Attachment A
RFP NNC08ZRP024R
Statement of Work

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1.0 Objective

The overall objectives of the work defined in this Statement of Work are to identify components and develop designs for High Energy and Ultra High Energy lithium-based cells in support of NASA's Constellation Programs.

2.0 Background

NASA's Exploration Technology Development Program, Energy Storage Project, is developing battery technologies to support Constellation's Altair, Extravehicular Activities (EVA), and Lunar Surface Systems projects. These customers require safe, very high specific energy, low volume batteries. The Energy Storage Project is responsible for the development and demonstration cells with the desired characteristics for High Energy and Ultra High Energy batteries, to TRL 6, by 2013 and 2014 respectively. The master schedule for the battery development is shown in Figure 1: Lithium-Based Battery Development Master Schedule
. Basic tasks and options for this procurement are shown in colored boxes.

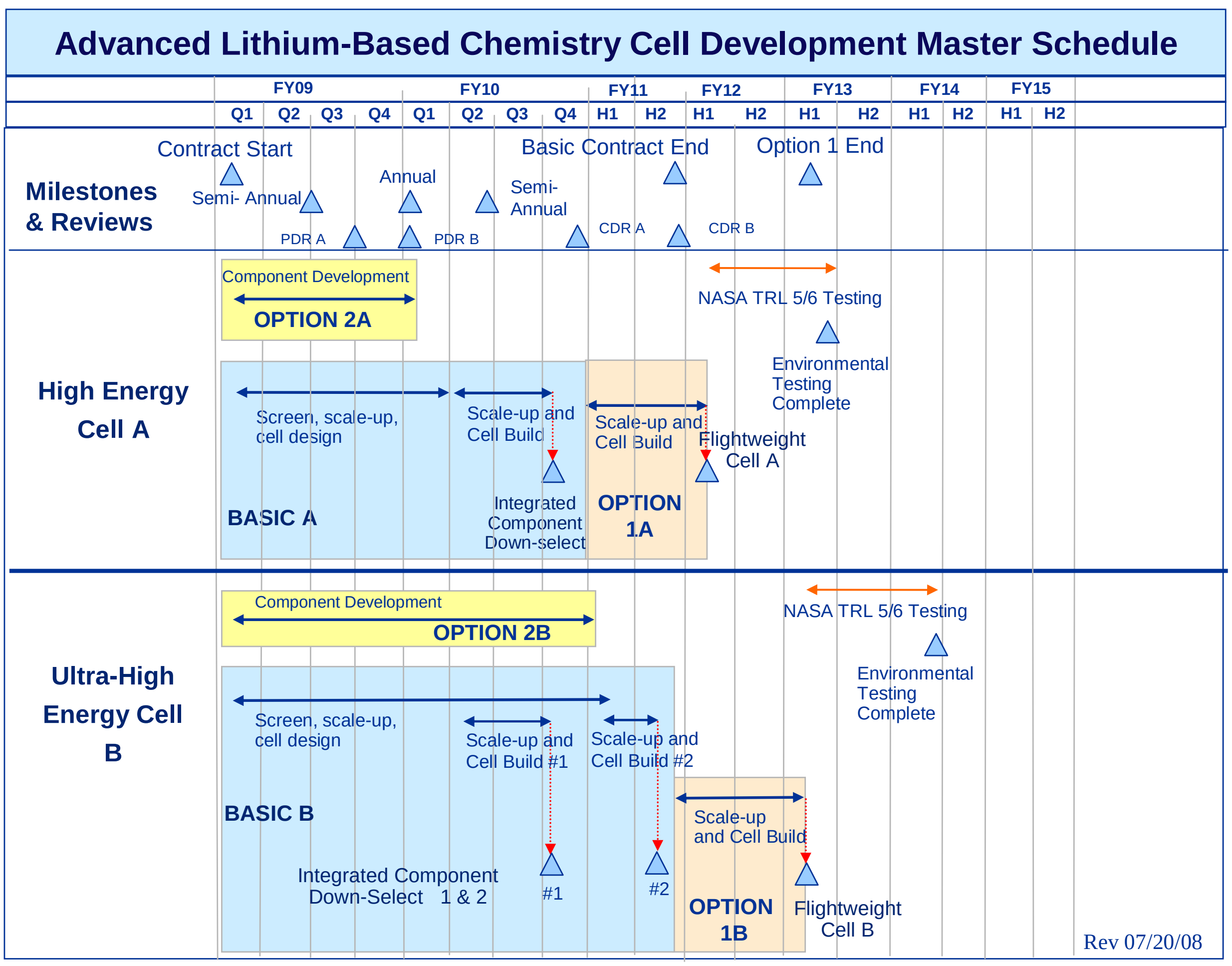

Figure 1: Lithium-Based Battery Development Master Schedule

The Energy Storage Project recently conducted extensive studies to identify the component options that will lead to advanced lithium-based batteries with the greatest potential to provide the best combination of safe, reliable performance with extremely high specific energy within the required timeframe. Parallel paths have been identified that focus on the cathode and anode, respectively, along with development efforts related to separators, electrolytes, and functional components that address system safety and reliability. Combinations of these components are shown in Figure 2, with the cell designated High Energy Cell A comprised of a commercial anode and a commercial or NASA-developed separator, combined with a NASA-developed cathode and electrolyte. The Ultra High Energy Cell B uses the same NASA-developed cathode, as well as a NASA-developed anode and separator. The electrolyte for Cell B may be the same as for Cell A or may be modified as necessary to achieve required safety performance and/or compatibility with the anode. Cell design optimization is required for both cells to meet the targeted goals.

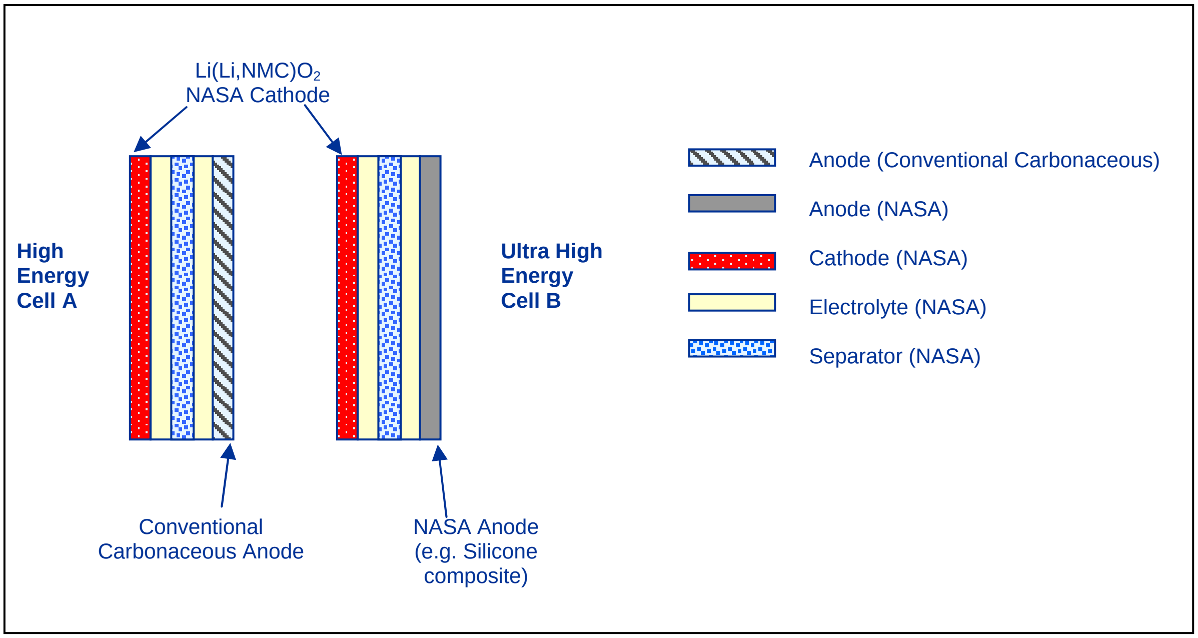

Figure 2: Schematic showing expected components of the High Energy Cell A and Ultra High Energy Cell B

Key Performance Parameters for the products delivered by the Energy Storage Project are defined in Table 1. The High Energy cell effort targets development of a lithium nickel manganese cobalt oxide [$Li(Ni,Mn,Co)O_2$] cathode paired with a conventional carbonaceous anode. The Ultra High Energy chemistry combines the cathode developed for the High Energy cell option with an advanced composite anode. Advanced electrolytes, separators and cell design features will be incorporated into both cell designs.

Key Performance Parameters for Battery Technology Development

Customer Need	Performance Parameter	State-of-the-Art	Current Value	Threshold Value	Goal
Safe, reliable operation	No fire or flame	Instrumentation/controllers used to prevent unsafe conditions. There is no non-flammable electrolyte in SOA	Preliminary results indicate a moderate reduction in the performance with flame retardants and non-flammable electrolytes	Benign cell venting without fire or flame and reduce the likelihood and severity of a fire in the event of a thermal runaway	Tolerant to electrical and thermal abuse such as over-temperature, over-charge, reversal, and external short circuit with no fire or flame
Specific energy	**Battery-level** specific energy*	90 Wh/kg at C/10 & 30°C 83 Wh/kg at C/10 & 0°C (MER rovers)	130 Wh/kg at C/10 & 30°C 120 Wh/kg at C/10 & 0°C	**135** Wh/kg at C/10 & 0°C "High-Energy"** **150** Wh/kg at C/10 & 0°C "Ultra-High Energy"**	**150** Wh/kg at C/10 & 0°C "High-Energy" **220** Wh/kg at C/10 & 0°C "Ultra-High Energy"
	Cell-level specific energy	130 Wh/kg at C/10 & 30°C 118 Wh/kg at C/10 & 0°C	150 Wh/kg at C/10 & 0°C	**165** Wh/kg at C/10 & 0°C "High-Energy" **180** Wh/kg at C/10 & 0°C "Ultra-High Energy"	**180** Wh/kg at C/10 & 0°C "High-Energy" **260** Wh/kg at C/10 & 0°C "Ultra-High Energy"
	Cathode-level specific capacity	140 – 150 mAh/g typical	$Li(Li_{0.17}Ni_{0.25}Mn_{0.58})O_2$: 240 mAh/g at C/10 & 25°C $Li(Li_{0.2}Ni_{0.13}Mn_{0.54}Co_{0.13})O_2$: 250 mAh/g at C/10 & 25°C 200 mAh/g at C/10 & 0°C	**260** mAh/g at C/10 & 0°C	**280** mAh/g at C/10 & 0°C
	Anode-level specific capacity	320 mAh/g (MCMB)	N/A 450 mAh/g Si composite	**600** mAh/g at C/10 & 0°C (with Si composite)	**1000** mAh/g at C/10 0°C (with Si composite)
Energy density	**Battery-level** energy density	250 Wh/l	n/a	**270** Wh/l "High-Energy" **360** Wh/l "Ultra-High"	**320** Wh/l "High-Energy" **420** Wh/l "Ultra-High"
	Cell-level energy density	320 Wh/l	n/a	**385** Wh/l "High-Energy" **460** Wh/l "Ultra-High"	**390** Wh/l "High-Energy" **530** Wh/l "Ultra-High"
Operating environment	Operating temperature	-20°C to +40°C	-50°C to +40°C	**0°C** to **30°C**	**0°C** to **30°C**

Assumes prismatic cell packaging for threshold values. Goal values include lightweight battery packaging.
* Battery values are assumed at 100% DOD, discharged at C/10 to 3.000 volts/cell, and at 0°C operating conditions
** "High-Energy" = Exploration Technology Development Program cathode with MCMB graphite anode
"Ultra-High Energy" = Exploration Technology Development Program cathode with Silicon composite anode

Revised 07/02/08

Table 1: Key Performance Parameters for Space-Rated Lithium-Based Battery Technology Development

The Government will develop the new components through a combination of NASA in-house, university, and industrial efforts that will be conducted in parallel with this contract. The purpose of the basic work portion of this contract is to screen and scale-up these new materials, incorporate them into small capacity cells for evaluation ("evaluation cells"), and to develop a design(s) for High Energy and Ultra High Energy flightweight cells that meet flight performance requirements. There is an option to fabricate cells to this design specification and there is also an option for component development to be performed under this contract. An explanation of what must be proposed for the basic work and options is given in Table 2, and the scope of work for the basic tasks and options is summarized in Table 3 and described in detail in Section 3.0.

The NASA-recommended materials shown in Figure 2 and Table 4 and described in Section 4.0 are the preferred approach for meeting the Key Performance Parameters and other technical goals listed in Table 1. However, the Contractor may propose all basic and optional work using different materials of their choosing. If the Contractor makes a compelling case that their proposed materials have a higher likelihood of meeting the Key Performance Parameter goals listed in Table 1 with acceptable risk, then the Government may choose to award all tasks based on this alternate chemistry. Only one set of cells will be funded: either cells based on the Government recommended materials;

or, cells based on an alternate chemistry proposed by the Contractor. If the Contractor proposes an alternate chemistry, component performance evaluations for the Contractor's recommended materials will be based on exceeding the threshold and goal values listed in Table 1.

	Basic Tasks	Option 1 Flightweight Cells	Option 2 Component Development
High Energy Cell A	Contractor must propose this task.	Contractor must propose this task (Option 1A). NASA will decide in FY2010 whether to exercise this option.	Contractor may propose this task (2A). NASA will decide at time of award whether to exercise this option.
Ultra High Energy Cell B	Contractor must propose this task.	Contractor must propose this task (Option 1B). NASA will decide in FY2011 whether to exercise this option.	Contractor may propose this task (2B). NASA will decide at time of award whether to exercise this option.

Table 2: Delineation of Basic Work Effort and Options

3.0 Scope of Work

The Contractor shall furnish personnel, facilities, materials, services, and equipment to accomplish the following basic tasks. For the rest of this document, it is assumed that the Contractor is proposing to use NASA-recommended materials unless otherwise stated. If the Contractor is proposing to use their own materials, "Contractor-recommended" should be substituted for "NASA-recommended" wherever it occurs.

The Contractor shall propose and provide rationale for selecting a "standard" aerospace cell chemistry and configuration to be used as a benchmark for comparison purposes for technology advances to be evaluated under this contract. The set of baseline components shall include an anode, a cathode, an electrolyte, and a separator. This "standard" configuration will be used to evaluate the performance of newly developed components against the Contractor's known heritage to assess performance metrics. The Contactor shall provide rationale for the selection of the components.

Basic Tasks:

- Evaluate NASA-recommended and screened component materials for their compatibility with commercial manufacturing processes
- Scale-up promising materials
- Optimize electrodes based on performance and manufacturability
- Design, fabricate, acceptance test, and deliver evaluation cells
- Develop High Energy and Ultra High Energy flightweight cell designs to meet NASA-defined performance requirements

Optional Tasks:

- Construct flightweight cells built to the design developed under the basic tasks
- Develop components that address NASA performance goals

These basic tasks and options are summarized in Table 3. Note that proposals must include all basic work and Option 1 for both cells (A & B). If the Contractor is proposing an alternate chemistry, component development, proposing Option 2, is mandatory.

<table>
<tr><th></th><th><u>Basic</u>
(34 months)</th><th><u>Option 1</u>
Flightweight Cell Fabrication
(15 months)</th><th><u>Option 2</u>
Component Development
(up to 24 months)</th></tr>
<tr><td>High Energy Cell A</td><td rowspan="2">· Component screening and evaluation for manufacturing suitability
· Component material scale-up
· Electrode optimization
· Fabrication and delivery of evaluation screening cells
· Flightweight Cell Design</td><td>Fabrication and delivery of 12-48 (TBR) High Energy, ~35 Ah (TBR) flightweight cells that incorporate cell-level safety components.</td><td>R&D for improved separators, cathodes, and/or electrolytes compatible with cells developed in Basic A and Option 1A.</td></tr>
<tr><td>Ultra High Energy Cell B</td><td>Fabrication and delivery of 12-48 (TBR) Ultra High Energy, ~35 Ah (TBR) flightweight cells that incorporate cell-level safety components.</td><td>R&D for improved anodes, separators, cathodes, and/or electrolytes compatible with cells developed in Basic B and Option 1B.</td></tr>
</table>

Table 3 Summary of Work Content of Basic Work and Options

The estimated period of performance for the basic work portion of this effort is 34 months. The estimated period of performance for the Option 1 work portion of this effort, if exercised, shall be 15 months for each flightweight design cell. The estimated period of performance for the Option 2 work portion of this effort, if exercised, shall be up to 24 months.

NASA plans to develop the component technologies at NASA and through NASA Research Announcement identified as NRA NNC08ZP022N. In addition, NASA will leverage relevant government and Small Business Innovative Research (SBIR) sponsored component technology development efforts.

The Contractor's primary role under this contract will be to screen component materials to evaluate their manufacturability, scale-up production of the component materials, fabricate and deliver evaluation test cells for integrated component evaluation, develop High Energy and Ultra High Energy ~35 Ah (TBR) flightweight cell designs to meet flight performance requirements listed in Table 1, and to optimize the components for integration into a manufacturable cell. Virtual cells that meet the required performance requirements are an option. At NASA's option, the Contractor will manufacture the flightweight cells. The cells will be advanced from TRL 4 through TRL 6 by performance and environmental testing by NASA. NASA defines TRL 4 to be the integration of the components into a cell, TRL 5 is reached by performance testing to verify cell-level goals, and TRL 6 demonstrates cell-level performance in a relevant thermal, vacuum, vibration, acoustic, electrical and radiation environment.

Term	Definition
High Energy Cell A	Expected cell-level specific energy: 180 Whr/kg specific energy at C/10 and 0^oC to 3.00 Volts/cell Expected components: NASA-defined $Li(Li,NMC)O_2$ cathode, electrolyte, separator and Contractor proposed carbonaceous anode NMC= Ni,Mn,Co Targeted Performance: 2,000 cycles at 100% DOD to 80% of original capacity at C/2
Ultra High Energy Cell B	Expected cell-level specific energy: 260 Wh/kg specific energy at C/10 and 0°C to 3.00 Volts/cell Expected components: NASA-defined $Li(Li,NMC)O_2$ cathode, electrolyte, separator, and silicon-composite anode NMC= Ni,Mn,Co Targeted Performance: 200 cycles at 100% DOD to 80% of original capacity at C/2
Component screening	Screening of NASA provided materials to assess suitability for scale-up and incorporation into electrodes or cells
Material scale-up	Production of component materials in sufficient quantities to support outlined cell builds
Evaluation screening cell	Small, inexpensive cells of a format to be proposed by the Contractor. Must be production cells of known form, fit, and function that will support the evaluation of the cell's tolerance to abuse such as defined in Table 1, with a minimum 2.0 Ah capacity that yield consistent performance that can be scaled to the ~35 Ah (TBR) Flightweight Cell or Virtual Cell configuration.
Flightweight cell	~35 Ah (TBR) cell (or equivalent virtual cell) that meets the Key Performance Parameter requirements specified in Table 1, and passes environmental acceptance and qualification tests tailored by NASA per GLM-QE-8700.2 (SARG), and CxP-70036 (CEQATR)
Cell lot	Group of cells manufactured at the same time under the same conditions using the same continuous production run of anodes, cathodes, separator, container, and electrolyte batch
Functional components	Additional components that contribute to the overall safety and reliability of the flightweight cell

Table 4. Definition of terms used in Tables 2 and 3

The safety requirement for batteries used in crewed space environment is two-fault tolerance to catastrophic failures. For lithium-ion batteries or batteries with lithium-based chemistries, the main hazards are over-charge, over-discharge, external and internal short and high temperatures. The safety goal for this effort is to develop lithium-ion cell/batteries that are tolerant to the above mentioned hazards and are listed in Table 1. Tolerance should be demonstrated by the fact that the cells or battery does not exhibit any flame or vent with fire under any of the conditions specified in Table 1. Tolerance can be demonstrated at the battery level.

Applicable Government Documents

The following documents shall be used for the design and fabrication of the flightweight cells required in the Optional Tasks 1A and 1B. The evaluation and screening cells will be held to the functional and workmanship standards of GLM-QE-8700.2 while the flightweight cells will be held to the qualification levels to successfully meet the NASA TRL 6 environmental and performance testing.

GLM-QE-8700.2	SPACE ASSURANCE REQUIREMENTS AND GUIDELINES (SARG) Revision C2, April 18, 2007
JSC-20793	Crewed Space Vehicle Battery Safety Requirements Rev. B, April 2006
SP-T-0023	Environmental Acceptance and Qualification Testing Specification, Revision C, Change Number 3, March 14, 2008
CxP-70036	Constellation Program Environmental Qualification and Acceptance Testing Requirements (CEQATR) Rev. A September 5, 2007

Documentation specific to the design of the vehicles planned for the Exploration missions is not currently available for release. The above documents should provide a basic indication of the design requirements. NASA will provide the most up to date information available at the time of the initiation of the relevant tasks.

4.0 Basic Tasks

The Contractor shall provide the technical expertise and capability to screen and scale-up NASA-recommended anode, cathode, electrolyte, and separator materials into quantities sufficient for the construction of evaluation cells as defined in Task A (High Energy Cell Development) and Task B (Ultra High Energy Cell Development).

The Contractor shall design, develop, and deliver High Energy and Ultra High Energy battery cell designs that address the Key Performance Parameters defined in Table 1.

To accomplish this work, the Contractor shall perform the specific tasks detailed below. All items requiring the approval of the NASA Project Manager shall be approved or disapproved within ten (10) working days of receipt by the NASA Project Manager. Unless other arrangements are made, the Contractor shall interpret the lack of response within the required time frame as approval to proceed with the work outlined in this statement of work.

The Contractor shall alert the NASA Project Manager by telephone or electronic mail within ten (10) working days of its knowledge of any issues that arise that may affect the consistency, performance, stability of the supply, or availability of materials. Written details of the issues must be provided in the earliest possible monthly report. The reporting shall contain a description of the issues, the current status of the issues, details of any efforts to resolve the issues, and the final resolution of the issues. Specific reporting on these issues shall be contained in each monthly report until the issues are resolved to the NASA Project Manager's satisfaction.

There will be a kick-off meeting within 30 days of contract award. The kick-off meeting will be held at the Contractor's facility, and shall be attended by the Principal Investigator, other key Contractor personnel, the NASA Project Manager, and other key NASA personnel. Teleconference meetings will be held at least bi-weekly to review the progress of the contract. Semi-annual and annual reviews will be held at the Contractor's facility, and shall be attended by the Principal Investigator, other key Contractor personnel, the NASA Project Manager, and other key NASA personnel.

Written status reports shall be delivered monthly from the Contractor to NASA. The status reports shall contain details regarding routine investigations, updates on component screening and evaluations, scale-up, optimization, evaluation cell design and build, flightweight cell design, optional tasks for any exercised options, and any issues, their status, proposed resolutions, and anticipated timeframe for resolution. A Final Report that summarizes accomplishments and expenditures over the entire project will be due one month prior to the planned final date of the contract.

A detailed Master Work Plan delineating how the Contractor will accomplish the goals and objectives of the proposed work including research methodologies, processes, and resources, and schedule shall be delivered within 30 days of contract award.

A summary of reporting requirements and deliverables for Basic Tasks A and B is given in Table 11 of Section 4.3. Details of the contents of task-specific written reports and deliverables are given in their respective sections.

4.1 Task A - High Energy Cell Development

The Contractor shall deliver, to the NASA Project Manager, a baseline design of a High Energy rechargeable battery cell that incorporates the features and characteristics described in Figure 2 and Table 1 above. The Contractor shall screen NASA-defined and recommended cathode materials, separator, and electrolytes for incorporation into evaluation test cells. The Contractor shall propose a suitable anode to be combined with the NASA-recommended materials for use in the High Energy Cell. The Contractor shall scale-up cell materials in the quantities required to build the defined number of evaluation test cells that have a minimum capacity of 2 Ah. The Contractor shall fabricate evaluation test cells that consist of the Contractor-proposed anode and different combinations of NASA-recommended components. The Contractor shall perform any process optimization necessary for production of materials in sufficient sizes, quantities and quality for use in evaluation test cell fabrication.

4.1.1 Task AA - Anode for High Energy Cell

NASA has baselined a carbonaceous anode for the High Energy cell design. The Contractor shall propose and specify a carbonaceous anode for use in the High Energy cells that has demonstrated performance in lithium-ion cells. The proposed anode material shall have the specific capacity and electrochemical and safety characteristics that meet or exceed those described for the High Energy cell as addressed in Table 1, Key Performance Parameters. The Contractor shall also provide the rationale for the selection and provide information regarding the future stability and availability of the candidate source material.

The Contractor shall provide samples of the electroactive anode material and fabricated anodes in the quantities listed in Table 5 within 120 days of the initiation of the contract.

	Quantity	**Due Date**
Electroactive Anode Powder	15 grams powder	120 days after start of contract
Fabricated Anodes	800 cm^2 minimum width 10 cm	120 days after start of contract

Table 5: High-Energy Anode Deliverable Quantities

4.1.2 Task AB - Component Material Screening for High Energy Cell

At specified intervals throughout the period of performance, battery cell component materials developed by NASA, or a third party, will be delivered to the Contractor. The approximate timeframes that NASA will deliver the components to the Contractor are given in Table 6. Table 7 lists the quantities of each material/component that will be delivered to the Contractor on each deliverable date. The Contractor shall screen and evaluate these materials for their manufacturability, compatibility with the production processing equipment proposed for use, and scalability for quantities and consistencies required to build and deliver fifty (50) ~35 Ah (TBR) flightweight cells or virtual cells. On an as needed basis, the Contractor shall communicate with the NASA project manager and third parties that developed the materials for the purposes of gaining insight into the materials, their proper handling and treatment, scale-up and fabrication methods, any specialized test procedures to evaluate materials and other relevant factors that may impact the screening, scale-up, manufacturability, or performance of the materials.

The Contractor shall provide screening criteria individual screening plans for the evaluation of each component. The Component Screening Plan shall document the processes and procedures that will be used to screen and evaluate the NASA-supplied cathode, separator, electrolyte, and safety and functional materials and components for their compatibility with material production processes capable of producing sufficient quantities of the component materials, compatibility with existing cell manufacturing equipment, and overall manufacturability. Typical screening assessments include, but are not limited to, physical dimensions, material properties, structural integrity, chemical compatibility, purity, specific capacity, reversible and irreversible capacity, rate capability, conductivity, flammability, wettability, and cost. The Component Screening Plan which includes the cathode, separator, and electrolyte materials shall be delivered to the NASA Project Manager within ninety (90) days of the initiation of the contract for review and approval. The Safety and Functional Components Plan shall be delivered within thirty (30) days of the definition of the nature of the components to be screened.

The screening and evaluation of each component shall be completed within forty-five (45) days of its delivery to the Contractor. Interim reporting on these evaluations shall be included in the monthly reports.

The Contractor shall submit a final report summarizing the overall results of the screening and evaluation of all components for the High Energy cell and containing a comparative assessment of the suitability of each component for use in the evaluation cells and the flightweight cells. The Contractor shall identify, prioritize, and recommend materials for use in the High Energy cell and support the selections with adequate technical rationale. This report shall be delivered fifteen (15) months after the initiation of the contract. Within two weeks of the delivery of this report, the Principal Investigator and other key personnel for the Contractor shall participate in a component downselection meeting with the NASA Project Manager to determine the materials that will be scaled-up for evaluation in the High Energy evaluation cells. Selection of the materials will be performed in consultation with and with the approval of the NASA Project Manager.

Approximate Timeframe NASA will provide cathodes, electrolytes, separators and safety devices
8 months after start of Contract
12 months after start of Contract

Table 6: Dates NASA will Provide Cathodes, Electrolytes, Separator and Safety/Functional Component Materials to Contractor

NASA will provide to the Contractor samples of component material developed through internal NASA efforts, efforts funded under the Exploration Technology Development Program Energy Storage Project's NASA Research Announcement (NRA) NNC08ZP022N, or other sources.

Components	Quantities
Cathodes	30 grams electroactive powder
Separators	2 sheets of 400 cm^2 separator
Electrolytes	75 ml electrolyte
Safety and functional	Deliverables and quantities will be defined at a later date

Table 7: Quantities of Cathodes, Electrolytes, Separator and Safety/Functional Component Materials NASA Provides to Contractor

4.1.2.1 Task ABA – Null

There is no anode screening task for the High Energy Cell.

4.1.2.2 Task ABB - Cathode Screening for High Energy Cell

NASA will identify and provide samples of the cathode materials to be evaluated for the High Energy cells. The general classes of cathode chemistry targeted for investigation include the $Li(Ni_{0.33}Mn_{0.33}Co_{0.33})O_2$ or a lithiated nickel manganese cobalt such as $Li(Li_{0.20}Mn_{0.54}Ni_{0.13}Co_{0.13})O_2$ with a general designation $Li(Li,NMC)O_2$.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) NASA-recommended cathode candidates in accordance with the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate cathode materials for their suitability for fabrication into completed electrodes. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to production level quantities sufficient to accommodate the fabrication of up to 48 flightweight ~35Ah cells or virtual cells while maintaining uniformity and electrochemical performance.

The Contractor shall investigate the manufacturability of the NASA-recommended cathode materials through various screening techniques that may include small-scale production lots as per the Contractor's standard aerospace lithium-based cell manufacturing techniques.

4.1.2.3 Task ABC - Electrolyte Screening for High Energy Cell

NASA will provide the electrolytes to be evaluated for the High Energy cells. The general classes of electrolyte chemistry for investigation include conventional $LiPF_6$ solutions in EC, PC, DEC, DMC or EMC mixtures and ionic liquids.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended electrolyte formulations/candidates via the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate electrolytes for their suitability for fabrication into completed lithium-based cells. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to large production level quantities of materials while maintaining uniformity and stable electrochemical performance.

The Contractor shall investigate the manufacturability of the new electrolyte materials through various screening techniques and the evaluation of the electrolyte compatibility with the cell production infrastructure.

4.1.2.4 Task ABD - Separator Screening for High Energy Cell

NASA will provide the separators to be evaluated for the High Energy cells. Classes of separator materials under consideration include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended separator candidates via the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The

Contractor shall evaluate the candidate separator materials for their suitability for fabrication into completed cells. The Contractor shall also evaluate the scalability of separator materials from the small laboratory batch sizes to large production level quantities of materials while maintaining uniformity and electrochemical performance.

4.1.2.5 Task ABE - Safety and Functional Components Screening for High Energy Cell

NASA will provide the safety/functional components to be evaluated for the High Energy cells. These components may be in the form of enhancements to electrolytes or electrodes or functional components that are physically incorporated into the cell.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended safety/functional candidates in accordance with the Safety and Functional Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate safety/functional components for their suitability for fabrication into completed lithium-based cells. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to large production level quantities of materials while maintaining uniformity and stable electrochemical performance.

The Contractor shall investigate the manufacturability of the safety and functional component materials through various screening techniques and the evaluation of their compatibility with the cell production infrastructure.

4.1.3 Task AC - Component Material Scale-up for High Energy Cell

The Contractor shall reproduce the sample materials that have been down selected and scale them up in the quantities and quality required for fabrication of the evaluation cells. The Contractor shall demonstrate that the selected process is capable of further scale-up and representative of the process required to manufacture materials to build up to 48 flightweight cells. The scale-up of component materials can be a sub-contracted effort. As needed, the Contractor shall communicate with the NASA Project Manager and third parties that developed the materials for the purposes of gaining insight into the materials, their proper handling and treatment, scale-up and fabrication methods, and other relevant factors that may impact the scale-up, manufacturability, or performance of the materials.

4.1.3.1 Task ACA – Null

There is no anode scale-up task for the High Energy Cell.

4.1.3.2 Task ACB - Cathode Scale-up for High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

The cathode materials targeted for scale up and incorporation into cells are lithiated mixed metal of oxides, with different proportions of Co, Ni and Mn. Specifically, these are solid solutions between $Li[Li_{1/3}Mn_{2/3}]O_2$- a non-intercalating phase and an

intercalation phase, for example, $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$. These could be the same or similar to the compositions listed below as examples:
Cathode 1: $Li_{1.0}(Li_{0.17}Ni_{0.25}Mn_{0.58})O_2$ Cathode 2: $Li(Li_{0.20}Mn_{0.54}Ni_{0.13}Co_{0.13})O_2$

4.1.3.3 Task ACC - Electrolyte Scale-up for High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

The electrolytes targeted for this demonstration are based on multi-component blends of ethylene carbonate and linear carbonates and may contain: i) low-viscosity co-solvents with adequate chemical and electrochemical stability, ii) fluorinated analogues for improved safety and stability at high voltages, iii) SEI enhancing additives, iv) thermally stable salts, v) thermally and electrochemically stable salts, vi) flame retardant additives, vii) self extinguishing electrolytes, viii) ionic liquids.

4.1.3.4 Task ACD - Separator Scale-up for High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

Classes of materials under consideration include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics.

4.1.3.5 Task ACE - Safety and Functional Components Scale-up for High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials. These components may be in the form of enhancements to electrolytes or electrodes or functional components that are physically incorporated into the cell.

4.1.4 Task AD - Electrode/Electrolyte Optimization and Fabrication for High Energy Cell

The Contractor shall perform electrode/electrolyte optimization to optimize the overall electrochemical and safety performance of the High Energy lithium-based cell.

The following parameters shall be specified for the electrodes: electrode substrate, substrate porosity, electrode thickness, active material source, binder and diluent additives, current collectors, and other parameters as they apply.

The Contractor shall identify the relevant parameters that shall be considered to optimize the cathode performance. These shall include the loading level, porosity, thickness, binder, diluent, manufacturing methods and material composition impacts. Since the Contractor is proposing an anode with proven performance, anode optimization will not be required.

In addition, the Contractor shall investigate the performance and interactions unique to individual cathode/electrolyte pairs and the anode/electrolyte pairs as well as the cathode/anode/electrolyte combinations.

4.1.5 Task AE - High Energy Evaluation Screening Cells

The Contractor shall propose a suitable cell format to be used for evaluation cells. The proposed cell format must be a production cell of a known form, fit, and function, and must be scalable to represent the final flightweight cell design. The evaluation cells shall have a minimum 2.0 Ah capacity. The cell format must support the evaluation of the cell's tolerance to abuse such as defined in Table 1. Pouch cells are not an acceptable vehicle for the evaluation cells due to the need for NASA to assess their safety attributes under abuse conditions. The evaluation cell may optionally include built-in functional safety components provided the component is intended for use in the final flightweight cell design.

The Contractor shall include sufficient rationale to support their choice of format for the evaluation cell. The Contractor shall address how the evaluation cells will be produced and how the Contractor intends to ensure consistency in capacity and performance. Extrapolation of the performance of the evaluation cell to the performance of the flightweight cell shall be provided.

4.1.5.1 Task AEA - High Energy Evaluation Cell Design

The Contractor shall deliver an evaluation cell design that reflects the use of the baseline cell components proposed in Section 3.0 Scope of Work. Cell hardware, projected cell capacity, cell dimensions, cell drawings, total anode and cathode cell area, and other relevant information shall be provided at 15 months after initiation of the contract. The Contractor shall also define how the NASA provided components will be substituted in the proposed evaluation cell and how the increased capacity of the advanced components will be accommodated in the evaluation cell design.

4.1.5.2 Task AEB - High Energy Evaluation Cell Fabrication

The Contractor shall deliver a total of one hundred and six (106) High Energy evaluation cells. Sufficient quantities of cells shall be fabricated to ensure delivery of the requisite numbers (10 or 12) of high quality cells with capacity variation within 10% of the average capacity for that lot and shall yield consistent performance.

The Contractor shall deliver ten (10) identical lithium-ion cells using the baseline components proposed in Section 3.0 Scope of Work.

These cells will serve as controls whose performance will provide the baseline for comparison and evaluation of the advanced components incorporated into the remaining cells.

The remaining 96 cells shall contain different combinations of cathodes, electrolytes, and separators. Twelve (12) replicates of eight (8) separately defined component combinations shall be delivered.

The Contractor shall manufacture sufficient materials and components in a single production lot such that variability due to manufacturing differences is eliminated. The Contractor shall deliver to NASA two (2) samples of at least 200 cm^2 areas of each of fabricated anode, cathode, and separator components and at least 25 ml of each electrolyte that will be incorporated into the evaluation cells from each lot.

The Contractor shall include in the cost proposal the total effort associated with the proposed High Energy evaluation screening cell effort. The Contractor shall break down the costs per a nominal twelve (12)-cell lot evaluation screening cell configuration. NASA will work with the Contractor after contract award to determine the exact types of material components and the quantity of material combinations to be fabricated into evaluation screening cells.

Long lead item components may be submitted to NASA for approval, so that component manufacturing can begin in order to meet fabrication schedules.

4.1.5.3 Task AEC – High Energy Evaluation Cell Acceptance Testing

The Contractor shall develop and deliver to NASA a High Energy Evaluation Screening Cell Acceptance Test Plan. The Evaluation Screening Acceptance Test Plan shall be subject to the review and approval by the NASA Project Manager. The Acceptance Test Plan shall incorporate the following:

Cell Activation

A cell activation procedure that covers the cell activation, including electrolyte fill, and formation cycling of the cells. Cell weight and dimensions shall be measured and recorded.

Capacity Determination

Capacity shall be measured at 20^{o}C and 0^{o}C after formation cycling. Three (3) separate capacity measurements shall be made at each temperature. The average of the 0^{o}C measurements at C/10 shall be defined as the capacity, C for the cell.

Charge Retention Measurement

Open circuit voltage decay shall be determined for 168 hours at 20^{o}C after charging to 100% state-of-charge. Voltage measurements to the millivolt level shall be taken at 6 hour periods or less during the open circuit period. Following the 168-hour open circuit stand, the cell shall be discharged to measure capacity.

The Contractor shall test the evaluation cells per the approved Acceptance Test Plan. The Contractor shall prepare and deliver all test data collected under this task in an Acceptance Test report. This report shall be delivered with the evaluation cells. The evaluation cells shall be delivered no later than September 14, 2010.

4.1.6 Task AF - High Energy Flightweight Cell Design

The Contractor shall develop and deliver to NASA a baseline design of a ~35 Ah (TBR) capacity lithium-ion aerospace flightweight cell or virtual cell incorporating components developed under the Exploration Technology Development Program, Energy Storage Project and evaluated and scaled-up via this contract. The cell design shall meet or exceed the environmental acceptance and qualification levels for Space Shuttle payloads (TBR) as referenced in SP-T-0023 Environmental Acceptance and Qualification Testing Specification as well as the Key Performance Metrics listed in Table 1. This High Energy cell is under development for Lunar Surface Systems customers.

At the initiation of this task, the specific performance parameters listed in Table 4 will be updated and augmented to reflect the latest available operating requirements for the High Energy cell/battery design. This update will address the battery capacity, battery operating voltage range, operating currents, operating and non-operating temperature range, cycle life, calendar life, shock and vibration loads and other specific requirements as available. A power profile for each of the customers will be provided if available.

Design Requirements

In addition to the performance requirements listed in Tables 1 and 4, the following component design acceptance testing requirements and qualification testing requirements covered by the documents listed in Section 3.0 Scope of Work, Applicable Government Documents, shall be met.

NASA will conduct the acceptance level testing for the TRL 5/6 cell-level environmental levels to verify performance to the specified parameters. TRL 5/6 acceptance level testing will include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The acceptance test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. All cells will undergo acceptance level testing. The Contractor shall conduct their standard cell-level acceptance testing to verify that performance and workmanship standards are met.

NASA will conduct the qualification testing for the TRL 5/6 cell-level environmental levels to verify performance to the design specifications. Qualification level testing will include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The qualification test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. A portion of the cells shall undergo qualification level testing and pass the required minimum performance criteria.

The Contractor shall consider the worst case conditions for Lunar Surface Systems customers when designing this optimized cell and then develop a bare-bones cell design that provides the stated cycle life and rate capability (C/2 at 0^{o}C) with minimum margin while minimizing mass and volume. Safety shall not be comprised. The cell designs developed under this task shall result in a minimum mass and a minimum volume solution at the battery level. Specifically, cell designs that minimize cell level mass and volume, but incur substantial penalties to meet requirements at the battery level (that negate the cell level gains) shall not be considered. The cell design developed under this task shall consider the evaluation of battery system level impacts, i.e., thermal effects, materials compatibility, battery packaging and integration, weight and volume and their effects on total battery system mass and volume. The Contractor shall build upon the existing knowledge base generated under Tasks AA through AE and incorporate component or design modifications that address performance enhancements for NASA.

The design requirements for the flightweight cells are discussed in the following sections. Items required at the Preliminary and Critical Design Reviews are summarized in Table 8.

4.1.6.1 Task AFA - High Energy Flightweight Cell Design Trade Studies

The Contractor shall perform trade studies to optimize the design of the High Energy flightweight cell. These studies shall consider the estimated performance of the candidate components selected for the anticipated cell design to accurately project cell and battery characteristics listed in Table 1. These studies shall be used to compare and evaluate hardware design options and electrochemical component options for the cell. These trades shall be used to define the solution that minimizes mass and volume at the battery level while maximizing the overall system safety. At a minimum, the periodic trade study results shall be delivered to NASA 30 days prior to the Preliminary Design Review, Critical Design Review, or when major design changes are contemplated or the Contractor deviates from previously Government approved plans and specifications.

4.1.6.2 Task AFB - High Energy Flightweight Cell Preliminary Design

The Preliminary Design Review is conducted when the design maturity is approximately at the 10-20% level. The Contractor shall conduct preliminary design efforts on the High Energy flightweight cell that meets the Key Performance Parameters in Table 1. The Contractor shall deliver a data package that contains the baseline documentation including preliminary design specifications, preliminary test plans, preliminary projected components, cell and battery level Key Performance Parameter characteristics, design limitations, parts, materials and processes lists, mass properties list, preliminary trade study analyses, and a planned manufacturing schedule and cost estimates. The Contractor shall also provide preliminary risk assessment and preliminary hazard analyses. For the purpose of the preliminary High Energy cell design, internal cell elements shall be identified using the best known and characterized components that target the required performance. Attributes that shall be considered in the selection of the components include electrochemical performance, weight, component availability, manufacturability, qualified processes, cost, and materials compatibility. The Contractor shall provide an engineering drawing tree outlining the High Energy flightweight cell design hierarchy and the necessary interface control documents to evaluate the planned cell dimensions. The Contractor shall provide the following plans as part of the Preliminary Design Review: Key Performance Parameter Measurement Plan, Product Assurance Plan, Contamination Control Plan, Producibility/Manufacturability Plan, Safety Analyses and Plans, and a Verification/Validation Plan. The Contractor shall provide a top level safety analysis of the High Energy flightweight cell design, Critical Items List, and a Limited Life Items List.

	Preliminary Design Review	Critical Design Review
Design Maturity Level	10%-20%	80%-90%
Documentation	Baseline documentation	Updated baseline documentation, as required
		Completion of PDR actions
	Preliminary Parts, Materials, and Process lists	Updated Parts, Materials, and Process lists
	Preliminary Design Specifications	Updated Design Specifications
	Preliminary Mass Properties List	Mass Properties List
	Preliminary Design Limitations	Updated Design Limitations and Margins
	Preliminary performance characteristics	Pertinent Test results and Descriptions
	Preliminary Trade Studies	Updated Design Trade Studies
	Preliminary Test Plans	Final Test Plans
	Preliminary Risk Assessment	Final Risk Assessment and Mitigation
	Preliminary cost and schedule data	Updated cost and schedule data
	Key Performance Parameter Estimates	Updated Key Performance Parameter Estimates
	Preliminary Hazard Analysis	Final Hazard Analysis
		Reliability Assessment
		Manufacturability of Selected Design
	Projected components	Updated projected components
Drawings	Engineering Drawing Tree	Detailed Engineering Drawings
	Interface Control Documents	Updated Interface Control Documents
Technical Plans	Key Performance Parameter Measurement Plan	Final Key Performance Parameter Measurement Plan
	Product Assurance Plan	Final Product Assurance Plan
	Contamination Control Plan	Final Contamination Control Plan
	Producibility/ Manufacturability Plan	Final Producibility/ Manufacturability Plan
	Safety Analyses and Plans	Final Safety Analyses and Plans
	Verification/Validation Plan	Final Verification/Validation Plan w/ requirements compliance matrix
		Final Activation Plan
		Acceptance Criteria
		Maintenance Plan
Safety	Top Level Safety Analysis	Updated Safety Analysis with verification
	Preliminary Critical Items List	Updated Critical Items List
	Preliminary Limited Life Items List	Updated Limited Life Items List

Table 8: Preliminary and Critical Design Review Deliverables

4.1.6.2.1 Task AFBA - High Energy Flightweight Cell Preliminary Design – Cell Electrochemical Components

The Contractor shall support recommendations and identify advantages, disadvantages, difficulties and limitations involved with the known baselined components along with necessary trade studies to achieve the performance goals listed in Table 1. Selection of the baseline candidates shall be in consultation with, and with the approval of, the NASA Project Manager.

The following cell components are required:

a. Cathode
b. Separator
c. Anode
d. Electrolyte

4.1.6.2.2 Task AFBB - High Energy Flightweight Cell Preliminary Design – Cell Mechanical Design

The design of the High Energy lithium-ion cell shall address the mechanical design of the following structural components for both the cell and battery level integration metrics:

a. Cell containment
b. Terminals
c. End plates
d. Mechanical support of cell
e. Seals
f. Other

The Contractor shall identify materials, dimensions, a conceptual design detailing component orientation, and a scheme for cell construction and activation. The Contractor shall support selections and identify advantages, disadvantages, difficulties and limitations involved with the selections along with necessary trade studies to compare options and project the performance parameters. Contractor recommendations regarding the cell mechanical design shall be those that best address the Key Performance Parameters listed in Table 1. Final selection of the High Energy Cell mechanical design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.2.3 Task AFBC - High Energy Flightweight Cell Preliminary Design – Cell Thermal Design

The Contractor shall perform and document top level thermal analyses and make predictions of thermal gradients for the High Energy cell design to ensure that adequate heat removal is provided to address temperature requirements for optimal operation, given the proposed operating conditions, design of the cell, cell components, and structural elements. Contractor recommendations regarding the thermal design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.2.4 Task AFBD - High Energy Flightweight Cell Preliminary Design – Safety/Functional Cell Components

This task addresses the incorporation of safety/functional components that are or may be physically incorporated into the cell. The Contractor shall assess the need for the incorporation of safety/functional features into the cell design. The Contractor shall support recommendations, identify the advantages, disadvantages, difficulties, and limitations involved with the incorporation of, and/or the omission of these components and justify their conclusions. Selection of the optional cell components shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.2.5 Task AFBE - High Energy Flightweight Cell Preliminary Design Review

The Contractor shall hold the Preliminary Design Review at NASA Glenn Research Center 9 months after contract award.

4.1.6.2.5.1 Task AFBEA - High Energy Flightweight Cell Preliminary Design Review Data Package

The Preliminary Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule and additional required documentation listed in 4.1.6.2 Task AFB - High Energy Flightweight Cell Preliminary Design . The Contractor shall submit two (2) hard copies plus an electronic copy of the Preliminary Design Review data package covering the information to be addressed at the PDR to NASA at least two (2) weeks prior to the design review with sufficient narrative to demonstrate adequacy of the High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

4.1.6.2.5.2 Task AFBEB - High Energy Flightweight Cell Preliminary Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete hard copies plus an electronic copy of the designs and specifications involved with the construction of the High Energy flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes.

4.1.6.2.5.3 Task AFBEC - High Energy Flightweight Cell Preliminary Design Review Summary Report

The Contractor shall provide a Preliminary Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two weeks after conducting the design review.

4.1.6.3 Task AFC - High Energy Flightweight Cell Critical Design

The Critical Design is conducted when the design maturity is approximately at the 80-90% level. The Government shall refine the specific environmental customer requirements for the High Energy cell prior to initiation of this effort. Pending the evaluation of test results from 4.1.5.3 Task AEC – High Energy Evaluation Cell Acceptance Testing, and subsequent life cycle testing, the Contractor shall revise the High Energy flightweight cell design. The Contractor shall conduct Critical Design Review efforts on the flightweight High Energy cell that meets the Key Performance Parameters in Table 1. The Contractor shall deliver a data package that contains the updated baseline documentation including completion of the Preliminary Design review actions, updated design specifications, final test plans, updated projected components, cell and battery level Key Performance Parameter characteristics, updated design limitations and margins, updated parts, materials and processes lists, updated mass properties list, updated design trade-off studies (thermal, structural, manufacturing), pertinent test results and evaluations and updated manufacturing schedule and cost estimates. The Contractor shall also provide a final risk assessment, mitigation plan, a final hazard analysis, a reliability assessment, and manufacturability of selected design. For the purpose of the Critical Design High Energy cell design, internal cell elements shall be identified using the best known and characterized components that target the required performance. Attributes that shall be considered in the selection of the components include electrochemical performance, weight, component availability, manufacturability, qualified processes, cost, and materials compatibility. The Contractor shall provide an engineering drawing tree outlining the High Energy flightweight cell design hierarchy and the necessary interface control documents to evaluate the planned cell dimensions. The Contractor shall provide the following plans as part of the Critical Design Review: Key Performance Parameter Measurement Plan, Product Assurance Plan, Contamination Control Plan, Producibility/Manufacturability Plan, Safety Analyses and Plans, a Verification/Validation Plan, a Check-out Activation Plan, Acceptance Criteria, and a Maintenance Plan. The Contractor shall provide a top level safety analysis of the flightweight High Energy cell design, Critical Items List, and a Limited Life Items List.

4.1.6.3.1 Task AFCA - High Energy Flightweight Cell Critical Design – Electrochemical Cell Components

The Contractor shall support recommendations and identify advantages, disadvantages, difficulties and limitations involved with the identified advanced components along with necessary trade studies to achieve the performance goals listed in Table 1. Selection of the cell components shall be in consultation with, and with the approval of, the NASA Project Manager.

The following cell components are required:

a. Cathode
b. Separator
c. Anode
d. Electrolyte

4.1.6.3.2 Task AFCB - High Energy Flightweight Cell Critical Design – Cell Mechanical Design

The design of the High Energy flightweight cell shall address the mechanical design of the following six (6) structural components for both the cell and battery level metrics:

a. Cell containment
b. Terminals
c. End plates
d. Mechanical support of cell
e. Seals
f. Other

The Contractor shall identify materials, dimensions, a conceptual design detailing component orientation, and a scheme for cell construction and activation. The Contractor shall support selections and identify advantages, disadvantages, difficulties and limitations involved with the selections along with necessary trade studies to achieve the performance goals listed in Table 1. The Contractor shall prepare and deliver periodic status reports summarizing the results of screening tests, scale-up evaluations, manufacturing issues, and optimized performance characteristics on the candidate components to NASA. Contractor recommendations regarding the cell mechanical design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.3.3 Task AFCC - High Energy Flightweight Cell Critical Design – Cell Thermal Analysis

The Contractor shall perform and document thermal analyses and make predictions of thermal gradients for the High Energy cell design to ensure that adequate heat removal is provided to address temperature requirements for optimal operation, given the proposed design of the cell, cell components, and structural elements. Contractor recommendations regarding the thermal design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.3.4 Task AFCD - High Energy Cell Flightweight Critical Cell Design – Optional Cell Components

The Contractor shall support recommendations, identify the advantages, disadvantages, difficulties, and limitations involved with the incorporation of, and/or the omission of these components and justify their conclusions. The Contractor shall prepare and deliver a status report summarizing the results of screening tests, scale-up evaluations, manufacturing issues, and optimized performance characteristics on the candidate components to NASA. Baseline selection of the optional cell components shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.1.6.3.5 Task AFCE - High Energy Flightweight Cell Critical Design Review

The Contractor shall hold the Critical Design Review at the Contractor's facility 27 months after the start of the contract.

4.1.6.3.5.1 Task AFCEA - High Energy Flightweight Cell Critical Design Review Data Package

The Critical Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule. The Contractor shall submit two (2) hard copies plus an electronic copy of the Critical Design Review data package covering the information to be addressed at the CDR to NASA at least two weeks prior to the design review with sufficient narrative to demonstrate adequacy of the High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

4.1.6.3.5.2 Task AFCEB - High Energy Flightweight Cell Critical Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete hard copies plus an electronic copy of the designs and specifications involved with the construction of the High-Energy flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes.

4.1.6.3.5.3 Task AFCEC - High Energy Flightweight Cell Critical Design Review Summary Report

The Contractor shall provide a Critical Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two weeks after conducting the design review.

4.2 Task B - Ultra High Energy Cell Development

The Contractor shall develop and deliver, to the NASA Project Manager, a baseline design of an Ultra High Energy rechargeable battery cell that incorporates the features and characteristics described in Figure 2 and Table 1 above. The Contractor shall screen NASA-defined and recommended anode and cathode materials, separator, and electrolytes for incorporation into evaluation test cells. The Contractor shall scale-up cell materials in the quantities required to build evaluation test cells that have a minimum capacity of 2 Ah. The Contractor shall design and fabricate evaluation test cells that consist of the NASA specified combinations of advanced components. The Contractor shall perform any process optimization necessary for production of materials in sufficient sizes, quantities and quality for use in evaluation test cell fabrication.

4.2.1 Task BA - Null

4.2.2 Task BB - Component Material Screening for Ultra High Energy Cell

At specified intervals throughout the period of performance, battery cell component materials developed by NASA, or a third party, will be delivered to the Contractor. The approximate timeframes that NASA will deliver the components to the Contractor are given in Table 9. The Contractor shall screen and evaluate these materials for their manufacturability, compatibility with the production processing equipment proposed for use, and scalability for quantities and consistencies required to build and deliver fifty (50) ~35 Ah (TBR) flightweight cells or virtual cells. On an as needed basis, the Contractor shall communicate with the NASA Project Manager and third parties that developed the materials for the purposes of gaining insight into the materials, their proper handling and treatment, scale-up and fabrication methods, any specialized test procedures to evaluate materials and other relevant factors that may impact the screening, scale-up, manufacturability, or performance of the materials.

The Contractor shall use screening criteria and individual screening plans for the evaluation of each component defined in Task A modified to address the screening of advanced anode materials that NASA will supply to the Contractor The addendum to the Component Screening Plan that covers anodes shall document the processes and procedures that will be used to screen and evaluate the NASA-supplied anode with material production processes capable of producing sufficient quantities of the component materials, compatibility with existing cell manufacturing equipment, and overall manufacturability. The addendum to the Component Screening Plan which includes the cathode, separator, and electrolyte materials shall be delivered to the NASA Project Manager within ninety (90) days after the initiation of the contract for review and approval.

The screening and evaluation of each component shall be completed within forty-five days of its delivery to the Contractor. Interim reporting on these evaluations shall be included in the monthly reports. A summary report on the anodes will be required fifteen (15) months after the initiation of the contract.

The Contractor shall submit a final report summarizing the overall results of the screening and evaluation of all components for the Ultra High Energy cell and containing a comparative assessment of the suitability of each component for use in the evaluation cells and the flightweight cells. The Contractor shall identify, prioritize, and recommend materials for use in the Ultra High Energy cell and support the selections with adequate technical rationale.

This report shall be delivered twenty-six (26) months after the initiation of the contract. Within two weeks of the delivery of this report, the Principal Investigator and other key personnel for the Contractor shall participate in a component downselection meeting with the NASA Project Manager to determine the materials that will be used in the Ultra High Energy evaluation cells. Selection of the materials will be performed in consultation with and with the approval of the NASA Project Manager.

Approximate Timeframe NASA will provide components after Start of Contract	**Item**
10 months	Anodes
17 months	Anodes
19 months	Cathodes, electrolytes, separators, and safety components
22 months	Anodes
24 months	Cathodes, electrolytes, separators, and safety components

Table 9: Delivery Dates of Materials to Contractor

NASA will provide to the Contractor samples of component material developed through internal NASA efforts, efforts funded under the Exploration Technology Development Program Energy Storage Project's NASA Research Announcement (NRA) NNC08ZP022N, or other sources. Table 10 lists the quantities of each material/component that will be delivered to the Contractor on each deliverable date.

Components	Quantities
Anodes	30 grams electroactive powder
Cathodes	30 grams electroactive powder
Separators	2 sheets of 400 cm^2 separator
Electrolytes	75 ml electrolyte
Safety and functional	Deliverables and quantities will be defined at a later date

Table 10: Quantities of Deliverable Materials to Contractor

4.2.2.1 Task BBA - Anode Screening for Ultra High Energy Cell

NASA will identify and provide samples of the anode materials to be evaluated for the Ultra High Energy cells. The general classes of anode chemistry for investigation encompass nano-scale, Group 13 – 15 elements and the oxides, intermetallics or composites of such, e.g., silicon-based/carbon composites. Selection of the anode material candidates shall be performed in consultation with, and with the approval of, the NASA Project Manager.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended anode candidates Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cells. The Contractor shall evaluate the candidate cathode materials for their suitability for fabrication into completed electrodes. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to production level quantities sufficient to accommodate the fabrication of up to fifty (50) flightweight ~35Ah cells or virtual cells while maintaining uniformity and electrochemical performance.

The Contractor shall investigate the manufacturability of the NASA-recommended anode materials through various screening techniques including small scale production lots as per the Contractor's standard aerospace lithium-based cell manufacturing techniques.

4.2.2.2 Task BBB - Cathode Screening for Ultra High Energy Cell

NASA will identify and provide samples of the cathode materials to be evaluated for the Ultra High Energy cells. The general classes of cathode chemistry targeted for investigation include the $Li(Ni_{0.33}Mn_{0.33}Co_{0.33})O_2$ or a lithiated nickel manganese cobalt such as $Li(Li_{0.20}Mn_{0.54}Ni_{0.13}Co_{0.13})O_2$ with a general designation $Li(Li,NMC)O_2$.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) NASA-recommended cathode candidates via the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate cathode materials for their suitability for fabrication into completed electrodes. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to production level quantities sufficient to accommodate the fabrication of up to fifty (50) flightweight ~35Ah cells or virtual cells while maintaining uniformity and electrochemical performance.

The Contractor shall investigate the manufacturability of the NASA-recommended cathode materials through various screening techniques that may include small-scale production lots as per the Contractor's standard aerospace lithium-based cell manufacturing techniques.

4.2.2.3 Task BBC - Electrolyte Screening for Ultra High Energy Cell

NASA will provide the electrolytes to be evaluated for the High Energy cells. The general classes of electrolyte chemistry for investigation include conventional $LiPF_6$ solutions in EC, PC, DEC, DMC or EMC mixtures and ionic liquids.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended electrolyte formulations/candidates via the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate electrolytes for their suitability for fabrication into completed lithium-based cells. The Contractor shall also evaluate the scalability of materials from the small laboratory batch sizes to large production level quantities of materials while maintaining uniformity and stable electrochemical performance.

The Contractor shall investigate the manufacturability of the new electrolyte materials through various screening techniques and the evaluation of the electrolyte compatibility with the cell production infrastructure.

4.2.2.4 Task BBD –Separator Screening for Ultra High Energy Cell

NASA will provide the separators to be evaluated for the Ultra High Energy cells. Classes of separator materials under consideration include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics.

The Contractor shall evaluate a minimum of three (3) and a maximum of five (5) (TBR) Government recommended separator candidates via the Component Screening Plan developed under Task AB - Component Material Screening for High Energy Cell. The Contractor shall evaluate the candidate separator materials for their suitability for fabrication into completed cells. The Contractor shall also evaluate the scalability of separator materials from the small laboratory batch sizes to large production level quantities of materials while maintaining uniformity and electrochemical performance.

4.2.2.5 Task BBE - Safety and Functional Components Screening for Ultra High Energy Cell

NASA will provide the safety/functional components to be evaluated for the Ultra High Energy cells. These components may be in the form of enhancements to electrolytes or electrodes or functional components that are physically incorporated into the cell.

The Contractor shall investigate the manufacturability of the new electrolyte materials through various screening techniques and the evaluation of the electrolyte compatibility with the cell production infrastructure.

4.2.3 Task BC – Component Material Scale-up for Ultra High Energy Cell

The Contractor shall reproduce the sample materials that have been down selected and scale them up in the quantities and quality required for fabrication of the evaluation cells. The Contractor shall demonstrate that the selected process is capable of further scale-up and representative of the process required to manufacture materials to build up to 48 flightweight cells. The scale-up of component materials can be a sub-contracted effort.

As needed, the Contractor shall communicate with the NASA Project Manager and third parties that developed the materials for the purposes of gaining insight into the materials, their proper handling and treatment, scale-up and fabrication methods, and other relevant factors that may impact the scale-up, manufacturability, or performance of the materials.

4.2.3.1 Task BCA – Anode Scale-up for Ultra High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

The anode materials targeted for scale-up and incorporation into cells include the classes of such materials may, for example, encompass nano-scale, Group 13 – 15 elements and the oxides, intermetallics or composites of such, e.g., silicon-based/carbon composites.

4.2.3.2 Task BCB – Cathode Scale-up for Ultra High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

The cathode materials selected for scale up and incorporation into cells are lithiated mixed metal of oxides, with different proportions of Co, Ni and Mn. Specifically, these are solid solutions between $Li[Li_{1/3}Mn_{2/3}]O_2$- a non-intercalating phase and an intercalation phase, for example, $Li[Ni_{1/3}Mn_{1/3}Co_{1/3}]O_2$. These could be the same or similar to the compositions listed below as examples:
Cathode 1: $Li_{1.0}(Li_{0.17}Ni_{0.25}Mn_{0.58})O_2$ Cathode 2: $Li(Li_{0.20}Mn_{0.54}Ni_{0.13}Co_{0.13})O_2$

4.2.3.3 Task BCC –Separator Scale-up for Ultra High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

Classes of materials under consideration include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics

4.2.3.4 Task BCD – Electrolyte Scale-up for Ultra High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials.

The electrolytes targeted for this demonstration are based on multi-component blends of ethylene carbonate and linear carbonates and may contain: i) low-viscosity co-solvents with adequate chemical and electrochemical stability, ii) fluorinated analogues for improved safety and stability at high voltages, iii) SEI enhancing additives, iv) thermally stable salts, v) thermally and electrochemically stable salts, vi) flame retardant additives, vii) self extinguishing electrolytes, viii) ionic liquids.

4.2.3.5 Task BCE – Safety and Functional Components Scale-up for Ultra High Energy Cell

The Contractor shall define the constituent components and determine quantities necessary for production of evaluation cells and shall scale-up materials. These components may be in the form of enhancements to electrolytes or electrodes or functional components that are physically incorporated into the cell.

4.2.4 Task BD – Electrode/Electrolyte Optimization for Ultra High Energy Cell

The Contractor shall perform electrode/electrolyte optimization to optimize the overall electrochemical and safety performance of the Ultra High Energy lithium-based cell. In addition, the Contractor shall investigate the compatibility of the anode and electrolyte interaction when optimizing performance of the Ultra High Energy Cell.

The following parameters shall be specified for the electrodes: electrode substrate, substrate porosity, electrode thickness, active material source, binder and diluent additives, current collectors, and other parameters as they apply.

The Contractor shall identify the relevant parameters that shall be considered to optimize the anode and cathode performance. These shall include the loading level, porosity, thickness, binder, diluent, manufacturing methods and material composition impacts.

In addition, the Contractor shall investigate the performance and interactions unique to individual cathode/electrolyte pairs and the anode/electrolyte pairs as well as the cathode/anode/electrolyte combinations.

4.2.5 Task BE - Ultra High Energy Evaluation Screening Cells

The Contractor shall use the cell format defined in response to 4.1.5 Task AE High Energy Evaluation Screening Cells as the vehicle for the Ultra High Energy Screening Cells.

There will be two separate builds of Ultra-High Energy cells used to evaluate components and component combinations as the materials under development mature.

4.2.5.1 Task BEA Ultra High Energy Cell Design

The Contractor shall identify modifications to the High Energy evaluation cell, if any, that will be needed to accommodate the Ultra-High energy cell components.

4.2.5.2 Task BEB - Ultra High Energy Evaluation Cell Fabrication Build 1

The Contractor shall deliver a total of ninety-six (96) Ultra High Energy evaluation cells that will contain different combinations of anodes, cathodes, electrolytes, and separators. Twelve (12) replicates of eight (8) separately defined component combinations shall be fabricated. Sufficient quantities of cells shall be fabricated to ensure delivery of the requisite numbers (10 or 12) of high quality cells with capacity variation within 10% of the average capacity for that lot and shall yield consistent performance.

The Contractor shall manufacture sufficient materials and components in a single production lot such that variability due to manufacturing differences is eliminated. The Contractor shall deliver to NASA two (2) samples of at least 200 cm^2 areas of each of fabricated anode, cathode, and separator components and at least 25 ml of each electrolyte that will be incorporated into the evaluation cells from each lot.

The Contractor shall include in the cost proposal the total effort associated with the proposed High Energy evaluation screening cell effort. The Contractor shall break down the costs per a nominal twelve (12) cell lot evaluation screening cell configuration. NASA will work with the Contractor after contract award to determine the exact types of material components and the quantity of material combinations to be fabricated into evaluation screening cells.

Long lead item components may be submitted to NASA for approval, so that component manufacturing can begin in order to meet fabrication schedules.

4.2.5.3 Task BEC - Ultra High Energy Evaluation Cell Acceptance Testing - Build 1

The Contractor shall make any necessary modifications to the Acceptance Testing Plan developed in 4.1.5.3 Task AEC to accommodate the acceptance testing of the Ultra-High Energy Cells.

Following cell fabrication, the Contractor shall test the evaluation cells per the approved Acceptance Test Plan. The Contractor shall prepare and deliver all test data collected under this task in an Acceptance Test report. This report shall be delivered with the evaluation cells. The evaluation cells shall be delivered no later than September 14, 2010.

4.2.5.4 Task BED - Ultra High Energy Evaluation Cell Fabrication - Build 2

The second delivery associated with the evaluation screening of Ultra-High Energy Cell components is scheduled 12 months after the first Ultra High Energy screening cells. The Contractor shall deliver a total of an additional ninety-six (96) Ultra High Energy evaluation cells using different combinations of anodes, cathodes, electrolytes, and separators. Twelve (12) replicates of eight (8) separately defined component combinations shall be fabricated. Sufficient quantities of cells shall be fabricated to ensure delivery of the of 12 high quality cells with capacity variation within 10% of the average capacity for that lot and with yield consistent performance.

The Contractor shall manufacture sufficient materials and components in a single production lot such that variability due to manufacturing differences is eliminated. The Contractor shall deliver to NASA two (2) samples of at least 200 cm^2 areas of each of fabricated anode, cathode, and separator components and at least 25 ml of each electrolyte that will be incorporated into the evaluation cells from each lot.

The Contractor shall include in the cost proposal the total effort associated with the proposed High Energy evaluation screening cell effort. The Contractor shall break down the costs per a nominal twelve (12) cell lot evaluation screening cell configuration. NASA will work with the Contractor after contract award to determine the exact types of material components and the quantity of material combinations to be fabricated into evaluation screening cells.

Long lead item components may be submitted to NASA for approval, so that component manufacturing can begin in order to meet fabrication schedules.

4.2.5.5 Task BEE Ultra High Energy Evaluation Cell Acceptance Testing - Build 2

The Contractor shall test the evaluation cells per the approved Acceptance Test Plan used for Ultra High Energy Evaluation Cell Build 1. The Contractor shall prepare and deliver all test data collected under this task in an Acceptance Test report. This report shall be delivered with the evaluation cells. The evaluation cells shall be delivered no later than August 25, 2011.

4.2.6 Task BF - Ultra High Energy Flightweight Cell Design

The Contractor shall develop and deliver to NASA a baseline design of a ~35 Ah (TBR) capacity lithium-ion aerospace flightweight cell incorporating components developed under the Exploration Technology Development Program, Energy Storage Project and evaluated and scaled-up via this contract. The cell design shall have as much commonality with the High Energy flightweight cell design as is feasible. The cell design shall meet or exceed the environmental acceptance and qualification levels for Space Shuttle payloads (TBR) as referenced in SP-T-0023 Environmental Acceptance and Qualification Testing Specification as well as the Key Performance Metrics listed in Table 1. This Ultra High Energy cell is under development for EVA suit and Altair customers.

At the initiation of this task, the specific performance parameters listed in Table 4 will be updated and augmented to reflect the latest available operating requirements for the Ultra High Energy cell/battery design. This update will address the battery capacity, battery operating voltage range, operating currents, operating and non-operating temperature range, cycle life, calendar life, shock and vibration loads and other specific requirements as available. A power profile for each of the customers will be provided if available.

<u>Design Requirements</u>

In addition to the performance requirements listed in Tables 1 and 4, the following component design acceptance testing requirements and qualification testing requirements covered by the documents listed in Section 3.0 Scope of Work, Applicable Government Documents, shall be met.

NASA will conduct the acceptance level testing for the TRL 5/6 cell-level environmental levels to verify performance to the specified parameters. TRL 5/6 acceptance level testing will include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The acceptance test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. All cells will undergo acceptance level testing. The Contractor shall conduct their standard cell-level acceptance testing to verify that performance and workmanship standards are met.

NASA will conduct the qualification testing for the TRL 5/6 cell-level environmental levels to verify performance to the design specifications. Qualification level testing will include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The qualification test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. A portion of the cells shall undergo qualification level testing and pass the required minimum performance criteria.

The Contractor shall consider the worst case conditions for EVA suit and Altair customers when designing this optimized cell and then develop a bare-bones cell design that provides the stated cycle life and rate capability (C/2 at 0^oC) with minimum margin while minimizing mass and volume. Safety shall not be comprised. The cell designs developed under this task shall result in a minimum mass and a minimum volume solution at the battery level. Specifically, cell designs that minimize cell level mass and volume, but incur substantial penalties to meet requirements at the battery level (that negate the cell level gains) shall not be considered. The cell design developed under this task shall consider the evaluation of battery system level impacts, i.e., thermal effects, materials compatibility, battery packaging and integration, weight and volume and their effects on total battery system mass and volume. The Contractor shall build upon the existing knowledge base generated under Tasks AA through AE and incorporate component or design modifications that address performance enhancements for NASA.

The design requirements for the flightweight cells are discussed in the following sections. Items required at the Preliminary and Critical Design Reviews are summarized in Table 8.

4.2.6.1 Task BFA - Ultra High Energy Flightweight Cell Design Trade Studies

The Contractor shall perform trade studies to optimize the design of the Ultra High Energy flightweight cell. These studies shall consider the estimated performance of the candidate components selected for the anticipated cell design to accurately project cell and battery characteristics listed in Table 1. These studies shall be used to compare and evaluate hardware design options and electrochemical component options for the cell. These trades shall be used to define the solution that minimizes mass and volume at the battery level while maximizing the overall system safety. At a minimum, the periodic trade study results shall be delivered to NASA 30 days prior to the Preliminary Design

Review, Critical Design Review or when major design changes are contemplated or the Contractor deviates from previously Government approved plans and specifications.

The design requirements for the flightweight cells are discussed in the following sections. Items required at the Preliminary and Critical Design Reviews are summarized in Table 8.

4.2.6.2 Task BFB - Ultra High Energy Flightweight Cell Preliminary Design

The Preliminary Design Review is conducted when the design maturity is approximately at the 10-20% level. The Contractor shall conduct preliminary design efforts on the Ultra High Energy flightweight cell that meets the Key Performance Parameters in Table 1. The Contractor shall deliver a data package that contains the baseline documentation including preliminary design specifications, preliminary test plans, preliminary projected components, cell and battery level Key Performance Parameter characteristics, design limitations, parts, materials and processes lists, mass properties list, preliminary trade study analyses, and a planned manufacturing schedule and cost estimates. The Contractor shall also provide preliminary risk assessment and preliminary hazard analyses. For the purpose of the preliminary Ultra High Energy cell design, internal cell elements shall be identified using the best known and characterized components that target the required performance. Attributes that shall be considered in the selection of the components include electrochemical performance, weight, component availability, manufacturability, qualified processes, cost, and materials compatibility. The Contractor shall provide an engineering drawing tree outlining the Ultra High Energy flightweight cell design hierarchy and the necessary interface control documents to evaluate the planned cell dimensions. The Contractor shall provide the following plans as part of the Preliminary Design Review: Key Performance Parameter Measurement Plan, Product Assurance Plan, Contamination Control Plan, Producibility/Manufacturability Plan, Safety Analyses and Plans, and a Verification/ Validation Plan. The Contractor shall provide a top level safety analysis of the High Energy flightweight cell design, Critical Items List, and a Limited Life Items List.

4.2.6.2.1 Task BFBA - Ultra High Energy Flightweight Cell Preliminary Design – Cell Electrochemical Components

The Contractor shall support recommendations and identify advantages, disadvantages, difficulties and limitations involved with the known baselined components along with necessary trade studies to achieve the performance goals listed in Table 1. Selection of the baseline candidates shall be in consultation with, and with the approval of, the NASA Project Manager.

The following cell components are required:

a. Cathode
b. Separator
c. Anode
d. Electrolyte

4.2.6.2.2 Task BFBB - Ultra High Energy Flightweight Cell Preliminary Design – Cell Mechanical Design

The design of the Ultra High Energy lithium-ion cell shall address the mechanical design of the following structural components for both the cell and battery level metrics:

a. Cell containment
b. Terminals
c. End plates
d. Mechanical support of cell
e. Seals
f. Other

The Contractor shall identify materials, dimensions, a conceptual design detailing component orientation, and a scheme for cell construction and activation. The Contractor shall support selections and identify advantages, disadvantages, difficulties and limitations involved with the selections and perform any necessary trade studies to compare options and project the performance parameters. Contractor recommendations regarding the cell mechanical design shall be those that best address the Key Performance Parameters listed in Table 1. Final selection of the Ultra High Energy Cell shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.2.3 Task BFBC - Ultra High Energy Flightweight Cell Preliminary Design – Cell Thermal Design

The Contractor shall perform and document top level thermal analyses and make predictions of thermal gradients for the Ultra High Energy cell design to ensure that adequate heat removal is provided to address temperature requirements for optimal operation, given the proposed operating conditions, design of the cell, cell components, and structural elements. Contractor recommendations regarding the thermal design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.2.4 Task BFBD - Ultra High Energy Flightweight Cell Preliminary Design – Optional Cell Components

This task addresses the incorporation of safety/functional components that are or may be physically incorporated into the cell. The Contractor shall assess the need for the incorporation of safety/functional features into the cell design. The Contractor shall support recommendations, identify the advantages, disadvantages, difficulties, and limitations involved with the incorporation of, and/or the omission of these components and justify their conclusions. Selection of the optional cell components shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.2.5 Task BFBE - Ultra High Energy Flightweight Cell Preliminary Design Review

The Contractor shall hold the Ultra High Energy Preliminary Design Review at NASA Glenn Research Center 14 months after contract award.

4.2.6.2.5.1 Task BFBEA - Ultra High Energy Cell Preliminary Design Review Data Package

The Preliminary Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule and additional required documentation listed in Section 4.1.6.2 Task AFB - High Energy Flightweight Cell Preliminary Design. The Contractor shall submit two (2) complete hard copies plus an electronic copy of the Preliminary Design Review data package covering the information to be addressed at the PDR to NASA at least two (2) weeks prior to the design review with sufficient narrative to demonstrate adequacy of the Ultra High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

4.2.6.2.5.2 Task BFBEB - Ultra High Energy Cell Preliminary Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete hard copies plus an electronic copy of the designs and specifications involved with the construction of the Ultra High Energy flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes.

4.2.6.2.5.3 Task BFBEC - Ultra High Energy Flightweight Cell Preliminary Design Review Summary Report

The Contractor shall provide a Preliminary Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two weeks after conducting the design review.

4.2.6.3 Task BFC - Ultra High Energy Cell Critical Design

The Critical Design is conducted when the design maturity is approximately at the 80-90% level. The Government shall refine the specific environmental customer requirements for the Ultra High Energy cell prior to initiation of this effort. Pending the evaluation of test results from 4.1.5.3 Task AEC – High Energy Evaluation Cell Acceptance Testing, and subsequent life cycle testing, the Contractor shall revise the Ultra High Energy flightweight cell design The Contractor shall conduct Critical Design Review efforts on the Ultra High Energy flightweight cell that meets the Key Performance Parameters in Table 1. The Contractor shall deliver a data package that contains the updated baseline documentation including completion of the Preliminary Design review actions, updated design specifications, final test plans, updated projected components, cell and battery level Key Performance Parameter characteristics, updated design limitations and margins, updated parts, materials and processes lists, updated mass properties list, updated design trade-off studies (thermal, structural, manufacturing), pertinent test results and evaluations and updated manufacturing schedule and cost estimates. The Contractor shall also provide a final risk assessment, mitigation plan, a final hazard analysis, and a reliability assessment. For the purpose of the Critical Design Ultra High Energy cell design, internal cell elements shall be identified using the best known and characterized components that target the required performance. Attributes that shall be considered in the selection of the components include electrochemical performance, weight, component availability, manufacturability, qualified processes, cost, and materials compatibility. The Contractor shall provide an engineering drawing tree outlining the Ultra High Energy flightweight cell design hierarchy and the necessary interface control documents to evaluate the planned cell dimensions. The Contractor shall provide the following plans as part of the Critical Design Review: Key Performance Parameter Measurement Plan, Product Assurance Plan, Contamination Control Plan, Producibility/Manufacturability Plan, Safety Analyses and Plans, a Verification/ Validation Plan, Final Activation Plan, Acceptance Criteria, and Maintenance Plan. The

Contractor shall provide a top level safety analysis of the Ultra High Energy flightweight cell design, Critical Items List, and a Limited Life Items List.

4.2.6.3.1 Task BFCA - Ultra High Energy Flightweight Cell Critical Design – Electrochemical Cell Components

The Contractor shall support recommendations and identify advantages, disadvantages, difficulties and limitations involved with the selections along with necessary trade studies to achieve the performance goals listed in Table 1. Selection of the baseline candidates shall be in consultation with, and with the approval of, the NASA Project Manager.

The following cell components are required:

a. Cathode
b. Separator
c. Anode
d. Electrolyte

4.2.6.3.2 Task BFCB - Ultra High Energy Flightweight Cell Critical Design – Cell Mechanical Design

The design of the Ultra High Energy lithium-ion cell shall address the mechanical design of the following structural components for both the cell and battery level metrics:

a. Cell containment
b. Terminals
c. End plates
d. Mechanical support of cell
e. Seals
f. Other

The Contractor shall identify materials, dimensions, a conceptual design detailing component orientation, and a scheme for cell construction and activation. The Contractor shall support selections and identify advantages, disadvantages, difficulties and limitations involved with the selections along with necessary trade studies to achieve the performance goals listed in Table 1. The Contractor shall prepare and deliver periodic status reports summarizing the results of screening tests, scale-up evaluations, manufacturing issues, and optimized performance characteristics on the candidate components to NASA. Contractor recommendations regarding the cell mechanical design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.3.3 Task BFCC - Ultra High Energy Flightweight Cell Critical Design – Cell Thermal Analysis

The Contractor shall perform and document thermal analyses and make predictions of thermal gradients for the Ultra High Energy cell design to ensure that adequate heat removal is provided to address temperature requirements for optimal operation, given the proposed design of the cell, cell components, and structural elements. Contractor recommendations regarding the thermal design shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.3.4 Task BFCD - Ultra High Energy Flightweight Cell Critical Design – Optional Cell Components

The Contractor shall support recommendations, identify the advantages, disadvantages, difficulties, and limitations involved with the incorporation of, and/or the omission of these components and justify their conclusions. The Contractor shall prepare and deliver a status report summarizing the results of screening tests, scale-up evaluations, manufacturing issues, and optimized performance characteristics on the candidate components to NASA. Baseline selection of the optional cell components shall be performed in consultation with, and with the approval of, the NASA Project Manager.

4.2.6.3.5 Task BFCE - Ultra High Energy Flightweight Cell Critical Design Review

The Contractor shall hold the Critical Design Review for the Ultra High Energy cell at the Contractor's facility thirty-two (32) months after the initiation of the contract.

4.2.6.3.5.1 Task BFCEA - Ultra High Energy Flightweight Cell Critical Design Review Data Package

The Critical Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule. The Contractor shall submit two (2) complete hard copies plus an electronic copy of the Critical Design Review data package covering the information to be addressed at the CDR to NASA at least two weeks prior to the design review with sufficient narrative to demonstrate adequacy of the Ultra High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

4.2.6.3.5.2 Task BFCEB - Ultra High Energy Flightweight Cell Critical Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete hard copies plus an electronic copy of the designs and specifications involved with the construction of the "Ultra High Energy" flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes.

4.2.6.3.5.3 Task BFCEC - Ultra High Energy Flightweight Cell Critical Design Review Summary Report

The Contractor shall provide a Critical Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two (2) weeks after conducting the design review.

4.3 Reporting Requirements, Deliverables Summary and Acceptance Criteria for Basic Tasks

Table 11 summarizes the reporting requirements and deliverables for the basic tasks. Note: This table breaks across three pages.

Table 12 summarizes the contract deliverables with acceptance criteria.

	Reporting Requirements and Deliverables	Due Date
Basic Tasks A and B	Bi-weekly teleconferences	Every two weeks
	Monthly status reports	Monthly
	Master Work Plan	30 days after start of contract
	Kick-off meeting	30 days after start of contract
	Semi-annual Review	Approximately 6, 18, and 30 months after start of contract
	Annual Review	Approximately 11, 23 and 33 months after start of contract
	Component Screening Plans (Anode, cathode, electrolyte, and separator)	90 days after start of contract
	Component Screening Plan for Safety and Functional components	Within 30 days of definition of nature of components
	Complete screening and evaluation of each component	Within 45 days of delivery of each component
	Component Screening and Evaluation report for High Energy Evaluation Cells and Ultra High Energy Build 1 Evaluation Cells	15 months after start of contract
	Evaluation Cell Acceptance Test Plan	45 days after starting Task AEA
	Component/Chemistry Downselect Meeting for High Energy Evaluation Cells and Ultra High Energy Build 1 Evaluation Cells	2 weeks after delivery of Component Screening and Evaluation report
	Scale-up and Manufacturability Report for High Energy Evaluation Cells and Ultra High Energy Build 1 Evaluation Cells	30 days after scale-up and fabrication of components, but no later than 21 months after start of contract
	Final report	33 months after start of contract

Table 11: Reporting Requirements and Deliverables Summary for Basic Tasks

	Reporting Requirements and Deliverables	Due Date
High Energy Cell Development Task A	High Energy Cell Trade Study Report	A minimum of 30 days prior to PDR and CDR plus major design alterations
	High Energy Evaluation Cell Design	15 months after start of contract
	High Energy Evaluation Cells	22 months after start of contract
	High Energy Evaluation Cell Component samples	Within 30 days of fabrication
	High Energy Evaluation Cell Acceptance Test Report	Deliver with Evaluation cells
	High Energy Flightweight Cells Preliminary Design Review Data Package	2 weeks prior to Preliminary Design Review
	High Energy Flightweight Cells Preliminary Design and Specifications	2 weeks prior to Preliminary Design Review
	High Energy Flightweight Cells Preliminary Design Review	9 months after start of contract
	High Energy Flightweight Cells Preliminary Design Review Summary	2 weeks after Preliminary Design Review
	High Energy Flightweight Cells Critical Design Review Data Package	2 weeks prior to Critical Design Review
	High Energy Flightweight Cells Critical Design and Specifications	2 weeks prior to Critical Design Review
	High Energy Flightweight Cells Critical Design Review	27 months after start of contract
	High Energy Flightweight Cells Critical Design Review Summary	2 weeks after Critical Design Review
	Chemistry Downselect Meeting for High Energy Flightweight Cell	1 month after Critical Design Review

Table 11: Reporting Requirements and Deliverables Summary for Basic Tasks (continued)

	Reporting Requirements and Deliverables	Due Date
Ultra High Energy Cell Development Task B	Ultra High Energy Cell Trade Study Report	A minimum 30 days prior to PDR and CDR plus major design alterations
	Ultra High Energy Evaluation Cell Build #1 Design	15 months after start of contract
	Ultra High Energy Evaluation Cell Build #1 Component Samples	Within 30 days of fabrication
	Ultra High Energy Evaluation Build #1 Cells	22 months after start of contract
	Ultra High Energy Evaluation Cell Build #1 Acceptance Test Report	Deliver with Evaluation cells
	Ultra High Energy Evaluation Cell Build #2 Design	24 months after start of contract
	Component Screening and Evaluation report for Ultra High Energy Build #2 Evaluation Cells	26 months after start of contract
	Component/Chemistry Downselect Meeting for Ultra High Energy Build #2 Evaluation Cells	2 weeks after delivery of Component Screening and Evaluation report
	Scale-up and Manufacturability Report for Ultra High Energy Build #2 Evaluation Cells	30 days after scale-up and fabrication of components, but no later than 33 months after start of contract
	Ultra High Energy Evaluation Cell Build #2 Component Samples	Within 30 days of fabrication
	Ultra High Energy Evaluation Build #2 Cells	34 months after start of contract
	Ultra High Energy Evaluation Cell Build #2 Acceptance Test Report	Deliver with Evaluation cells
	Ultra High Energy Flightweight Cell Preliminary Design Review Data Package	2 weeks prior to Preliminary Design Review
	Ultra High Energy Flightweight Cell Preliminary Design and Specifications	2 weeks prior to Preliminary Design Review
	Ultra High Energy Flightweight Cell Preliminary Design Review	14 months after start of contract
	Ultra High Energy Flightweight Cell Preliminary Design Review Summary	2 weeks after Preliminary Design Review
	Ultra High Energy Flightweight Cell Critical Design Review Data Package	2 weeks prior to Critical Design Review
	Ultra High Energy Flightweight Cell Critical Design and Specifications	2 weeks prior to Critical Design Review
	Ultra High Energy Flightweight Cell Critical Design Review	32 months after start of contract
	Ultra High Energy Flightweight Cell Critical Design Review Summary	2 weeks after Critical Design Review

Table 11: Reporting Requirements and Deliverables Summary for Basic Tasks (continued)

Deliverable	Acceptance Criteria	Acceptance Test
Materials from representative scaled-up process to address flight cell production quantities	Sufficiently similar to source material	Chemical and physical analyses SEM, EDS, XRD
Electrode and separator samples	Workmanship Expected performance based on material used	Physical and chemical analyses SEM, EDS, thickness, thermal stability (DSC) coin cell/half cell performance
High Energy evaluation screening cells	Workmanship	Performance requirements of aerospace electro-chemical devices as outlined in MIL-STD-454, Requirement 9. and visibly clean to NASA-SN-C-0005
Ultra High Energy evaluation screening cells	Workmanship	

Table 12: Summary of Basic Contract Deliverables with Acceptance Test Criteria

5.0 OPTIONS 1A and 1B – Manufacturing Flightweight Cells

The following tasks, Option 1A and 1B, must be proposed but their award is optional at the unilateral discretion of the Government. The primary purpose of Option 1A is the fabrication/production of ~35 Ah (TBR) capacity High Energy Lithium-ion cells that meet or exceed the target values in Table 1. The primary purpose of Option 1B is the fabrication/production of ~35 Ah (TBR) capacity Ultra High Energy Lithium-ion cells that meet or exceed the target values in Table 1. These High Energy and Ultra High Energy cells are defined in Figure 2 and Table 4. The High Energy and Ultra High Energy cells shall be built according to the designs developed under the base portion of this effort. The tasks listed below are the same for both the High Energy and Ultra High Energy cells, differing only in the specific materials and performance requirements. It should be noted that as requirements mature, the Ultra High Energy design may not be a unique cell design but rather a modification to the High Energy Design. In addition, there is a potential that the two designs will have different ampere-hour capacities.

Progress and status of all optional tasks shall be included in the monthly status report discussed in Section 4.0. All deliverables and their due dates for the Optional Manufacturing Flightweight Cells Tasks 1A and 1B are summarized in Table 14 in Section 5.3.

5.1 Optional Task 1A - High Energy Flightweight Cells

5.1.1 Task 1AA - Final High Energy Flightweight Cell Design

The Contractor shall complete the design of the High Energy Cell that was initiated under Task AF of the basic portion of the contract. The Critical Design Review Package completed under Task AFCEA shall serve as the basis for final High Energy Cell Flightweight Design.

Specific component combinations identified following the completion of NASA run testing of the screening cells delivered in Task AEB shall be factored into the final cell design.

The design requirements for the flightweight cells are discussed in the following sections. Items required at the Final Design Reviews are summarized in Table 13.

	Final Design Review
Design Maturity Level	100%
Documentation	Final Baseline Documentation
	Completion of CDR actions
	Final Parts, Materials, and Process lists
	Product Built-To Specifications
	Final Mass Properties List
	Final Design Limitations and Margins
	Supporting Trade-Off Analyses and Data
	Final cost and schedule data
	Final Key Performance Parameter Estimates
	Final Logistics/Manufacturing of Selected Design
	Fabrication, Assembly, Integration, Test Plans and Procedures
	Final components
	Failure Modes and Effects Analysis
Drawings	Final Detailed Engineering Drawings
	Final Interface Control Documents
Safety	Final Safety Analysis with verification
	Final Critical Items List
	Final Limited Life Items List

Table 13: Final Design Review Requirements

5.1.1.1 Task 1AAA - High Energy Flightweight Cell Final Design Review

The Contractor shall hold the Final Design Review for the High-Energy Cell at NASA Glenn Research Center forty-five (45) days after award of Optional Task 1A.

5.1.1.2 Task 1AAB - High Energy Flightweight Cell Final Design Review Data Package

The High Energy Flightweight Cell Final Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule. The Contractor shall submit two (2) complete hard copies plus an electronic copy of the Final Design Review data package covering the information to be addressed at the FDR to NASA at least two weeks prior to the design review with sufficient narrative to demonstrate adequacy of the High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

5.1.1.3 Task 1AAC - High Energy Flightweight Cell Final Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete copies plus an electronic copy of the designs and specifications involved with the construction of the High-Energy flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes. The Contractor shall not proceed with further work on Task 1AA until the design is approved with the exception of the long lead items already approved. Pre-approved items may be subject to modifications based on additional review.

5.1.1.4 Task 1AAD - High Energy Flightweight Cell Final Design Review Summary Report

The Contractor shall provide a Final Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two weeks after conducting the Final Design Review.

5.1.2 Task 1AB - Fabrication of High Energy Flightweight Cells

After successfully completing Task 1AAA and with approval from the NASA Contracting Officer, the Contractor shall proceed with fabricating cells to the NASA approved drawings, procedures, and methods specified under Task 1AAC. The quantity cells to be fabricated and delivered to NASA can vary between 12 and 48.

Acceptance Testing Requirements

Acceptance level testing shall include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The acceptance test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. All cells will undergo acceptance level testing. The Contractor shall conduct their standard cell-level acceptance testing to verify that performance and workmanship standards are met. The Buyer will conduct the acceptance level testing for the TRL 5/6 cell-level environmental levels to verify performance for Lunar Surface Systems customers.

Qualification Testing Requirements

Qualification level testing shall include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The qualification test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. The cells shall undergo qualification level testing and pass the required minimum performance criteria. The Buyer will conduct the qualification testing for the TRL 5/6 cell-level environmental levels to verify performance for Lunar Surface Systems customers.

5.1.3 Task 1AC – Acceptance Testing of High Energy Flightweight Cells

The Contractor shall acceptance test each of the High Energy flightweight cells fabricated in Optional Task 1AB following completion of their activation. The Contractor shall submit the High Energy Acceptance Test Plan for the testing to NASA forty-five (45) days prior to activation. The acceptance test plan is subject to the review and approval of the NASA Project Manager. Upon approval of the High Energy Test Plan, the Contractor shall activate the cells, initiate formation cycling, make the capacity determination, and charge retention measurements.

As a minimum, the following data shall be monitored and recorded for each test of the High Energy flightweight cells:

a. individual cell voltages
b. cell temperatures
c. charge/discharge current
d. time stamp
e. charge Ah
f. discharge Ah
g. watt-hours on charge
h. watt-hours on discharge
i. cycle number
j. test conditions

5.1.3.1 Task 1ACA - High Energy Flightweight Cell Acceptance Test Plan

The High Energy Acceptance Test Plan shall incorporate the following at a minimum:

Cell Activation

A cell activation procedure that covers the cell activation, including electrolyte fill, and formation cycling of the cells.

Capacity Determination

Capacity shall be measured at 20^oC and 0^oC after conditioning cycling. Three separate capacity measurements shall be made at each temperature. The average of the 0^oC measurements at C/10 shall be defined as the capacity, C for the cell.

Charge Retention Measurement

Open circuit voltage decay shall be determined for 168 hours at 20^oC after charging to 100% state-of-charge. Voltage measurements to the millivolt level shall be taken at 6 hour periods or less during the open circuit period. Following the 168 hour open circuit stand, the cell shall be discharged.

5.1.3.2 Task 1ACB - High Energy Flightweight Cell Test Report

The Contractor shall submit a report for review and NASA approval covering the results pertaining to activation, formation, capacity determination testing, charge retention testing, and the Contractor's standard acceptance testing to determine suitable temperature and ampere-hour capacity performance.

5.1.4 Task 1AD - Delivery of High Energy Flightweight Cell

Upon completion of the Contractor's acceptance testing of the cells, the NASA Project Manager shall direct the shipment of the hardware to NASA Glenn Research for further characterization testing for specific mission applications to demonstrate TRL6.

Cells shall be delivered no later than April 13, 2012.

Data Package and Component Sample Delivery

The Contractor shall maintain a log documenting the actual procedures and details of the cell construction and activation. Information relating to the component and electrolyte weights, temperatures, pressures, charge and discharge rates and times, and cell voltages shall be included in the log. Two (2) copies of the log shall be delivered to NASA.

The Contractor shall deliver four (4) samples of at least 200 cm^2 area of each anode, cathode, and separator components and 25 ml of each electrolyte incorporated into the hardware to NASA from each lot. A lot is defined as a continuous manufacturing production run of material.

5.2 Optional Task 1B - Ultra High Energy Flightweight Cells

5.2.1 Task 1BA - Final Ultra High Energy Flightweight Cell Design

The Contractor shall complete the design of the Ultra High Energy Cell that was initiated under Task BE of the basic portion of the contract. The Critical Design Review Package completed under Task BFCEA shall serve as the basis for final Ultra High Energy Cell flightweight design.

Specific component combinations identified following the completion of NASA testing of the evaluation cells delivered in Task BD shall be factored into the final cell design.

The design requirements for the flightweight cells are discussed in the following sections. Items required at the Final Design Reviews are summarized in Table 13.

5.2.1.1 Task 1BAA - Ultra High Energy Flightweight Cell Final Design Review

The Contractor shall hold the Final Design Review for the Ultra High Energy Cell at NASA Glenn Research Center 45 days after award of Optional Task 1B.

5.2.1.2 Task 1BAB - Ultra High Energy Flightweight Cell Final Design Review Data Package

The Ultra High Energy flightweight cell Final Design Review data package shall contain performance characteristics, design limitations, test plans, pertinent test results and descriptions, parts, materials and processes lists, mass properties list, and manufacturing schedule. The Contractor shall submit two (2) complete hard copies plus an electronic copy of the Final Design Review data package covering the information to be addressed at the FDR to NASA at least one week prior to the design review with sufficient narrative to demonstrate adequacy of the Ultra High Energy flightweight cell design to meet or exceed the target performance requirements in Table 1.

5.2.1.3 Task 1BAC - Ultra High Energy Flightweight Cell Final Design, Drawings, Specifications and Processes

The Contractor shall submit two (2) complete hard copies plus an electronic copy of the designs and specifications involved with the construction of the Ultra High-Energy flightweight cells to NASA for review and approval. If the designs, specifications, or plans are disapproved, the NASA Project Manager will indicate specifically what changes are necessary to obtain approval and the Contractor shall execute the necessary changes. The Contractor shall not proceed with further work on Task 1BA until the design is approved with the exception of the long lead items already approved. Pre-approved items may be subject to modifications based on additional review.

5.2.1.4 Task 1BAD - Ultra High Energy Flightweight Cell Final Design Review Summary Report

The Contractor shall provide a Final Design Review summary report containing at least the meeting minutes and roster of attendees, information and agreement items, identification and assignment to a responsible individual of each action item with a due date. The summary report shall be delivered to NASA within two (2) weeks after conducting the Final Design Review.

5.2.2 Task 1BB - Fabrication of Ultra High Energy Cells

After successfully completing Task 1BAA and with approval from the NASA Project Manager, the Contractor shall proceed with fabricating cells to the NASA approved drawings, procedures, and methods specified under Task 1BAC. The quantity cells to be fabricated and delivered to NASA can vary between 12 and 48.

Acceptance Testing Requirements

Acceptance level testing shall include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The acceptance test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. All cells will undergo acceptance level testing. The Contractor shall conduct their standard cell-level acceptance testing to verify that performance and workmanship standards are met. The Buyer will conduct the acceptance level testing for the TRL 5/6 cell-level environmental levels to verify performance for EVA and Altair customers.

Qualification Testing Requirements

Qualification level testing shall include as a minimum functional tests, shock, acoustic, random vibration, thermal vacuum, thermal cycle, and leakage tests. The qualification test procedures and levels listed in SP-T-0023, CxP-70036, and GLM-QE-8700.2 will be used for testing purposes. The cells shall undergo qualification level testing and pass the required minimum performance criteria. The Buyer will conduct the qualification testing for the TRL 5/6 cell-level environmental levels to verify performance for EVA and Altair customers.

5.2.3 Task 1BC – Acceptance Testing of Ultra High Energy Flightweight Cells

The Contractor shall test each of the Ultra High Energy flightweight cells fabricated in Optional Task 1BB following completion of their activation. The Contractor shall submit Ultra High Energy Test Plan for the testing to NASA 45 days prior to activation. The test plan is subject to the review and approval of the NASA Project Manager. Upon approval of the Ultra High Energy Test Plan, the Contractor shall activate the cells, initiate formation cycling, make the capacity determination, and charge retention measurements.

As a minimum, the following data shall be monitored and recorded for each test of the Ultra High Energy flightweight cells:

a. individual cell voltages
b. cell temperatures
c. charge/discharge current
d. time stamp
e. charge Ah
f. discharge Ah
g. watt-hours on charge
h. watt-hours on discharge
i. cycle number
j. test conditions

5.2.3.1 Task 1BCA - Ultra High Energy Flightweight Cell Test Plan

The test plan shall incorporate the following:

Cell Activation

A cell activation procedure that covers the cell activation, including electrolyte fill, and formation cycling of the cells.

Capacity Determination

Capacity shall be measured at 20^{o}C and 0^{o}C after conditioning cycling. Three (3) separate capacity measurements shall be made at each temperature. The average of the 0^{o}C measurements at C/10 shall be defined as the capacity, C for the cell.

Charge Retention Measurement

Open circuit voltage decay shall be determined for 168 hours at 20^{o}C after charging to 100% state-of-charge. Voltage measurements to the millivolt level shall be taken at 6 hour periods or less during the open circuit period. Following the 168-hour open circuit stand, the cell shall be discharged.

5.2.3.2 Task 1BCB - Ultra High Energy Flightweight Cell Test Report

The Contractor shall submit a report for review and NASA approval covering the results pertaining to activation, formation, capacity determination testing, charge retention testing, and the Contractor's standard acceptance testing to determine suitable temperature and ampere-hour capacity performance.

5.2.4 Task 1BD - Delivery of Ultra High Energy Flightweight Cell

Upon completion of the Contractor's acceptance testing of the cells, the NASA Project Manager shall direct the shipment of the hardware to NASA Glenn Research for further characterization testing for specific mission applications to demonstrate TRL6.

Cells shall be delivered no later than May 27, 2013.

Data Package and Component Sample Delivery

The Contractor shall maintain a log documenting the actual procedures and details of the cell construction and activation. Information relating to the component and electrolyte weights, temperatures, pressures, charge and discharge rates and times, and cell voltages shall be included in the log. Two copies of the log shall be delivered to NASA.

The Contractor shall deliver four (4) samples of at least 200 cm^2 area of each anode, cathode, and separator components and 25 ml of electrolyte incorporated into the hardware to NASA from each lot. A lot is defined as a continuous manufacturing production run of material.

5.3 Reporting Requirements and Deliverables Summary for Optional Manufacturing Flightweight Cells Tasks

Table 14 summarizes the reporting requirements and deliverables for Optional Tasks 1A and 1B Manufacturing Flightweight Cells.

Table 15 summarizes the contract deliverables with acceptance criteria.

	Reporting Requirements and Deliverables	Due Dates
Option 1A High Energy Flightweight Cells	Progress and status reported in monthly report	Monthly
	High Energy Flightweight Cells Final Design Review Data Package	2 weeks prior to Final Design Review
	High Energy Flightweight Cells Final Design and Specifications	2 weeks prior to Final Design Review
	High Energy Flightweight Cells Final Design Review	45 days after award of Optional Task 1A
	High Energy Flightweight Cells Final Design Review Summary	2 weeks after Final Design Review
	High Energy Flightweight Cells Acceptance Test Plan	45 days prior to activation
	High Energy Flightweight Cells Acceptance Test Report	Deliver with Flightweight Cells
	High Energy Flightweight Cells	13 months after start of Option 1A
	High Energy Flightweight Cells Construction and Activation Log	Deliver with Flightweight Cells
	High Energy Flightweight Cells Component Samples	Within 30 days of fabrication
	Final Report	Within 30 days of cell delivery
Option 2A Ultra High Energy Flightweight Cells	Progress and status reported in monthly report	Monthly
	Chemistry Downselect Meeting for Ultra High Energy Flightweight Cell	2 weeks after award of Optional Task 1B
	Ultra High Energy Flightweight Cells Final Design Review Data Package	2 weeks prior to Final Design Review
	Ultra High Energy Flightweight Cells Final Design and Specifications	2 weeks prior to Final Design Review
	Ultra High Energy Flightweight Cells Final Design Review	45 days after award of Optional Task 1B
	Ultra High Energy Flightweight Cells Final Design Review Summary	2 weeks after Final Design Review
	Ultra High Energy Flightweight Cells Acceptance Test Plan	45 days prior to activation
	Ultra High Energy Flightweight Cells Acceptance Test Report	Deliver with Flightweight Cells
	Ultra High Energy Flightweight Cells	12 months after start of Option 1B
	Ultra High Energy Flightweight Cells Construction and Activation Log	Deliver with Flightweight Cells
	Ultra High Energy Flightweight Cells Component Samples	Within 30 days of fabrication
	Final Report	Within 30 days of cell delivery

Table 14: Reporting Requirements and Deliverables for Optional Tasks 1A and 1B

Deliverable	Acceptance Criteria	Acceptance/Qualification Test
Option 1A: Flightweight cells	KPP high-energy cell-level threshold value and environmental test	Performance and environmental tests
Option 1B: Flightweight cells	KPP Ultra High Energy cell-level threshold value and environmental test	

Table 15: Summary of Options 1A and 1B Contract Deliverables with Acceptance and Qualification Test Criteria

6.0 Options 2A and 2B Component Development

The following tasks, Options 2A and 2B, may be proposed by the Contractor. NASA will decide at the time of award whether to exercise these options. These tasks are focused on the development of components and/or their constituents that will enable the performance metrics for the High Energy and Ultra High Energy cells defined in Figure 2 and Table 4.

NASA has issued NASA Research Announcement NRA NNC08ZP022N to develop component technologies for the High Energy and Ultra High Energy cells. Optional Tasks 2A and 2B mirror exactly the NRA focus, with the exceptions that materials and components developed under this Contract will not be required to be made available to anyone other than NASA and that deliverable dates and the required quantities differ.

A synopsis describing the NRA call for battery cell component candidate task areas for research and development was released under NNC08ZP022N and is available at: https://www.fbo.gov/index?s=opportunity&mode=form&id=987d8932b2a8eb18fa38ad7d1ca522b3&tab=core&_cview=0

Progress and status of all optional tasks shall be included in the monthly status report discussed in Section 4.0. All deliverables and their due dates for Optional Component Development Tasks 2A and 2B are summarized in Table 16 in Section 6.3.

6.1 Task 2A – Component Development for High Energy Cell

The primary purpose of these Options is the development of cathodes, electrolytes, and/or separators for incorporation into the High Energy cells. There is no anode development option for the High Energy Cell. The Li-ion components and investigative areas of interest for the anticipated research are listed below.

Note: Any electrode that is not among the general classes of materials stated here is considered an alternate chemistry. The component development option must be proposed as part of a "Contractor-recommended Alternate Chemistry" proposal.

6.1.1 Task 2AA – Null

There is no anode development for the High Energy Cell.

6.1.2 Task 2AB – Cathode Development for High Energy Cell

Targeted performance improvements at the High Energy battery cell level entail advanced cathode materials with the following characteristics:

i) specific energy values >1100 Wh/kg,
ii) improved thermal stability compared to the conventional lithiated cobalt oxide or nickel cobalt oxide systems,
iii) high lithium diffusivity compared to lithiated cobalt oxide or nickel cobalt oxide systems (10^{-10} cm^2/s), to support discharge rates of C/5 or higher (with minimal de-rating in the specific energy over a temperature range of -10^{o}C to +40^{o}C),
iv) good chemical and electrochemical stability combined with good reversibility to provide ~ 80% of the initial capacity after 2000 cycles at 100% DOD at C/2 for the "High Energy" cell (See Table 1).
v) Overall safety, in terms of tolerance to overcharge and to exposure to high temperatures, comparable or superior to the conventional lithiated cobalt oxide or nickel cobalt oxide systems and
vi) low toxicity, once again comparable or better than the conventional lithiated cobalt oxide or nickel cobalt oxide systems.

The Contractor shall develop cathode materials to meet these characteristics. Materials may include: lithiated layered mixed metal oxides of nickel, manganese and cobalt with suitable dopants and surface coatings. Other classes of cathodes, e.g., spinel and olivine compounds may also be considered, if the specific energy considerations are met. Materials shall have relatively simpler synthetic approaches that are readily scalable and amenable to large scale electrode processing, using standard battery component production equipment. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected at the cell and/or battery level. The Contractor shall demonstrate practical cathode structures that demonstrate necessary mechanical integrity, performance characteristics and compatibility with other cell components, in order to address desired cell-level performance and cycle life requirements.

6.1.3 Task 2AC – Electrolyte Development for High Energy Cell

The targeted performance enhancements, especially in the specific energy, energy density and safety warrant new and improved electrolyte systems compatible with the advanced cathode and anode materials being developed simultaneously in this project. Such new and advanced electrolytes will have improved characteristics, compared to the conventional $LiPF_6$ solutions in ethylene carbonate (EC), polypropylene carbonate (PC), diethyl carbonate (DEC), dimethyl carbonate (DMC) or (ethyl methyl carbonate (EMC) mixtures, such as the following:

i) Reduced flammability or flame-retardant as demonstrated by the material properties,

ii) Viable electrochemical stability over a wide electrochemical window of 0 to 5 Volts vs. Li, to be compatible with the high voltage cathodes as well as adequate electrochemical and chemical stability at the electrode potentials, to ensure minimal growth in the interfacial impedance,

iii) Sufficient ionic conductivity to support discharge rates of C/5 or higher with at least 80% capacity of the low rate (C/10) capacity over the temperature range of -10^{o}C to +40^{o}C,

iv) Enhanced protection with appropriate additives to eliminate side reactions, especially which may occur with new non-carbonaceous anode materials,

v) Ability to be adopted in cell designs capable of functioning in harsh space environments of temperature and vacuum, and

vi) Low toxicity comparable or better than the conventional aliphatic carbonate electrolytes.

The Contractor shall develop electrolytes such as new solvents, salts or additives to achieve the desired objectives. Materials shall have synthetic approaches, comparable to or even simpler than those for the state-of-the-art electrolytes, and are readily scalable and amenable to large scale production and handling, as with the conventional lithium-ion battery electrolytes. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected.

6.1.4 Task 2AD – Separator Development for High Energy Cell

The Contractor shall develop advanced alternative cell separator materials to enhance inherent cell-level safety and reliability relative to state-of-the-practice materials found in present-day cells for consumer use and positively influence the High Energy cell-level key performance goals presented in Table 1. For example, a thinner and less resistive separator coupled with an increased mechanical integrity and thermal stability may be developed. Materials shall be of high quality and possess uniform material-level properties, and the separator material shall not impede the electrical performance of the cell under normal operating conditions. Classes of such materials can include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics.

Of particular interest for enhanced safety for human-rated aerospace missions, are the cell-level tolerance to thermal abuse conditions, which could result from mechanical abuse (e.g., a short circuit), environmental exposure and/or from abnormal operating conditions, such as overcharge. Thus, a significant reduction in the risk of a hazardous cell-level thermal and/or electrochemical runaway event shall be addressed. For example, a low separator shutdown temperature coupled with sustained mechanical integrity at a temperature that is significantly above the shutdown temperature may impede the occurrence of an internal short circuit and, thus, afford a greater margin of cell-level safety.

Proposals should amply describe the anticipated impact of the proposed technology enhancement and what specific performance could be expected.

6.1.5 Task 2AE - Safety and Functional Components Development for High Energy Cell

The Contractor shall develop components or approaches that will increase the tolerance of the cell to hazardous conditions and that can also be easily integrated with the NASA-selected chemistries. Tolerance should be demonstrated by the fact that the cell or battery does not exhibit any flame or vent with fire under any of the above mentioned conditions. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected.

6.2 Task 2B – Component Development for Ultra High Energy Cell

The primary purpose of Option 2B is the development of anodes, separators and/or electrolytes for incorporation into the Ultra High Energy cells. The Li-ion components and investigative areas of interest for the anticipated research are listed below.

6.2.1 Task 2BA - Anode Development for Ultra High Energy Cell

The Contractor shall synthesize and develop advanced, alternative electroactive materials for the negative electrode of lithium-ion cells, as well as for the fabrication and delivery of negative electrode (anode) structures that enable the desired "Ultra High Energy" cell-level key performance parameter goals presented in Table 1. Such advanced materials of interest are those with electrode potentials more positive than lithium metal or lithiated carbon, having a high specific reversible capacity (i.e., > 800 mAh/g) and capable of reversibly alloying with or intercalating lithium. Methods for improving the cycling stability of such powder-based anodes are sought.

Classes of such materials may, for example, encompass nano-scale, Group 13 – 15 elements and the oxides, intermetallics or composites of such, e.g., silicon-based/carbon composites. Materials that exhibit minimal capacity fade with time and are both electrochemically and thermally stable are advantageous, as well as those that do not reduce or decompose the cell electrolyte to form a highly-resistive surface layer or form performance-limiting or gaseous reaction products. For example, a thermal or overcharge abuse condition could lead to the occurrence of detrimental side reactions at the anode surface, which could result in limited cell life or possibly a hazardous temperature excursion. Materials synthesis should be readily scalable, and materials should be able to be processed by standard battery component production equipment.

The Contractor shall fabricate and demonstrate practical full negative electrode structures that exhibit the attributes of mechanical integrity, thermal and electrochemical stability, specific capacity, electrical conductivity and compatibility with other cell components such that the desired cell-level performance requirements and overall endurance will be addressed. This includes the optimization of all components of a composite electrode structure. Engineering development approaches for optimizing the overall performance of the anode structure (e.g., electrolyte additives or current collection enhancement), anode reactivity and safety issues shall be addressed. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected at the cell and/or battery level.

6.2.2 Task 2BB – Cathode Development for Ultra High Energy Cell

There is no specific cathode development task for the Ultra High Energy Cell. If the option to renew the cathode development task is exercised for a second year, development should continue on the same materials that were under development for the High Energy cell with the goal of continuing to improve performance for their use in the Ultra High Energy Cell.

6.2.3 Task 2BC - Electrolyte Development for Ultra High Energy Cell

The targeted performance enhancements, especially in the specific energy, energy density and safety warrant new and improved electrolyte systems compatible with the advanced cathode and anode materials being developed simultaneously in this project. Such new and advanced electrolytes will have improved characteristics, compared to the conventional $LiPF_6$ solutions in ethylene carbonate (EC), polypropylene carbonate (PC), diethyl carbonate (DEC), dimethyl carbonate (DMC) or (ethyl methyl carbonate (EMC) mixtures, such as the following:

i) Reduced flammability or flame-retardant as demonstrated by the material properties,

ii) Viable electrochemical stability over a wide electrochemical window of 0 to 5 Volts vs. Li, to be compatible with the high voltage cathodes as well as adequate electrochemical and chemical stability at the electrode potentials, to ensure minimal growth in the interfacial impedance,

iii) Sufficient ionic conductivity to support discharge rates of C/5 or higher with at least 80% capacity of the low rate (C/10) capacity over the temperature range of $-10^{o}C$ to $+40^{o}C$,

iv) Enhanced protection with appropriate additives to eliminate side reactions, especially which may occur with new non-carbonaceous anode materials,

v) Ability to be adopted in cell designs capable of functioning in harsh space environments of temperature and vacuum, and

vi) Low toxicity comparable or better than the conventional aliphatic carbonate electrolytes.

The Contractor shall develop electrolytes such as new solvents, salts or additives to achieve the desired objectives. Materials shall have synthetic approaches, comparable to or even simpler than those for the state-of-the-art of electrolytes, and are readily scalable and amenable to large scale production and handling, as with the conventional lithium-ion battery electrolytes. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected.

6.2.4 Task 2BD - Separator Development for Ultra High Energy Cell

The Contractor shall develop advanced alternative cell separator materials to enhance inherent Ultra High Energy cell-level safety and reliability relative to state-of-the-practice materials found in present-day cells for consumer use and positively influence the "Ultra High Energy" cell-level key performance goals presented in Table 1. For example, a thinner and less resistive separator coupled with an increased mechanical integrity and thermal stability may be developed. Materials shall be of high quality and possess uniform material-level properties, and the separator material shall not impede the electrical performance of the cell under normal operating conditions. Classes of such materials can include microporous polymeric films, inorganic ceramics or composites of such, which could also embody multi-layered structural characteristics.

Of particular interest for enhanced safety for human-rated aerospace missions, are the cell-level tolerance to thermal abuse conditions, which could result from mechanical abuse (e.g., a short circuit), environmental exposure and/or from abnormal operating conditions, such as overcharge. Thus, a significant reduction in the risk of a hazardous cell-level thermal and/or electrochemical runaway event shall be addressed. For example, a low separator shutdown temperature coupled with sustained mechanical integrity at a temperature that is significantly above the shutdown temperature may impede the occurrence of an internal short circuit and, thus, afford a greater margin of cell-level safety.

Proposals should amply describe the anticipated impact of the proposed technology enhancement and what specific performance could be expected.

6.2.5 Task 2BE - Safety and Functional Components Development for Ultra High Energy Cell

The Contractor shall develop components or approaches that will increase the tolerance of the cell to hazardous conditions and that can also be easily integrated with the NASA-selected chemistries. Tolerance should be demonstrated by the fact that the cell or battery does not exhibit any flame or vent with fire under any of the above mentioned conditions. Proposals should define the impact of the proposed technology enhancements and what specific performance could be expected.

6.3 Reporting Requirements and Deliverables Summary for Optional Component Development Tasks 2A and 2B

The reporting requirements and required deliverables for the Optional Component Development Tasks 2A and 2B, as they apply, and their quantities are given in Table 16.

		Year 1		**Year 2 (if option is exercised)**	
Due Date / Component	**Monthly**	**6 months after start of contract**	**11 months after start of contract**	**18 months after start of contract**	**23 months after start of contract**
Cathodes and Anodes	Progress and status reported in monthly report	10 grams powder and 1 sheet of 200 cm^2 electrode	10 grams powder and 2 sheets of 200 cm^2 electrode	10 grams powder and 1 sheet of 200 cm^2 electrode	10 grams powder and 2 sheets of 200 cm^2 electrode
Separators	Progress and status reported in monthly report	1 sheet of 400 cm^2 separator (minimum width = 10 cm)	2 sheets of 400 cm^2 separator (minimum width = 10 cm)	1 sheet of 400 cm^2 separator (minimum width = 10 cm)	2 sheets of 400 cm^2 separator (minimum width = 10 cm)
Electrolytes	Progress and status reported in monthly report	75 ml electrolyte	125 ml electrolyte	75 ml electrolyte	125 ml electrolyte
Safety and Functional Components	Progress and status reported in monthly report	Propose suitable deliverables and quantities	Propose suitable deliverables and quantities	Propose suitable deliverables and quantities	Propose suitable deliverables and quantities

Table 16: Reporting Requirements, Deliverable Dates, and Quantities of Deliverable Materials from Contractor to NASA