidirectional system of communicating with the grid, of communicating with the home. Those are critical features in order for us to optimize the use of electric vehicles and make them really functional the way a driver is dealing with them.

TONY POSAWATZ

Let me try a different perspective representing the Chevrolet Volt team and how we're looking at this thing. First and foremost, to make this new electrified vehicle era work, we have to make the cars work; we have to make the batteries last. To the points that Richard and Jit made, those are the first priorities, and if that doesn't work, then much of the long-term vision that we seek won't happen.

But let me share with you a couple of quick stories here that relate our focus in this regard. We think there's tremendous value to providing the capability to load-manage, load-shed, peak-shave—whatever terminology you want to use—electric vehicles when they are taxing the grid during the day, as we talked about. Mark said it very well: You'd want to charge these cars overnight when the grid is not being utilized, when you're sleeping, when the car's not driving. That's the primary charging episode and situation. But if you were charging during the day, wouldn't it be nice, then, to offer that capability to the grid and perhaps even create some value and monetize that capability? We have an interesting technology on the Volt called OnStar, it's something that we've developed for 14 years at General Motors, and it's a huge enabler for us to create a smart car to talk to the smart grid to talk to the smart appliances.

Let me cite a quick example, and then we'll let Mark close this out because he's the most qualified to talk on this subject. Today our OnStar telemetric wireless platform can send a signal to assist authorities in a stolen vehicle high-speed chase and literally depower the car to avoid a high-speed chase and apprehend the criminal. I recently saw a video that showcased a police trooper pulling up behind a car. He had his video camera on, and it caught the guy try to scramble through the sunroof, and we sent a command to lock the sunroof so the trooper could apprehend the crook. Given the capability we have today, I think in a stationary vehicle, if a utility asks us to stop a charging event because it's the middle of August and three in the afternoon, that's something that we would gladly afford and provide that technology for, because the health of the grid depends on it. This relationship we're forming with our new fueling partner is very, very important.

MARK DUVALL

I think everyone that works in the electric vehicle industry, whether you're on the utilities side or the vehicle side, would say that it's important that the batteries first run the wheels, drive the wheels, and that we then look at more advanced things. So I think the first step is really to establish what we would call smart charging; it's kind of a corny name, but you'll hear it again and again and again. It means that we will synchronize how these vehicles work with the electric system so that we'll be charging off-peak. Utilities will be designing low rates to encourage drivers to charge off-peak. Today, if you are a PG&E customer, you can get an off-peak rate for your electric vehicle at six cents per kilowatt-hour. That's like buying gas at about 50 cents a gallon, or less, so that is really as close as you will ever come again to driving that inexpensively.

These are really good steps, and they set us off to do something in the future. Solar energy at the home—residential solar energy—was very good at allowing people to start to become power generators. You use the grid to store your electricity because at noon, when your solar panel's at its highest output, chances are you're at work, so you don't really need that energy. You put it out on the grid, and then you ask for it back later that day, and you pay the difference. With electric vehicles, there could be something like that in the future, but first let's get as many out on the road as possible and get the cost down and really understand what makes this industry go, and by then we'll understand if that makes economic sense. It's still not clear that you can sell power back to the grid through your car, pay for the equipment, liability, and still have it be profitable.

KERRY CURTIS

Thank you, Mark Duvall, of the Electric Power Research Institute. Here's a somewhat challenging question from an audience member, specifically for Tony: Tony, if we look at the specifications of the Volt, it is obviously overbuilt: more battery capacity than it will use, larger electric motor than it needs to power an average sedan, etc. Does this mean that we may have seen this platform used in other vehicle applications? Is it valid, what the questioner is saying?

TONY POSAWATZ

Certainly the Volt is built with a lot of capability. We put a lot of our most precious talent

and treasure into the Volt program, and it's really built on the shoulders of many of our other efforts. We could have not done the Volt program, if we had not done an EV1, if we had not done a fuel cell, if we had not done the hybrid program General Motors had done, if we had not taken the initiative to look at the various biofuel options, and the like. We feel that the Volt is a very, very capably engineered product.

To Jit's point, I'm going to punctuate a very important point that the fun-to-drive element of this car is incredible. There are a few people in the room smiling at me right now who drove the car this morning. When I talk about instantaneous torque, no transmission shifts, the eerie quiet of a car—that just gives you a whole different peaceful experience. In a Volt, we have set this thing up to have a wider track. The center of the gravity of the battery makes the riding and handling experience even more incredible. But back to the question, the Volt is not a singular play for General Motors. We chose an existing vehicle platform, our architectural parent vehicle, so that we could perhaps build other models on it, and if they happen to be a bigger model, a crossover SUV or whatever, the capability that exists in the propulsion system has to be able to propel a vehicle like that, a bigger vehicle.

So these are things that we're studying in the future. We haven't finalized what happens after Volt, but General Motors is sincerely and absolutely committed to create products that are electrically driven, that build off the learnings from the Volt. But everything has to be built on a successful Volt, and that's why the Volt really has specifications that will delight customers—such as driving from zero to 60 in eight seconds. If you get more than one charge a day, you may be able to avoid using any fuel on an annual basis. And we've talked about the cost benefits. We think there are a lot of opportunities in the future, so stay tuned.

KERRY CURTIS

I have three interrelated questions from the audience, all for Richard. I'm going to give you all three at once: How do people pay to charge at one of your stations? Are there different requirements—do some vehicles need a different kind of charging than others, and how do you handle that? And, finally, how long does it take to charge the car at a public charging station, and does it make sense if you're shopping or something?

RICHARD LOWENTHAL

Good questions. First of all, how do you pay? Our stations have the ability for you to pay with a credit card, and you can either use a loyalty card, like FastTrak, where it takes money periodically out of your credit card, or you can use a credit card by calling a toll-free number, or you can use the wireless credit cards, but it's a little bit unusual. Most of the owners of the stations won't ask us to collect money, so most of the stations you're going to encounter will actually be free. These are people incentivizing you to use their parking lot, or maybe it's your employer or maybe it's your local grocery store that wants you to come and stay for a long time while you charge your vehicle. So we're going to see a lot of free stations. We leave that up to the station owner, whether they want to charge or not. If they do, it goes by credit card, and you swipe this little ID tag at the station and it knows who you are.

The U.S., fortunately, has standardized on a connector for the vehicles, so the vehicles you'll see from the major manufacturers will have the same connector on them, which allows you to use a public infrastructure. If you were a driver like I was ten years ago in the trial in California, there were really four different standards out there, which led to some difficulties, but, fortunately, we don't have that case now. There's a standardized connector in the U.S., so that's good; we're not quite there in the rest of the world. Our shipments are only 50 percent in the U.S., and, for example, in Italy, as you might expect, they have six different connectors, which are all quite elegant, but they haven't quite licked that problem, but it's good in the U.S. You won't have a problem with that.

With regard to charge time, the cars generally, on average, if you put them in a pool, they take about four hours to charge from completely depleted to completely full, but you tend not to do that. In an average day you drive 29 miles, and so that takes much less time. You're talking now more about charging for an hour per day. You won't even notice because it will be where you park anyway. And will it help to charge while you're at Costco? Well, it'll help Costco because you'll linger longer, but it does help the car, too. These batteries have no memory, so everything you can do to keep the batteries up is good. I always leave my car plugged in when I'm at work; that way I've got the full range of the vehicle any time I want to go somewhere during the day. So those of us who drive electric cars now tend to think of charging as part of the parking experience. If you're going to park, you charge, and that way, you've given up the pleasure of going to the gas station. You need to park anyway, so it's just a part of parking.

KERRY CURTIS

Thank you, Richard.

MARK DUVALL

We did a survey several years ago about how people would view charging, because, at that time, the common wisdom in the auto-industry was that it was seen as an inconvenience: Oh, I've got to plug this car in every day. And out of that survey, seven out of ten people said that they would strongly prefer to charge at home rather than go to the gas station. One in ten people did say they would prefer to go to the gas station, so it takes all kinds.

KERRY CURTIS

Weirdos, obviously. Here's a question from the audience. Looking down the road a few decades, the question is, are there limits to electricity becoming the solution to greenhouse gas emissions from the transportation sector as a whole? Are there any parts of the system where it might not work?

RICHARD LOWENTHAL

Well, let me tackle one piece of that, which is the limit on the vehicle end. One of the nice things about electric motors is they're about 90 percent efficient, compared to a gasoline engine, which is about 20 percent efficient. So your gasoline car has a radiator, and most

of the gasoline you put in the car goes up as heat out of the radiator. You'll notice EVs don't have a radiator. That's because most of the energy that goes in the EV spins the wheels, so this is a very, very efficient way to move the vehicle. There still is, as Mark said, a lot of work to be done on generation, but as far a vehicle goes, this is a great way to move you around.

KERRY CURTIS

Thank you. One of the things that keep coming up when you're talking about electric vehicles is battery swapping. So you're driving along, and you run out of juice in your battery, and you pull into a station, and the gas station or the service station person will take your battery out and put another one in, and then you can go on your way. I'm paraphrasing this audience member's question, so I'll just keep doing that: What does it take to make that kind of a network of battery-swapping stations work?

RICHARD LOWENTHAL

I'll talk at the risk of talking about one of my competitors. The biggest challenge, first, is the interchangeable battery, and as much as Jit and Tony love each other here, there's a five-foot long T-shaped battery in the Volt. It's not going to fit in Jit's motorcycle. The interchangeability of batteries hasn't really been worked out, and so far there's just one manufacturer that wants to have this swappable battery, so you've got to get the auto makers to agree on the new "D" cell, which we haven't quite gotten to. The second piece of that is the big challenge in converting to another fuel—and we've seen it with hydrogen—building up an acceptable infrastructure so you can go anywhere you want. The reason electricity is nice is that Mark has already made it so that we have electricity everywhere, and the reason that gasoline, or the other fuels that Tony's vehicle uses, is good as a fuel for the long-range trip is that we've got gasoline everywhere. To get these battery-swap stations everywhere is very, very difficult. We expect to be able to refuel every 30 miles. That's a lot of those things to get built out there, so it's just a tough challenge to deploy in the U.S.

MARK DUVALL

I think you'll hear more about this; there's a company in Silicon Valley working on this. You'll hear more about two things: one is battery exchange; the other is called fast charging. Fast charging is, instead of pulling into one of Richard's stations and charging for a few hours, you would pull into a much larger station and it would pump DC energy directly into your battery. You could charge in maybe 30 minutes. If you just needed to get home, maybe five minutes, so sometimes it's called quick charging.

These are ways to make electric vehicles more usable. They both have some merits; however, they are expensive—very expensive—technology, and they force you to create an infrastructure that looks more like a grid, evenly spaced on a map, so that I can drive anywhere between all these different points and have a charger somewhere, whereas if you want to pump the most electricity into vehicles, you look at clustering, so the chargers are located where people are parking, which means at home, at work, at shopping malls,

in dense urban areas. No guy wants to own the charger that's halfway between LA and Barstow and try and make money off that, because only one electric vehicle passes there every couple of weeks, so the challenges of making that grid—we would have to figure it out, because I doubt you can do even one of them fully, let alone both types of technologies. But you'll hear much more about it; it's not a settled debate.

TONY POSAWATZ

Or you can have an extended-range feature on your vehicle and utilize one of the 170,000 existing refueling stations until better technology and infrastructure are in place.

KERRY CURTIS

Why am I not surprised that Tony Posawatz would make that comment?

SPEAKER BIOGRAPHIES

MARK DUVALL, PH.D.

Mark Duvall is director of electric transportation at the Electric Power Research Institute, also known as EPRI. EPRI is an independent, nonprofit center for public interest in energy and environmental collaborative research. Dr. Duvall is responsible for EPRI's research and development program for electric transportation, including electric plug-in hybrid and fuel-cell vehicle programs, and related advanced infrastructure. He oversees a number of partnerships and collaborations between EPRI and electric utilities, automotive companies, local and federal state agencies, national laboratories, and academic research institutions. His work currently is focused on plug-in hybrid electric vehicle research, development and demonstrations in collaboration with major automotive manufacturers, such as the EPRI Daimler-Chrysler PHEV Sprinter Van Program—advanced battery system development and testing, electric charging infrastructure, and environmental analysis of air quality and greenhouse gas emissions and characteristics of plug-in hybrids and other electric transportation technologies. Prior to joining EPRI, Dr. Duvall was principal development engineer at the Hybrid Electric Vehicle Center of the University of California at Davis. He holds B.S. and M.S. degrees in mechanical engineering from the University of California at Davis and a Ph.D. in mechanical engineering from Purdue University.

TONY POSAWATZ

Tony Posawatz is vehicle line director of General Motors new Chevy Volt. Mr. Posawatz has led the development of the Volt and continues to help lead the development of the 2011 production vehicle. He has served as a GM vehicle line director for the past 11 years. He and his development teams have received seven General Motors Chairman's Honors Awards for excellence and have overseen the development of cars and trucks, from concept initiation to production and market launch, in four different countries. Mr. Posawatz is also co-chairman of the Electric Drive Transportation Association.

JIT BHATTACHARYA

Jit Bhattacharya is CEO of Mission Motors, creators of the Mission One electric motorcycle. He began as COO in 2008 and assumes the leadership role as the company prepares to bring the Mission One to market. His engineering background includes experience with the product design firm Ideo. He also holds an MBA from the Haas School of Business at University of California at Berkeley. Mr. Bhattacharya has been involved with energy and clean tech for over five years, most recently as co-president of the Berkeley Energy and Resources Collaborative, where he helped lead the launch of UC Berkeley's new Center for Energy and Environmental Innovation.

RICHARD LOWENTHAL

Richard Lowenthal is founder and CEO of Coulomb Technologies, Inc., developers of electric vehicle charging station infrastructure. He was instrumental in starting several companies, including Lightera, Pipal Systems and Procket Networks. He has served as vice president

and general manager of Cisco Wide Area Network Access Products division and was co-founder and vice president of engineering for Stardent Computers and vice president of engineering for Conversion Technologies. He is also a former mayor of Cupertino and is deeply involved in the nonprofit world. He holds a B.S. degree in electrical engineering from University of California at Berkeley.

KERRY CURTIS (MODERATOR)

Kerry Curtis chairs The Commonwealth Club Environment & Natural Resources member-led forum and is a member of The Commonwealth Club Board of Governors

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