Technology Transition Case Study

United States Advanced Battery Consortium

1. USABC Case Study Context

Introduction of USABC and Technical Focus: The Department of Energy's (DOE's) Vehicle Technologies Office (VTO) supports the research, development, demonstration, and deployment of a broad portfolio of advanced transportation technologies that improve the nation's energy security by reducing dependence on petroleum, reduce greenhouse gas emissions, and strengthen U.S. global economic competitiveness. Activities focus on reducing the cost and improving the performance of a mix of medium- and long-term technologies including advanced energy storage devices (batteries and ultracapacitors), power electronics and drive motors, advanced structural materials, advanced combustion engines, fuels and lubricants, and other enabling technologies. VTO funds high-reward/high-risk research at the national laboratories, as well as competitively-awarded, cost-shared projects with university, industry, and other partners.

While VTO pursues a portfolio of technologies that, collectively, can reduce our dependence on petroleum, vehicle electrification is an essential and significant part of the solution. The global automotive industry is already moving in this direction. A transition to electrification will benefit not only the national economy and energy security but also individual consumers – today's plug-in electric vehicles (PEVs) can "fuel" for the equivalent of about $1/gallon, and next-generation vehicles will bring even bigger savings. The Department's EV Everywhere Grand Challenge set key technical targets necessary for enabling PEVs to be as convenient and affordable as today's gasoline vehicles by 2022. A focus of this effort is energy storage and the development of more cost-effective, longer lasting, and more abuse-tolerant PEV batteries.

VTO's energy storage R&D effort includes multiple activities, ranging from focused fundamental materials research to battery cell and pack development and testing. The R&D activities involve both short-term directed research by commercial developers and national laboratories and exploratory materials research generally spearheaded by the national laboratories and universities.

Since 1991, VTO has worked in close collaboration with industry through a series of Cooperative R&D Agreements with the United States Advanced Battery Consortium (USABC). The cooperative agreements support R&D to develop a domestic advanced battery industry whose products can meet the performance requirements of a wide range of electric drive vehicle architectures. The USABC is an umbrella organization for pre-competitive automotive battery research and development among Fiat-Chrysler Automobiles, Ford Motor Company, and General Motors Company. The USABC has supported the development of energy storage systems for the entire range of vehicle electrification platforms, from 12V start stop, through hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs), to full battery powered electric vehicles (EVs). With cost share and in cooperation with VTO, the USABC has supported the development of a number of energy storage technologies, including nickel metal hydride batteries, Lithium ion batteries, Lithium metal batteries, ultracapacitors, hybrid ultracapacitor

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cells, and hybrid systems that contain both Lithium ion batteries and ultracapacitors.

Activity Focus and Funding:

The VTO-USABC cooperative agreements' cost-shared R&D activities focus mainly on the development of robust battery cells and modules to significantly reduce battery cost, increase life, and improve performance and abuse tolerance. For high-energy and high-power energy storage technologies, the USABC:

- Develops electric drive vehicle battery performance requirements and test procedures,
- Solicits, reviews, and selects proposals to develop advanced battery technology,
- Manages ongoing contracts and assures progress toward achieving the VTO-USABC Partnership goals.

The current cooperative agreement between VTO and the USABC was awarded after an open, competitive solicitation (FOA 0000722 dated November 30, 2012) in which the DOE sought applicants that would "be led by associations or consortia which include automobile manufacturers that intend to commercialize electric vehicles." VTO provides funding for most of the battery development contracts awarded through the consortium, which are cost-shared 50% by the battery developer. The US automakers supply personnel for "in kind" contributions to the consortium.

Benefits of the Cooperative Agreement Between DOE and USABC to the US Taxpayer: The DOE-USABC Cooperative Agreement allows the combined technical and financial resources of the DOE, domestic Original Equipment Manufacturer (OEM) automakers, battery development partners, and independent testing laboratories to join forces in conducting advanced battery research and development. The primary advantages of this consortium are that it: 1- furthers DOE's goal of reducing the nation's dependence on foreign oil; 2 – cost shares the critical R&D needed by US battery companies to compete with (predominantly) Asian companies who currently dominate the energy storage field; and 3 - DOE's collaboration with automakers through this consortium enhances both the relevance and the potential for success of the R&D programs, as the automakers bring the perspective of the end user directly to the R&D effort.

2. **USABC Formation**

Industry Input and Membership: The USABC was formed in 1991 by the "big three" US automakers, General Motors, Ford Motor Company, and Chrysler, to engage in pre-competitive R&D into emerging energy storage technologies for automotive use. (Note: One year later, in 1992, the same US automakers formed the United States Council for Automotive Research LLC, or USCAR, to facilitate collaborative R&D across a broader technology portfolio.) The automakers sought to share the costs and the benefits of the long-term effort needed to bring electric drive energy storage technology to market. From the beginning of the consortium, the USABC has stressed the collaborative use of metrics-driven research, the use of standards (for both performance and cost estimates) and requirements, and the use of independent testing to validate claims and results.

Mission: USABC's mission is to develop electrochemical energy storage technologies that support commercialization of electric drive vehicles. The USABC seeks to promote long-term R&D within the domestic electrochemical energy storage (EES) industry and to maintain a consortium that engages automobile manufacturers, EES manufacturers, the National Laboratories, universities, and other key stakeholders.

3. DOE-USABC Cooperative Agreement Governance

Management Structure: The USABC is organized into several management layers. The USABC Management Committee (MC) is comprised of one management employee from each of the auto companies; one of these individuals serves as Chair. The MC makes both personnel and funding level decisions for the USABC: they allocate staff to various USABC functions and decide if a given proposal will ultimately be funded. The management committee meets at the USCAR headquarters in Southfield, Michigan once per quarter, and holds a teleconference in between each in-person meeting.

The cooperative agreement calls for “Substantial Involvement” by DOE regarding program direction, funding, proposal review and selection, and project review. An appropriate DOE employee (currently David Howell, Program Manager for Hybrid Electric Systems, in EERE’s Vehicle Technologies Office) participates in MC meetings related to the technical and contractual activities of the cooperative agreement. The DOE representative to the MC is supported by the Technical Project Officer from the Federal contracting organization (currently the National Energy Technology Laboratory). The DOE representative provides input on DOE policies and goals to the MC. He can (and does) veto any DOE funding of a battery development project that the Department does not support. Note that the USABC can fund development programs, or hire consulting staff, with non-DOE funding.

The Technical Advisory Committee (TAC) provides technical guidance and recommendations to the MC. The TAC is made up of 20-30 technical experts in the battery development field and is drawn from each of the automotive OEMs, DOE, and the National Laboratories. TAC members write the requests for proposals, perform technical reviews of those proposals, oversee and manage ongoing battery and ultracapacitor development programs, develop energy storage requirements for various applications (like HEVs, PHEVs, and EVs), and develop standardized test procedures. A subset of TAC members forms a work group that is assigned to a specific development program. Work groups hold quarterly reviews with that developer and report back to the full TAC during in-person quarterly meetings in Southfield. In addition, teleconferences are held in between each in-person meeting.

The TAC has established a number of working groups that perform specific tasks such as developing or updating test procedures, developing or modifying performance or cost requirements, or researching a specific technical area (e.g., the means of inducing an internal short circuit in a battery cell). As with other TAC activities, DOE representatives participate in these working groups.

The OEM members to the MC and TAC bring a wide breadth of information, experience, and expectations to their respective teams. They concentrate on automotive requirements, on specific automotive needs that battery developers may be unaware of, and the development of test procedures that would be of most value for automotive use. The national lab staff who work with the TAC bring testing expertise, electrochemical (scientific) knowledge, and experience from decades of battery R&D.

Similarly, the DOE representatives to the TAC bring a long history of exploratory and applied research funded by the DOE, technical expertise, and a critical perspective regarding the U.S. government's interests and needs to the USABC.

USABC Technical Review: The USABC and its projects are reviewed each year at the VTO Annual Merit Review.

Non-disclosure Agreements (NDAs) and Conflicts of Interest: The USABC members will not sign formal NDAs, but they do designate all information provided to the USABC by developers as "protected information" and commit to holding that information within the USABC for five years from the conclusion of a development program. Under the terms of the cooperative agreement, information that is "protected information" may not be released under the Freedom of Information Act (FOIA) while it is in "protected" status.

The objectives of the cooperative agreement are to develop electrochemical energy storage technologies in a pre-competitive environment, which support commercialization of electric drive vehicles. The USABC automakers do not manufacture batteries but purchase them from suppliers. Conflicts of interest may arise occasionally but are mitigated before the start of any battery development project.

4. R&D Execution

Technical Engagement of National Labs: As mentioned above, several members of the national laboratory R&D community participate in TAC activities, including members from Argonne National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, and Sandia National Laboratory. National laboratory researchers participate in the quarterly TAC and project working group progress review meetings and in the conference calls. They provide independent performance, thermal, and abuse testing support, technical input, and analysis of test and diagnostics data.

Project Planning: The USABC requires that milestones and deliverables be included in every development contract that it issues, which is considered to be a "best practice" by DOE. Baseline deliverables are required at the beginning of each contract so that advances can be objectively and quantitatively measured throughout the period of performance. In all cases final deliverables are required (interim deliverables are also required in most cases) in order to gauge progress at mid-points of each program.

Other "best practices" include: (1) the USABC develops and publicizes electric drive vehicle battery performance requirements and test procedures before the solicitation of battery development proposals for a specific vehicle architecture, and (2) the USABC insists on testing a company's baseline technology before it will engage in a full development contract. This has permitted the USABC to greatly reduce the likelihood of embarking on a long (some projects are three years long) and expensive (some contracts can exceed $10,000,000 in total cost) contracts with companies who are unable to perform at the expected level.

Independent Validation Testing: Each developer is required to subject its cells, modules, and packs to internal testing following the USABC test procedures. When the developer is confident in how its deliverables will perform, prototype battery cells and modules are sent to one or more national laboratories for independent performance, thermal, and/or abuse testing in order to independently confirm or validate the battery developers' results.

Contract Solicitation, Review, and Approval Process: When the USABC prepares to issue a new request for proposal information (RFPI) on an existing or new topic (HEV batteries, PHEV batteries, etc.), a TAC work group is formed to lead the RFP development, to create or update existing quantitative proposal review forms, and to technically review the submitted proposals. The work group typically contains members of each OEM, and one or more national laboratory researchers and one or more DOE members also participate in these discussions. The quantitative review forms are a critical component of the review process, permitting a fast and accurate measure of each organization's support for a proposal. The results of each stage of this process – RFPI development, review form development, and quantitative review of each proposal – are presented to the full TAC for review and approval, and in the case of RFPs and proposal reviews, to the MC for approval.

One challenge with having national laboratory staff participate in USABC activities is the potential for conflict of interest between the staff member's research activities and the R&D activities of the industrial battery developer. DOE has taken a very active role in removing any such conflict of interest, or appearance of conflict of interest, by ensuring that national laboratory researchers refrain from participating in any meetings involving topics in which they are actively engaged.

5. USABC Results

A 2013 analysis by RTI International in Research Triangle Park, NC determined that the DOE's $971 million R&D investment in advanced battery technology for electric drive of vehicles (EDVs) from 1991-2012 directly led to the commercialization of the 2.4 million EDVs sold between 1999-2012 that incorporate nickel metal hydride and lithium ion batteries, which are projected to reduce U.S. fuel consumption by $16.7 billion through 2020. The study also found that VTO-funded research contributed to the knowledge base in energy storage that resulted in 112 patent families in energy storage over the period 1976 to 2012 and is ranked first in patent citations among the top-ten companies.

Technologies Produced: The USABC has a long track record of helping to develop energy storage technologies that have been subsequently commercialized.

Nickel Metal Hydride Battery Technology for Hybrid Vehicles: In 1992, under a cooperative agreement with DOE, the USABC initiated development of nickel metal hydride (NiMH) battery technology. DOE funding through that cooperative agreement was instrumental to the development of NiMH technology at two manufacturers, Energy Conversion Devices, Inc. (ECD Ovonics) and SAFT America. ECD Ovonics' NiMH technology is now manufactured at COBASYS, LLC, its 50-50 manufacturing joint venture with Chevron Technology Ventures, LLC. ECD is also licensing its technology to Sanyo, which supplies NiMH batteries for the Ford Escape, Cmax, and Fusion hybrid vehicles; to Honda, for its hybrid vehicles; and to

Panasonic, which supplies batteries for Toyota hybrid vehicles. Under the terms of the original ECD contract, a small fraction of these licensing fees have been remitted to DOE and the USABC.

Lithium ion Battery Technology for Hybrid Vehicles: From 2003 to 2008, the USABC awarded Johnson Controls Inc (JCI) contracts to develop a 40kW Lithium ion HEV battery. Under this program, JCI developed the VL6P Lithium ion battery cell, which offers twice the energy and power for the same weight and volume of NiMH batteries and at a lower cost. In 2009, JCI launched production of its Lithium ion battery for the Mercedes-Benz S400, the first Lithium ion HEV battery to be commercialized. JCI received production contracts with BMW for its 7 series ActiveHybrid in early 2010. In 2014, JCI announced that it is supplying Lithium ion batteries for the Hybrid Range Rover.

Figure 1: JCI High Power Lithium Ion battery for the BMW ActiveHybrid 7 Series, including the VL6P cell developed with support from DOE & USABC.

Lithium ion Battery Technology for Plug-in Electric Vehicles: Later, in the early 2000s, the USABC supported the development of the core cell technology that is currently used in the Chevrolet Volt PEV battery (see Figure 2) and the Ford Focus EV battery. The cell, which contains a graphitic anode and a mixture of layered and spinel oxides, was developed in collaboration with LG Chem Michigan from early 2004 through 2012.

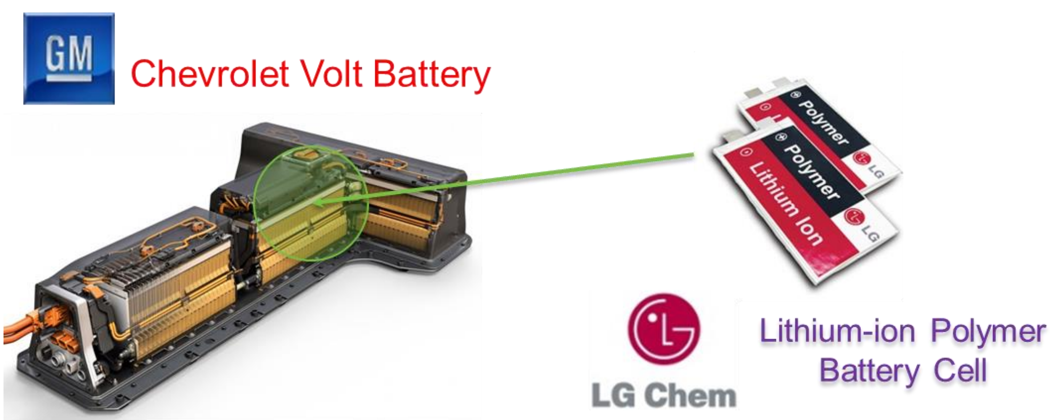

Figure 2. Chevrolet Volt Battery and LG Chem Lithium Ion Polymer Battery Cell

Ultracapacitor Commercialization: Maxwell Technologies developed higher voltage, higher-energy ultracapacitors as part of a USABC 42V start stop development program in the mid-2000s. The cell developed in that program, Figure 3, was eventually commercialized and used to power hybrid buses in China, and today, Maxwell ultracapacitors are installed in over 1 million vehicles on the road.

Figure 3. Maxwell BoostCap Ultracapacitor

PEV Battery Cost Reduction: DOE, in close collaboration with the USABC, has reduced the cost of Lithium ion batteries by nearly 70% and improved their energy density by 60% during the last five years. As shown in Figure 4, the modeled cost of PHEV batteries under development has been reduced from $1,000 per kilowatt-hour of useable energy in 2008, to a current cost of $289 per kilowatt-hour. Three USABC battery developers have made significant advances in cost reduction using improved cathodes. These battery development projects focus on advanced cathodes, processing improvements, cell design, and pack optimization. Standard electrolytes and graphite anodes were used by each developer. These battery cost projections are derived by the manufacturer using USABC's battery manufacturing cost model based on a production volume of 100,000 batteries per year for specific battery cell and module designs that meet DOE/USABC requirements for power, energy, and cycle life as well as calendar life.

Concurrently, the size and weight of PEV batteries have also been reduced by over 60% and the battery energy density has increased from 60 Wh/liter in 2008, to 150 Wh/liter in 2013.

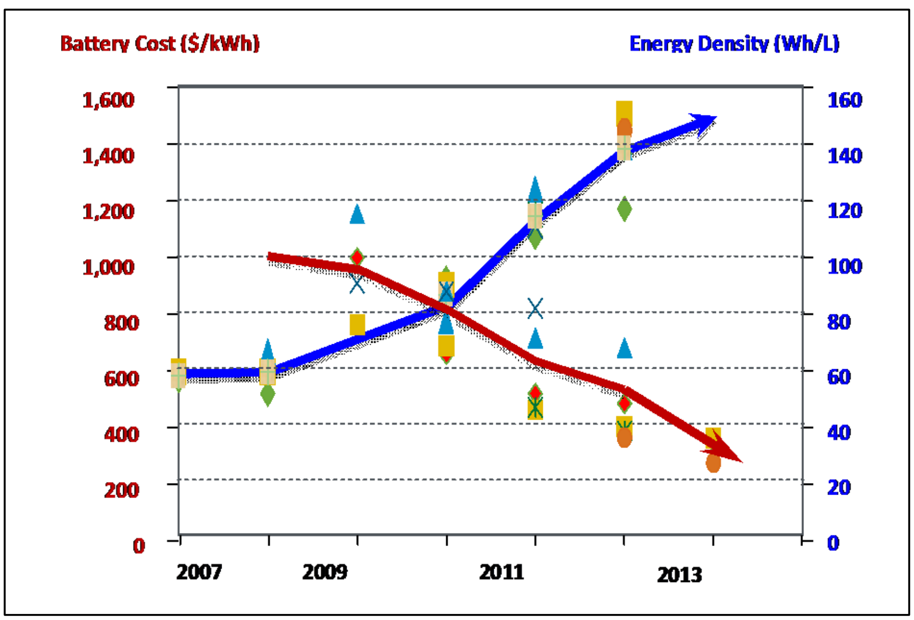

Figure 4. Modeled cost and energy density of PEV batteries developed and tested.

Methods Used to Monitor How Program Goals are Being Met:

Development and Use of Requirements and Testing Standards*:* One of the other major achievements of the USABC has been its development and publication of both electric drive vehicle battery performance requirements and test procedures. Prior to the issuance of a request for proposal on any topic (HEV batteries, EV batteries, etc.), the USABC TAC members either develop or confirm battery requirements through in depth consultation with staff at their respective companies. National lab staff may aid in this process by performing vehicle simulations using various battery technologies in order to understand the fuel economy differences among various performance requirements. This process, particularly if it is for new or substantially updated requirements, can take many months, and sometimes more than a year. However, having performance targets agreed to by all participants and that permit a quantitative evaluation of multiple technologies is a major benefit of this process. As an example, performance requirements for EVs and 12V start/stop batteries are shown in Tables 1 and 2.

Table 1 – Subset of EV Battery Requirements

Parameter of Fully Burdened System	Units	Long Term Goals
Power Density	W/l	600
Specific Discharge Power (80% DOD, 30 sec)	W/kg	400
Specific Regen Power (20% DOD, 10 sec)	W/kg	200
Energy Density (C/3 discharge)	Wh/l	300
Specific Energy (C/3 discharge)	Wh/kg	200
Life	Years	10
Cycle life (80% DOD)	Cycles	1000
Selling price (25k 40kWh units)	$/kWh	100
Operating temperature	C	- 40 to +85

Table 2 – Subset of 12V Start Stop Battery Requirements

End of Life Characteristics	Units	Under Hood Target
Discharge Pulse (1 second)	kW	6
Max discharge current (.5 sec)	A	900
Cold cranking power at -30 °C	kW	6
Minimum voltage under cold crank	Vdc	8.0
Available energy	Wh	360
Peak recharge rate	kW	2.2
Cycle life	Engine starts/miles	450k/150k
Calendar life at 45 °C	Years	15
Weight	Kg	10
Volume	L	7
Price	$	220

Once the performance targets are finalized, TAC members, in collaboration with national laboratory battery testing personnel, either create or update existing test procedures. This process, like the requirements definition process, can take several months. The way a device is tested can have a major impact on the results, and as such, the USABC and DOE take great care to ensure that the test procedures are as relevant to the auto industry as possible, and that they maximize the ability of the USABC and DOE to compare results from generation to generation along a development path. A sample of currently published test procedures is shown in Figure 5.

Figure 5. USABC Test Procedures, see (http://www.uscar.org/guest/article_view.php?articles_id=86).

Common requirements and test procedures have been a major factor enabling the comparison of one developer's technology vs. another, or for comparing multiple versions of the same technology. Many battery developers approach DOE or the USABC with claims of vastly superior performance compared to their competitors. Having standard test procedures has, essentially, leveled the field and enabled a fully independent and defensible test of those claims.

Use of Standard "Gap Chart to Track R&D Progress: Finally, at each quarterly technical review meeting, developers are required to present standardized "gap charts" (see Table 3), which contain device parameters, associated USABC goals, and hardware performance metrics that are critical to evaluating the progress of the program. Typically, and as shown below, the gap chart contains goals, the baseline cell beginning-of-life parameter values, and the parameter values that the cell or system is presently delivering. In the case shown in Table 3, results are shown after 150 EV cycles. Often the parameter values are shaded green, yellow, or red depending on whether they are meeting, are just barely meeting, or are no longer meeting a specific target.

Table 3: Sample EV Cell Development Program Gap Chart

EV Targets	USABC Cell Level Goal	QUARTERLY PROGRESS	
		Developer Data	
		Beginning of Test	Present Performance
Power Density (W/L)	460	1215	670
Discharge Pulse Power @80% DOD(W/kg)	300	721	298
Regen Pulse Power @20% DOD(W/kg)	150	1837	1228
Energy Density (Wh/L)	230	360	345
Specific Energy C/3 Discharge (Wh/kg)	150	214	205
Power/Energy Ratio	2	6	1.45
Calendar Life (Yrs)	10	tbd	0.43
Maximum System Weight (kg)		0.337	0.337
Maximum System Volume (Liters)		0.2	0.2
Cycle Life 80% DOD (DST profile)	1000	tbd	150
Maximum Operating Voltage (Vdc)		4	4
Minimum Operating Voltage (Vdc)		2	2
Estimated Battery Pack Cost ($/kWh)	$125	$290	$290

Use of Standard Cost Model*:* Finally, the USABC has published, and requires its developers to use, a detailed cost model which helps to build confidence in a developer's claims regarding product production cost and selling price. The cost model is based on a sales volume of 100,000 batteries per year and includes material costs, purchased material costs, plant and equipment depreciation, and other costs. The model is available on the USABC website for download at http://www.uscar.org/guest/article_view.php?articles_id=143.

The USABC uses the independent performance tests on contract deliverables, completed cost models, and the battery requirements to gauge progress towards consortium goals.

IP and Licensing: None of the USABC members directly compete with battery or ultracapacitor developers. Rather, the member organizations are users and purchasers of that technology. As such, IP issues have been rare. In addition, it is relatively difficult, in any research program, for a funding organization to prove that a commercialized technology was developed using that organization's support.

6. Lessons Learned

The DOE/USABC cooperative agreements have been an extremely successful industry/government collaborative R&D effort. Over 20 years, this collaboration has successfully completed an extraordinarily large number of development programs, has developed technology that has been commercialized and put into use, has published requirements and test procedures that are recognized and used worldwide, and has greatly accelerated the development and adoption of petroleum-saving energy storage technologies across the globe. It has been observed that the Toyota Prius and Honda Insight were launched within several years after the USABC began its HEV battery research, and, in fact, the battery suppliers to both companies licensed the technology developed by the USABC. In addition, the recent enhanced focus on PHEVs and EVs follows closely the USABC's funding of high energy Lithium ion batteries for those applications.

Modifications if Starting New: If the program were starting new, DOE could consider permitting a "sliding scale" of cost-share requirements for developers. The current requirement of 50% cost share is most appropriate for technologies that are "more mature," with a TRL level of approximately four. This 50% cost share worked well when developers focused on Lithium ion batteries for hybrid vehicles that had been demonstrated in consumer electronic devices and were already capable of meeting the power and energy targets but fell short on cycle life (10,000 HEV cycles vs. the 300,000 HEV cycle target) and cost ($100/kW vs. $25/kW).

Recently, however, the USABC has moved to supporting R&D involving less mature technologies (like Silicon-based anodes and high-voltage cathodes) that show promise to meet the extremely aggressive EV Everywhere goals. Cells made from these materials often show cycle lives of 100s, as opposed to the 1,000 to 5,000 cycle life requirement. In addition, the materials themselves may not be available in high volume or with high batch-to-batch consistency. More established companies may hesitate to engage in R&D on such high risk technology at the 50% cost share level.

Procedures to Definitely be Used Again: The procedures that we would recommend be used again in a new program are the ones highlighted above. To summarize, we would continue to use the following:

1. Membership in the consortium would include end users (automotive OEMs), national lab personnel (for independent testing, outside electrochemical and testing expertise), and DOE.
2. Quantitative performance requirements would be used for all applications.
3. Quantitative proposal review forms would be used to evaluate all proposals.
4. Standard cost model would be required to be used by all developers.
5. Standardized test procedures for all performance and abuse requirements would be used by all developers and by testing labs.
6. Independent performance and abuse testing of all contract deliverables.
7. Quarterly technical review meetings with USABC staff and developer teams, these meetings permit the early identification of potential issues and thus allow timely remediation plans to be put in place.
8. The use of standardized "gap charts," which contain critical parameters that are tracked at Quarterly Progress reviews.