APPENDIX B

GENERIC REPORTING

AND

DATA ACQUISITION OUTLINE

FOR

PERFORMANCE AND LIFE TESTING

OF

ELECTRIC VEHICLE BATTERIES

GENERIC REPORTING AND DATA ACQUISITION OUTLINE FOR ELECTRIC VEHICLE BATTERY TESTING

1.0 Purpose and Applicability

This outline defines the general formats and types of information to be acquired and reported to the U. S. Advanced Battery Consortium (USABC) for both the performance and life testing of electric-vehicle batteries. Sections 2 through 6 apply to reporting requirements. Data acquisition and retention requirements are described in Section 7.

1.1 Assumptions

This outline assumes the existence of a test plan that defines the testing to be performed on (each sample of) a given battery, the rationale (purpose) for this testing, and a body of procedures that specify in detail how to conduct each type of test. The test plan and the corresponding procedures should be referenced so that detailed procedural information need not be included in the reporting of test results.

The term 'battery' is used generically in this outline to designate any hardware test unit of whatever size, including cells, modules, battery packs and complete battery systems.

2.0 Test Report Format and Content

The general structure of a testing report is outlined below. Some reports may not contain all the indicated sections if less than the full spectrum of tests are performed. For example, not all batteries will be subjected to performance testing, life testing and post-test analysis. Also, the reported battery descriptive information may be limited if the battery in question is one of a group of identical items being tested. If interim reports are issued during testing, it may not be appropriate to repeat some information. In the most general case, however, testing reports should contain the following types of information:

- Executive Summary (Abstract, Conclusions, Recommendations)
- Testing Objectives
- Battery Descriptive Information
- Performance Test Results
- Life Cycle Test Results
- Post-Test Teardown and Analysis Results
- Conclusions
- Recommendations
- References

Each of these categories of information is briefly summarized below; subsequent sections treat those topics requiring more detailed definition.

2.1 Executive Summary

The executive summary is a compilation (limited to 1-2 pages) of the information that would be most significant to the casual reader. It should contain an abstract as the first part and a reiteration of any conclusions or recommendations contained in the report. The abstract itself is a brief statement (typically less than 200 words) of the purpose of the work, methods, and results. It should be a

stand-alone summary of what was done, the results, and any significance of the results.

2.2 Testing Objectives

A brief statement should be provided that describes the purpose(s) for which the reported testing was done. This should be agreed to with the USABC prior to the start of testing. A test plan for the battery should have been constructed to satisfy these objectives. The report should show how and to what extent these objectives are satisfied.

2.3 Battery Descriptive Information

A description of the battery or battery system that was tested is to be provided in sufficient detail to identify what was tested. This should include any general descriptive information that was not supplied by the developer or the USABC, e.g., battery weights, photographs of fabricated assemblies, etc. Additional information is provided in Section 3.

2.4 Performance Test Results. A description of test results to be reported from performance testing is provided in Section 4.

2.5 Life Cycle Test Results. A description of test results to be reported from life cycle testing is provided in Section 5.

2.6 Post-Test Teardown and Analysis Results. Results to be reported from teardown and analysis after performance or life-cycle testing are discussed in Section 6.

2.7 Conclusions

A conclusions section is to be included to summarize the significance of the reported results, with particular emphasis on (1) the degree to which testing objectives were satisfied; and (2) the extent to which the measured battery behavior approaches the USABC goals or other pre-established requirements for the technology.

2.8 Recommendations

Recommendations should be included where appropriate to convey technical judgments or opinions, suggestions for follow-on testing or problem resolution, or other information that goes beyond interpreting the test results. Recommendations should be directed specifically at battery developers, the USABC and its program managers.

2.9 References

The battery specific test plan and all procedures used in the conduct of reported testing should be referenced at the appropriate reporting stages so that these plans and procedures can be unambiguously related to the testing performed. This will permit subsequent questions about the possible influence of testing methods on test results to be addressed.

2.10 Other Information

Test reports should include adequate definition for nomenclature used in the reports, along with

acronyms and abbreviations where appropriate. Nomenclature should be consistent with the USABC glossary to avoid the need for extensive definitions.

3.0 Battery Information and Description

The initial information to be reported for any battery should be a description of the battery itself, in sufficient detail to unambiguously identify the battery and any unique conditions or limitations imposed on its testing. The intent of this information is two-fold: to clearly distinguish this particular battery and its test regime from other similar ones; and to document information other than test results that was acquired by the test laboratory during testing. In general this would include the following categories of information:

- Physical Characteristics (size, weight, number & condition of cells, interconnection, breakdown of auxiliary equipment etc.)
- Chemical/Electrochemical Characteristics (include manufacturer's specifications for capacity and power, cell voltage etc.)
- System Control, Thermal Management, Operating Description
- Battery Operating/Discharge Limits
- Charging Considerations and Requirements
- Safety Considerations (if they affect testing)

Where appropriate, this information should be supplemented by photographs or diagrams of the battery system and important components.

If only a single battery of a given type is tested, this information will normally be reported along with the performance test results. Where multiple samples of the same battery design are tested, this (common) information could be compiled once and supplied to the test sponsor after review by the laboratory(ies) conducting the testing. For multiple batteries, only the information common to all batteries need be included here; for example, if different charge algorithms are required for different test batteries, these different charging requirements can be included with the performance test results for each battery.

3.1 Battery Identification

A unique identifier will be assigned for each test battery by the USABC when the battery is delivered for testing. The battery information section will tabulate this identifier along with other descriptive data, so that all reported results can be easily related back to this identifier. The method for assigning the battery identifier is detailed in Appendix D.

4.0 Performance Test Reporting

Batteries may be subjected to a wide spectrum of performance tests, ranging from the minimum core tests (presently 6 cycles) to a test sequence requiring several months. Multiple samples of a given hardware deliverable may, in many cases, be subjected to a common test regime. Hence, the extent and frequency of performance test reporting must necessarily be tailored to the length of testing and number of test units. The minimum reporting from the testing of a single test unit is described in Section 4.1. For particular batteries, this summary information will be supplemented with appropriate graphical or other data of specific interest, as outlined in Sections 4.2-4.6. Note that this supplemental information is not expected to be provided for every battery tested; instead only selected samples of a given technology will be examined (as specified in test plans) for these aspects of battery behavior.

Where justified by the extent of testing, a final full report will be published at the conclusion of testing. This report may summarize the performance of an entire group of identical batteries; in some cases it may also include subsequent life cycle test results and/or post-test analysis results. Because of the delays inherent in generating such a report, summary performance test status information is required periodically (generally monthly) for any battery where testing lasts 2 months or more.

4.1 Summary Performance Test Results

Performance test results for each battery tested should be summarized using the format shown in Table B1. This table identifies the particular test unit and lists the key information derived from each type of test specified in the test plan as results become available. Where only minimum core testing is performed, this summary table may be the only performance test reporting required. In other cases, it will be updated as testing progresses and used for periodic reporting. Where a full performance test report is prepared, the final version of this table will be appended to the report.

Where multiple identical samples of a battery are subjected to common test conditions, an overall summary of the test results for each battery in such a group should be provided to permit easy comparison of their performance. A suggested format for such an extended results summary is shown in Table B1a. This may be extended where appropriate to include multiple groups for a given technology. The suggested format for such a high-level summary is shown in Table B2.

In addition to summarizing the general performance test results, these tables provide a mechanism for showing cycle life and for noting any changes in test conditions or battery configuration that occurred during testing.

4.2 Battery Capacity

The measured capacity of the battery in ampere-hours and watt-hour or kilowatt-hours should be reported for the following test regimes if performed:

Constant Current Discharge
Constant Power Discharge
Variable Power Discharge (DST/FUDS)

These results should be representative, in that they are likely derived from multiple tests. For batteries that require time or exercise to reach a stable capacity, both the initial and the stable capacities should be reported.

4.3 Voltage-Current Behavior

Battery voltage (over time or as a V-I plot) should be reported graphically for variable power discharge cycles. This should include open circuit voltage behavior during the rest periods (if any) and after the end of discharge. Voltage-current behavior during a charge cycle should also be reported graphically. For batteries incorporating multiple modules or sub-units, a graphical representation of the voltage variations between modules should be reported for one or more constant current or constant power tests.

Table B1. Summary Test Results

HARDWARE CHARACTERIZATION SUMMARY

USABC ID: _____ REPORTING DATE: _____ Weight (kg): _____

START DATE: _____ COMPLETION DATE: _____ Volume (L): _____

(* CORE TESTS) Basis: _____

PROCEDURE#	DESCRIPTION	RESULTS	COMMENTS
2 (part)	C/3 Capacity Verification	____ Ah _____Wh	
2 12	Charge/Dischg Effic: (Coul) (Energy) Fast Charge	_____ % Ah _____ % Wh __ % Ah ___% Wh	(Describe Charge Method)
2	* Constant Current @ C/3 Constant Current @ C/2 Constant Current @ C/1	___ Ah ____ Wh ___ Ah ____ Wh Ah Wh	
4	* Constant Power @ ____ W Constant Power @ ____ W Constant Power @ ____ W	___ Ah ___ Wh ___ Ah ___ Wh Ah Wh	(Highest value [CORE TEST] should be that required to remove 75% of battery energy in 1 hour)
5	* Variable Power w/DST or FUDS	____/_____ Wh net/gross ____/_____ Ah net/gross	(For DST, report Wh & Ah at unreduced and reduced power conditions, and any procedure deviations)
3	* Derived Peak Power (30s at 80% DOD)	_____ W	(Note the rated peak power if significantly different than the derived value.)
7	Stand time ___h	% Loss	
8	Hill Climb (6 minutes)	Max. % DOD	
6	Partial Discharge	% Loss	
14	Life (DST) Status (cycling start date _____)	__ Cycles total __ Cycles DST	(Also report most recent Reference Performance Tests: capacity on DST, 80% DOD power on Peak Power)

Note: for multiple identical deliverables, this table may be extended with additional Results columns. See Table B1a for example.

Table B1a
Summary Test Results (Extended for Multiple Test Units)

Report Date: _____ USABC Number(s) _____

Procedure	Description	Units	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
1	Mass Volume	kg l										
2 (part)	C/3 Capacity	Ah Wh/kg Wh/l										
2 (part)	Efficiency	% Ah % Wh										
12	Fast Charge	% Acceptance										
2	CC @ C_3/3 CC @ C_2/2 CC @ C_1/1	Ah Ah Ah										
4	CP @ E_3/3 CP @ E_2/2 CP @ E_1/1	Wh/kg Wh/kg Wh/kg										
5	Variable Power DST	Wh/kg Wh/l										
3	Peak Power 30s @ 80% DOD	W/kg W/l										
7	Stand Test 1h 48h 168	 % Loss % Loss % Loss										
8	Hill Climb (6m)	Max. % DOD										
6	Partial DOD Cycles to Full	% Loss Cycles										
14	Life: Peak Pwr 3h Rate DST	Cycles Cycles Cycles										
	Test Plan (Brief Description)											

Note: Comments on Table B1 should be observed for this summary test results table also.

Table B2
Summary Test Results (Multiple Groups of Identical Test Articles)

Report Date: _____

PERFORMANCE AND STATUS SUMMARY OF _____ CELLS/MODULES/BATTERIES UNDER TEST AT _____									
Identification Number	Weight kg	Volume L	Specific Energy C/3 Initial Ah	Specific Energy C/3 Initial Wh/kg	Specific Energy C/3 Present Ah	Specific Energy C/3 Present Wh/kg	Net Specific Energy DST Initial Ah	Net Specific Energy DST Initial Wh/kg	Net Specific Energy DST Present Ah	Net Specific Energy DST Present Wh/kg	Peak Power @ 80% DOD, W/kg Initial	Peak Power @ 80% DOD, W/kg Present	Total & DST Cycles Accrued As of___

NOTE: Weights or volumes used for calculating normalized performance values (e.g. Wh/kg, Wh/l, W/kg) should be the actual measured values of the units under test; otherwise a clearly defined basis for these values must be provided.

4.4 Other Observations

Observed battery behavior that could significantly affect the interpretation or understanding of test results should be noted in narrative fashion. This may include, for example, deviations from procedures due to equipment or battery limitations, or test anomalies which are outside the expected range of results. Also reliability or maintenance concerns that might affect the suitability of the battery for life cycle testing should be reported.

5.0 Life Cycle Test Reporting

Summary status tables (e.g., Tables B1 and B2) are to be used as the basic means of reporting accumulated cycles and degree of performance degradation during life cycle testing. This status report (with accompanying pertinent graphical data) will be provided throughout the lifetime of the unit under test at periodic intervals. This reporting will act as a supplement to the summary reports provided during performance characterization. The final report will summarize the life cycle history of the test unit (or an entire group of identical batteries where appropriate.)

5.1 Life Cycle Tests

For any selected life-cycle testing regime, the initial test(s) should be reported in the same level of detail as the comparable (variable power discharge) performance test. Reporting for subsequent tests should be confined to a small number of selected parameter values, preferably as specified in the test plan. For example, if a life cycle discharge is to be terminated after a fixed number of Ah is removed from the battery, the voltage at end of discharge should be reported; conversely, if the test is terminated on a predetermined voltage limit, the battery capacity should be reported. A graphical representation of the selected parameters versus (cumulative) cycle count should be provided.

5.2 Frequency of Reporting

Because life-cycle tests on a given battery may require months or years to complete, the reporting of such results should take place on a periodic basis to provide timely status information to the test sponsor. Initial life cycle test results will be reported in accordance with the test plan (e.g., after the second RPT set is performed). Subsequent status updates would then be provided at agreed-on intervals (e.g. monthly or quarterly) depending on the expected duration of the testing.

Note: additional guidance for periodic reporting of test results (e.g. quarterly and/or weekly) is under development and will be provided in a future revision to this manual.

6.0 Post-Test Teardown and Analysis Reporting

Detailed procedures for post-test teardown and analysis have not yet been defined. Presumably, the results of such analyses would be reported as photographic/microphotographic records, chemical analysis values, and narrative information. Requirements for such analysis (and resulting reporting) should be specified in the test plan for each test unit.

7.0 Data Acquisition and Retention Requirements

7.1 Measurement Parameters

The basic requirement of the data acquisition system is to sample battery parameters in a manner that assures that the test unit response to load demand can be accurately measured and/or reproduced.

All battery discharge/charge cycling requires three fundamental measurements: voltage, current, and temperature. Measurement to be performed during vibration testing are described separately in Procedure #10. The time that each parameter is sampled is recorded with the measurement. For laboratory charge/ discharge testing, it is generally adequate to derive battery power from the multiplication of current and voltage. However, if more than 1 millisecond elapses between any voltage and current samples used to derive power, a power measurement instrument must be used to acquire battery power information.

Data acquired from these measurements is used to derive the remaining battery discharge/charge parameters such as cell/module/battery resistance, capacity (ampere-hours), and energy (watt-hours).

7.2 Test Modes and Data Sampling Requirements

The modes in which electrical testing may be performed on a battery are as follows:

Constant Current Discharge (CC)
Constant Power Discharge (CP)
Variable Power Discharge (VP) FUDS, DST
Peak Power Discharge (PP) (is a Variable Current Discharge)
Recharge (RCG) (CC and/or CP)

These tests modes have varying sample requirements. Recharge, Constant Current Discharge, and Constant Power Discharge testing require a minimum of one sample (a) every 10 minutes or (b) whenever any measurement changes by more than 2% of its previous value (of current, voltage or temperature) to be recorded during the full duration of a test.

Variable Power or Peak Power discharge tests require sampling of all measurements at a minimum of one sample per second during periods of current or power changes. Acquisition systems capable of programmable sampling may be set up to reduce the amount of data storage by decreasing sampling during static portions of tests (e.g. the constant current periods during a Peak Power Test.) If sample rates for slowly moving parameters such as temperature can be programmed independently, further reduction in the amount of stored data may be effected by decreasing the number of samples (per channel) for such parameters to the same as those required for RCG, CC or CP tests.

Sampling requirements for Life Cycle DST discharges (Procedure #5A) may be reduced by the following two-step process: (a) sampling test unit voltage and current (only) near the beginning and end of each power step in a DST profile; and (b) sampling all measurements near the end of the maximum discharge (100%) and maximum regen (50%) steps for each 360 second DST profile completed.

7.3 Measurement Accuracies

Required accuracies for the respective measurements are:

Measurement	Accuracy (% of Reading except as noted)
Voltage	< 1.0
Current	< 1.0
External Temp	+/- 3°C
Internal Temp	+/- 3°C
Ambient Temp	+/- 3°C
Power	< 3.0
Vibration (Accel)	< 4.0

The implied accuracy for other derived (calculated) data such as accumulated energy or Ah capacity is data system dependent but generally should not exceed 3%.

7.4 Data Retention

For each discharge/charge cycle during both performance and life cycle testing, a tabulation of summary data, including cycle number, test duration, calculated values (e.g., energy and capacity), and starting and ending values for parameters such as open circuit voltage and temperature, will be permanently retained.

For the characterization performance tests and the Reference Performance Tests during life cycle testing, the minimum number of samples identified in Section 7.2 should be retained permanently for each discharge/charge cycle.

For life cycle testing, the recorded data identified in Section 7.2 must be retained a minimum of 2 months, after which it can be deleted (except for summary results) with the written consent of the program manager. Any summary results that must be retained for each life cycle should be identified in the test plan.

7.5 Data Formats

Test results and other data may be retained in at least 4 formats as appropriate: narrative, numerical/tabular, graphical, and computer files. All data to be retained should be stored in permanent, secure, and backed-up computer files. For graphs having relatively few data points, the values should also be retained and reported in numerical/tabular form for subsequent analysis use.