In FY 1992, the Department of Energy (DOE), through the Office of Transportation Technologies, embarked in a new direction to bring about the return of electric vehicles (EVs) to the marketplace. A $262 million (50/50 cost share) agreement was reached between government and industry to forge an integrated effort on pre-competitive battery development. We have passed the mid-point in the four years of this initial agreement, and much has been accomplished under the banner of the United States Advanced Battery Consortium (USABC). An array of development proposals on diverse battery technologies has been evaluated, and to date, eight contracts (totaling $156 million) have been awarded. In addition, cooperative R&D agreements totaling $33 million have been established with five DOE laboratories to support these programs in areas such as test and evaluation, cell chemistry, materials development, modeling, and thermal enclosure development. Battery goals have also been established for both mid-term and long-term performance. Achievement of these goals would initially double the range and acceleration of electric vehicles and ultimately make electric vehicles comparable to internal-combustion cars in terms of performance, life, and total cost.

The sponsored battery technologies face both technical and materials challenges to meet these goals. For each technology, the specific set of challenges varies. The materials issues for both the mid-term and long-term batteries will be the focus of this presentation.

**Mid-Term Technologies:**

The lithium-ion program was initiated very recently. In this technology, lithium ions shuttle back and forth between two intercalation compounds, a carbon-based anode and a manganese dioxide cathode, through an inorganic salt dissolved in an organic solvent. The team of VARTA Batteries AG and Duracell, Inc., will strive to improve the utilization and cycle life of both of these materials as they scale up the technology to EV-size cells.
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Two separate programs are underway to develop nickel/metal-hydride batteries. For this technology, hydrogen from the metal hydride crystal structure reacts with the water in an alkaline electrolyte to replenish the supply of hydroxide ions consumed on the cathode side in the conversion of nickel oxyhydroxide to nickel hydroxide. On charge, this process is reversed. The high cost of the active materials in comparison to many other systems places a premium on maximizing active material utilization. The metal-hydride chemistry favored by the Ovonic Battery Company is based on mixtures of refractory metals (AB₂), whereas SAFT is developing anodes loosely based on lanthanide nickel (AB₅) or misch metal. Generally speaking, the AB₂ formulations provide greater hydrogen storage capacity, but the AB₅ chemistries require less internal cell pressure for hydrogen absorption to occur. Both programs seek to optimize metal hydride chemistries in terms of cost, hydrogen storage, and internal pressure. The high cost of nickel electrodes led to a new program with Yardney Technical Products. This program supplements the existing contracts and seeks to lower the cost of nickel electrodes through advances in electrode substrates and reductions in costly catalytic agents such as cobalt. The long-term cost of this battery can be lowered dramatically with the implementation of an effective recycling program.

The other, long-term battery system under study is sodium/sulfur, which uses an alumina-based solid electrolyte to conduct sodium ions between molten electrodes of sodium and sulfur. On discharge, molten sodium polysulfides are formed in the sulfur compartment. These polysulfides are highly corrosive at the operating temperature of ~335°C, and the search continues for lower-cost materials for use in the cathode. Silent Power GmbH uses sophisticated technology to fabricate the electrolyte tubes, as well as the ceramic-to-ceramic and ceramic-to-metal seals required for maintaining hermetic conditions. Still, improvements are also sought in the areas of sodium-resistant seal glasses and electrolyte-tube processing.

Long-Term Technologies:

The two initiatives on lithium-polymer batteries are headed up by 3M and W. R. Grace. The electrochemistry is similar to the lithium-ion technology except that a solid polymer, such as polyethylene oxide doped with an inorganic lithium salt, is used as the electrolyte. Because of the relatively low ionic conductivity of polymer electrolytes, the electrode and electrolyte layers are extremely thin to maximize the surface area. Some developers also favor above-ambient operating temperatures to further enhance ionic transport. The anode may be metallic lithium or an intercalation carbon film. With the longer time line to commercialization, there is also a greater diversity in cathode materials under active investigation. In addition to manganese dioxide, oxides of cobalt and vanadium and sulfides of titanium are candidates.

Lithium ions are also the active species in the lithium-aluminum/iron-disulfide
battery. On discharge, the ions are removed from the alloy, transported through a molten halide electrolyte, and react with the sulfide. The molten salt provides exceptional ionic conductivity, but necessitates operation at −450°C. SAFT America is developing a battery based upon a bipolar cell design. This design is made possible by a chalcogenide-based sealant material developed at Argonne National Laboratory. Key materials issues include alternative materials to molybdenum for use as bipolar plates and improved ceramic structures for use as electrode separators.

Expected Demand for Battery Materials:

At present, initial annual production of mid-term technologies is foreseen to be 400 MWh in terms of energy-storage capability. If successful technologies achieve a specific energy of 80 Wh/kg, this production volume equates to 5,000 metric tons. (A similar calculation can be made for long-term technologies using a specific-energy target of 200 Wh/kg.) Breaking this tonnage down to specific components is obviously dependent on the specific technology, the ultimate design, and materials selections made by the developers. Some crude approximations can be made for ambient batteries based on the following weight estimates for the primary components: anode and substrate, 25%; cathode and substrate, 30%; electrolyte, 15%; other cell hardware, 25%; battery hardware, 5%. High temperature batteries have the added burden of a thermal enclosure and tend to have less weight concentrated in the active material in comparison to the electrolyte. Estimated component weight percentages are: anode and substrate, 15%; cathode and substrate, 20%; electrolyte, 20%; other cell hardware, 25%; battery hardware and enclosure, 20%. All of these estimates are ±5% at best, but they do serve to illustrate the potential demand for battery-related materials at the close of this millennium.

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