Smart Garage Charrette Report

RMI | move
mobility + vehicle efficiency

Rocky Mountain Institute

v2.0, December 2008

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Thanks to these companies who participated in the charrette that generated this document,

A123 Systems

Aerovironment

Arcadian Networks

Austin Energy

Better PLC

Bonneville Environmental Foundation

Bonneville Power Administration

Bright Automotive

CalCars

Cisco

Comverge, Inc.

Coulomb Technologies

Current Communications Group

Duke Energy

Ecotality

EDS

EPRI

Etec

Fast Company

Ford Motor Company

General Motors

Gilbarco Veeder-Root

Google

Gridpoint

Gridwise Alliance

IBM

iTron

Johnson Controls, Inc.

Lemelson Foundation

Matter Media

McKinsey & Co.

MIT

Nissan North America

NREL

Oregon PUC

P&G Future Works

PG&E

PGE

Portland State University

Rocky Mountain Institute

Sling Media

State of Oregon

Tesla Motors

University of California at Berkeley

Vantage Point

Wal-Mart

Zipcar

Special thanks to: Lemelson Foundation and Google.org for their generous support of Rocky Mountain Institute's Smart Garage work.

Table of Contents

It's 2025. The world has changed—and the change was driven by what and how we drive.

Fossil fuels are loosening their grip on the economy, carbon emissions from our transport and electricity are falling in absolute terms, and a dramatic shift in engineering design has given the devices, buildings, and machinery we use in our daily lives a pervasive emphasis on energy efficiency. Our vehicles are no exception. In 2025 they run, for the most part, on silent electric drivesystems powered by clean electricity.

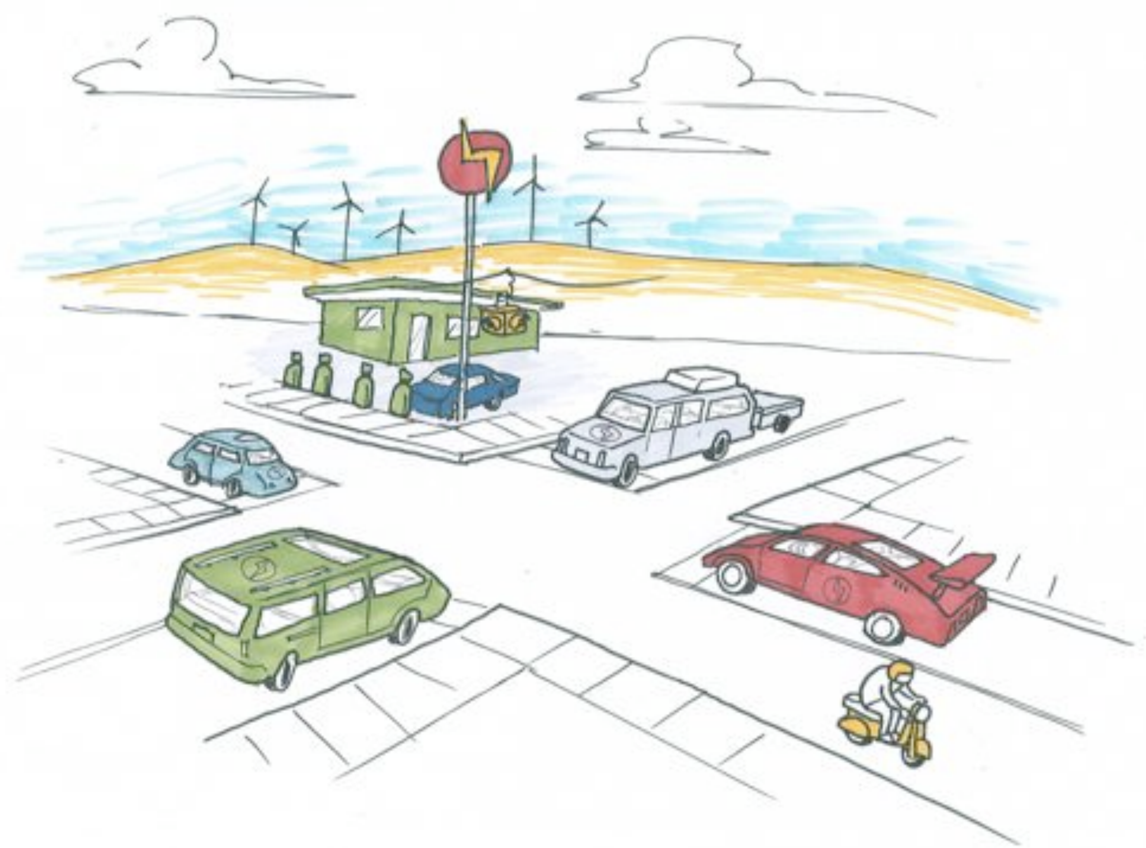
A typical day might go something like this: after work, you drive home in your plug-in hybrid, pull into the garage, and connect your vehicle to a power cord that connects to your house. Your car and house "shake hands"—the car tells your house the state of its battery, and the house's energy management system figures out how best to charge your car. The car then spends part of the night recharging on cheap electricity that comes from a new big wind farm. In fact, your car charges in sync with how fast the wind is spinning the turbines—guaranteeing you are only getting "green" electrons. In the morning, you check your home energy dashboard to review the status of your car's charge, and you happily drive to work in your vehicle, which uses electricity most of the time. If your commute takes a few extra turns, an efficient little biofuel, gasoline, or diesel engine comes on to provide extra range.

You get to work, drive into the parking lot, and plug your car into another electric charging system. It automatically recognizes *your* car and links to your credit card and your utility account. Your car and utility share information in both directions—how much electricity the battery has or needs, how much it costs (now and perhaps later in the day). Based on the preferences you previously set online, your car and utility decide the best, cheapest, and greenest way to get the energy your mobility requires.

Say it's a hot summer day, and electricity is in high demand and more expensive. Based on your preferences, the utility and the vehicle converse. The car declines the day's charging because the price is extremely high. In addition, the utility would prefer to draw power *from* the car and pay its value back to your credit card. The price is right, so your car, seeing a juicy "carbitrage" opportunity, decides to use its electrical storage to earn you some money. At 5 p.m., you climb into your pleasant, pre-cooled car and drive home mostly on advanced, environmentally-friendly biofuel.

Your cousin, meanwhile, lives in the city and owns a 150-mile-range fully electric vehicle, which can cover almost all of her driving needs. She charges mostly overnight, like you, but her apartment's garage has set up charging stations. Better, she gets her fuel for free: the building's garage works with the utility to provide "grid services" from the parked cars to subsidize the free charging—while also enabling the utility to put more wind on its grid. On those weekends when she takes a trip to the 'burbs for shopping, she's goes to a big-box retailer that has free fast-charge stations. Her car is charged while she shops and the power comes from the retailer's rooftop solar array (in fact, due to this array and its efficient design, this store is a "net-zero" energy building). Since the charging service draws her to the store for a set period of time, it is worth it to the retailer to provide free charging. Your cousin is able to drive without paying a cent for energy—unheard of a decade earlier in 2015 when oil spiked at more than $200 a barrel.

Bringing electrified vehicles, advanced net-zero buildings, and a smart renewable grid together in innovative ways to provide clean, cheap mobility and electricity: that is the vision of Smart Garage. This report outlines the thinking of 25 leading organizations, convened by Rocky Mountain Institute on 8–10 October 2008 in Portland, Oregon, on how to get there.



Executive Summary

Bringing electrified vehicles, advanced net-zero buildings, and a smart renewable grid together in innovative ways to provide clean, cheap, and secure mobility and electricity: that is the vision of Smart Garage. But how to get there?

RMI convened 80 individuals from 25 companies, universities, non-profits, and national labs who are all affected by the transition to Smart Garage in a "charrette," or intensive interdisciplinary design workshop. The charrette focused on identifying and busting the most important barriers to successful Smart Garage implementation.

Short Term Vision: What is the First Step?

It's easy to imagine Smart Garage in the long-term, but harder to describe how to get there. Charrette participants came to a clear consensus that the near-term vision was "V1G": highly integrated systems doing sophisticated one-way charging that could reap many of Smart Garage's benefits relatively rapidly.

V1G offers tremendous benefits with less cost and complexity than V2G (though it is not simple or cheap), and implementation can launch within two to five years.

Deep Dives on Value Chain: Who Are the Stakeholders?

RMI divided Smart Garage's ecosystem into five main components, listed here with one charrette insight each.

- Consumers: proof of consumer demand will be the chicken that lays the egg for Smart Garage;
- Vehicle- and battery-makers: participants see value in breaking the battery and vehicle value chains apart, taking battery risk off the OEMs and seeking innovative ways of financing the battery;
- Places to charge: potentially high value (financial and consumer adoption-related) in providing charging infrastructure, but who will pay for it? Several likely candidates exist, from government to utilities to start-ups;
- Connectors (energy, data/information, and billing services): this group has near-infinite potential for creative business models and is uniquely centered on start-ups. Communication standards and charging infrastructure are pre-requisites; and
- Grid-related (utility): utilities do have a lot to gain, and as a result could be asked to give a lot in terms of infrastructure, consumer incentives, and battery financing. Regulatory groups (nationally fractured) could oversee the benefits and ability of utilities to support other groups.

Top Barriers

One of the most valuable outcomes of the charrette was sifting through dozens of barriers to arrive at the top five, and creating solutions that could be turned into concrete projects:

Figure 1: Overview of top barriers and solutions

Top Barrier	Solution Strategies	Next Step Project *RMI is advancing each of these projects. To get involved check out move.rmi.org/smartgarage
Uncertain consumer demand hampers ability to start building xEVs in significant volumes	• Consumer education programs, • Quantify demand creatively, • Use demo projects to learn how to scale, • Utilize fleet car programs	**"Project Consumer Demand,"** a collaborative project, would craft a compelling story about why people should buy PHEVs while collecting hard data that will help OEMs plan and widely publicize that plan in conjunction with an effort to quantify consumer demand for these vehicles.
Who will pay for the charging infrastructure?	• Strategic placement for consumer confidence, • Use public funds, emphasizing the public good, • Develop innovative business cases around the charging station.	**"Project Get Ready"** would work with a number of cities interested in becoming leaders in the PHEV revolution to create a bundle of incentives (financial, lifestyle, service, and value-related) that make owning an electrified vehicle better than owning an ICE for early local adopters, and share lessons learned from the early adopters to refine the system as it heads to mass roll-out.
		"Charge Baby Charge" aims to map and rigorously quantify the many types of value that result from charging infrastructure, so that public and private investors would be better able to understand the opportunity and issues related to widespread EV/PHEV adoption.
High battery costs/ uncertainty for key parameters	• Consider secondary battery markets to reduce upfront cost, • Stabilize supply side, • Feebates/gov't subsidies, • Right-size battery, vehicle efficiency	**"Project Second Life"** quantifies and analyzes the value of used batteries and how they can best be deployed.
How do we support consistency in utility regulation?	• Lobby for major federal regulation, • Voluntary, broad alliance for uniform framework	**"National Utility Policy Project"** establishes a consortium that seeks to create a national framework of policies and regulations for utilities that could enable the Smart Garage paradigm by eliminating the barrier of differing and incompatible regional systems.
Communications, billing, and charge management services/structures don't exist	• Design a rigid-enough yet flexible standard that allows innovation, • Go around standards institutions by using a *de facto* dominating commercial format, • Spread awareness of ongoing institutional standards-making work	**"Project Get Involved"** is a commitment to get as many diverse perspectives involved in the standards-making process as possible.

Chapter 1: What Is Smart Garage?

Smart Garage would bring transport, the electricity grid, and the built environment together for the first time via the enabling technology of electrified vehicles[1] and their smart integration with the grid.

Until now, our transport infrastructure operated nearly independently of both electricity and buildings. Now these three sectors are about to fuse via the rapid commercialization of a new generation of electrified vehicles that would not just plug into the grid but communicate with it, help firm and regulate its operation, and possibly act as a mobile electricity storage resource. If implemented with foresight and care, Smart Garage would integrate building, vehicle, and grid energy systems to improve the efficiency of all three, while also increasing customers' control and choice. Smart Garage could do for electricity and mobility what Tivo did for broadcast media, letting you choose the energy you want to use, when and where you want it, both in your car and in your building.

Long-Term Vision: Advanced Integration of Cars, Buildings, and Grid

In the longer term—over the next fifteen to twenty years—Smart Garage could be a critical part of a transport, building, and electricity system that is highly interlinked and interdependent, very secure and resilient, increasingly distributed, and run primarily—perhaps entirely—by renewable energy. Power flows would include not just traditional customer and utility assets but also electrified vehicles—creating a versatile new class of power users, storage, and suppliers.

This system would take customers from being passive bill-payers into the world of gas and electricity prices and supply where they exist at the center of an information-rich set of new choices. Users would know what they spend on the energy they use, at the time they use it, and can either make choices in real-time, or set a few preferences and let a smart system pick the cheapest, greenest (if they prefer), and most convenient way of getting energy. We envision a system that will accept a variety of car models and sizes, and a connection/telecommunication system that is universally available, flexible, and compatible, nationwide and beyond. The plug-and-play ubiquity of cellphones would come to electrified cars: charging and behind-the-curtains account settlement would be as widespread as a wireless phone signal is today.

1 These include plug-in hybrids (PHEVs), extended-range EVs (EREVs), and battery-electric vehicles (EVs). The report will also refer to electrified vehicles as "xEVs."

We envision a society that embraces electric vehicles because consumers find them more convenient ("I can fuel up at home"), cost effective ("it only costs me pennies per mile"), and fun ("the low-end acceleration is fantastic"). Dramatic reductions in oil dependence and carbon emissions—via the efficiency of the vehicles[2] and their enabling of a more renewables-intensive grid—are byproducts of consumer choice.

Electrified vehicles coupled tightly with a smart grid would enlarge markets for renewable energy, such as night wind power. Electrified vehicles are a clean, dispatchable resource for the next generation of utilities that could help facilitate higher (above 30 percent) reliance on variable renewables integrated within the utility system. Smart Garage could provide other transmission and distribution (T&D) services that make the grid work more reliably and economically. And it increases options for emergency power supply when the grid fails.

We envision that Smart Garage would enhance national security, as supply disruptions would become far less important for oil and far less possible for electricity: the more diverse, distributed, renewable grid would help prevent major failures like the Northeast Blackout of 2003, which knocked out power to 50 million customers.

The business case for Smart Garage is strong, requiring hundreds of billions in new investment, but with a significant net present value (NPV). In fact, RMI's Smart Garage model (see Box 4) baseline shows a $100-billion NPV to key stakeholders with a substantially renewable national power mix (V2G NGU). Importantly, Smart Garage promises to stimulate new industry with significant and diverse business opportunities in vehicles, energy storage, charging, metering, building energy systems, software,

Box 1: What is this report?

On October 8–10, 2008, Rocky Mountain Institute convened 80 leading practitioners representing the broad reach of stakeholders that will drive the convergence of vehicles, buildings, and the grid at an event called the "Smart Garage Charrette." A charrette is a term from architecture that describes an interdisciplinary design event.

Over the course of three dynamic days in Portland, Oregon, the group hashed out a common vision for Smart Garage, identified the key barriers to realizing that vision, and created solutions for those barriers that leverage collaboration between players.

This report contains the outcome of that event: the shared vision, insights into the value chain, the top barriers, and specific solutions to tackle the barriers.

The comprehensive research that preceded the event as well as appendices, reports on post-charrette work, and updates to this document can be found at our website, www.smartgarage.rmi.org.

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2 A recent study by the Natural Resources Defense Council (NRDC) and the Electric Power Research Institute (EPRI), found that widespread deployment of plug-in hybrid electric vehicles by 2050 could require no new generating capacity—yet could reduce U.S. greenhouse-gas emissions by more than 500 million tons annually. We believe this study stays on the conservative side of the potential environmental benefits of Smart Garage, not including the possibility of more efficient xEVs or coupling xEVs aggressively with renewables.

targeted marketing, communications, retail, finance, and location-based services.

Short-Term Vision: Scaling and Linking the Pieces

It's easier to envision the Smart Garage world than how to get there. Every piece of the Smart Garage puzzle exists today; the challenge is linking and scaling them. This report outlines the needed short-term steps, key barriers to overcome, and strategies to do so.

Smart Garage is coming together today because vehicles, batteries, communications technologies, and the national grid have reached the level of maturity to support the functions and services required to connect vehicles to buildings and the grid.

Vehicle electrification has emerged as a dominant new trend in the automotive sector, with over a dozen xEVs in the U.S. pipeline and many more on the way. Lithium-ion batteries are ready for early commercial applications, though no single chemistry has emerged as the leader (and may never, since certain applications favor certain chemistries). Across America, electric grids are being upgraded to the "internet age," with digital sensors, smart meters, and advanced communications. Even an early charging infrastructure exists for PHEVs because they can use a standard 120-volt outlet.

What will the early, "first generation" of Smart Garage look like? How would the pieces fit together over the next five to ten years? Boxes 2 and 3 outline six scenarios of how xEVs, buildings, and the grid can interconnect. Options include the range from relatively simple, tested "timed charging" (using electricity rate incentives like some utilities did in the 1990s to encourage customers to charge off-peak) to leapfrogging to bi-directional charging, which would leverage xEVs as mobile storage devices.

Box 2: Many ways to plug-in

One of the core insights of RMI's research was the importance of differentiating between different "flavors" with which xEVs plug-in to the grid/buildings. RMI developed six important scenarios, briefly outlined below We use the terminology defined in this box throughout the document.

V0G (Convenience charging): vehicle starts to charge as soon as it's plugged in, like a typical appliance.

TC (Timed charging): vehicle doesn't charge until a given time (from an installed program or a signal from the utility) when rates and grid load are low.

V1G (Smart Charging): vehicle communicates with the grid in real time, and charges exactly when the grid needs it to. The vehicle also can provide ancillary services for extra revenue.

V2B (Vehicle-to-Building): like V2G, except the electrified vehicle does NOT communicate with the grid but instead with an individual building's energy management system.

V2G (Vehicle-to-Grid): like V1G, except the car can discharge, allowing a wider range of grid services as well as storage and back-up power.

V2G NGU: V2G but in the future, when the grid has become smarter and more reliant on renewables, efficiency, etc.

Charrette participants came to a clear consensus that the near-term vision was V1G: highly integrated systems doing sophisticated one-way charging that could reap many of Smart Garage's benefits relatively rapidly. This was a welcome outcome for many participants: "a key positive item that emerged from the RMI Smart Garage charrette was the convergence around the importance of smart charging—the ability to manage charging of EVs to provide customer flexibility, promote attractive rates to customers, match demand from charging with supply (ideally from renewables) and not create additional strain on the grid or increase the need for more generation," said one.

This convergence on a surprisingly attractive near-term solution, V1G, rests on five main findings:

1. V0G—unintegrated roll-out—carries significant risks for the grid, particularly at peak times, and misses many valuable benefits.
2. Timed Charge is a simple variant on V0G that reduces but doesn't fully mitigate its risks to the grid, and again misses many available opportunities.
3. V1G can achieve many of the benefits of V2G without the attendant stress on the battery, technological difficulty of feeding power back on to the grid, and higher sophistication of the system (see Box 3).
4. V2G offers potentially valuable energy storage and grid-services benefits in a world where renewables make up an increasing share of electricity generation, so V2G mustn't be precluded by installing infrastructure or technology that's not ultimately capable of bidirectional charging. Some battery and grid technologies need further maturation to facilitate this, incurring additional expense.
5. V2B offers an intriguing path toward V2G since it avoids many challenges by using the buildings as an intermediary and aggregator thereby reducing the number of touch points (and therefore complexity and expense).

In short, V1G offers tremendous benefits with less cost and complexity

Box 3: What does each connectivity scenario include?

benefits	Real Time Comm with Utility	Cheaper Fuel for Customers	Timed Charging	Back-up Power	Uni-Directional Ancillary Services (A/S)	Bi-Directional A/S	Off-Peak Load	Load Shifting for Wind Firming
V0G	✗	✓	✗	✗	✗	✗	✗	✗
TC	✗	✓	✓	✗	✗	✗	✗	✗
V1G	✓	✓	✓	✗	✓	✗	✓	✗
V2B	✗	✓	✓	✓	✗	✗	✓	✓
V2G	✓	✓	✓	✓	✓	✓	✓	✗
V2G NGU	✓	✓	✓	✓	✓	✓	✓	✓

than V2G (though it is not simple or cheap), getting us towards the visions laid out above in the next five to ten years. Coalescing on V1G allowed the participants to move from talking about Smart Garage as something that will happen "in the future" to something that we are starting right now.

What does it mean to converge on V1G as the short term solution? It means that utilities, OEMs, civic leaders, infrastructure providers, connectors, software and hardware providers, standards-making bodies, retailers, and car/home owners will have to work together to create an integrated communication and charging infrastructure—starting today.

A blossoming of new start-ups and products could then emerge to serve this new system (billing, energy services, data, and more). Homes with smart meters would charge cars when electricity prices are low. Builders would be required to include charging facilities in new homes, and new standards would make trans-regional charging possible. Public infrastructure would be able to fill any gaps in charging electrified vehicles.

This vision requires that:[3]

- xEV cars be profitably made and sold in large numbers. As one participant said, "The best surrogate for success metric is vehicle sales";
- consumers see how xEVs can improve their mobility, perhaps even their energy use and security;
- utilities and their regulators welcome xEVs but use pricing or technical controls to discourage their onpeak charging (otherwise new distribution and generating capacity could be required);
- simple and attractive public recharging needs to be provided in areas likely to get many xEVs but lacking suitable private overnight charging capabilities;
- national or international standards for information flow emerge to ensure reasonable interoperability, and vehicles have the ability to send and receive messages with utilities in near real-time (or with third parties who provide connecting services);
- Level 2 charging is reasonably widespread (though Level 1 can provide much of the base);
- regulators—of air quality, car efficiency, electricity, and other public policy arenas—collaborate to achieve new shared benefits; and

[3] Some of these requirements are unique to V1G, and some are required for any scenario of Smart Garage to get started.

- business models mesh to create, and/or policy incentives provide, an encouraging business environment where the most profitable players can offset others' capital needs or exceptional losses, notably those of the OEMs.

In addition, it would be very helpful if:

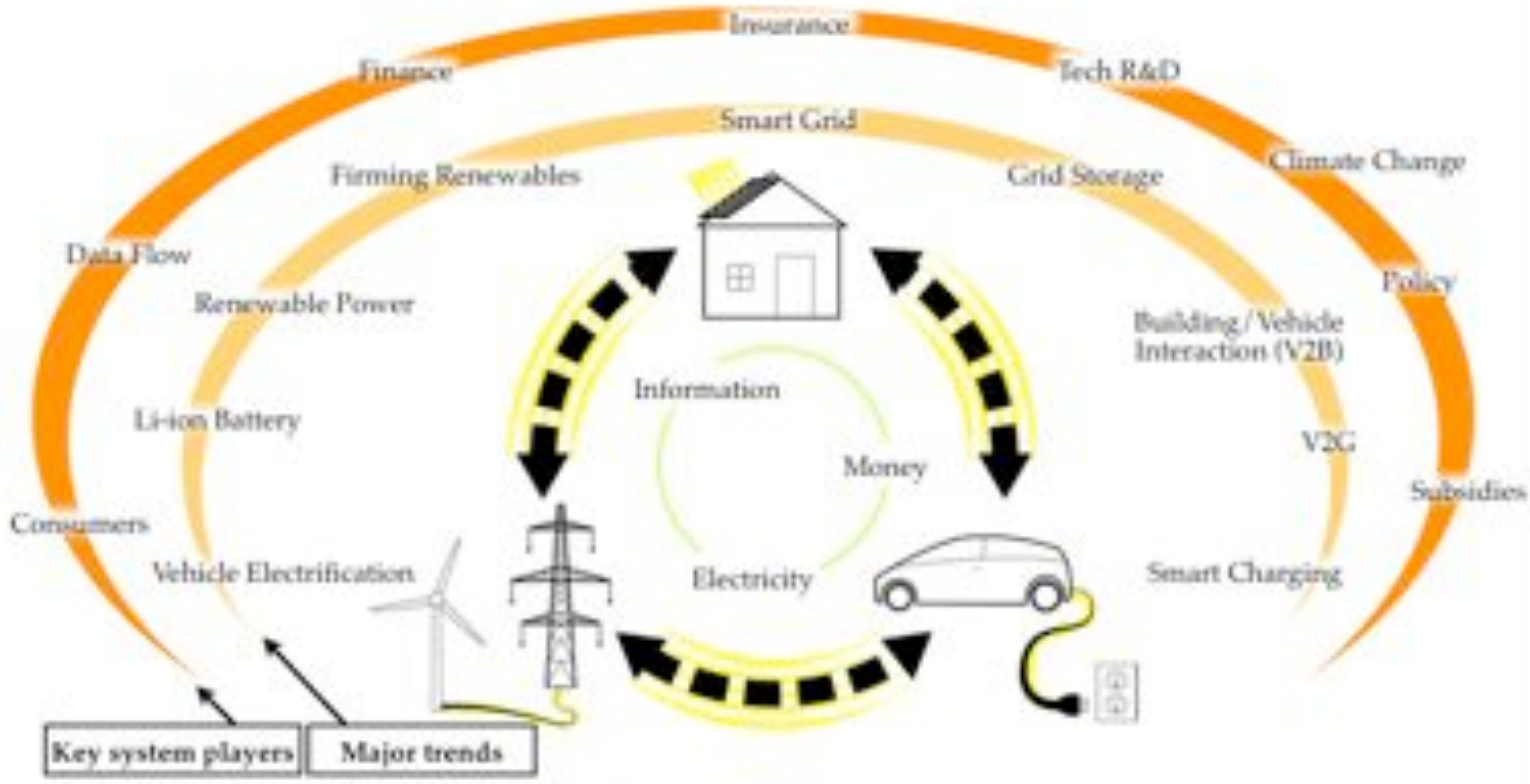
- lithium automotive batteries continued to improve in cost and durability, or cars gain at least equivalently in range per kWh (chiefly through lightweighting and aerodynamics);
- government incentives were at least neutral and preferably friendly to vehicle efficiency (*e.g.*, subsidizing PHEVs by range rather than by kWh of battery capacity);
- automotive fuel prices stayed relatively high, or at least have a floor set by public policy;
- smart grid significantly advanced and scaled, or at least utilities were able to signal simply to customers when charging would be most advantageous;
- ancillary service and grid service markets accept xEVs individually or in aggregate;
- one or more major players saw sufficient benefits and first-mover advantage in V1G to fuel risk appetite; and
- regulators accepted necessary changes in their practices and assumptions so they can achieve both old and new objectives simultaneously and without undue compromise.

Finally, V1G defers the need to:

- utilize two-way remote controlling (though hardware deployed now should be designed to accommodate it if/when it comes);
- have a grid with full net-metering and the ability to take on large numbers of small generators; and
- pay for/develop batteries that can sustain higher numbers of cycles.

By no means do the charrette participants and RMI advocate taking V2G off the table. They instead believe that wherever the Smart Garage leads, V2G or some hereto unimagined future, V1G is a powerful and faster first step that will help get xEVs on the road and renewables on the grid.

Figure 2: Smart Garage aligns several industry trends



Box 4: how do you calculate the value of Smart Garage

Smart Garage is a complex ecosystem, with many potential flows of money and resources. How, then, can we predict how much net present value it will have? There's no absolute answer, but a range of answers depending on key variables (including connectivity scenarios). To analyze the value, RMI created a dynamic model that looks at the mots important cash flows for four critical stakeholders: vehicle makers, consumers, utilities, and building owners/3rd parties. We did not include "connector" companies, retailers, or battery makers.

The model, which you can download at move.rmi.org/smartgarage, is an open document and under continuous improvement. It will allow you to analyze the system impact of several key variables, notably the connectivity level (V1G vs. V2G), price of gasoline, type of vehicle, electricity rates and market values, discount rates, miles travelled, battery pack cost/size, and more.

We created a set of default assumptions based on research and discussions with our participants, and used that default set to generate the numbers found in this report and our pre-read. Some of our key findings:

System NPV relies most heavily on the connectivity scenario, and can range from negative to positive

Within each scenario, there is a wide range of value depending the key variables:

Capital costs (battery + drivetrain) make consumers likely to be net negative compared to an ICE-future, but with a small capital cost reduction which could be realized by battery financing/advancement or a subsidy like the one recently passed in Washington, will have a huge positive effect on the system,

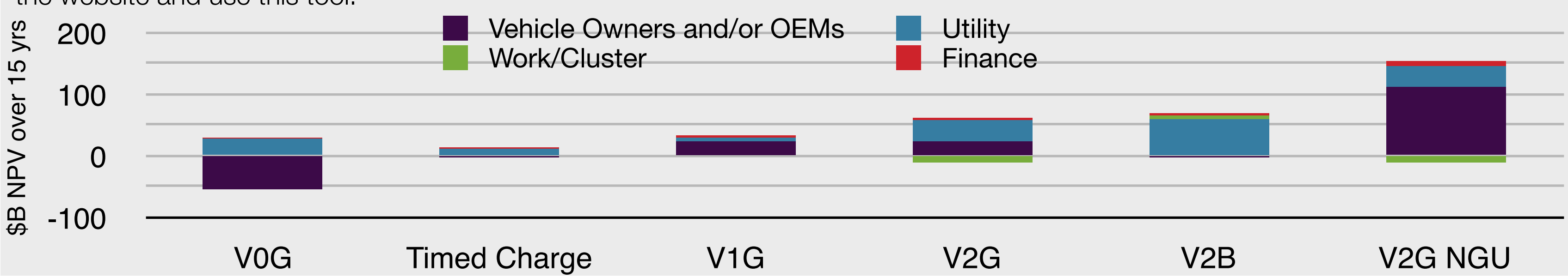
Gas price matters, as does the baseline to which you compare fuel use (if ICE cars get 50% better on average, the comparable cost of ownership will go down),

It's currently unclear how OEMs and consumers will "share" the high capital costs of batteries and powertrains,

Utilities will be the largest winners (not counting innovating 3rd party connectors) based on avoided cost benefits, ancillary service benefits, and new revenues, if they are allowed to realize all benefits by their regulators, and

V2B has the most unknowns, but has significant savings in hardware and electricity arbitrage for the building.

The graph below shows the costs and benefits to the main stakeholders in each connectivity scenario under one possible set of assumption (we updated it from our pre-read to reflect participant input). We're not claiming this is what the exact value will be; we're saying this is one viable way it could look for certain stakeholders. We welcome debate and improvement to our model, so please visit the website and use this tool.



Chapter 2: Who is in Smart Garage?

The Smart Garage will be a "system of systems," as one charrette participant noted. In other words, it's a large, complex system comprising interconnected major stakeholder groups, analogous to an "ecosystem." The need for collaboration between these players is considerable and nearly unprecedented.

Who are the stakeholders in the Smart Garage ecosystem? They range from big companies to small, from mature to start-up, from manufacturing to IT, and more. The players fall into five main groups: automakers/suppliers, utilities/grid operators, charging places, connectors, and consumers.

The groups are described in the graphic below, which orients the entire ecosystem relative to the group's maturity (the vertical axis) and the consumer (the horizontal axis). Utilities and automakers are among the most mature industries, with a strong tie to the consumer. Charging places and connectors will be new industries: currently the physical infrastructure is limited and the IT services are just getting off the ground. Several industry groups, like battery suppliers and renewable electricity generators, will play a key role in Smart Garage but will not be directly connected to the end user.

Figure 3: Smart Garage Ecosystem Organized by Consumer Proximity and Industry Maturity

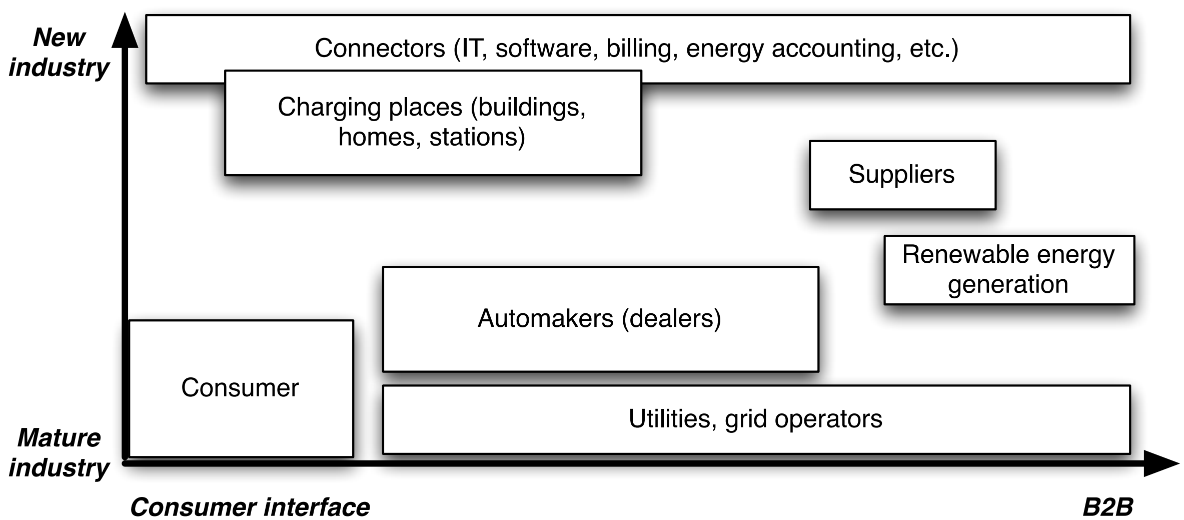


Figure 4: Smart Garage System Map in V1G

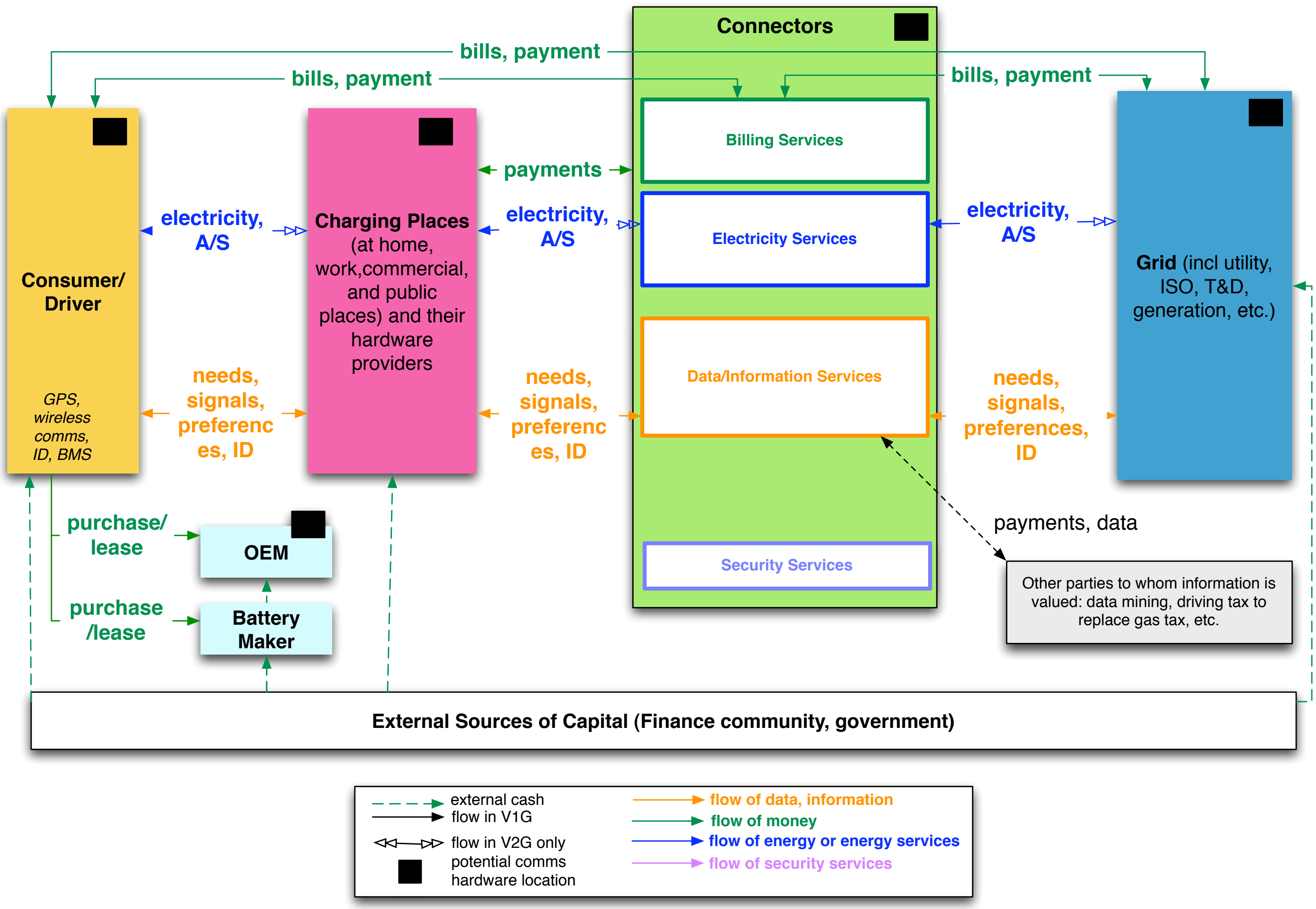


Figure 4 dives deeper in how stakeholders could transact information and money. Moving from left to right in Figure 4, we start with the consumer. In addition to electricity, the consumer (via his or her vehicle made by an OEM) will probably receive information like price signals, requests for types/rates of charge, and other interesting data (like "where is the closest public charge spot?"). Financially, the consumer might get funding from government incentives or innovative private-sector financing arrangements, and might be paid by the connectors/energy sector for providing unidirectional grid services such as regulation. The consumer could have a billing relationship (for the car) directly with the utility, or she/he could go through a third-party connector that has contracted with the utility; either way, the relationship will be analogous to that of a cell phone service situation.

In return, the consumer must pay the connector or the utility for the electricity, and someone for the vehicle, which might be financed through an innovative mechanism such as a pay-per-mile program (like Better Place) or a pay-per-hour program (like Zipcar). Consumer preferences for payment, charging, and driving range must also be set. In advanced scenarios, the consumer could also provide electricity back to a building (V2B) or to the grid (V2G) .

The charging places between connectors and consumers would be the physical point of contact that makes all the electricity, and this value chain, flow. The charging spots basically act as a "middle agent" for the electricity flow (and, if the charging place is intelligent, for the information flow) between the consumers and other actors.

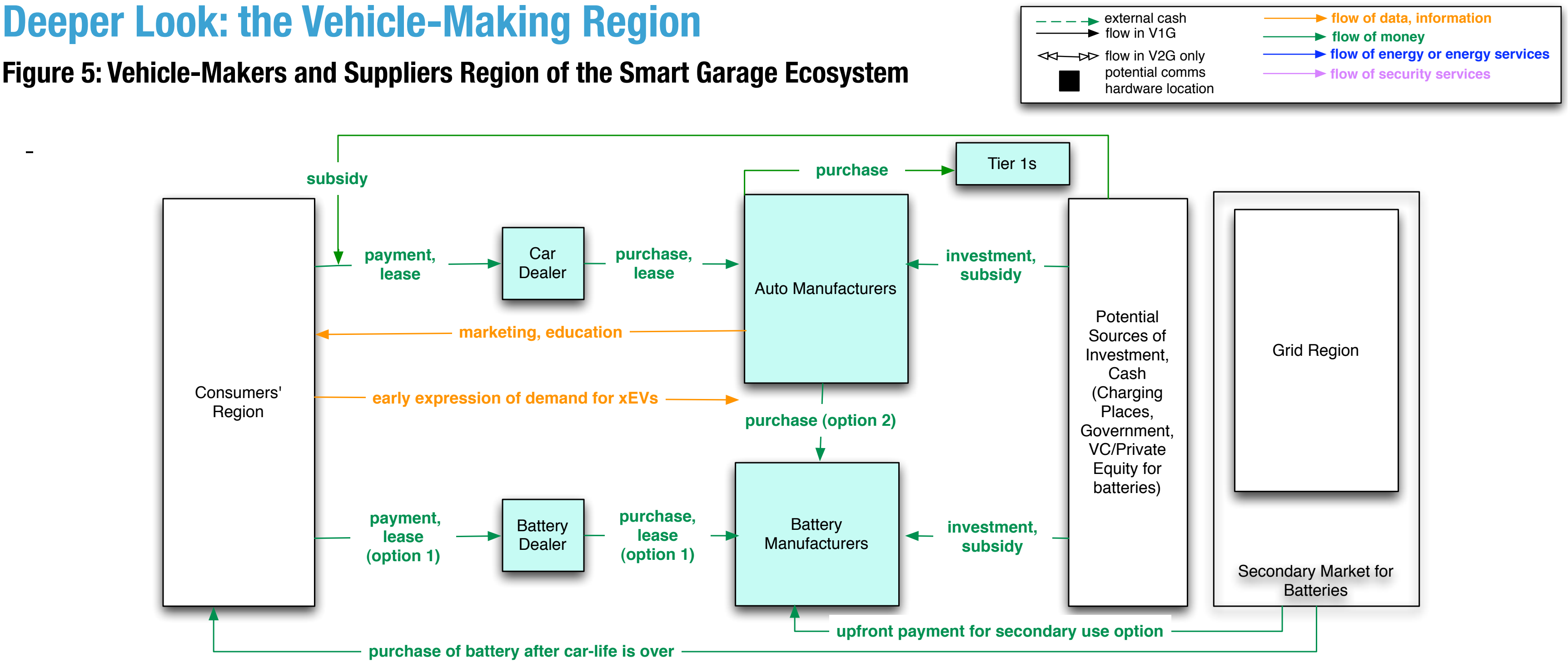
The connectors, shown in the green box, would manage all the services, as shown by the colored lines. They make sure money gets transacted to/from the right stakeholders, and they would collect a fee for providing that service (akin to a credit card today). They could also help manage critical data (prices, consumer preferences, utility requests, etc.) and, based on these inputs, control which xEVs should take on how much electrical charge and when. The connectors might also aggregate vehicles so the utility can use them in larger blocks of either controllable demand (V1G) or mobile storage (V2G). Finally, the connectors ensure the appropriate security and privacy of these transfers of information.

The gray box connected to the consumers represents third-party companies that might use the information generated by this system to provide a new type of service. For example, it might leverage the vehicle's Smart Garage communication capabilities, with the user's permission, to target advertisements that relate to the vehicle location, or to provide advanced two-way GPS and traffic information services. Charrette participants hypothesized that new and potentially significant value could thus be funneled into the Smart Garage ecosystem.

Finally, utilities, ISOs, public utility commissions (PUCs), and other grid-related stakeholders are represented by the blue box on the right. These stakeholders take payments for electricity and coordinate the information needed to run the grid more reliably and efficiently—notably electricity prices, grid service requirements, and demand response requests. In V2G and some advanced V1G scenarios, the utility may actually pay connectors or consumers for grid services.

Deeper Look: the Vehicle-Making Region

Figure 5: Vehicle-Makers and Suppliers Region of the Smart Garage Ecosystem



At the charrette, the discussions about the vehicle-making portion of the ecosystem—which includes OEMs, battery makers, and other "Tier 1" suppliers that make such critical components as electric motors and power electronics—centered largely on the OEMs, like Ford, GM, Nissan, etc. Currently, these players have the least compelling value proposition because they are they are embedded in the "upfront capital investment" part of the Smart Garage, with neither clear pathways in capturing the direct downstream economic benefits in fuel savings, grid services, and information flows, nor the broader societal benefits in energy security and climate protection.

Simply put, xEVs cost more to build than ICEs, primarily due to their battery packs. The battery cost is offset by fuel savings (and potentially other revenue streams like grid services), but the *customer* captures those, absent an innovative business model, government incentive, or financing scheme. It is currently unclear to OEMs how much the customer will pay upfront to gain these life-cycle revenues and other unique attributes of xEVs. OEMs and consumers face a classic "split incentive": costs and benefits accrue to different parties, sub-optimizing a potentially profitable opportunity for all.

Furthermore, while automakers know electrification is a strategic imperative, this time of enormous competitive and market stress is inopportune for pursuing such sweeping change. Even if OEMs had the capital and head-count available (which a few do, but many critical ones do not), they do not yet see a compelling business case for mass-producing xEVs due to the split incentives: "We're going to have to lose money on these vehicles for a couple of years at least," one participant said.

How can we tackle the split incentives and thus help the automakers realize a compelling business case for the transition to Smart Garage?

One way is relieve the OEM of the biggest capital burden—the battery pack. As shown in Figure 5 (delineated as Option 1), the consumer buys or leases the battery from a separate entity, placing durability/warranty risk on the battery manufacturer or a third-party dealer (like Project Better Place). The battery cost could fall via smart financing or by capturing secondary market value upfront.

OEMs and suppliers need capital infusions, and few have the cash reserves to provide it internally. Therefore the "potential sources of capital" group, shown in Figure 5, is critical, including recently announced government-backed loans for retooling to xEVs. The group also discussed getting other players to invest capital in the vehicle-and-battery-making region, especially the connectors/charging places as a way to distributed operational benefits.

The vehicle discussion revealed the importance of predictable consumer demand (shown by "information" lines): to trigger appropriate levels of OEM investment, consumers must demand xEVs years before they hit the market (via marketing analyses, outreach campaigns, community activism, etc.).

Box 5: GM's "Moonshot" into xEVs

GM is building the Chevy Volt, an extended-range electric vehicle (a form of series hybrid). The company, which was hit very hard during the 2008 economic downturn, is spending hundreds of millions of dollars on the vehicle. Already dealing with significant cashflow issues, GM executives have been open about expecting to lose money on each Volt sold for at least the early years.

Why, then, is GM moving forward with the program with such ferocious intent to succeed? Vice chairman Bob Lutz in fact referred to the Volt as GM's "moonshot."

GM is making a bet that the program will pay off in the long run as the technologies mature and decrease in cost, and that Volt will establish GM as a leader in the xEV race.

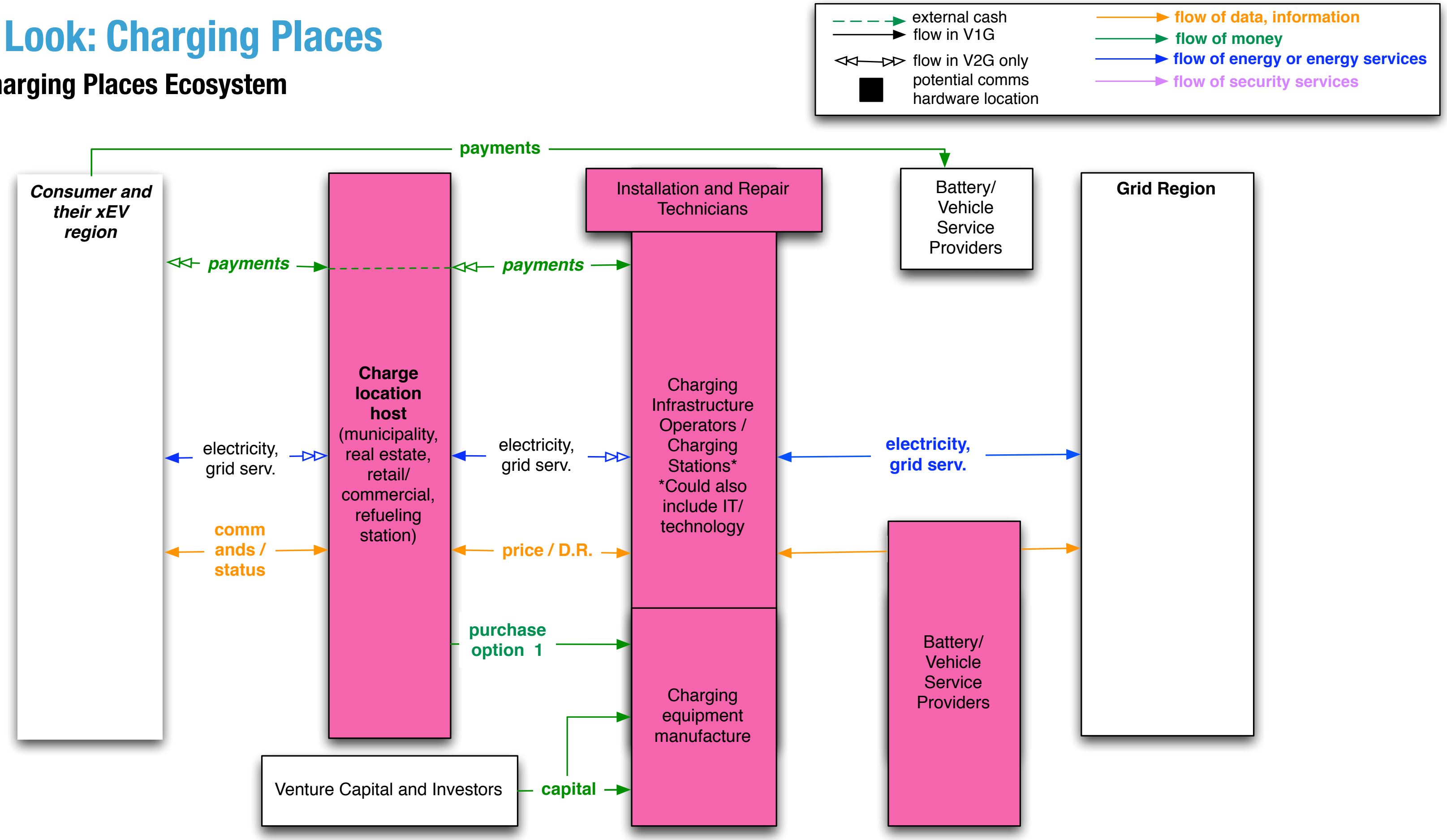
According to Lutz, "If we pull [the Volt] off successfully, it can really put us back at the top of the heap of automotive technology instead of being called laggards that are being left behind by the Germans and the Japanese."

A critical element in Smart Garage is getting xEVs to scale, and quickly. Clearly, it will be difficult for cash-strapped OEMs to scale an unprofitable vehicle with uncertain demand. The keys are making the vehicle profitable by tackling the split-incentive issue via incentives or new business models; securing predictable demand for the car so OEMs like GM can lower their risk of investment in an uncertain economic environment; and achieving a stable and attractive price-point.

Main Costs: the battery, R&D for new platforms.
Main revenues: sales of vehicles to consumers.
Strengths: Potential to pursue non-traditional business models (*e.g.*, Better Place); the opportunity to separate the risk and cost of the battery from the rest of the vehicle through valuing secondary markets (*e.g*,. stationary storage); the opportunity to gain brand and industry leadership.
Weaknesses: Bearing the biggest risk and upfront cost in the value chain, without a clear short-term win; OEMs, due to the power of their brands, will in practice be held responsible for potential quality and safety issues, even for components they don't directly manufacture or control (*e.g.*, batteries, charging stations).
Top two barriers: High upfront cost of producing xEVs, particularly battery packs; consumer adoption risk.

Deeper Look: Charging Places

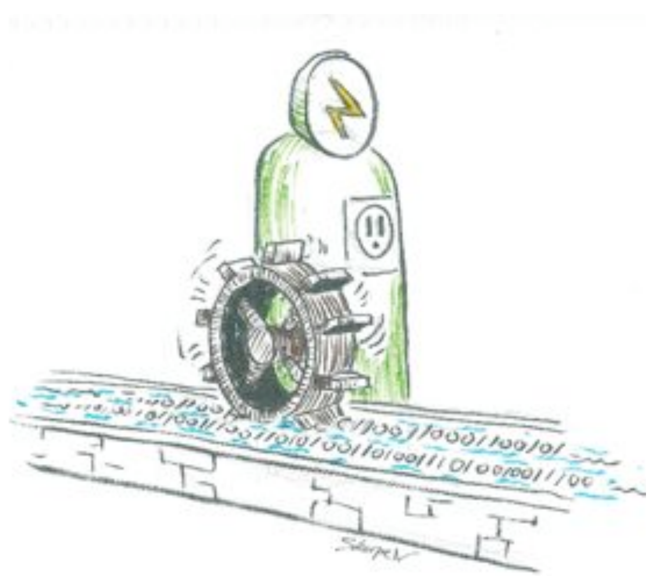
Figure 5: Charging Places Ecosystem



Charging places include homes, buildings, public charging spots on the street and in parking lots, and special charging stations—anywhere you would plug in an xEV. This stakeholder group also includes hardware and maintenance providers. Charging stations are seen as a key enabler for xEV consumer acceptance (though many participants noted that the *appearance* of charging spot availability for all could be achieved by strategically placed chargers). The balance between the risk of investing in charging spots and waiting for xEVs is challenging: "It's a chicken and egg thing. Is there infrastructure? Are there vehicles? Which comes first?," asked one participant with long experience in the xEV charging world.

The charging places group of the ecosystem overlaps considerably with the connectors, as shown in Figure 5 above. In fact, both groups decided that the most robust business model for these parts of the ecosystem might be a shared one—a firm that both manages the hardware and provides the services of the connectors. Each charging place has a host: the consumer if the charge spot is at home, or a retailer who wants to attract consumers, or an office seeking benefits to its employees, or a municipality who wants to provide a service, or a dedicated charging station (*e.g.*, a converted gas station). The host purchases the charge equipment hardware and necessary services from some combination of providers. Those providers also support the billing and information flow between the host and the utility/grid.

The presence of charging infrastructure also opens up the possibility of innovative new businesses that take advantage of the marketing, data, and location-based services, as shown by the "3rd party" box in Figure 5. "I felt like there was some fun dreaming going on in the charge station group," said one participant, reflecting on the impres-



Charging places can enable innovative new information and energy service-based businesses.

Box 6: Coulomb and Better Place Aim to Scale the Buildout of Charging Places

Coulomb Technologies and Better Place are startup companies that may help scale the buildout of charging places through their family of "smart charging" products and services, via distinct business models.

As one charrette participant said, "Any [charging] business model that relies [only] on digging trenches fails." Coulomb and Better Place have developed unique and robust models that go far beyond digging trenches in their attempts to build charging place networks.

Coulomb is taking an "ATM franchise"-like approach, developing charging hardware and offering it to municipalities like San Jose (and ultimately retailers) to buy and install. Leveraging its charging platforms, Coulomb will offer "connector" services in consumer service plans to demand-response aggregation for utilities to enhance its revenue and ultimately provide a broad charging network—just as today you can find an independent ATM almost anywhere.

Better Place is taking a "cellphone"-like approach, developing and investing in its own integrated system of charging hardware and connector services. Consumers will select a Better Place-compatible car (Renault-Nissan is the first OEM to sign up) and pay a monthly bill for a certain number of miles—just as they would buy a cellphone with a minutes plan. Better Place guarantees you these miles through its charging network and, when necessary, battery swap stations. Denmark, Israel, and Australia are the first countries signed on; regions of the U.S. could be following soon.

sive variety of ideas that came out of just a few hours' brainstorming.

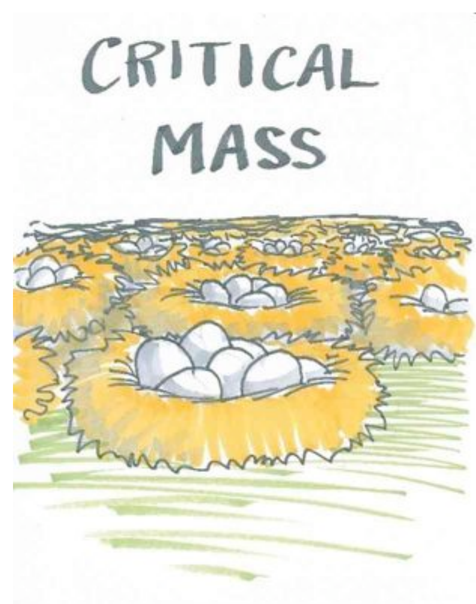
Costs: Capital for hardware and installation.

Revenues: Electricity fees, parking fees, utility avoided cost (if shared), potentially others from novel uses of the charge spot (advertising, attraction, etc.).

Strengths: With standards, lots of parties can set these up, and data collected could be highly valuable to a broad variety of parties. Convenience of charging could be more valuable than the electricity.

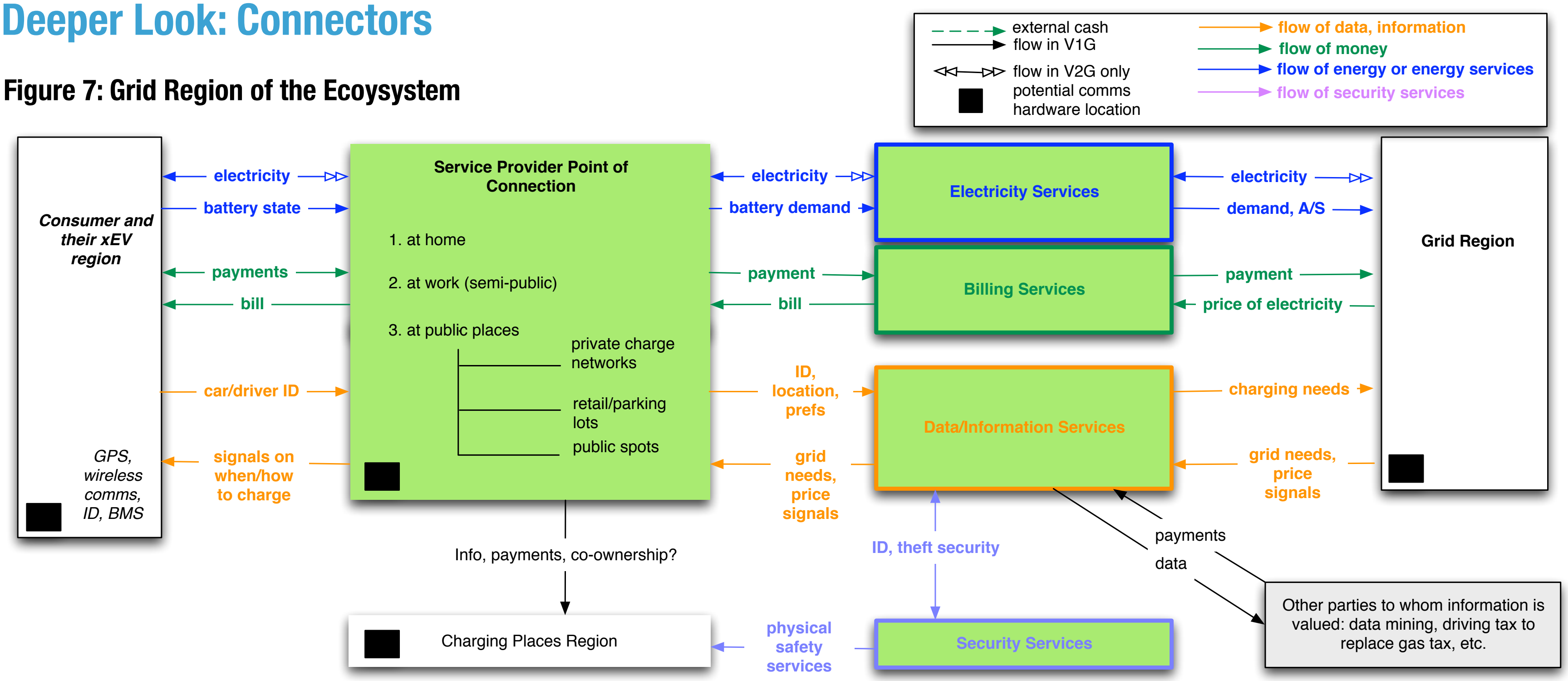
Weaknesses: A company installs charging devices and then sees the standards change will have stranded assets, akin to the inductive charge infrastructure installed in California in the 1990s, or to technologically obsolete cellphone networks. If the charging devices don't make money directly but enable others to get money or service, then who should pay to install them all? If there isn't Level 2 charging (or very efficient vehicles to make it unnecessary), value may be unrealizable.

Top two barriers: What is the business model for public charging infrastructure, and who will pay for it?; not knowing when/how many xEVs will come.



Deeper Look: Connectors

Figure 7: Grid Region of the Ecoysystem



The "connectors" group is the most nascent and least clearly defined, and has the widest and most innovative potential for new business models. It includes the IT, software, and data services necessary to make the Smart Garage ecosystem flow. The connectors and the charging places are interdependent portions of the ecosystem: the connectors can't provide their services without the physical connection, while the charging places can't get returns without the services the connectors provide. Many companies in the connectors region, such as V2Green/Gridpoint, Coulomb, and Better Place, serve both connector- and charging-place functions. The connectors region is also notably dependent on start-ups (as well as new innovation from existing businesses) partnering with larger companies. "I'd love to have a robust platform like that, that I've rate-based, that serves as my jumping board to be able to do these things. But we don't have the ability to develop anything like that. It's going to have to be [innovative start-ups]," said a participant from a large company.

As shown in Figure 7, the connectors will likely provide four types of services: electricity services (including grid services), billing services (non-trivial if vehicles charge in many different locations and utility regions), data/information services (including charge needs, user ID and preferences, price signals, etc.), and security services. Most of these services are mediated through some physical point of connection with the consumer. The consumer will probably have some form of contract with one or more connector company. Connector companies might have a direct relationship with the utility that could enable them to mediate between the consumer and the utility for more sophisticated energy services. Finally, much of the value to connectors could come through associations with third-party service companies that take advantage of the information created by this system (shown in gray box).

Another important outcome of the connectors discussion, also shown in Figure 7, is the dispersion of intelligence, as shown by the black boxes: "There's going to be intelligence at all different levels. It's really about what's the scope of smarts that's being managed at the car level, building, switch, grid....It's building on a system of systems," explained one participant. The connectors coordinate the smarts.

"When everyone wins [but only] a little bit, things go pretty slowly," one participant noted. Connectors are one group with the opportunity to win a lot, so those companies will be a key component of accelerating the Smart Garage.

Costs: Low if they don't include the physical infrastructure.

Revenues: Huge array, from billing services to electricity service to transaction commissions to novel uses of data for marketing, data mining, taxing, etc.

Strengths: Focus on the consumer and innovation, new jobs, in synch with customization information trends in many sectors. Huge opportunity for businesses to spring up in this region.

Weaknesses: May depend on charging place buildout with significant Level 2 capabilities, smart grid buildout, and some form of standards/regulatory uniformity. We are moving into "Big Brother" territory with some data-based businesses. May be expected to "pay for" capital expenses in other regions.

Top two barriers: Standards and standards-making processes; how to get the infrastructure installed/paid for.

Box 7: Gridpoint/V2Green Leverages Cross-System Collaboration

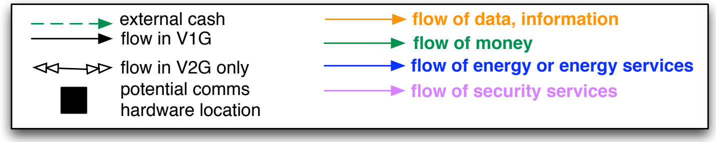
Gridpoint, a growing and leading provider of Smart Grid hardware and software for homes, recently acquired V2Green, a start-up and leader in software for V1G and V2G charge management for xEVs. These two companies exemplify the importance of start-ups and innovators in the connector space, and the overlap with smart grid.

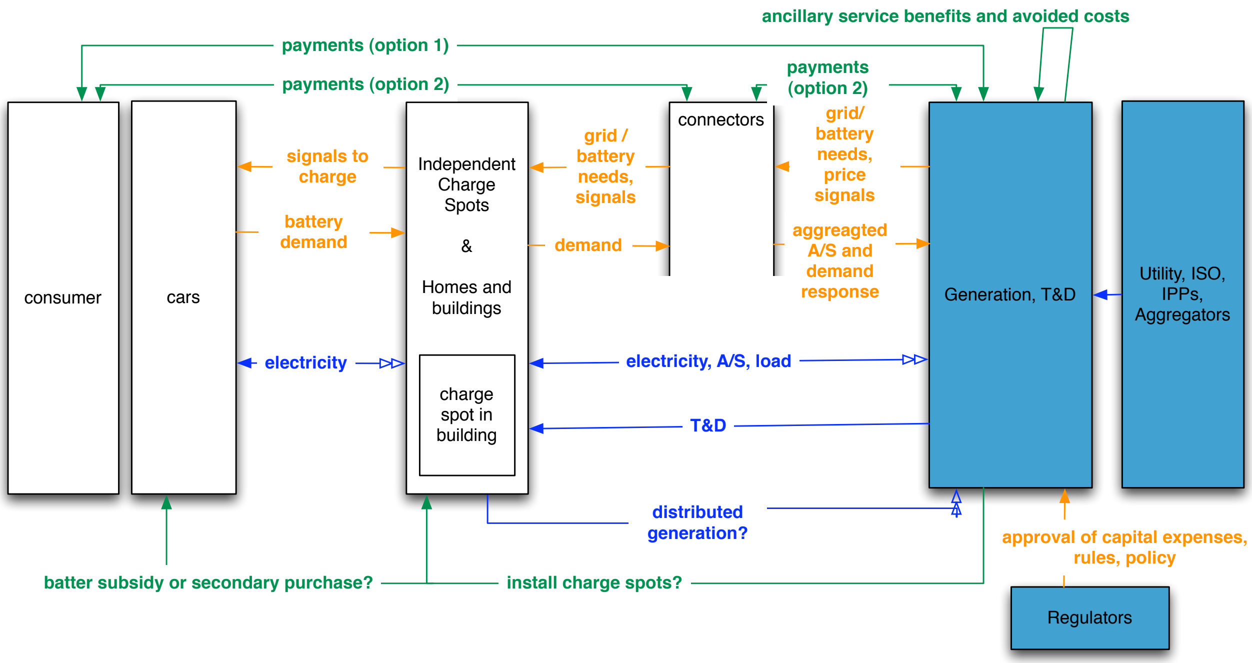
Charrette participants hypothesized that the ideal timing for "connectors" is to start with hardware investments, and provide hardware implementation upfront, and then reward that investment with the promise of long-term service-based income. V2Green/Gridpoint is using that model.

The merger also validates the hypothesis that Smart Garage is synergistic with other important trends, and that it can become a lever to accelerate important changes like the smart grid.

Deeper Look: Grid

Figure 8: Grid Region of the Ecosystem





The utilities, part of the grid group, probably have the most to gain from Smart Garage, after the start-up connectors.

The utility gets payments for electrical services, and Smart Garage brings utilities valuable savings: paying less for ancillary services (by buying them from the xEVs) and avoiding long- and short-term capital costs by smart-charging xEVs at off-peak times.

In return, the utility and grid operators must provide price signals. This requires some agreement on communications standards (in progress, but not finished) and interoperability between utilities. The grid region must continue to deliver consistent and reliable power with xEVs on-line and properly sort all the transactions involved with Smart Garage.

Because of the large potential benefits to utilities, many participants suggested that the utility support other portions of the value chain by paying for some or all of the battery and / or the charging infrastructure, as shown in Figure 8. On the battery question, utilities expressed mixed feelings (more in the battery barrier discussion), but were generally enthusiastic about installing charge spots. For both the battery and infrastructure investment, the utilities pointed out the crucial role played by regulators: for a capital investment, and a relatively unprecedented type of capital investment, utilities will need potentially hard-to-get regulatory permission to raise the funds.

Finally, this question arose: "Will the utility have to put in smart grid to smart charge xEVs?" Smart grid functions can be covered by more on-board (or on-plug) technology, but leveraging an existing smart grid would save costs and improve total grid system functionality.

The grid region's relationship to other groups is not fixed. As the grid group facilitator said, "They really had a hard time narrowing down to 'This is the value chain,' because there are so many options." For example, as shown in payment Options 1 and 2, the utility may either interface directly with the customer, or via intermediary connectors that manage more sophisticated services. The group concluded that acquiring a communication standard and regulatory consistency is more important than a fixed value chain.

Costs: Smart metering, smart grid and/or other infrastructure, transaction costs.
Revenues: Avoided costs, ancillary services benefits, increased sales.
Strengths: In a position for maximum financial benefit, can improve utilization of existing assets, system can facilitate bringing renewables on-line.
Weaknesses: "Roaming" could be challenging, capital is constrained, could be penalized for taking transport's greenhouse-gas allowances or reductions, don't know what information must flow from grid to car for V1G (or V2G), reliance on standards organization success, no history in managing small, distributed generation resources.
Top two barriers: Non-supportive and inconsistent regulatory construct, no communications/charge management protocols.

To utilities, xEVs are just another appliance to manage, albeit a uniquely large and dispatchable one.

Box 8: Duke Energy Exemplifies Utility Preparation for Smart Garage

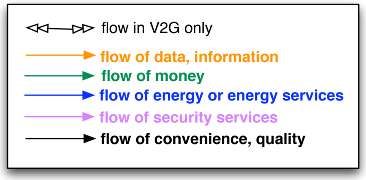
Duke Energy provides electricity services to customers in North Carolina, South Carolina, Indiana, Kentucky, and Ohio. Duke Energy is one of several leading utilities that exemplify the preparation needed to avoid the risks and capture the benefits of xEVs.

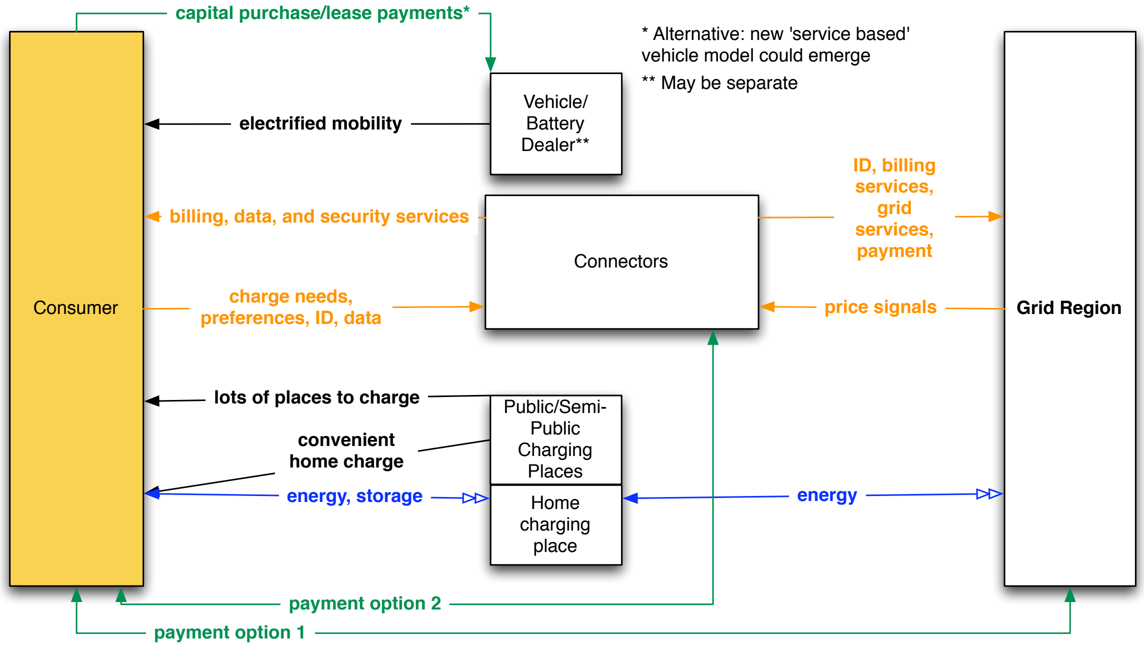
The company is leading the industry in developing an understanding of the potential impacts and value of plug-in electric vehicles on the electric utility system. Duke Energy has compiled a detailed database of its customer demographics and potential market adoption of plug-in electric vehicles. It uses this information, along with electricity demand profiles at the individual feeder level, to model potential impacts on distribution system reliability and investment.

Separately, it uses internal cost-to-serve data with collaboratively developed consulting tools to model the net value of location- and time-specific charging of plug-in vehicles at the individual feeder level. The executive team at Duke Energy views plug-in vehicles as the consummate smart appliance because of their combined capabilities of energy storage, mobility, communications, and other onboard intelligence.

Deeper Look: Consumer

Figure 9: Grid Region of the Ecosystem





Consumer pull could be the chicken that lays the egg in the Smart Garage ecosystem, and the consumer uniquely touches every other region. The consumer drives all value and all behavior. Uncertainty about consumer adoption of xEVs (*e.g.*, how, when, where, etc.) has been cited as a major barrier for all other regions of the ecosystem, and was voted the most important system-wide barrier by charrette participants. Finding ways to increase consumer demand, reducing costs for the consumer, and improving consumer experience are the aim of many of the solutions the group created and the source of value for many of the start-ups in the connector/charging place region.

Figure 9 highlights some of the new inputs and outputs that a consumer in Smart Garage will experience. First, as shown at the top of the graph, the consumer may purchase a vehicle in the traditional way, or she/he might purchase the vehicle and battery separately, or purchase "mobility services" in the form of leasing or car shares to mediate the high cost of the battery. In return, the consumer gets electrified (clean, quiet) mobility, which includes convenient home charging in addition to recharging options at work and about town. The consumer will also probably enter into a relationship with a new type of company, the "connector" or energy service provider, analogous to a cellphone provider.

Costs: Up-front cost of car (battery), home-charging equipment.
Revenues: Fuel savings, providing grid services, other data-based revenues (?), improved mobility/info services.
Strengths: All parties are working to reduce consumer costs, getting a more customized, active energy experience that works in tandem with values, target beneficiary for government incentives (financial and other).
Weaknesses: In the current vehicle–ownership model, the consumer is responsible for significant upfront costs for the battery and without good IT services and education, may be burdened with a more complex or confusing energy system.
Top two barriers: Upfront costs of the vehicle/battery/infrastructure, unclear consumer demand hampers rest of system.

Laying the Egg: xEV Early Adopters are Better than Soccer Fans

Volt-nation.com, an independent site started by Dr. Lyle Dennis, became an Internet phenomenon, drawing thousands of viewers into discussion about the Chevy Volt, and creating a "nation" of enthusiastic fans wanting to own a Volt.

The website created such extraordinary buzz that it caught the attention of GM, and Vice Chairman Bob Lutz thanked the Volt Nation for its "boundless enthusiasm" and the extra motivation it gave the Volt development team in Detroit.

Unfortunately, as the Volt nears production, GM felt that the expectations being set by Volt Nation were unrealistic and would hurt the car in the long run, so it shut the site down.

xEV enthusiasm continues across the web, from calcars.org and RechargeIT, which feature videos of almost every known plug-in conversion driving around town, to the months-long queue for hybrid-to-PHEV conversions, to the fans of the early EV-1s, who held vigils as their cars were taken off the road. Dedicated consumers have kept the xEV dream alive for over a decade, and are pushing it forward today. The trick is to transfer the enthusiasm of these passionate early adopters to the mainstream, and for industry—both big and small—to partner effectively with consumers to prove mass demand in a way that resonates with financiers and other decision-makers.

How can we cross this chasm? Early adopters play an essential role in being willing to pay higher premiums during the early years, helping to iron out snafus, and spreading awareness, desire, and knowledge about xEVs to their friends and the public at large. Studies have found that consumer desire for PHEVs is currently low, until survey respondents are educated about what PHEVs are—but then they all want one.

As one charrette participant said, "these are people who will go hungry for their cars."

Convening the Players at a Charrette

Because of the complexity of this ecosystem, and how success requires near unprecedented collaboration between players, from 8 to 10 October 2008 Rocky Mountain Institute held a "charrette" that brought together ~80 of the leading experts in the utilities, battery, meters, switches, automotive, regulatory, philanthropic, and business development sectors to explore Smart Garage. The event convened the broadest assortment of stakeholders yet assembled on this topic. The charrette explored system-wide barriers and solutions (and additional barriers) arising from collaboration across the ecosystem.

What is a charrette? A charrette is a very intensive, transdisciplinary, roundtable design workshop with an ambitious deliverable. Typically, in the early stages of the design process—conceptual and some early schematic design—it brings together stakeholders and experts for small- and large-group brainstorming, discussion, and convergence on synergistic solutions. In our experience this approach yields exceptionally rapid progress. By fostering creativity across boundaries, charrettes can reveal new solutions obscured by conventional thinking. Participants who might not ordinarily collaborate—even though they share a common interest in the outcome—exchange ideas and devise recommendations that can later be refined into specific designs or actions. RMI conducts about 25 charrettes a year in diverse industries, and has over a decade of experience in designing charrettes that achieve breakthroughs in innovation and implementation.

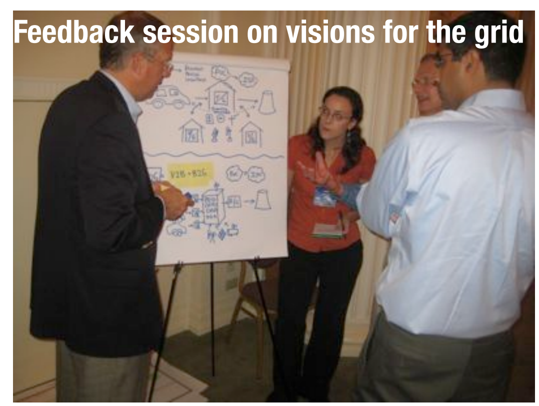
In other words, a charrette is a perfect medium for the challenges of Smart Garage.

The event alternated between three types of session:

- Plenary sessions, in which the participants discussed topics as a whole and voted on key issues (the results of these are throughout this report, and in Appendix B),


Plenary Session on value chains


Breakout group on charging


Feedback session on visions for the grid

- Breakout groups, in which participants were assigned to focus on answering a given question through the eyes of one specific piece of the ecosystem, and
- Feedback sessions, in which breakout groups presented their research to other breakout groups, discussed alignments and disagreements, and shared feedback.

The breakout groups are the heart of the charrette. While each breakout group was assigned to focus on one piece of the ecosystem (vehicles/batteries, grid, charging places, or connectors), the members of each group represented a cross- section of the value chain. For example, a "grid" group would have members from OEMs, IT providers, consumer products, etc. Each session had a dedicated RMI facilitator and scribe capturing audio, written minutes, and charts.

There were ten breakout sessions during the three-day event, and participants moved between focus groups. The ten sessions, combined with plenary and feedback sessions, were carefully designed to move participants from alignment on vision to barrier identification and solutions, as shown below.

Day	Outcome
Day 1	Immersion and Vision: Ground participants in consumer experience, work to find common threads in participants' short-to-mid term visions, then use these to clarify stakeholders' roles and needs under different money and resource flow scenarios.
Day 2	Identify and Bust Barriers: Test robustness of money/resource flows using a couple of extreme scena-rios. Use the insights gained to create a list of top barriers for each stakeholder. Brainstorm strategies to mitigate barriers. Brainstorm long-term visions and check that mitigation strategies align with it.
Day 3	Create 3–6 concrete project plans that tackle top barriers, build trust and buy-in among stakeholders, and elicit commitment to kicking off new projects.

As is always the way with charrettes, the RMI team adapted and changed the agenda as the event progressed, reacting to participants' requests and to topics that got hotter (or colder) than expected.

At the end of the event, the participants achieved the chief goal: 3–6 concrete project plans to help Smart Garage succeed. The worksheets generated throughout the event can be found in Appendix A. This report is a synthesized analysis of the output. The content from the sessions, the top barriers, and the top projects are all covered in the following section.

The format worked. "Everyone has been saying how smart the people in this room are. But that could be a proxy for the ability to see all those viewpoints in one place, at one time, in a concentrated manner," noted RMI's CEO Michael Potts.

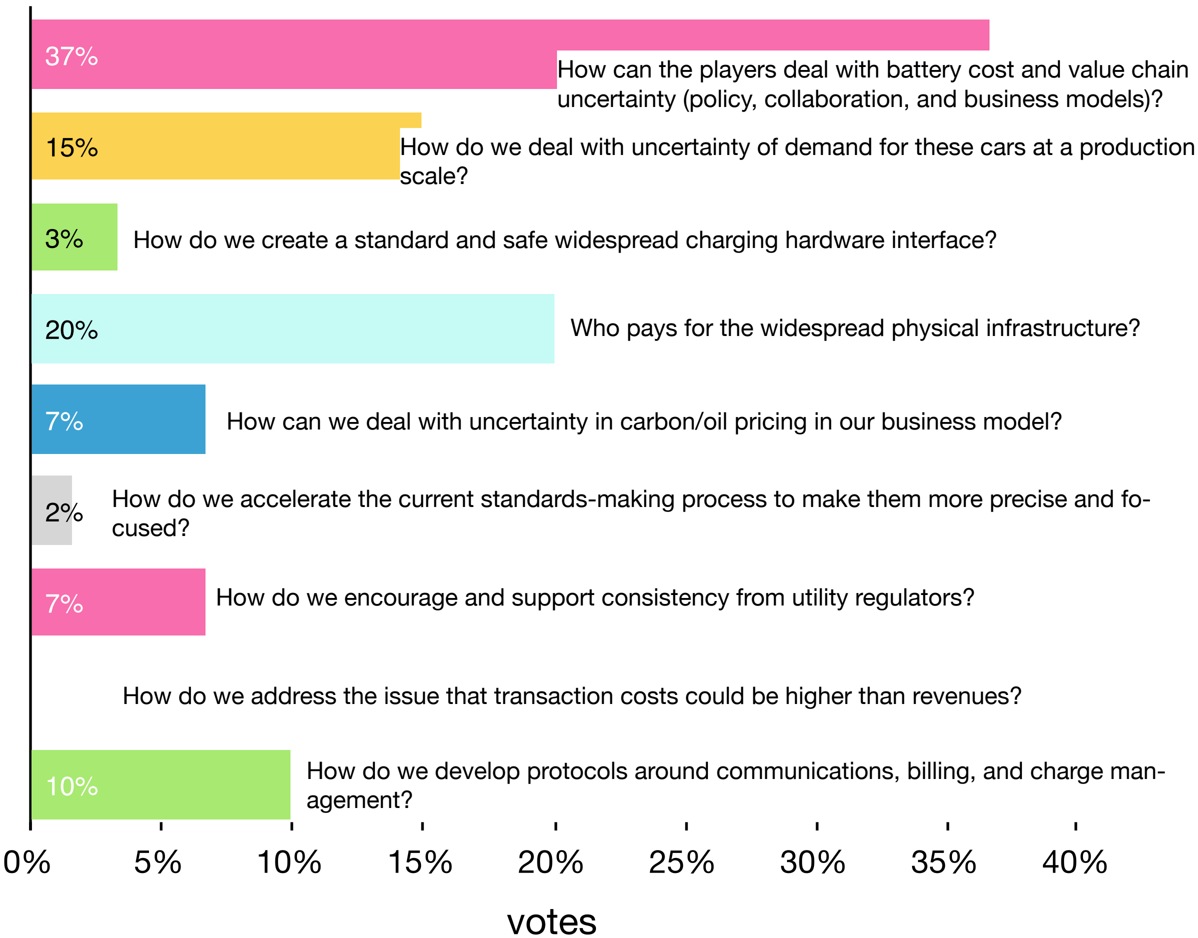
The other recurring theme from participants was how glad they were to have the opportunity to spend so long talking to each other, both in sessions and over meals: "There are a lot of smart people in this space that honestly I think should have been talking to each other more in the past and need to continue talking to each other in the future. I was struck by how little people knew about technology progression in other industries besides their own. If nothing else was accomplished in this charrette, I think it was key [that] smart market players have gotten much better appreciation of where other partners in the value chain really are today versus what they thought." Another participant noted, "The biggest benefit was to drive and interact with a variety of different parties that are players that you just wouldn't come into contact with in any other context. To see the vehicle makers and the battery makers and...those pieces of glue in between was very valuable and a great intensive experience to get a lot of those perspectives very quickly." A third agreed: "Everyone's coming from a very different perspective and has been working on this issue almost in isolation or without a whole lot of interaction from people outside their own sector or their own company....Being able to communicate across those different viewpoints and vantage points was extremely valuable."

An overheard moment between a grid-side participant, speaking for his vehicle-focused group in a feedback session perhaps says it all: "I'm presenting for the vehicle group, so I'm out of my comfort zone here, demonstrating role model behavior for the coming convergence of these two industries."

Chapter 3: How do we get there?

What could keep us from getting to the Smart Garage vision of the seamless integration of cars, the grid, and buildings? Surprisingly, the chief roadblocks are not technological in nature. The charrette revealed that most of the cornerstone technologies in Smart Garage—lithium-ion batteries, smart metering, wireless communications, charging hardware, etc.—are mature enough to be implemented for V1G. Instead, the barriers center on accelerating consumer adoption, coordinating implementation, applying existing technologies (like communications) to fit within the system, and designing this system carefully so that all stakeholders are incentivized and actively engaged.

Figure 10: Results of participant "top barrier" vote



Most of the barriers underline the need for collaboration across the value chain, and others emerge from the difficulties inherent in such collaboration. During the course of RMI's research, literally hundreds of barriers emerged. However, as discussions at the charrette progressed, a handful rose to the surface as the most critical, new ones were discovered, and some were identified as mostly solved. Convening on a short-list of the most critical barriers is one of the most valuable charrette outcomes. The rest of this chapter is dedicated to an in-depth discussion of the most critical barriers, as voted upon by the participants (Figure 10). Next, Figure 11 goes into more depth on the debate surrounding each of these and other critical barriers.

RMI and many participants were surprised at the results of this winnowing process. As one participant noted, “Some of the early grappling for where can we get a toehold to define a [barrier] and narrow it was a little frustrating...but I think like anything, you just need to have some patience with that and trust in the process....I was amazed at how well it was condensed and presented at the end.”

Another noted, “The charrette process was new for me...I didn't know what a charrette was before this week….It did seem like by the end of the process we arrived at the objective we were trying to get to, which, considering the number of participants and the broad skill sets involved and experience levels behind them, maybe is a minor miracle. So it appears to work.”

Barriers that didn’t make the top cut are listed in the Hot Topics section of the pre-read and the Appendix G: Barriers (both download-able at move.rmi.org/smartgarage).

A potential unintended consequence of Smart Garage

Figure 11: Top barriers

Top Barriers	Perspectives
A) Uncertain consumer demand hampers ability to start building xEVs in significant volumes	• **Consumer: "**This is all so new, how do I know this technology will work as promised, and what is best for me in the future? How do I know I'm not going to be inconvenienced and spend too much money?" • **OEMs:** "We've been burned on new technology before. When issues emerge behind the scenes, like with our suppliers, it's our brand image and stock that take the hit. Current success stories of Teslas don't really convince us that we can translate it into our business model, which produces at *much* higher volumes and lower costs across multiple product platforms." • **Charging entrepreneurs:** "We need to know when, where, and how many xEVs are coming, and how to work with their specifications." • **Utilities:** "We know that adoption of xEVs can affect our service costs and reliability. Not sure what we can do proactively—either because of lack of information and/or lack of funds to invest in preemptive measures (if we even knew what those might be)." • **xEV advocates:** "We believe xEVs will become popular when consumers get a chance to drive them so the OEMs have to start making the cars! There certainly is a lot of consumer education needed, which would help create demand. There are things that we can do to assist this."
B) High battery costs/ uncertainty for key parameters	• **Battery Manufacturing: "**Battery costs will come down over time, when we get to scale and high volumes." • **OEMs:** "We're looking for the financial instrument that will bring the long-life value of the battery upstream, offsetting the initial cost of xEVs to the customer. In addition to financial risks, the battery industry is not proven or well-established for packs of this size and scale. Who has to carry the risks of meeting production schedules and delivering on warranties in the field? At this point, it's us." • **Utilities:** "Everyone thinks we'll benefit most from owning/using high volumes of distributed batteries or using them end-of-life as stationary storage. While this might become the case, we're not interested in carrying assets of uncertain performance and value on our books, especially when you propose that these assets can't be utilized immediately. There is no clear way of recouping initial costs through our current rate-based revenue model, which is highly regulated. What really is the full battery value proposition for us?"
C) Who will pay for the charging infrastructure?	• **Consumer: "**I am already paying for a more expensive car and now you tell me there is a $1,000 extra fee to charge at home? I don't like it." • **Utilities:** "We might be able to pay for this (which would allow us more control) if we can rate-base it, but that's uncertain." • **Connector start-ups: "**If people will install the hardware for the charging spot, I can begin to get value from the services I provide. Is it worth enough for me to put in the infrastructure myself?" • **Municipalities/Retailers: "**A public charging spot could be a good attraction for my citizens/customers. But what will it cost me?"
D) How do we support consistency in utility regulation?	• **OEMs**:"We need to interface with 3,000+ retail utilities in the country that are regulated at either the state or local levels. Each state and community will have its own set of regulations, understanding, and openness to xEVs. That's overwhelming!" • **Utilities**: "We each are at different stages of understanding with xEVs and will approach business models differently, if left unchecked." • **Regulators**: "We want to see evidence that V1G or V2G will have benefits to electric customers before we allow utilities to implement any infrastructure investments, particularly in new and different business models such as vehicle battery ownership."
E) Communications, billing, and charge management services/ structures don't exist	• **Consumer:** "I may not want be a part of this system if my xEV can work with one proprietary charging network, or only with my home utility." • **Bigger institutional players:** "There are standards-making groups already on this, let their process work." • **Connector start-ups: "**Waiting for these standards is just wasted time, and we can't get started without some agreement because it puts our future at risk. How do we know the standard organization will get the right balance of strict and fluid to allow innovation?" • **Some IT/SW/HW players: "**A major player or consortium of players could push a de-facto standard that is geared towards enabling entrepreneurship and working fast." • **Utilities:** "We need to have a basic set of information about each xEV, and know as soon as possible what that set is going to look like."

Why it matters (matches rows from previous page)	What was said at the Charrette
This chicken-and-egg relationship between the OEMs and consumers could hinder the growth of the system.	While consumer demand for a novel product is very hard to predict several years out, the participants felt that proving demand is critical to the chicken-and-egg conundrum. Adventurous and innovative ways to prove demand should get underway.
Battery packs are the most expensive piece in the Smart Garage system, and make xEVs more expensive in upfront costs than ICEs.	Batteries will get to or below ~$550/kWh pack-level in the near term, which is helpful but still too expensive. Some experts expect ~$400/kWh in a couple of years. Most groups agreed that exploring ownership models with the battery seen as a separate asset from the vehicle (*e.g.*, the battery as a consumable) is a promising way to explore financing and other innovative ways of reducing the upfront cost burden on OEMs or buyers. Many concerns were voiced about the investment needed to scale up battery-manufacturing infrastructure.
A paid-for infrastructure can bring down costs for consumers and potentially accelerate adoption. Infrastructure (especially Level 2) is a key enabler for many of the connectors' business models.	Socializing the costs is appealing, but depends on locality-by-locality policy which will be slow and erratic. The mandate to find ways to get the infrastructure to "pay back" directly or as a loss-leader opens up many new and intriguing business opportunities connected to the information and services of Smart Garage.
Lack of uniform regulatory policies or a coherent policy framework could delay achieving the full Smart Garage vision, including smart charging and vehicle-to-grid, providing ancillary services and firming renewable generation.	There may come a point where utilities will have to install or update their grid infrastructure. Indeed, updates are continuously conducted anyhow. The regulators will make utilities prove the business case for any acceleration or elaboration of normal upgrade/renewal practice and show the value for electric customers. This will be difficult because such new business models as battery ownership or V2B are a whole new realm for regulators. And this will happen state by state, with different PUCs possibly favoring different flavors of infrastructure and funding models. National standards for regulation would be nearly unprecedented in this industry, but xEVs might offer a lever that finally enables that step.
Without some form of standard, it will be hard for a vehicle to travel region to region, and will hamper many of the entrepreneurship opportunities. The lack of standards could lead to separate, proprietary systems.	We should support the ongoing standards-making bodies. It's important to influence standards in the direction of welcoming entrepreneurship and openness. Also, a "de facto" standard or certification created by a leading technology or certification group could fill this gap, à la WiMax or BluRay. A wide range of knowledge and awareness about the progress and intent of the standards-making institutions existed at the charrette. Many but not all experts agreed that ongoing institutional work is pretty good, and the best way to support it is to get informed and involved.

Barrier

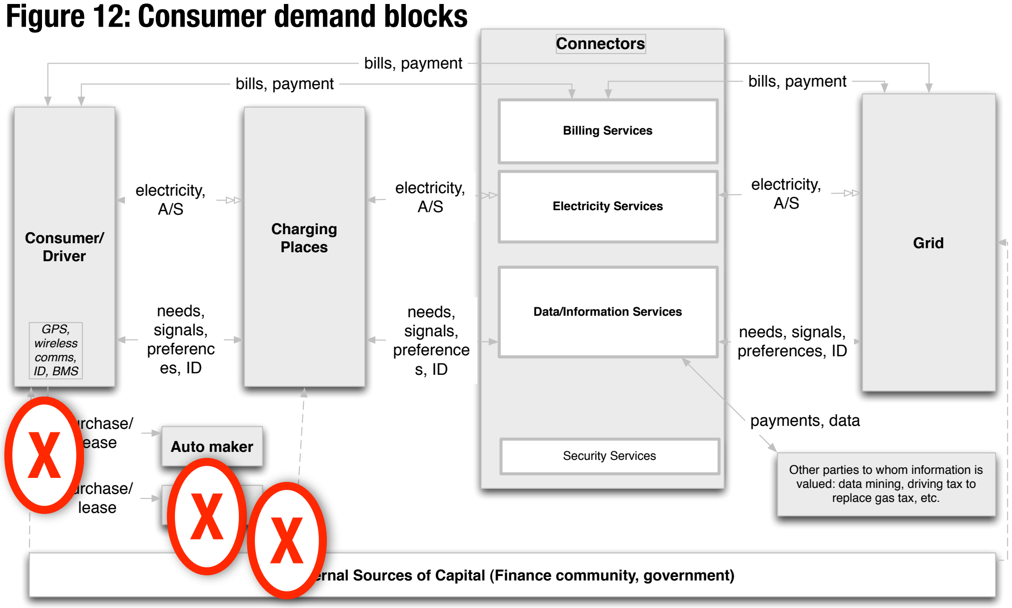
Barrier A: How do we predict mainstream consumer demand for xEVs?

The question of consumer demand generated some of the most heated debate at the charrette. The uncertainty of consumer demand makes it difficult for OEMs to commit to xEVs in significant numbers in the near term. This uncertainty, in turn, affects the charging infrastructure buildout, then this lack of convenient infrastructure creates uncertainty in consumer demand, and so on.

Consumers can be the chicken that lays the egg: that instigates OEM production and infrastructure build out. But how to prove it exists?

The participants agreed that for mainstream consumers to flock to xEVs, basic economic and mobility value propositions have to be satisfied, and the cars have to be safe and reliable. Yet what is hard to quantify is the emotional decision inherent in purchasing a vehicle, particularly for products as novel as xEVs. With uncertainty in costs (in particular the cost of oil and hence saved fuel) and at-times irra-

Figure 12: Consumer demand blocks



What it blocks:

There's very little traditional data to help forecast consumer demand for xEVs, which makes it difficult for the OEMs to convince their management and stockholders to invest significantly in xEVs.

Most consumers don't know that this technology is coming, much less what if will offer them. Without education and preparation, forecasting will be impossible.

Upfront capital (for OEMs and charge infrastructure) is large and risky if not consumer adoption is assured.

Barrier

tional consumer preferences, no fact base exists that can confidently predict a large demand for xEVs in the near term. Moreover, xEVs are an entirely new category of vehicle, so market projections drawing from historical trends aren't applicable.

With the recent spikes in the price of oil, OEMs acknowledge they must have xEVs in the pipeline to prepare for future volatility, but as of October 2008, no OEM (big or small, established or startup) has committed to producing xEVs in significant volumes (hundreds of thousands per year). And, faced with significant cash and operational constraints, OEMs are understandably hesitant to make huge bets on such uncertain terrain.

Solutions For the OEMs to feel like mainstream consumer demand for xEVs is "proven," several things have to happen:

1. Consumers have to hear the story of xEVs/Smart Garage, how this technology will significantly benefit them, and that many of the supporting elements (charging infrastructure, servicing, billing, etc.) are being implemented nearby;
2. That story has to sound good enough to consumers to show a commitment to buy (*e.g.*, purchase an option); and
3. The commitments have to be at volumes significant enough (hundreds of thousands to millions) to merit mass production.
4. Concerns from the consumer perspective—reliability, hesitance to adopt new and unfamiliar technology, and long-term commitment to this new technology by the manufacturers—need to be addressed head-on with incentives. Also, education is necessary to help consumers see the value, empowerment, and fun that Smart Garage can bring them (but making those expectations accurate), is a challenge since, according to one study, 69 percent of Americans reported low or no familiarity with PHEVs.[4]

Predicting and validating xEV demand requires clear vision on the goals, understanding and analyzing users in an innovative ways, proactive education and awareness programs, and a method to effectively quantify—and possibly monetize—the customers to justify significant investments.

Strategy: Incentivize and "trick-out" xEVs to make a better-than-ICE consumer experience.

Strategy: Create consumer education and awareness programs.

Strategy: Help quantify the demand, the potential and the main customer experience points that are essential to get right.

Strategy: Establish (commercial fleet?) demo projects that will educate consumers and cities, as well as provide learnings about how best to scale.

Related Charrette Project: Chocolate Box , Charge Baby Charge

Solution

Axsen, Jonn and Kenneth S. Kurani (2008) The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-22

Barrier

How do we overcome high upfront costs of the xEV vehicles to the consumer?

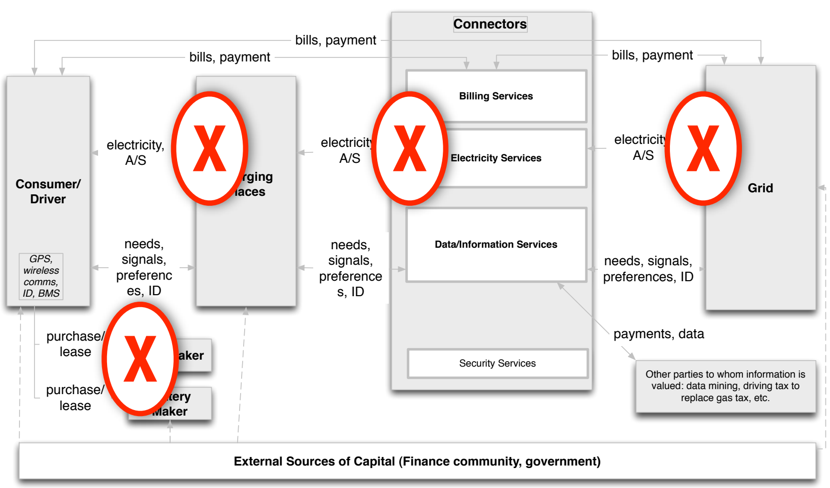
Barrier B: High battery costs and uncertainty about performance at scale

Battery costs and uncertainty about the longevity and safety of production packs are barriers to the mass production, cost, and hence wide adoption of xEVs.

With roughly 250 million passenger vehicles registered in the U.S., a meaningful penetration of xEVs means that millions will have to be produced in the next decade—and with them millions of battery packs. Even at a likely pack cost in the near term of $550/kWh (see Figure 14), the upfront cost of xEVs that will have packs from 5 kWh (*e.g.*, a PHEV conversion) to 50+ kWh (*e.g.*, a Tesla) will be significant. As well, most OEMs will have tested their xEV battery packs for less than three years, but consumers could expect them to last ten years or more.

Performance barriers: While lithium-ion chemistries were considered ready for xEV applications, charrette participants felt that performance barriers could emerge when batteries are scaled. These barriers include warranty and durability concerns, actual and perceived safety, and functioning under real-world conditions, such as extreme temperatures and "hacked" or designed V2G. Also, ramping up produc-

Figure 13: Battery blocks



What it blocks:

- OEM scaling: to make batteries at scale, new investment will be needed now in manufacturing facilities and training employees. Without batteries at scale, no xEVs at scale.
- The batteries are the reason xEVs will cost more, and hence be less attractive to consumers.

Barrier

tion capability, while feasible, is expensive (several hundred million dollars per battery pack plant) and, given the lead time for ramp-up, requires commitment soon.

Cost barriers: Quite simply, lithium-ion batteries are expensive. A typical xEV should be able to go 4–5 miles per kWh; at $550/kWh, that implies ~$110–140 of battery cost per mile of range. And to make sure to mitigate the performance barriers mentioned above, OEMs and their battery suppliers can't make quality or tolerance-related cost cuts. Because OEMs have to keep total vehicle costs down as consumers in the mass market are price-sensitive, even a 40-mile electric range PHEV poses a cost and price challenge to automakers.

Solutions The group focused on how to recognize the battery's full life-cycle value in avoided gasoline, and monetized it.

Potential solutions included the consideration of secondary "end-of-vehicle-life" markets, and various approaches to separating battery and vehicle ownership.

For secondary markets, the question is whether the size and value of the secondary markets can justify the costs of removing the packs and appropriating them for new uses, such as stationary power. The understanding and valuation of secondary markets is rudimentary and requires further study. If the market proved valuable, interesting opportunities could include purposely designing xEV packs for a shortened in-vehicle application (say, three years, when the vehicle owner would replace the battery), with the intention of redeploying them for stationary applications.

Strategy: Reduce the impact of battery costs and performance uncertainty by **considering secondary market business models,** including specifying batteries for a 3-year primary life on the vehicle for later secondary use

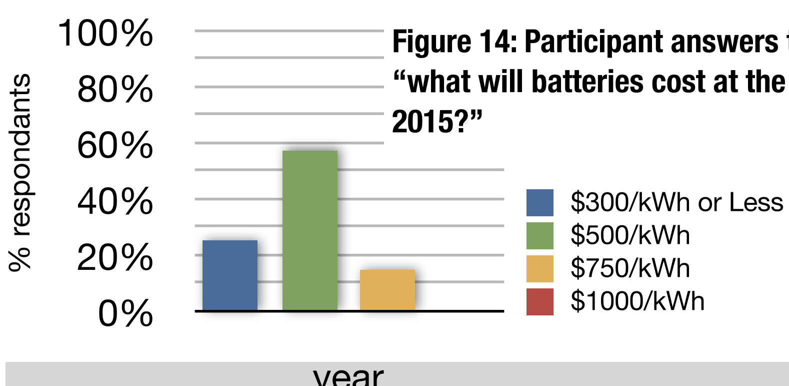


Figure 14: Participant answers to the question: "what will batteries cost at the pack level in 2015?"

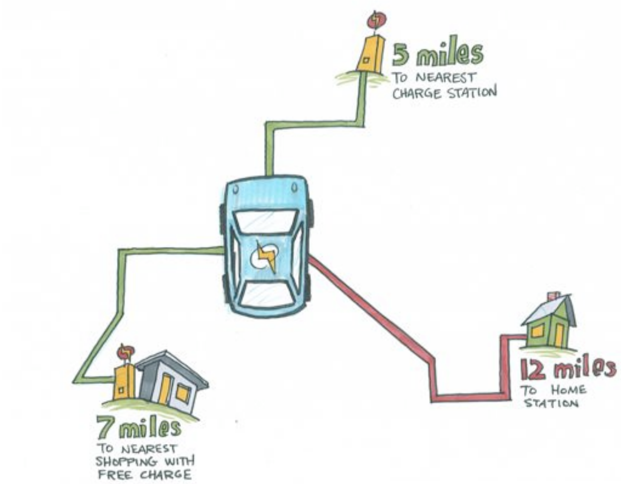
Strategy: Utilize feebates and/or government incentives to "kick-start" the initial vehicle purchases on consumer side.

Strategy: Right-size the batteries for the application. Whether through platform efficiencies or through making the range and feature set "good enough," design change and decisions can also reduce battery cost for the vehicles.

Related Charrette Project: Project Second Life

Solution

Barrier



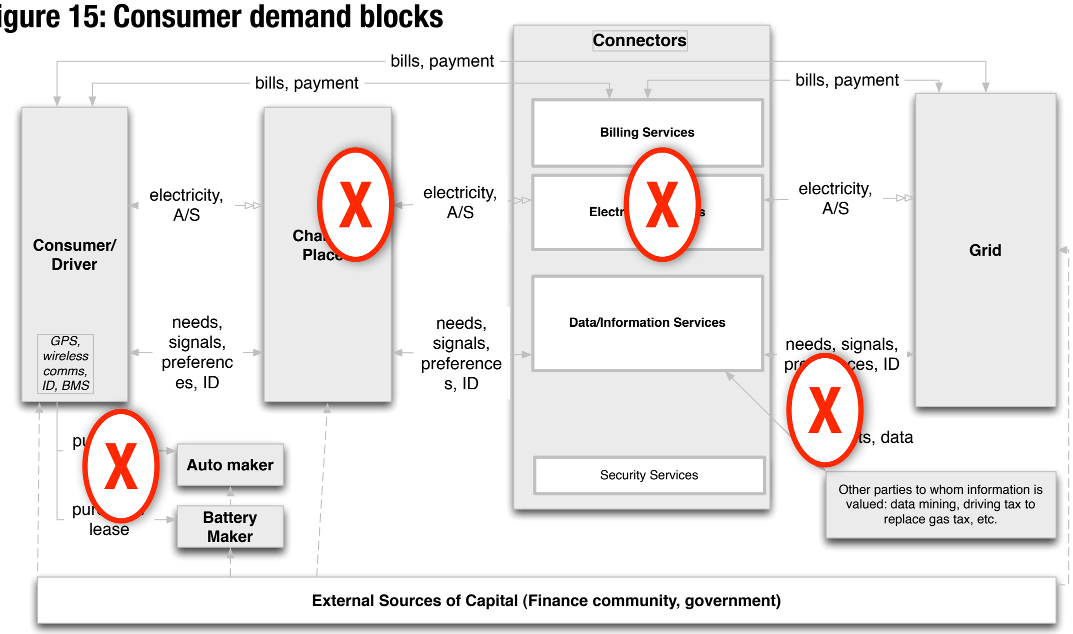
We agree that infrastructure is important for consumer adoption, but who should pay? Government? OEMs? Citizens? Entrepreneurs? Utilities?

Barrier C: Who will pay for the public and home charging infrastructure?

Most participants agreed that the expense of charging infrastructure (both in homes/offices and public infrastructure) could be a large and potentially risky upfront capital investment with a very long payback period, or even no payback, if its profits come solely from selling electricity. At the same time, building a comprehensive charging infrastructure soon can accelerate consumer adoption and enable profitable "connector" businesses.

Who should pay for the infrastructure and start building it? Currently, it's unclear: utilities could see it as part of their electricity service offerings, governments could see it as public infrastructure, businesses could see it as an investment, or consumers could see it as part of the cost of owning an xEV. Said one participant, "We spent a lot of time talking

Figure 15: Consumer demand blocks



What it blocks:

- Those whose businesses are based on providing services to Smart Garage via charging (connectors);
- Consumer adoption if consumers need assurance that charging will be available, and home stations not burdensome.

Barrier

about public infrastructure and about who is the appropriate party to take on the risk...The issue really became where do we see operations evolving. It wasn't clear to us whether this should be private or public risk. It will probably be more of a combination." Lags in installing infrastructure can in turn slow consumer adoption, which will, in turn, discourage more infrastructure build-out, into another chicken-and-egg problem.

The charrette participants discussed reasons for this difficult ROI: the electricity itself may cost about a dime per kilowatt-hour,[5] making payback to the charge station provider extremely slow. In fact, the electricity, the nominal purpose of the charging station, may be the smallest financial driver for building the charge stations. More likely, the value of potential revenue streams, like preferred parking, grid services, or advertising, will dwarf the value derived from electricity sales. But the business models for these non-electricity services are not yet widely understood. Finally, standards have not yet been set (though are underway) on communications, slowing build-out because of fear of stranded assets that don't conform to eventual standards.

With no clear funding candidate, and a difficult ROI based purely on electricity sales, infrastructure build-out may not move forward at the pace needed to assure consumers convenient charging options.

Solutions The group created three strategies for success, outlined at left. None are mutually exclusive and all could begin at once. We expect the eventual national solution will be a mix of public and private funding for the infrastructure. It's compelling to consider charging infrastructure purely a public responsibility, as it affords many opportunities for "green collar" jobs and helps with national security and climate issues. However, the participants felt that relying predominantly on public funding or a heavily regulated scheme would be misguided, as the private sector,

Strategy one: strategic placement for consumer confidence The *appearance* of widespread stations can be achieved through carefully placed and advertised spots, limiting initial investments.

Strategy two: use public funds, emphasizing the public good Cities/states/federal government could pay for public (and potentially home) charging. Or regulators could allow utilities to rate-base the cost of infrastructure, and install it.

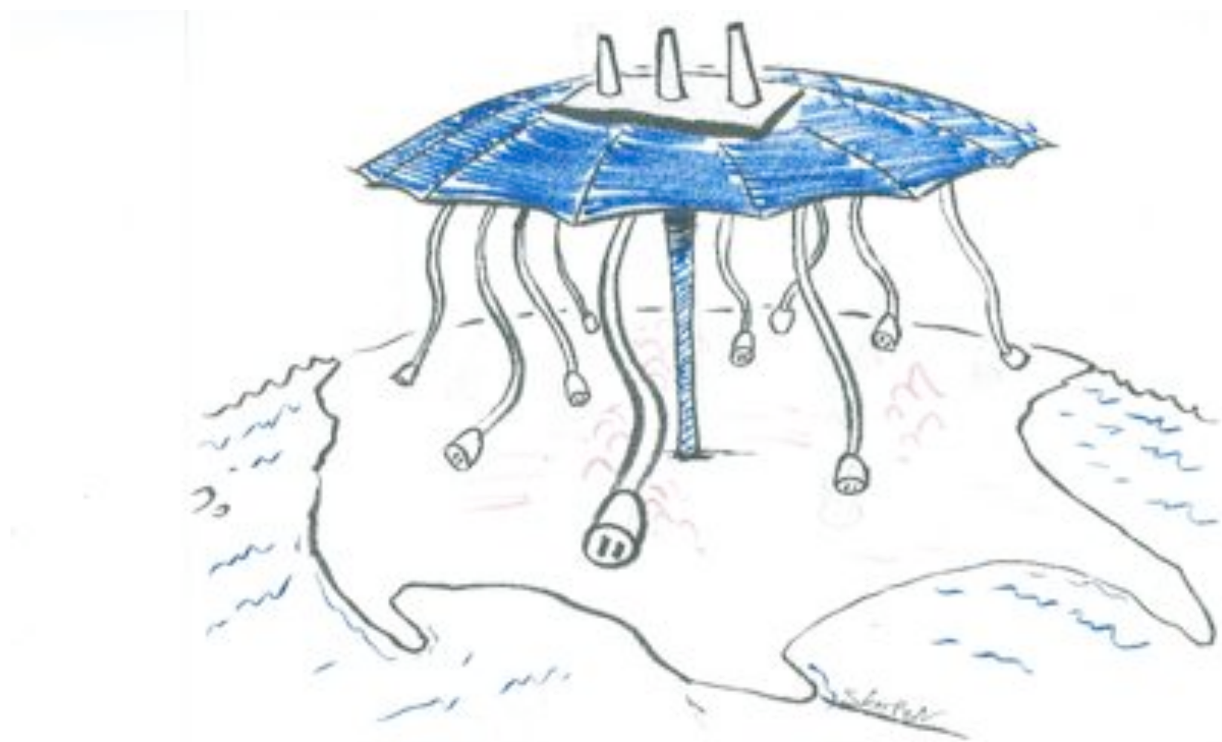
Strategy three: develop innovative business cases around the charging station Innovative models include the value for retailers of getting early-adopter consumers in your parking lot, data mining, customized advertising, grid services, etc. Invest as a loss-leader, in the same way that gas stations make most of their profits off snacks, not gas.

Related Charrette Project: Project Get Started, Charge Baby Charge

Solution

[5] Adding a significant margin on the electricity will probably be limited in the U.S. at least, considering the economics of xEV versus ICE fueling per mile.

properly incentivized, can likely scale the infrastructure faster and foster more innovation. Moreover, public funding—in vogue in late 2008 with recent trends in government support of the banking, automotive, and housing sectors—could ultimately be compromised if the political climate changes. Figuring out the innovative business models and incentives that will show a strong financial return is essential to ensuring that the infrastructure gets built, lest its scarcity block consumer adoption.



Barrier

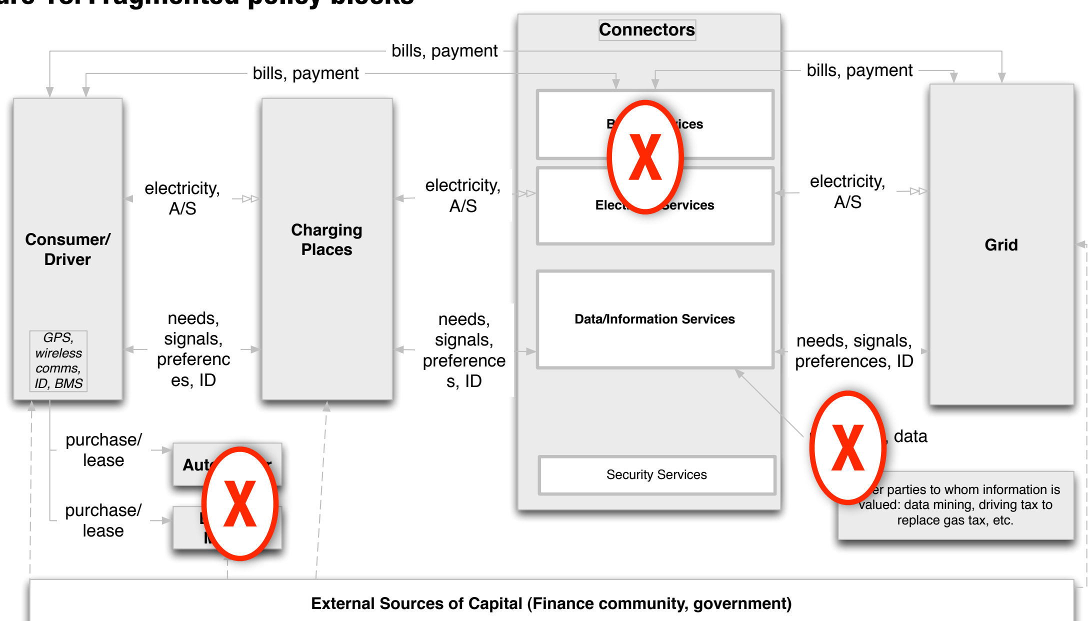
For utilities, the difficulties of dealing with their individual policy constraints are compounded by the diverse array of policies across the nation.

Barrier D: Fragmented and disparate policy causes a problem for utilities

"Smart Garage [and xEVs are] going to highlight the fragmentation of the utility industry," said one charrette participant. The lack of uniform and consistent laws and rules between state PUCs, between other agencies at all levels, and at the federal level is a major policy barrier to Smart Garage—at least in the U.S., and notably not in some other places with single or dominant, even state-owned, utilities.

Participants were very vocal about the need for regulatory consistency across the states. "I would have a hard time seeing an automaker saying, 'Yeah, we'll put the meter in the car,' and then Texas utility regulators saying, 'No, that won't do,'" said one participant, "It's very important to have uniformity on the regulation side, educate regulators about it, and push a uniform standard across state

Figure 16: Fragmented policy blocks



What it blocks:

- If OEMs need to design their xEVs to interface separately with each of the 3000+ retail utilities in the country about metering, billing, and other hardware and communication issues with their cars, they will be hesitant about scaling up their production plans
- Customers will want a seamless experience in their charging and billing, just as gas stations today are the same, state to state

Barrier

regulatory commissions, at least in the beginning." "Common standards and regulations act as an 'anchor'," said another. Otherwise, states could individually "start doing things and you need a common standard to steer them back."

Further thought quickly reveals an onion of complexity for regulatory reformers, *e.g.*:

- Air-quality regulators may need to adapt emissions-control rules to accommodate the unexpected dynamics of a system that controls vehicles' grid interactions according to real-time electricity prices;
- GHG emissions legislation and near-term increase in GHG emissions in the utility sector (even though xEVs result in reductions in GHG emissions system-wide); and
- Instead of having just two flavors of air-quality rules for cars (California and "The Rest") plus one national fuel-efficiency rule (and perhaps two or more carbon-intensity rules), these could all be overlaid by ~50 PUC-created state variants as electricity becomes, in effect, a "new fuel" for cars.

Solutions The group identified and discussed three approaches to this challenge:

- Impose top-down preemptive federal legislation (as FERC and NERC have lately been doing);
- Encourage bottom-up voluntary efforts to develop uniform policies, analogous to the IEEE 1547 islandable-distributed-generation consensus standard; and
- Embedding advanced metering capabilities in the vehicle that is compatible with a host of fragmented regulations. However, this would shift additional significant burdens to OEMs (already a stakeholder group that faces significant and unique barriers) and standards-making bodies, or possibly connectors—none of which will likely be at the scale to effectively deal with thousands of utilities.

After analyzing the merits and drawbacks of each, the group decided on the voluntary approach via the development of a broad-based industry alliance (strategy two). Top-down policy would be significantly difficult to pass and implement in a timely manner.

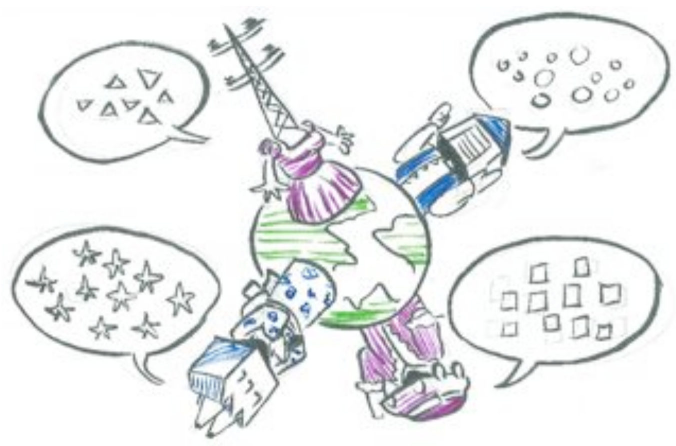
Strategy one: Top-Down, Federal regulation that supersedes authority of the state PUCs. PUCs become a lobbyist rather than a decision maker.

Strategy two: Bottom-Up, voluntary action of a broad-based and powerful alliance to push a uniform policy framework and guidelines at the Federal level.

Solution

Related Charrette Project: National Policy Project

Barrier



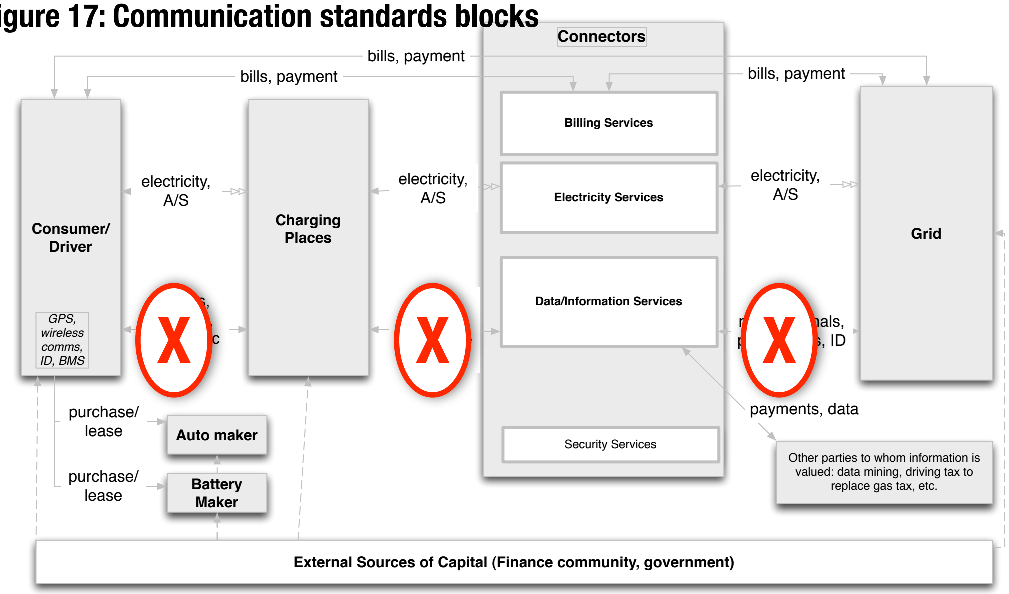
Does a successful smart garage require national communication standards? If so, how can we get adequate standards in a timely manner?

Hurdle E: Making Good on the Promise of the Communications Standards Progress

A standard for communication between parties in the Smart Garage was widely recognized as an absolutely critical enabler for success (V1G). Some debate emerged about whether such a standard was underway in the traditional standards-making bodies (it is), and, if so, whether that work included the right perspectives and considerations to make it effective. This debate was one of the "hottest" at the charrette, so we felt it would be valuable to spend a few pages compiling information about that process.

We feel that the scope and progress of the standards-making organizations is impressive and in the right direction. The hurdle (not quite a barrier) that remains is making sure that all parties are informed about the process, and that the work delivers on the heavy task of designing a standard that enables Smart Garage success.

Figure 17: Communication standards blocks



What it blocks:

- Entrepreneurs are waiting for a standard to launch their platform;
- If companies move forward without a standard, they risk being left with stranded assets if they make the wrong bet; and,
- If we don't have a standard, we could end up with incompatible systems, hurting scalability and consumer experience.

Charrette discussion: key standard attributes

The participants struggled with the balance between flexibility and rigidity: too flexible a standard could still lead to incompatible system elements, while too rigid a standard could suppress innovation and adaptability. The group sought a happy medium: "Just tell me what the pipe is going to be. I don't care what people put through it, or around it, but I need to know what the pipe will be, " said one participant. The ideal is an open standard akin to XML.

But even with agreement on what type of standard would make the system succeed, the group pointed out significant challenges in the standards-development process for such a nuanced outcome. The question arose: is the best way forward to work with a institutional standards-making organization, or allow a proprietary format to become a *de facto* standard like WiMax? "Plenty of standards just don't work," one participant noted. Standards-making bodies can be hampered by competing commercial interests: for Smart Garage "We need to make people see that it's better to have a standard and get 20 percent of a huge pie than to stop the standard and get 80 percent of a tiny pie," another noted. Said a third on the challenge of designing a workable universal standard: "A lot of folks were asking the question, Should there be one standard?, and I don't really think that's practical. You'll have 10 percent of your utilities...going to be AMI [Advanced Metering Infrastructure] deployed in the next 5 years, and 10 percent won't be for 20 years. And you probably won't have the same technologies and standards for both those groups."

Solutions

The group created three strategies for success, outlined at left. None are mutually exclusive and all could begin at once.

The participants, many of whom have years of experience with various standards-making processes, emphasized one clear message: "Don't let the perfect be the enemy of the good.

By the end of the charrette, many (but not all) participants had decided that learning about and supporting the ongoing standards-making

Strategy one: design a standard that is rigid enough to prevent incompatible systems, but flexible enough to allow innovation over time.

Strategy two: go around the traditional standards making process, for an example see the history of WiMax

Strategy three: learn about and publicize the on-going standards-making work and **support** the traditional institutional process.

Related Charrette Project: Utility Policy Consortium and Project Get Involved work was the best path forward. To facilitate that, RMI conducted several follow-up interviews about what is going on and generated a brief overview of communications standards progress below.

The communications standard-making work has three major components: two SAE standards (J2836 and J2847) plus one alliance of companies focused on creating a Smart Energy Profile v2.0. All three groups are working together. In brief:

- The Smart Energy Profile (SEP) Alliance is a group of utility and other grid-side players (now including xEV makers) creating an application layer standard[6] for how smart appliances, including xEVs, will communicate with utilities and other grid service providers. This group emerged from the Zigbee Alliance and Home Area Network (HAN) protocol work surrounding Advanced Metering Infrastructure (AMI).
- SAE J2847 is a series of use cases, currently being created, that the SAE committee will give to the SEP Alliance to inform their standard. SEP Alliance will work on their standard in parallel, and coordination with, the J2836 committee.
- SAE J2836 is creating a standard for which messages that must be sent between the vehicle and other players.

Key difference: All SAE standards are requirements that OEMs must meet. The SEP Alliance standard isn't required, but will certify that a given hardware/software/product is compatible with all alliance members' products/services (analogously to USB connectivity). The certification will be open to any company to try to achieve.

Figure 18: Approximate Timeline of Communications Standards Work

Q4 08	Q1 09	Q2 09	Q3 09	Q4 09	Q1 10	Q2 10	Q3 10	Q4 10
J2847 cases developed	Use cases given to SEP and J2836	SEP drafted, J2836 drafted		SEP certification open, J2836 ballotted	J2836 and SEP refined, finalized		compatible hardware, services being produced	

In the words of one interviewee, "This standards process is significant because of the wide group of stakeholders involved...and now we've gotten them all to agree to the direction moving forward, and that's a big deal with this many stakeholders."

[6] For more on the differences between different "layers" see: http://en.wikipedia.org/wiki/OSI_model

Key questions include:

Wired *vs*. Wireless: The SEP standard is applications layer, and the J2836 is for messages, which means that nothing in this process predicates the protocol or medium for the communication. It could be power-line communication, cellphone signal, WiFi, Zigbee, radio, series, etc. However, during the use case creation, stakeholders have found that wired communication, or at least back-up, seems critical to meet reliability needs, though it is not required by the standard.

Will this cut out third parties and start-ups? The short answer is "no." The SAE standards will be published like other SAE standards, and the SEP Alliance's standard will have a certification process available to any company. Involved stakeholders have noted that for many of the overarching services (such as energy service aggregation, and being a clearinghouse for billing between multiple utilities) a marked preference has been shown for established major IT and metering players because by nature these services need to be all-encompassing. Other participants from the utility and OEM side noted that they would like a third party to come to them with a packaged solution for Smart xEV charge management instead of developing new capabilities in house.

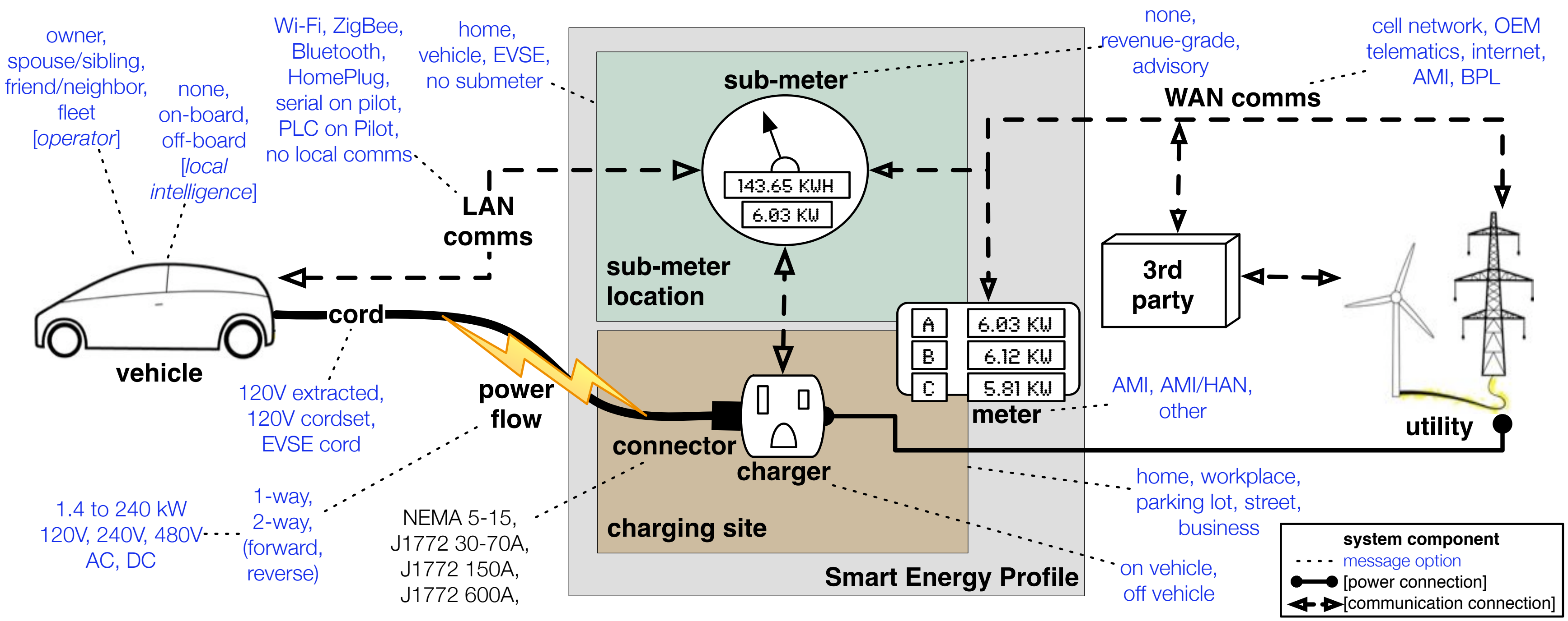
Is the standard useless in AMI-less regions? While the genealogy of this work stems from AMI, its applicability is not predicated on AMI presence. Several companies involved in the process are already developing solutions that allow vehicles to communicate directly with the utility/grid service provider, or install smart plugs, enabling V1G capability without a full AMI grid or smart grid.

Are there any negative unintended consequences? A few unintended consequences have emerged from this work. The first is that CARB emissions monitoring requirements are affected by communication between vehicles and other parties. This issue is twofold: if a signal fails to initiate electric charging, or directs the vehicle to use gasoline, emissions may rise; also, new communications standards may need to interface with current On-Board Diagnostics (OBD-II), a well-established set of standards requiring considerable vehicle integration. The group is working with CARB to iron out this potential conflict. Another consequence is the unexpected need to work with suppliers to create vehicle-grade chips.

How to support/be involved? Participate in the committees that are developing these standards. SAE committee membership is approved by the chair of the given SAE committees. More information can be found at www.sae.org/standardsdev. SEP Alliance membership is open, and more information can be found at www.zigbee.org/en/join.

Drawing from interviews and literature, RMI created the diagram below to illustrate the connections of assets involved in the communications standards.[7]

Figure 19: Graphic representation of scope of communication standards



[7] Scholer, Rich; *J2836 Status Update*; June 4, 2008; et.epri.com/documents/E229630_05_Scholer_June_2008.pdf

After identifying top barriers, and creating solution strategies, RMI and the charrette participants took things a step further and designed concrete projects that would activate one of the solution strategies. Six such project arose as the clear best choices. They are described briefly in the section that follows. RMI and the charrette participants are taking these forward, and more information and information on how to get involved can be found at move.rmi.org/smartgarage.

Figure 20: Follow-up projects

Top Barrier	Project
Uncertain consumer demand hampers ability to start building xEVs in significant volumes	**"Project Consumer Demand,"** a collaborative project to craft a compelling story about why people should buy PHEVs, collect hard data that will help OEMs plan and widely publicize that plan, and clearly quantify the consumer demand for these vehicles;
Who will pay for the charging infrastructure?	**"Project Get Started,"** which would work with a number of cities interested in becoming leaders in the PHEV revolution to create a bundle of incentives (financial, lifestyle, service, and value-related) that make owning an electrified vehicle better than owning an ICE for early local adopters, and share lessons learned from the early adopters to refine the system as it heads to mass roll-out;
	"Charge Baby Charge," an effort to rigorously map and quantify the many types of value that result from charging infrastructure, so that public and private investors would be better able to understand the opportunity and issues related to widespread EV/PHEV adoption;
High battery costs/ uncertainty for key parameters	**"Project Second Life,"** quantification and analysis of the value of used batteries and how they can be deployed;
How do we support consistency in utility regulation?	**"National Utility Policy Project,"** a consortium that creates a national framework of policies and regulations for utilities that could enable the Smart Garage paradigm by eliminating the barrier of different regional systems; and
Communications, billing, and charge management services/structures don't exist	**"Project Get Involved"** is a commitment to get as many diverse perspectives involved in the standards-making process as possible.

Chapter 4: Disruptive Ideas

So far, this report has told the story of Smart Garage. Chapter 1 detailed the long-term and shorter-term (V1G) vision, Chapter 2 outlined the ecosystem and its key stakeholders, and Chapter 3 highlighted the top five barriers to its successful implementation. We've found that the short-term vision is practical, the ecosystem is evolving, and the barriers, while significant, are tractable. In this chapter, we diverge to talk about the wild cards: what can be truly disruptive about Smart Garage? Below are the dozen most disruptive ideas generated during the charrette—the paradigm-shifting ideas, the ideas that launched new thinking and rearranged many participants' mental furniture. Not all participants would agree that each is a good idea, but all are worth noting in order to stimulate thinking as Smart Garage continues to evolve.

Consumer Adoption: transitioning from early adopters to mass market
1. The entire value chain centers on the consumer: keep the focus always on the end user.
2. It's not the technology, but how we roll it out, that matters. We need to sweat the small stuff that's most visible to consumers.
3. Make the mobility experience better for an xEV, there's more to the value proposition than economics. Car-buying is an emotional experience.
4. Match the technology to the mission, segment the car usage scenarios and differentiate consumers.

Batteries
5. Shift from a 10- to a 3-year battery design life for the primary vehicle application to minimize warranty risk. Plan for secondary uses to keep the cost down.
6. There are other ways to make the battery cheaper than bringing down the cost/kWh.
7. Used vehicles, not stationary power, are the biggest secondary market opportunity.

Charging
8. Electricity is cheap, so you might as well give it away to gain bigger benefits.

What's "Smart" for Utilities?
9. Use neighborhood networks to implement V1G.
10. V2G = V2B + B2G
11. Just plug your smart phone into your xEV.
12. You can do ancillary services with unidirectional charging.

Consumer Adoption – early adopters to mass market

"We should shift our perception of the market map to be successful."

Many came into the charrette focused on the needs of vehicle OEMs and utilities to achieve scale, or dove into specific technologies, but the prime mover that will drive Smart Garage development will be the consumer. In the end, it's not about electrified cars, or renewables, or communications: it's about creating consumer value and choice. The whole value proposition needs to focus on the consumer.

"Electricity cost is so small compared to everything else, you might as well give it away."

There is a significant difference between the complete value of a fast, convenient charge and the true cost of providing that electricity to the xEV owner. Huge opportunity exists to reap value from other services associated with the activity of charging an xEV. Some of those services could be so valuable they justify giving away the energy as a loss-leader. For example, attracting shoppers to a retail store, and perhaps even keeping them there longer, may be worth far more to the retailer than the electricity and charging infrastructure cost.

"It's not the technology, it's the roll out strategy — that influences consumer adoption."

"It's the little stuff that becomes the most visible"

It benefits everyone to avoid highly visible snafus, like if xEV fleet cars trip circuit breakers on public buildings, or when a broken plastic plug socket decommissions the entire vehicle (both have happened to one early adopter). Goals like having widespread infrastructure in place on Day 1 are less important than getting the details of the first consumer experiences right. Ideally, the three big players coordinate to optimize the customer experience—the vehicle OEMs, charge service providers, and the utilities. If the experience is positive, adoption spreads by word of mouth. Likewise, just a few house blackouts or dead batteries could have a very harmful ripple effect that kills the technology for a generation, as happened with immature early U.S. diesel cars. The first few years will be critical.

Consumer Adoption – early adopters to mass market

> "How to move from early adopter to mass scale? Make it so that it's *better* to own a plug-in, not just on an economic basis."

> "Match the technology to the mission"

What's the best way to address the risks associated with consumer adoption, including potential early-stage snafus? Optimize what makes driving an xEV a better mobility experience than driving a conventional car. Some strategies:

Match the technology to the mission, targeting specific classes of usage scenarios

Those with experience introducing xEVs to consumers know that the economic pay-off and customer satisfaction increases when the usage matches what the technology is best suited for. Rather than position new xEVs as one-to-one replacements for conventional cars, consider that car owners may have one or two main usage profiles worth targeting, such as commuting, high-mileage, or urban driving. Models such as car-sharing (Zipcar) can even give consumers access to a diverse suite of mission-specific vehicles.

Create convenient, integrated energy systems for the owner

Provide value in convenience and "subscription" models, in addition to price-stable mobility. For example, create the completely integrated system for homeowners by financing transport (xEV purchase + fueling costs), mortgage, and utilities (renewables and net-metering) together in one convenient monthly bill.

Provide access and special privileges with ownership

Opportunities exist to provide unique personal services, such as battery technician house calls (no more oil changes at the dealership), more convenient fueling (I refuel at home!), dedicated parking spaces, use of HOV lanes, operational benefits ("free fuel"), etc. These benefits can be of equal value to financial incentives.

> "At the end of the day, car buying is an emotional decision."

Batteries and Vehicles

.

"What about 3-year battery life for the primary vehicle application, instead of 10 years."

Making a battery that lives for three years inside an xEV, then is switched out as part of routine maintenance and sold to secondary markets, will reduce OEMs' technology risks and provide more consistent, reliable residual value (indicated by an onboard ship) in secondary markets.

"There are other ways to make the battery cheaper"

The numbers work out to incentivize xEVs through feebates

Say 15 million cars are sold annually in the U.S. Make 1 million of those xEVs. Levy a $500 fee on the remaining 14 million oil-dependent vehicles—and that provides a $7k rebate to each xEV, completely revenue-neutral to the Treasury.

Make the car 2–3x more efficient and downsize the battery 2–3x. Make the car far lighter and lower-drag, or build it around a usage scenario that requires a reduced range. "All the negative NPVs for the base-case scenarios go positive, and no winners become losers, if you double the platform efficiency of the vehicles," said one participant, estimating that a safe, same-size, ultralight BEV could pay back in just a few years at near-term prices.

Used vehicles, not stationary power, are the biggest secondary-market opportunity for batteries.

When considering viable secondary markets for batteries, it doesn't make sense to put a new battery into an old car. Use an aftermarket battery with a lower certified range (*e.g.*, put a used 150-mile battery into a 40-mile AER vehicle after the 40-mile original battery gets sold to the utilities for stationary storage). And then there's a [smaller] aftermarket for the battery even beyond that use. Create a waterfall battery market differentiated by reliable range.

Getting Smart on the Grid Side

"Neighborhood networks are a beachhead for V1G"

"V2G = V2B + B2G"

Even V1G will be hard to do for residents because of the high number of touchpoints. Aggregators should step in to create neighborhood networks that collectively act as a single grid service demand response unit. xEVs in a neighborhood must still communicate among themselves, but utility / xEV communications will become far simpler.

It may be substantially easier to implement, grow and manage V2G by breaking it into two components, V2B and B2G. Building owners are beginning to actively manage building loads. They will be extremely motivated to properly incorporate vehicle loads. Meanwhile, utilities and energy services companies are already developing smart grid and demand response relationships with buildings. Buildings could add new vehicles to their systems without increasing the number of utility contacts. And reducing the number of users that the utility has to communicate with—buildings rather than individual vehicles—addresses the concern that V2G may not be viable due to the logistical difficulty and transaction costs associated with high volumes of connections. "There's an interesting little business proposition being enabled here," reflected one intrigued participant.

"You can do lots of ancillary services with just unidirectional charging—you *can* regulate load both up *and* down."

"Why bother making your car smart and building new widgets, much less making your grid smart. just plug your smart phone into your xEV and it becomes part of the system."

"Regulation" refers to the ability to adjust a grid-connected vehicle's charge or discharge level temporarily to match a utility's demand load and power generation more closely in real time. Under the V1G scenario, only the vehicle's charge level can be adjusted; its load is either increased (regulation down) or decreased (regulation up) to match power generation. Under the V2G scenario, however, vehicle discharge can also be dispatched to provide regulation—*i.e.*, the vehicle can also generate electricity to meet current load (also regulation up). The services provided are the same in both cases. However, in V2G the vehicle owner could also receive a payment for the electricity delivered to grid, valued at the wholesale market price of electricity, and store renewable energy for later use.

Chapter 5: Moving Forward

Converging on a near-term vision

RMI's Smart Garage charrette allowed participants to delve deeply into various areas of the Smart Garage ecosystem and examine barriers and challenges to implementation—starting with the "chicken and egg" issue. Can we build infrastructure before xEVs hit the road? Will consumers want xEVs before the infrastructure is in place? Will OEMs build the cars if they aren't sure customers will buy them? And how will customers know or show they want to buy them when only a few xEVs are available for purchase? To be sure, a chicken is an egg's idea for making eggs, and an egg is a chicken's idea for making chickens, but one must clearly do many interlocked things at once, requiring collaboration and forethought to manage risk.

The participants honed in on these and several other "critical few" barriers—a drastic boil-down from a list of well over 50 key barriers generated before and during the event (Appendix G).

As first steps forward, the group designed six projects aimed at speeding xEVs' adoption, nicknamed Project Get Started, Charge Baby Charge, Project Second Life, National Utility Policy Project, PHEV Demand Response 1.0, and Project Consumer Demand.

To stay up to date on the activities of the groups working on these initiatives, please check http://smartgarage.rmi.org/tiki-index.php. Use the menu on the left side of the website to find forums, photographs, and documents (including preliminary and final reports).

After V1G

The benefits of synthesizing a near-term path forward are undeniable. As Andrew Tang, Senior Director of PG&E's Smart Energy Web, observed: "A key positive item that emerged from the RMI Smart Garage charrette was the convergence around the importance of smart charging [V1G]—the ability to manage charging of EVs to provide customer flexibility, promote attractive rates to customers, match demand from charging with supply (ideally from renewables), and not create additional strain on the grid or increase the need for more generation."

However, to converge on key issues, we must omit others nearly as important and abridge a deeper discussion of what comes after our short- term vision. The most intriguing ideas that didn't fit the main narrative are in Chapter 4—Disrupters. Covered below, for the path beyond V1G, are both our ideal vision and the potential for unintended consequences.

V1G and V2G: Not an either/or choice

By convening on the near-term goal of V1G, we consciously defer mass efforts to work on V2G.

This constrains Smart Garage's ultimate benefits. The electricity system matches demand to generation. V1G can adjust demand, expand renewables, and improve grid operations. But V2G can adjust demand and generation, further expanding renewables and ancillary services while making the grid more stable.

So why defer V2G? Because it is technically more difficult—for the battery, grid integration, and communications—hence more costly. Waiting for V2G might delay Smart Garage indefinitely, making the perfect the enemy of the good. Instead, we and most participants see V1G as the first step on a Smart Garage path that will probably lead to V2G, as long as V1G succeeds and variable renewables, energy storage and/or grid service needs, and electric mobility—all reasons to continue to V2G—increase. Perhaps in a few years RMI will host the "V1G to V2G Transition Charrette."

Moreover, the basic assumptions behind V2G—more variable renewables, higher values for storage and grid services, lack of superior competitors for doing the same thing, and perhaps a higher security and resilience value for distributed power sources—could shift unpredictably. It's therefore prudent to preserve V2G's option value now, while not taking it as proven and hence, if V2G's expected value fails to materialize, losing V1G's indisputable near-term value meanwhile.

We currently see four potential paths from V1G to V2G:

- Building out infrastructure with V1G capabilities in the short term, but using technology that can be easily upgraded to V2G later when the utilities, communications, and batteries are ripe.
- An intermediate step—V2B—where vehicles plug into buildings with bidirectional interfaces and the vehicles become a source of backup power. V2B offers many important advantages. First, it reduces the number of users the utility would have to communicate with (buildings rather than individual vehicles). Buildings could thus add individual vehicle users while not requiring additional infrastructure immediately. Second, it offers a fairly easy transition as it's already happening in many parts of the country as utilities and energy services companies develop smart grid and demand response relationships with buildings. Third, many large buildings already have sophisticated energy management systems that could easily embrace V2B. And fourth, a V2B + B2G = V2G paradigm would address the concern that V2G may prove unviable—or at least logistically difficult—due to the transaction costs and interoperability complexities of direct connections to numerous individual vehicles.

- Rebuilding an initial V1G infrastructure to shift to V2G; this seems costly and unnecessary.
- Patchwork: some individual regions or communities could establish V2G on their own. This possibility must be acknowledged, as well as the vehicles and infrastructure designed to accommodate it by defaulting to V1G or other low-level operation. That is, if the evolution looked less like the imminent "big bang" of the U.S. HDTV transition and more like the adoption of U.S. cellphone standards, each owner and region should still be able to benefit from the degree of evolution it has achieved.

Unintended Consequences

While RMI and charrette participants all believe that Smart Garage has great potential to do environmental, security, and economic good, we must acknowledge the possibility of unintended harm, by, for example:

- Increase in miles driven: Might Smart Garage prompt people to drive more as operating cost per mile falls? Interactions between Smart Garage vehicle usage, public transit, congestion, and land-use may merit study.
- Grid problems: certainly if done wrong, and perhaps even if done right, onpeak, coincident, or fast charging of xEVs could cause grid problems, especially in distribution. "If there's a major black-out pointed at PHEVs NERC will just shut the whole thing down."
- Other unintended consequences mentioned include lithium depletion, lithium-battery import dependence, potential opposition by oil companies, shift of highway infrastructure's revenue base from fuel taxes to other sources, and more inequity between xEV owners and others who can't afford them but must still help pay for their infrastructure via taxes or electricity rates.

It is important to note that few participants believe that V1G (which includes xEVs charging at smart times of day) will create a need for more power plants, specifically

coal plants, a belief supported by impact studies such as the NRDC/EPRI one referenced before.

All these issues could be avoided through collaboration and careful design, but this requires foresight.

Long-Term Vision

Ultimately, the Smart Garage paradigm is about energy freedom. For most of our lives—and those of our parents, grandparents, and great-grandparents—energy has been a mysterious and autonomous product of remote institutions. It has created unparalleled personal mobility, convenience, and prosperity, but at a cost to community, climate, and security.

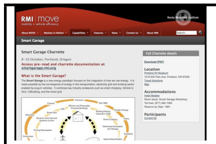
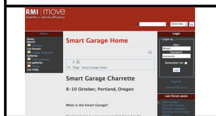
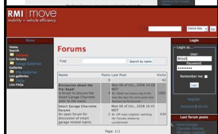
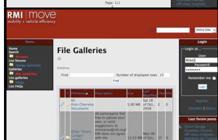
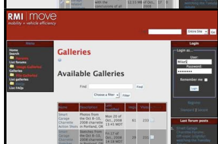
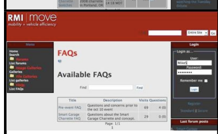
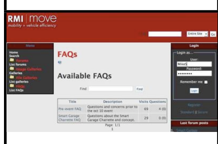
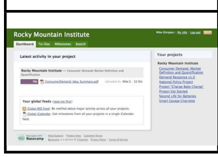
Now Smart Garage promises importantly expanded choices about the types, qualities, and amounts of energy we use. It allows players across the energy spectrum, including ordinary drivers and homeowners, to become actively involved with and responsible for the energy they use, how much, when, why, and what they pay for it.

When charrette participants were asked to describe a successful Smart Garage in the long term, they imagined news stories about Smart Garage with headlines like "EPA Dismantled Due to Lack of Pollution," "National V2G Project Successful," "Ford and GM Announce their Small Cars Will No Longer Have Internal Combustion Engines," "Automakers Play Large Part in Helping the Country be Energy Independent," and "EV Sales Top 20 Million as U.S. Accelerates Fleet Turnover."

The Smart Garage is an extraordinary opportunity to tackle several huge challenges confronting the U.S. and the world—climate change from fossil fuel combustion, oil dependence, a brittle power grid, vanishing jobs, rising energy bills—and solve them simultaneously while improving the quality of life and mobility for everyone. The challenge is great, but so is the prize.

WATCHING THE GAS PUMP RUN BACKWARDS

Web resources connected to this report:

	Site	Address	Description
	Smart Garage Home Page	move.rmi.org/smartgarage	Charrette motivation and background Charrette participant list Access portal to the Wiki
	Smart Garage Wiki	smartgarage.rmi.org	Hub for Charrette discussion, collaboration and file sharing
	Smart Garage Forums	smartgarage.rmi.org/tiki-forums.php	Message board for questions, ideas, and discussions between RMI and Charrette participants
	Smart Garage Documentation	smartgarage.rmi.org/tiki-list_file_gallery.php	Central location of all Charrette-related files, logs, and related literature
	Smart Garage Images and Sketches	smartgarage.rmi.org/tiki-galleries.php	File download site for all pictures related to the Charrette, including sketches
	Smart Garage Extra Resources	smartgarage.rmi.org/tiki-list_faqs.php	Center for Frequently-Asked Questions and miscellaneous data
	Smart Garage Financial Model	smartgarage.rmi.org/tiki-list_file_gallery.php	Open and public model (in Excel) that allows users to input assumptions and see system implications on Smart Garage stakeholders
	Smart Garage Project *Basecamp**	smartgarage.basecamphq.com/login	Collaborative project management site designed to maintain connection between project teams. File sharing, task management, messaging etc.

AMI Advanced Metering Infrastructure

BEV Battery Electric Vehicle

BOM Bill of Materials

CapEx Capital Expenses

CO2-eq Greenhouse Gases normalized to equivalent GWP of CO2

DoD Depth of Discharge

EREV Extended Range Electric Vehicle

FCEV Fuel Cell Electric Vehicle

GWP Global Warming Potential

HEV Hybrid Electric Vehicle

HWFET Highway Fuel Economy Cycle

ICE Internal Combustion Engine

LAN Local Area Network

LiIon Lithium Ion

LiPo Lithium Polymer

NGU Next Generation Utility

NiMH Nickel Metal Hydride

NPV Net Present Value

O&M Operations and Maintenance

OEM Original Equipment Manufacturer

OpEx Operating Expenses

PbA Lead Acid

PHEV Plug-in Hybrid Electric Vehicle

PTW Pump-to-Wheels, Plug-to-Wheels

PV Present Value

R&D Research and Development

SG Smart Garage

SOC State of Charge

TOU Time of Use

UDDS Urban Dynamometer Driving Schedule

USABC United States Advanced Battery Consortium

V0G Vehicles Plug-in without Logic/Control

V1G Vehicles Plug-in with Logic/Control regulated charge

V2B Vehicles Plug-in to Buildings/Communities with regulated charge/discharge

V2G Vehicles Plug-in with Logic/Control regulated charge/discharge

WACC Weighted Average Cost of Capital

WAN Wide Area Network

WTP Well-to-Pump, Well-to-Plug

WTW Well-to-Wheels

xEV Generic Electric Vehicle