USABC Development of 12 Volt Battery for Start-Stop Application

Preprint

Harshad Tataria
General Motors Company

Oliver Gross
Chrysler Group LLC

Chulheung Bae
Ford Motor Company

Brian Cunningham and James A. Barnes
U.S. Department of Energy

Jack Deppe
Deppe Consulting LLC

Jeremy Neubauer
National Renewable Energy Laboratory

Presented at EVS27 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium
Barcelona, Spain
November 17–20, 2013

Conference Paper
NREL/CP-5400-62680
February 2015

Contract No. DE-AC36-08GO28308

NOTICE

The submitted manuscript has been offered by an employee of the Alliance for Sustainable Energy, LLC (Alliance), a contractor of the US Government under Contract No. DE-AC36-08GO28308. Accordingly, the US Government and Alliance retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at http://www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) photo by Pat Corkery, NREL 16416, photo from SunEdison, NREL 17423, photo by Pat Corkery, NREL 16560, photo by Dennis Schroeder, NREL 17613, photo by Dean Armstrong, NREL 17436, photo by Pat Corkery, NREL 17721.

NREL prints on paper that contains recycled content.

EVS27
Barcelona, Spain, November 17-20, 2013

USABC Development of 12 Volt Battery for Start-Stop Application

Harshad Tataria[1], Oliver Gross[2], Chulheung Bae[3], Brian Cunningham[4], James A. Barnes[4],
Jack Deppe[6], Jeremy Neubauer[5]

1Corresponding Author harshad.s.tataria@gm.com, Tel: 248-836-7894, Fax: 586-492-4420, General Motors Company, Warren, MI, USA
[2]Chrysler Group LLC, Auburn Hills, MI, USA
[3]Ford Motor Company, Dearborn, MI, USA
[4]U.S. Department of Energy, Washington, DC, USA
[5]National Renewable Energy Lab, Golden, CO USA
[6] Deppe Consulting LLC , Davidsonville MD, USA

Abstract

Global automakers are accelerating the development of fuel efficient vehicles, as a part of meeting regional regulatory CO_2 emissions requirements. The micro hybrid vehicles with auto start-stop functionality are considered economical solutions for the stringent European regulations. Flooded lead acid batteries were initially considered the most economical solution for idle-stop systems. However, the dynamic charge acceptance (DCA) at lower state-of-charge (SOC) was limiting the life of the batteries. While improved lead-acid batteries with AGM and VRLA features have improved battery longevity, they do not last the life of the vehicle. The United States Advanced Battery Consortium (or USABC, a consortium of GM, Ford, and Chrysler) analyzed energy storage needs for a micro hybrid automobile with start-stop capability, and with a single power source. USABC has analyzed the start-stop behaviors of many drivers and has developed the requirements for the start-stop batteries (Table 3). The testing procedures to validate the performance and longevity were standardized and published. The guideline for the cost estimates calculations have also been provided, in order to determine the value of the newly developed modules. The analysis effort resulted in a set of requirements which will help the battery manufacturers to develop a module to meet the automotive Original Equipment Manufacturers (OEM) micro hybrid vehicle requirements. Battery developers were invited to submit development proposals and two proposals were selected for 50% cost share with USABC/DOE.

Keywords: HEV, Micro Hybrid, 12 V Start-Stop, Batteries

---

1 USABC Introduction

Mission: To develop electrochemical energy storage technologies which support commercialization of fuel cell, hybrid, and electric vehicles.

Strategic Vision: 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.

Objectives: For high-energy and high power energy storage technologies and models, the USABC shall continue its focus on understanding and addressing the following activities:

- Continue development of high-power battery technologies to reduce cost to $20/kW and extend life to 15 years.
- Develop battery technology to support electric, hybrid and fuel cell vehicles.
- Develop ultracapacitor technology for hybrid electric vehicle applications.
- Conduct benchmarking activities for both high power and high energy batteries and ultracapacitors to validate technologies.
- Publish technical goals and associated test procedures to guide the development of electrochemical energy storage systems.

2. Start-Stop Battery Introduction

While HEVs (mild, moderate, and strong) and PHEVs can achieve significant improvements in CO_2 emissions of individual vehicles, start-stop and micro hybrid technology can greatly reduce the cumulative vehicle fleet CO_2 emissions and improve fuel economy with a minimum increase in vehicle cost of hybridization. It is estimated that more than 16 million vehicles in North America and 80 million vehicles globally will be produced annually. Widespread adoption of HEVs which shuts the engine off during idle is already underway in Europe and Asia. It is expected that, by 2017 in excess of 70% of all vehicles manufactured in North America will include start-stop functions.

USABC has been developing the HEV, PHEV, and EV batteries and ultracapacitor energy systems for more than 20 years with the help of U.S. Department of Energy (DOE). The USABC has identified the need for a start-stop technology which will be cost competitive with current batteries, e.g. Pb-Acid, NiMH, and Li-Ion. With the help of the National Renewable Energy Laboratory (NREL) modeling and simulation capability, the USABC has developed start-stop energy storage technology requirements (Table 3). This paper presents the analysis and vehicle data – actual and simulation - used to determine these requirements. The size, weight and cost were also estimated to complete the requirements.

3. Vehicle and Data Analysis

The strategy for the battery requirements and module development was to build a simplified model for a mid-size vehicle and apply real-world drive data to characterize start-stop energy storage system requirements and potential benefits. Drive data from a large number of vehicles / drivers in three cities – Austin and San Antonio, Texas [1] and Los Angeles, California [7] in the USA, was utilized for this purpose. It consisted of 1,984 vehicle days of second-by-second vehicle speed histories. Figures 1 and 2 show the respective frequency distribution of engine start events observed in this data set, per day and per mile, assuming each vehicle is equipped with a start-stop system. For the 95th percentile driver, this corresponds to 73 start events per day (3.5 starts per mile).

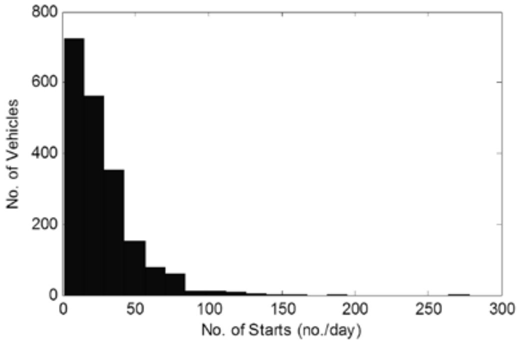


Figure 1: Number of Vehicle Starts/Day Frequency Distribution

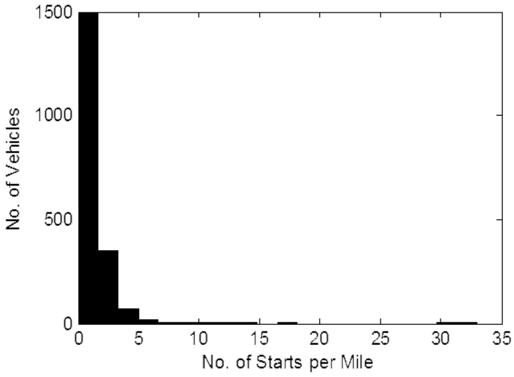


Figure 2: Number of Starts/Mile Frequency Distribution

The datasets employed did not contain information on the state of the vehicle ignition (i.e. whether the ignition was “on” or “off”). It was therefore assumed that any stop shorter than 2.5 minutes was a key-on stop (where the start-stop energy storage system must sustain the auxiliarly loads of the vehicle over the duration of the stop), and any stop greater than 2.5 minutes was a key-off stop. Given the 95% of all stops are less than 2.5 minutes in duration (figure 3), this assumption will capture the majority of stop events in the data as key-on events..

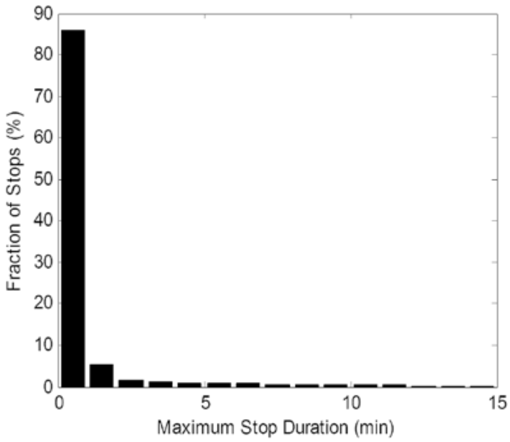


Figure 3: Maximum Stop Duration Frequency Distribution

A simplified vehicle model was run for each of the available vehicle speed histories. A nominal alternator load on an idle vehicle has been set to 60A and 12.5V = 750W. This model calculated the energy storage system state of charge (SOC) as a function of time assuming that 750 W of power is available to charge the battery when the vehicle is driving, and that it is discharged at a rate of 750 W when stopped in the key-on state. 1.7 Wh was assumed to be discharged for every start event. An annotated example for a single vehicle is shown in Figure 4. A key output of this simulation is the required amount of energy a start-stop system must make available to sustain start-stop operation during a day of real-world driving, shown in Figure 5.

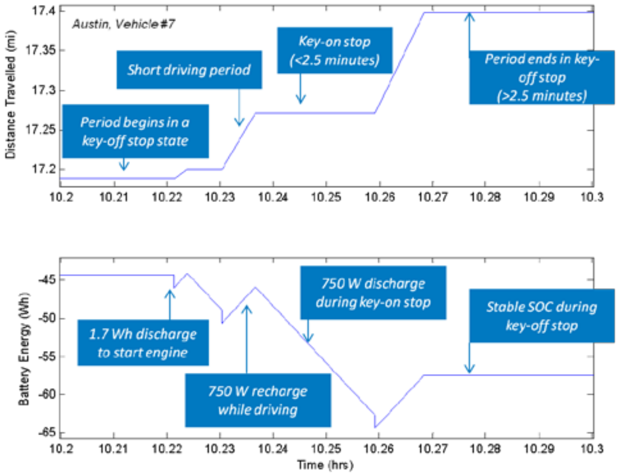


Figure 4: Example Energy Storage System Simulation Result

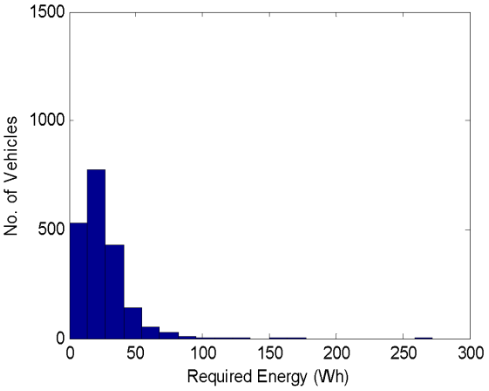


Figure 5: Total Energy Required Frequency Distribution

The data in Figure 5 suggests that the median required energy for start-stop functionality is 21 Wh, and that 56 Wh is necessary to cover the 95th percentile driver. To determine the minimum energy content of the energy storage system this value was added for the 95th percentile driver to the critical loads of cranking the engine, reserve needed for parasitic loads during long term parking, emergency hazard flasher and the accessory loads (Table 1). The energy needed for climate control were not included assuming the engine may not turn off if the need for climate control is sensed. The total energy needed is conservatively estimated to be about 360Wh and is labeled available energy to support the listed loads.

Table 1: Energy Estimation

Load	**Req'd Energy**	**Req'd Power**
Start-Stop (95th percentile)	56 Wh	~6 kW
Cold Start Reserve	9.2 Wh	~6 kW
High Accessory Load (12 min)	150 Wh	750 W
Parasitic Load (15 mA for 30 days)	130 Wh	n/a

Energy throughput on a per mile basis is also useful, as presented in Figure 6.

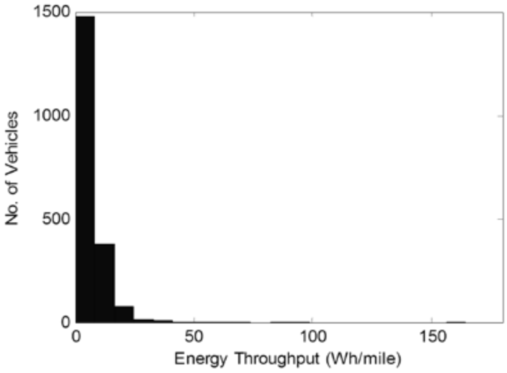


Figure 6: Energy Delivered/Mile by the Battery Frequency Distribution

This same model was also employed to calculate the potential fuel savings of a start stop system. Here the idle fuel rate of a vehicle without a start-stop system is assumed to be 0.28 g/s, and that the overall efficiency of the engine and alternator is 22% when recharging. Results of this analysis (Figure 7) show that the median annual fuel savings is ~7.5 gallons per year. However the 95th percentile driver can save 29 gallons per year. This corresponds to a total fuel savings of 2 to 6%, which agrees well with the urban dynamometer driving schedule (UDDS) test cycle results reported in the reference[6].

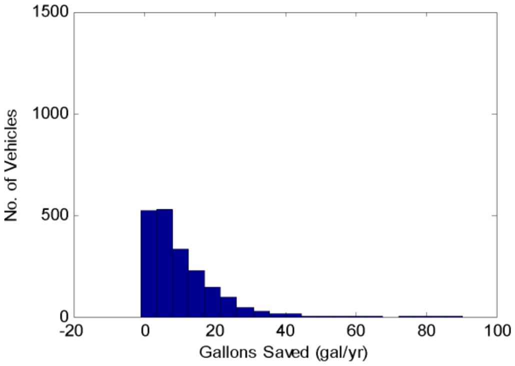


Figure 7: Annual Fuel Saving Frequency Distribution

Using the median annual fuel savings and the U.S. Energy Information Administration (EIA) 2011 high-oil price scenario gas price forecast (~$5/gallon on average between 2015 and 2030) [5], one can calculate the total fuel savings in dollars per vehicle. Conservatively assuming a 10% discount rate and 2.5% inflation rate, the present value of the fuel savings offered by a start-stop system to the driver is approximately $384. Note that the cost of the system to the OEM must be considerably lower than this to account for markup factors and competitive market factors.

An ALABC study [4] computed CO_2 reductions for a similar start-stop system (Table 2), reporting 6-8% reductions. While CO_2 savings were not directly computed in this analysis, the ALABC numbers are in line with the 95th percentile driver when it is assumed that CO_2 savings are proportional to fuel savings.

Table 2: ALABC Study [4]

Metric	Micro-Hybrid
Battery Voltage (V)	12
Regen. Power (kW)	0.5-3.0
OEM On-cost ($)	200-900
CO_2 Emission Reduction (%)	6-8
Cost / Benefit ($ / % CO_2 reduction)	50-130

4. Life-cycle Test Based on Study Findings:

4.1 Life Cycle Testing [2]

The most common test (SBA S 0101:2006 derived by Japan SAE), was studied. The test was standardized to determine the cycle life for Pb-Acid batteries for vehicles with idling-stop systems. The procedure is outlined in Figure 8.

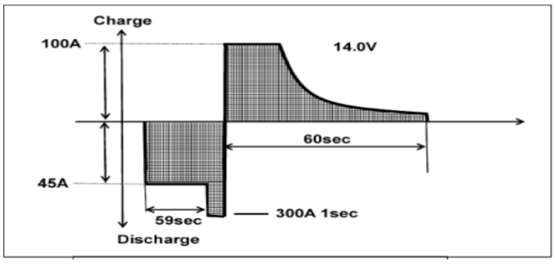


Figure 8: SBA Testing Profile

Since the USABC was looking for a 12 Volt battery which would last the life of vehicle and be maintenance free, the procedure was revised to comply with the features of advanced batteries (e.g. Li-Ion using a charge neutral profile to maintain the target SOC (State of Charge)) (Figure 9).

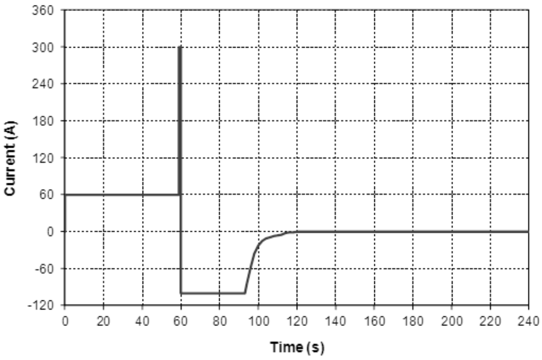


Figure 9: 12 Volt Start-Stop Cycle Life Test Profile

4.2 Cold-Cranking Profile:

Cold cranking power analysis, shown in Figure 10 included the battery data for a cold crank for a Class 1, ¾ ton pickup truck (5.3 L V-8 engine, automatic transmission, 5W30 oil). The cold cranking profile was simplified for testing based on the original testing results, and defined for -30°C.

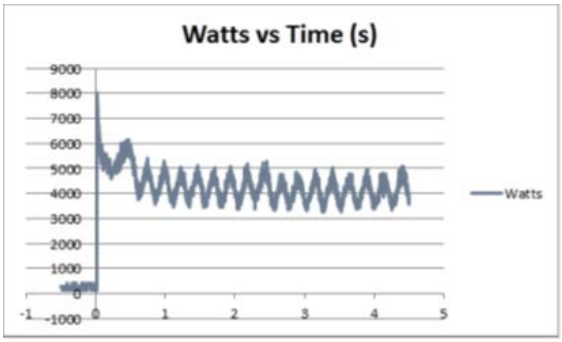


Figure 10: Original Cold Cranking Profile

The simplified profile is as shown below, in Figure 11.

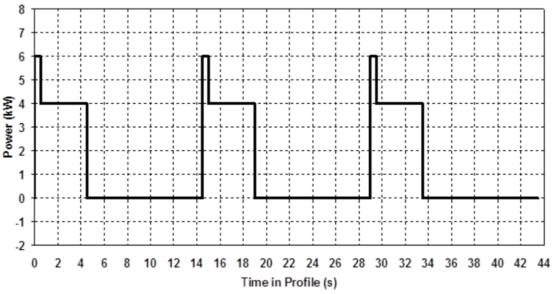


Figure 11: Simplified Cold Cranking Profile

5. Vehicle

A 12 Volt vehicle electric and electronic system is considered for these battery requirements. The cost/benefit ratio for a 12 V system operating only in a stop-start mode was also considered from a business-study point of view. The regen capability of the vehicle during the vehicle deceleration was not considered for an optimum vehicle and battery cost/benefit ratio. There are vehicles in the field operating with this type of configuration. The battery in a conventional ICE vehicle is charged by the alternator at 50-60 A. It was assumed that start-stop battery will be charged whenever there is an opportunity and it was not planned to regen at very high currents. Also there was no power assist expected during the launching of vehicle after an auto start. Cabin climate control during auto stop was expected to be limited, so the auxiliary loads do not include the cabin climate control.

The auto-start-stop function switches off the ICE engine automatically when the vehicle is stopped at a traffic light or traffic jam, etc. The function also starts the engine automatically on driver's demand. The battery is maintained at a desired state of charge (SOC) by using the opportunity charging available from the alternator. The fuel not used during the auto stops thus improves the fuel economy and reduces the total CO_2 emissions.

The estimated fuel saving and CO_2 emissions are reported in Figure 7 and Table 2.

The battery voltage is very critical for the vehicle load maintenance. If the battery voltage is too low and the engine is cranked the high current draw by the starter motor induces a large transient voltage disturbance on the electrical system. The auxiliary electrical load performance is noticeably affected by the changes of electrical system voltage during the auto stop, and the customer may sense a performance quality impact during the engine restart. The target SOC therefore must be kept high without sacrificing the life of the battery.

6. Battery Technology

Two present battery technologies appear well suited to the needs of start-stop systems:

Advanced Lead-Acid Batteries: AGM batteries have demonstrated a longer life than conventional Start Light Ignition (SLI) batteries. According to ALABC the Lead-Carbon (PbC) UltraBattery may have a longer life.

Li-Ion Batteries: USABC has been developing Li-Ion batteries with graphite anodes for various hybrid and EV applications. The life testing of these batteries estimate that the batteries will last the life of the vehicles in HEV, PHEV, and EV applications. The 12 V start-stop batteries will be stressed by repeated starting and may not have sufficient power for a cold-cranking operation. The new development of a Lithium Titanium Oxide (LTO) anode may solve these problems. USABC is providing funding to develop the following couples for commercialization of 12 Start-Stop batteries in near future.

NMC/LTO Couple: 5 cells in series show an excellent match to meet USABC voltage requirements.

LMO/LTO Couple: 5 Cells in series will provide the maximum and minimum voltage to match 6 cells in series combination with Lead-Acid batteries. The rate capability and low temperature performance is expected to match the requirements in Table 3.

7. Conclusion

The hybrid vehicles with lowest level of hybridization are growing worldwide. There will be some vehicles with micro hybrid and mild hybrid capability in some countries, however the most economical application will be with start-stop. This will increase the fuel economy and lower CO_2 emissions

Li-Ion batteries are the dominant and most promising battery technology for the most economical single 12V battery solution and it will have the potential to last the life of the vehicle. The Li-Ion battery technology will reduce the weight and volume of the battery and reduce the life cycle cost when compared with the conventional lead-acid battery solution. The estimated cost of the USABC specified battery is challenging. However, the response from the Li-Ion battery developers shows that the LTO anode may provide the desired cost, life, and durability. Currently USABC has awarded two contracts to develop and deliver the batteries to DOE national labs for verification.

Acknowledgments

The U.S. Department of Energy (DOE) Office of the Vehicle Technology Office supported this effort. We appreciate the technical guidance provided by the USABC Technical Advisory Committee (TAC) and Management Committee (MC).

References

[1] 2006 AUSTIN/SAN ANTONIO GPS-ENHANCED HOUSEHOLD TRAVEL SURVEY, TECHNICAL SUMMARY by Mark Ojah, Assistant Research Specialist, Texas Transportation Institute and David F. Pearson, Ph.D., P.E., Program Manager, Transportation Planning, Texas Transportation Institute, August 2008

[2] SBA S 0101:2006 Lead-Acid Batteries for Vehicles with Idling-Stop Systems

[3] Battery Test Manual For 12 Volt Start-Stop Vehicles, http://www.uscar.org/guest/article_view.php?articles_id=86

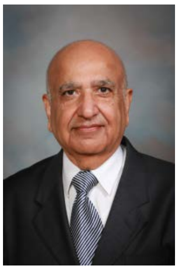
[4] ALABC 2013-2015 Prospectus

[5] http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMM_EPMR_PTE_NUS_DPG&f=W [Accessed: June 5, 2012].

[6] Lohse-Busch, Henning, et. al, "APRF/AVTA Idle Stop Vehicle Testing," http://www.transportation.anl.gov/D3/reports/ANL_APRF_IdleStopvehicleStudy_August2011.pdf [Accessed: June 25, 2013]

[7] *Year 2000 Post-Census Regional Travel Survey: Final Report of Survey Results*, Southern California Association of Governments, Fall 2003.

Authors



Mr. Harshad Tataria, Manager, Technical Advisory Committee, USABC and Tech Team, USDRIVE is a Staff Project Engineer at General Motors Corp, Mr. Tataria has over 40 years of experience in battery development. He has obtained 5 patents and published 34 papers in various scientific journals. In 2013 he was awarded Life Time Achievement Award by USCAR for his leadership and commitment to USCAR.

Mr. Oliver Gross, Manager, Technical Advisory Committee, USABC and Tech Team, USDRIVE is a Senior Energy Storage Systems Specialist at Chrysler Group, Mr. Gross has over 20 years of experience in battery development and manufacturing. His experience includes Lead-Acid, NiMH, Li metal primary and secondary, and Li-Ion batteries. He has obtained 9 patents and published 21 papers in various scientific journals, as well as frequent conference presentations and seminars.

Dr. Jeremy Neubauer is a Senior Engineer with NREL's Center for Transportation Technologies and Systems, where his research activities focus on lifetime analysis of batteries and optimizing battery use strategies for automotive and grid applications. Dr. Neubauer has a Bachelors, Masters, and Doctorate in Mechanical Engineering from Washington University in St. Louis.

Dr. Chulheung Bae, Manager, Technical Advisory Committee, USABC is a battery cell development engineer at Ford Motor Company. Dr. Bae has over 16 years of experience in battery research and development for various applications. He has obtained 4 patents and published 11 papers in various scientific journals

Mr. Brian Cunningham, Manager, Technical Advisory Committee, USABC is a Technology Development Manager at the United States Department of Energy's Vehicle Technologies Office. Mr. Cunningham has over 3 years of experience in battery research and development

Dr. James A. Barnes, Manager, Technical Advisory Committee, USABC is a Research Chemist on assignment to the United States Department of Energy's Vehicle Technologies Office. He has over 30 years of experience in battery research and development and has written a wide range of technical and review presentations.

Dr. Jack Deppe is a member of the USABC Technical Advisory Committee and the USDrive, and works closely with the DOE energy storage national laboratory programs. His concentration is in energy storage for automobiles with 20 years of experience in energy storage and electrochemistry, with concentrations in ionic conduction, materials research, ultracapacitors, and modeling.

Table 3: USABC Goals for Advanced Batteries for 12V Start-Stop Vehicle Applications [3]

End of Life Characteristics	Units	Target	
		Under hood	Not under hood
Discharge Pulse, 1s	kW	6	
Max current, 0.5s	A	900	
Engine-off accessory load	W	750	
Cold cranking power at -30 °C (three 4.5-s pulses, 10s rests between pulses at lower SOC)	kW	6 kW for 0.5s followed by 4 kW for 4s	
Extended Stand Test (30 days at 30°C followed by cold crank test)	kW	6 kW for 0.5s followed by 4 kW for 4s	
Min voltage under cold crank	Vdc	8.0	
Available energy (750W)	Wh	360	
Peak Recharge Rate, 10s	kW	2.2	
Sustained Recharge Rate	W	750	
Cycle life, every 10% life RPT with cold crank at min SOC	Engine starts/miles	450k Starts /150k Miles	
Calendar Life at 30°C, 45°C if under hood	Years	15 at 45°C	15 at 30°C
Minimum round trip energy efficiency	%	95	
Maximum allowable self-discharge rate	Wh/day	10	
Peak Operating Voltage, 10s	Vdc	15.0	
Sustained Max. Operating Voltage	Vdc	14.6	
Minimum Operating Voltage under load	Vdc	10.5	
Operating Temperature Range (available energy to allow 6 kW (1s) pulse)	°C	-30 to + 75	-30 to +52
30 °C – 52 °C	%	100 (to 75°C)	100
0 °C	%	50	
-10 °C	%	30	
-20 °C	%	15	
-30 °C	%	10	
Survival Temperature Range (24 hours)	°C	-46 to +100	-46 to +66
Maximum System Weight	kg	10	
Maximum System Volume	L	7	
Maximum System Selling Price (@100k units/year)	$	$220	$180