EAC
Electricity Advisory Committee

Energy Storage Activities in the United States Electricity Grid

May 2011


Credit: A123 Systems


Credit: Beacon Power

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Overview

Energy storage technologies offer cost-effective flexibility and ancillary services needed by the U.S power grid. As policy reforms and decreasing technology costs facilitate market penetration, energy storage technologies offer increasingly competitive alternative means for utilities to engage these ancillary services. This report summarizes energy storage technology activities and projects in the U.S. electric power grid as of May 2011.

Energy Storage Technologies Today

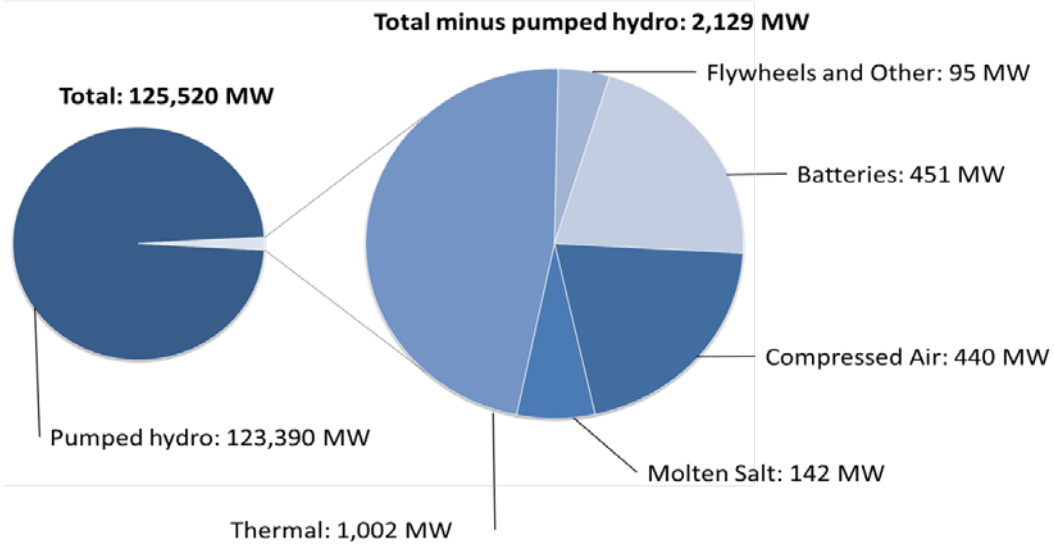
Installed energy storage technologies worldwide currently total over 125 GW. Pumped hydroelectric (pumped hydro) power dominates the global and U.S. energy storage markets, accounting for about 98 percent of installed storage technologies. Japan (23 GW) and Western Europe (13 GW) lead the deployment of pumped hydropower.[1]

The fastest-growing energy storage market is the use of flywheels and lithium-ion batteries in frequency regulation applications. This "fast storage" application has been shown to be more cost-effective than conventional fossil fuel plant generation, with the added benefit of reduced greenhouse gas emissions.

Thermal peak shaving applications provide significant benefits when used in air conditioning systems. The benefit ice storage can provide is significant in summer load periods, when the electric power grid traditionally sees its maximum load peaks.

The following chart illustrates the estimated global energy storage capacity:

Estimated Installed Capacity of Energy Storage in Global Grid (2011)



Source: StrateGen Consulting 2011.

Note: Estimates include thermal energy storage for cooling only. Figures are current as of April 2010.

[1] Analysis based on data from MWH Americas, Chicago, Illinois.

Energy storage in the U.S. electric power grid totals just over 23 GW, with 96 percent provided by existing pumped hydro systems. The following chart estimates active energy storage systems in the United States.

Estimated Installed Capacity of Energy Storage in U.S. Grid (2011)	
Storage Technology Type	Capacity (MW)
Pumped Hydro Power	22,000
Compressed Air	115
Lithium-ion Batteries	54
Flywheels	28
Nickel Cadmium Batteries	26
Sodium Sulfur Batteries	18
Other (Flow Batteries, Lead Acid)	10
Thermal Peak Shaving (Ice Storage)	1,000
Total:	**23,251**

Note: Analysis based on data from the Electricity Storage Association.

U.S. Department of Energy (DOE) Energy Storage Technology Program

The U.S. Department of Energy (DOE) launched its significant energy storage program in 2009 as part of funding from the American Recovery and Reinvestment Act (ARRA). ARRA provided $185 million in federal matching funds to support energy storage projects with a total value of $772 million. These projects generated 537 MW of new storage systems to be added to the grid. A breakdown of ARRA-funded projects, organized by project category, is shown below. Appendix A (SNL ESS 2010) provides a complete listing of ARRA-funded projects.

ARRA-Funded Energy Storage Technology Demonstration Projects			
Category	Power (MW)	Project Value	DOE Funds
1. Battery storage for utility load shifting or wind during operation and ramping control	57.0	$145,168,940	$60,784,483
2. Frequency regulation ancillary services	20.0	$48,127,957	$24,063,978
3. Distributed storage for grid support	7.5	$44,468,944	$20,350,142
4. Compressed air storage (CAES)	450.0	$480,962,403	$54,561,142
5. Demonstration of promising storage technologies	2.8	$53,075,574	$25,230,027
Total:	537.3	$771,803,818	$184,989,700

Source: SNL ESS 2010.

DOE also provided $1.25 billion for new electric drive battery and component manufacturing facilities. Appendix B (SNL ESS 2011a) provides a complete listing of these ARRA-funded projects.

DOE's Advanced Research Projects Agency-Energy (ARPA-E) also pursues energy storage activities. Investment in grid-scale, rampable intermittent dispatchable storage (grid) projects totals over $55 million for fiscal year (FY) 2010 and FY 2011. Appendix C (SNL ESS 2011b) provides a complete listing of ARPA-E projects.

The new DOE FY2012 budget (DOE 2011, 25, 35) contains $550 million for continued ARPA-E activities, $40 million for the Energy Storage Technology Program in the DOE Office of Electricity Delivery and Energy Reliability, and $450 million for three Energy Innovation Centers, which were recommended in the Electricity Advisory Committee report to Congress in 2008 (EAC 2008).

Energy Storage Technology Regulatory and Legislative Activities

The Federal Energy Regulatory Commission (FERC, Commission) requested input on grid storage during summer 2010 (FERC 2010). In its February 2011 meeting, the Commission acknowledged the benefits of faster ramping resources, which improve operational and economic efficiencies and reduce costs to consumers (FERC 2011), by issuing a Notice of Proposed Rulemaking (NOPR) to adjust the current compensation practices for frequency regulation service. The changes in compensation proposed in the NOPR would allow market operators to pay "fast storage" resources on a basis commensurate with the benefits they provide.

In September 2010 the California Legislature passed AB2514, which requires the California Public Utilities Commission and publicly owned utilities to evaluate procurement targets for energy storage, which creates the necessary regulatory focus and process to build a market for grid-connected energy storage in California.

Future Energy Storage Technology Activities

Efforts are underway to add more pumped hydro plants to the grid. Advances in pump control technology (variable-speed drives) increase pumped hydro plants' capability to perform in the ancillary services market, even when water is being pumped for storage. The National Hydropower Association reports that new pumped storage plants totaling 24 GW of capacity are in the planning and permitting process and are scheduled to be completed by 2025 (Smith 2011).

A KEMA study commissioned in 2010 by the Electricity Storage Association showed that distributed storage systems could reach an installed capacity of approximately 18 GW by 2020. The same report estimates that adding an Investment Tax Credit (ITC) for storage similar to the wind power ITC would significantly increase the size and pace of storage system growth (ESA 2010).

U.S. storage manufacturers are also seeing their business opportunities expand. A 16 MW battery storage system for spinning reserve was deployed in Chile in 2009 (AES 2009), and a 32 MW storage system was deployed in 2011 in Belington, West Virginia (AES 2011).

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Appendix A: ARRA Energy Storage Demonstrations

ARRA Energy Storage Demonstrations						
AWARDEE (*TECHNOLOGY*)	SIZE-POWER (ENERGY)	APPLICATION	TITLE-DESCRIPTION	LOCATION	UTILITY	FUNDING-ARRA (*TOTAL*)
1. BATTERY STORAGE FOR UTILITY LOAD SHIFTING OR FOR WIND FARM DIURNAL OPERATIONS AND RAMPING CONTROL						
DUKE ENERGY BUSINESS SVCS. (TBD)	24MW (15MW slow)	Renewables and Demand	**Notrees Wind Storage** - Deploy a wind energy storage demonstration project at the Notrees Wind power Project in western Texas. The project will demonstrate how energy storage and power storage technologies can help wind power systems address intermittency issues by building a 24 megawatt (MW) hybrid-energy storage system capable of optimizing the flow of energy.	Goldsmith, TX	Duke	$21,806,219 ($43,612,445)
PRIMUS POWER (*ZINC-CHLORIDE FLOW BATT.*)	25MW (*75MWhr*)	Renewables	**Wind Firming EnergyFarm™-** Deploy a 25 MW - 75 MWh EnergyFarm for the Modesto Irrigation District in California's Central Valley, replacing a planned $78M / 50 MW fossil fuel plant to compensate for the variable nature of wind energy providing the District with the ability to shift on-peak energy use to off-peak periods.	Alameda, San Ramon, Modesto, CA	Modesto Irrig. Dist.	$14,000,000 ($*46,700,000*)
SOUTHERN CALIF. EDISON CO. (*LITHIUM-ION BATT.*)	8MW (*4 hrs*)	Renewables	**Tehachapi Wind Energy Storage Project** –Deploy and evaluate an 8 MW utility-scale lithium-ion battery technology to improve grid performance and aid in the integration of wind generation into the electric supply. The project will evaluate wider range of applications for li-ion batteries that will spur broader demand for the technology, bringing production to a scale that will make this form of large energy storage more affordable.	Tehachapi, CA	So. Calif. Edison	$24,978,264 ($*54,856,495*)
						ARRA Sub-Total: $60,784,483 **(*Project Value Sub-Total*): $145,168,940**
2. FREQUENCY REGULATION ANCILLARY SERVICES						
BEACON POWER (*FLYWHEELS*)	20MW (*5MWhr*)	Frequency	**Beacon Power 20MW Flywheel Frequency Regulation Plant –** Design, build, test, commission, and operate a utility-scale 20 MW flywheel energy storage frequency regulation plant in either Hazle Township, PA or Chicago Heights, Illinois, and provide frequency regulation services to the grid operator, the PJM Interconnection. The project will also demonstrate the technical, cost and environmental advantages of fast response flywheel-based frequency regulation management.	Tyngsboro, MA; Hazle Township, PA or Chicago Heights, IL	PPL Corp. (PA site); Midwest Energy (IL site)	24,063,978 ($*48,127,957*)
						ARRA Sub-Total: $24,063,978 **(*Project Value Sub-Total*): $48,127,957**

ARRA Energy Storage Demonstrations						
AWARDEE (*TECHNOLOGY*)	SIZE-POWER (ENERGY)	APPLICATION	TITLE-DESCRIPTION	LOCATION	UTILITY	FUNDING-ARRA (*TOTAL*)
3. DISTRIBUTED ENERGY STORAGE FOR GRID SUPPORT						
CITY OF PAINESVILLE (*VANADIUM-REDOX BATT.*)	1MW *(6-8MWhr)*	Coal Efficiency	**Painesville Municipal Power Vanadium Redox Battery Demonstration Program** - Demonstrate 1 MW vanadium redox battery (VRB) storage system at the 32 MW municipal coal fired power plant in Painesville. The project will provide operating data and experience to help the plant maintain its daily power output requirement more efficiently while reducing its carbon footprint.	Painesville, Parma, OH; Johnstown, PA; Alexandria, VA; Evansville, IN; Devens, MA	Painesville Municipal Power	$4,242,570 ($*9,666,324)*
DETROIT EDISON CO. *(LITHIUM-ION BATT.)*	25kW (*20 units of 50 kWhr each*)	Frequency, Demand and Renewables,	**Detroit Edison's Advanced Implementation of A123s Community Energy Storage Systems for Grid Support** – Demonstrated proof of concept for aggregated Community Energy Storage Devices in a utility territory. The project is comprised of the following major research objectives: 1) The 20 Community Energy Storage (CES) devices across a utility territory; 2) The installation and use of a centralized communication across the service territory; 3) The integration of a renewable resource with energy storage; 4) The creation of algorithms for dispatching CES devices for peak shaving and demand response; 5) The integration and testing of secondary-use electric vehicle batteries; and 6) The use of Energy storage devices to provide ancillary services to the power grid.	West Lebanon, Hanover, NH; Saxonville, MA	Detroit Edison	$4,995,271 ($*10,887,258)*
EAST PENN MFG. CO. (*ULTRACAPACITOR / LEAD-ACID BATT.*)	3MW (*1-4MWhr*)	Frequency / Demand	**Grid-Scale Energy Storage Demonstration for Ancillary Services Using the UltraBattery Technology** - Demonstrate the economic and technical viability of a 3MW grid-scale, advanced energy storage system using the lead-carbon UltraBattery technology to regulate frequency and manage energy demand.	Lyons Station, PA	Met-Ed	$2,543,746 ($*5,087,269*)
PREMIUM POWER CORP. (*ZINC-BROMINE BATT.*)	5-500 kW (*6 hrs*)	Renewables & Micro-grid	**Premium Power Distributed Energy Storage System Demonstration for National Grid and Sacramento Municipal Utility District** - Demonstrate competitively-priced, multimegawatt, long-duration advanced flow batteries for utility grid applications. This three-year project incorporates engineering of fleet control, manufacturing and installation of five 500-kW/6-hour TransFlow 2000 energy storage systems in California and New York to lower peak energy demand and reduce the costs of power interruptions.	North Reading, MA; Syracuse, NY; Sacramento, Rancho Cordova, CA	National Grid & Sacramento Municipal Utility Dist.	$6,062,552 ($*12,514,660*)

ARRA Energy Storage Demonstrations						
AWARDEE (*TECHNOLOGY*)	SIZE-POWER (ENERGY)	APPLICATION	TITLE-DESCRIPTION	LOCATION	UTILITY	FUNDING-ARRA (*TOTAL*)
PUBLIC SVC. CO. OF NM (PNM) (*ADVANCED LEAD ACID BATT.)*	500kW (*2.5MWhr*)	Renewables and Modeling	**PV Plus Storage for Simultaneous Voltage Smoothing and Peak Shifting** – Demonstrate how a 2.5MWh Advanced Lead Acid flow battery along with a sophisticated control system turns a 500kW solar PV installation. into a reliable, dispatchable distributed generation resource. This hybrid resource will mitigate fluctuations in voltage normally caused by intermittent sources such as PV and wind and simultaneously store more energy for later use when customer demand peaks.	Albuquerque, NM	PNM	$2,505,931 ($*6,313,433*)
					ARRA Sub-Total: $20,350,070	
					(*Project Value Sub-Total*): $44,468,944	

4. COMPRESSED AIR ENERGY STORAGE (CAES)						
IBERDROLA USA (NY STATE ELEC. & GAS CORP.) (*CAES*)	150MW (*2-8 hrs*)	Peaking	**Advanced CAES Demonstration Plant (150MW) Using an Existing Salt Storage Cavern** - Demonstrate an advanced, less costly 150 MW Compressed Air Energy Storage (CAES) technology plant using an existing salt cavern. The project will be designed with an innovative smart grid control system to improve grid reliability and enable the integration of wind and other intermittent renewable energy sources.	Watkins Glen, NY	Iberdrola USA	$29,561,142 ($*125,006,103*)
PACIFIC GAS & ELECTRIC CO. (*CAES*)	300MW (*10 hrs*)	Renewables, Spinning Reserve, VARS	**Advanced Underground CAES Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir** - Build and validate the design, performance, and reliability of an advanced, underground 300 MW Compressed Air Energy Storage (CAES) plant using a saline porous rock formation located near Bakersfield, CA as the storage reservoir.	Kern County, CA	Pacific Gas & Electric	$25,000,000 ($*355,956,300*)
					ARRA Sub-Total: $54,561,142	
					(*Project Value Sub-Total*): $480,962,403	

5. DEMONSTRATIONS OF PROMISING ENERGY STORAGE TECHNOLOGIES						
AQUION ENERGY, INC. (*SODIUM-ION BATT.*)	10-100 kWhr	Renewables	**Demonstration of Sodium Ion Battery for Grid Level Applications** - Partner with Carnegie Mellon University to demonstrate a new, low cost, long-life, highly efficient, environmentally friendly, stationary energy storage battery that uses a proven and fully novel cell chemistry. Specifically, an aqueous sodium-ion based electrolyte is used in conjunction with simple highly scalable electrode materials housed in low cost packaging.	Pittsburgh, PA	AES Duke Energy	$5,179,000 ($*10,359,827*)

ARRA Energy Storage Demonstrations						
AWARDEE (*TECHNOLOGY*)	SIZE-POWER (ENERGY)	APPLICATION	TITLE-DESCRIPTION	LOCATION	UTILITY	FUNDING-ARRA (*TOTAL*)
AMBER KINETICS, INC. (*FLYWHEELS*)	50 kW (*50kWhr*)	Frequency	**Amber Kinetics Flywheel Energy Storage Demonstration** - Develop and demonstrate an innovative flywheel technology for use in grid connected, low-cost bulk energy storage applications. This demonstration effort, which partners with AFS Trinity, will improve on traditional flywheel systems, resulting in higher efficiency and cost reductions that will be competitive with pumped hydro technologies.	Fremont, CA	(In-house)	$3,694,660 ($*10,003,015*)
KTECH CORP. (*IRON-CHROMIUM REDOX FLOW BATT.*)	250kW (*1MWhr*)	Renewables	**Flow Battery Solution for Smart Grid Renewable Energy Applications** - Demonstrate a prototype flow battery system with an intermittent renewable energy source – a helios dual-axis tracker photovoltaic system. The project will combine a proven redox flow battery chemistry with a unique, patented design to yield an energy storage system that meets the combined safety, reliability, and cost requirements for distributed energy storage.	Albuquerque, NM; Sunnyvale, Snelling, CA	(none)	$4,764,284 ($*9,528,567*)
SEEO, INC. (*LITHIUM-ION BATT.)*	(*25kWhr*)	CES	**Solid State Batteries for Grid-Scale Energy Storage** - Develop and deploy a 25kWh prototype battery system based on Seeo's proprietary nanostructured polymer electrolytes. This new class of advanced lithium-ion rechargeable battery will demonstrate the substantial improvements offered by solid state lithium-ion technologies for energy density, battery life, safety, and cost. These batteries would be targeted for utility-scale operations, particularly Community Energy Storage projects.	Berkeley, Van Nuys, CA	PG&E	$6,196,060 ($*12,392,120)*
SUSTAINX (*CAES*)	1MW (*4MWhr)*	Renewables – both	**Demonstration of Isothermal Compressed Air Energy Storage to Support Renewable Energy Production** - Design, build, and deploy a utility-scale, low-cost compressed air energy storage system to support the integration of renewable energy sources onto the grid. The 1 MW/4hr system will store potential energy in the form of compressed air in above-ground industrial pressure facilities. The technology utilizes isothermal gas cycling coupled with staged hydraulic compression and expansion to deliver an efficient and cost-effective energy storage solution.	W. Lebanon, Hanover, NH; Saxonville, MA	AES Energy Storage	$5,396,023 ($*10,792,045*)
					ARRA Sub-Total: $24,063,978	
					(*Project Value Sub-Total*): $48,127,957	
					ARRA TOTAL FUNDING: $184,989,700	
					***(PROJECT VALUE TOTAL: $771,803,818*)**	

Appendix B: Recovery Act Awards for Electric Drive Vehicle Battery and Component Manufacturing

Applicant	DOE Award (Dollars in Millions)	Project Locations	Technology
Cell, Battery, and Materials Manufacturing Facilities			
Johnson Controls, Inc.	$299.2	Holland, MI Lebanon, OR (Entek)	Production of nickel-cobalt-metal battery cells and packs, as well as production of battery separators (by partner Entek) for hybrid and electric vehicles.
A123 Systems, Inc.	$249.1	Romulus, MI Brownstown, MI	Manufacturing of nano-iron phosphate cathode powder and electrode coatings; fabrication of battery cells and modules; and assembly of complete battery pack systems for hybrid and electric vehicles.
KD ABG MI, LLC (Dow Kokam)	$161	Midland, MI	Production of manganese oxide cathode / graphite lithium-ion batteries for hybrid and electric vehicles.
Compact Power, Inc. (on behalf of LG Chem, Ltd.)	$151.4	St. Clair, MI Pontiac, MI Holland, MI	Production of lithium-ion polymer battery cells for the GM Volt using a manganese-based cathode material and a proprietary separator.
EnerDel, Inc.	$118.5	Indianapolis, IN	Production of lithium-ion cells and packs for hybrid and electric vehicles. Primary lithium chemistries include: manganese spinel cathode and lithium titanate anode for high power applications, as well as manganese spinel cathode and amorphous carbon for high energy applications.
General Motors Corporation	$105.9	Brownstown, MI	Production of high-volume battery packs for the GM Volt. Cells will be from LG Chem, Ltd. and other cell providers to be named.
Saft America, Inc.	$95.5	Jacksonville, FL	Production of lithium-ion cells, modules, and battery packs for industrial and agricultural vehicles and defense application markets. Primary lithium chemistries include nickel-cobalt-metal and iron phosphate.
Exide Technologies with Axion Power International	$34.3	Bristol, TN Columbus, GA	Production of advanced lead-acid batteries, using lead-carbon electrodes for micro and mild hybrid applications.
East Penn Manufacturing Co.	$32.5	Lyon Station, PA	Production of the UltraBattery (lead-acid battery with a carbon supercapacitor combination) for micro and mild hybrid applications.

Appendix C: ARPA-E Awarded Projects in Energy Storage

ARPA-E AWARDED PROJECTS IN ENERGY STORAGE	
- **Lead Research Org.** - **(Partner Orgs.)** - **Amount Awarded** - **Project Location**	**PROJECT DESCRIPTION**
FY2011	
ABB Inc (SuperPower Inc.; Brookhaven National Lab.) **$4,200,000** Cary, NC	**Superconducting Magnetic Energy Storage (SMES): Superconducting Magnet Energy Storage System with Direct Power Electronics Interface**
Beacon Power Corp. (Imlach Consulting Engr; IONICORP) **$2,250,000** Tyngsboro, MA	**Flywheel: Development of a 100 kWh/100 kW Flywheel Energy Storage Module**
Boeing **$2,264,136** Huntington Beach, CA	**Flywheel: Low-Cost, High-Energy Density Flywheel Storage Grid Demonstration**
CUNY Energy Institute (Rechargeable Battery Corp) **$3,000,000** New York, NY	**Battery: Low-cost Grid-Scale Electrical Storage using a Flow-Assisted Rechargeable Zinc-Manganese Oxide Battery**
Fluidic Energy Inc. **$3,000,000** Scottsdale, AZ	**Battery: Enhanced Metal-Air Energy Storage System with Advanced Grid-Interoperable Power Electronics Enabling Scalability and Ultra-Low Cost**
General Atomics (UC San Diego) **$1,986,308** San Diego, CA	**Flow Battery: GRIDS Soluble Lead Flow Battery Technology**
General Compression **$750,000** Newton, MA	**Compressed Air Energy Storage (CAES): Fuel-Free, Ubiquitous, Compressed Air Energy Storage and Power Conditioning**
Lawrence Berkeley Nat. Lab. (DuPnt; Bosch; 3M; Proton Energy) **$1,592,730** Berkeley, CA	**Flow Battery: Hydrogen-Bromine Flow Batteries for Grid-Scale Energy Storage**
Primus Power **$2,000,000** Alameda, CA	**Flow Battery: Low-Cost, High Performance 50 Year Electrodes**
Proton Energy (Penn State University) **$2,148,719** Wallingford, CT	**Fuel Cell: Transformative Renewable Energy Storage Devices Based on Neutral**
United Technologies Research Center (Univ. of TX; Clipoper Windpower; Pratt & Whitney; Sandia National Laboratories **$3,000,000** East Hartford, CT	**Flow Battery: Transformative Electrochemical Flow Storage System (TEFSS)**

ARPA-E AWARDED PROJECTS IN ENERGY STORAGE	
- **Lead Research Org.** - **(Partner Orgs.)** - **Amount Awarded** - **Project Location**	**PROJECT DESCRIPTION**
Univ. of So. California (Jet Propulsion Laboratory) **$1,459,324** Los Angeles, CA	**Battery: A Robust and Inexpensive Iron-Air Rechargeable Battery for Grid-Scale Energy Storage**
FY2011	
Arizona State University (Fluidic Energy, Inc.) **$5,133,150** Tempe, AZ	**A new class of metal-air batteries using ionic liquids, with many times the energy density of today's lithium-ion batteries. Could enable long range, low cost plug-in hybrid and all electric vehicles.**
EaglePicher Technologies (Pacific Northwest National Laboratory) **$7,200,000** Joplin, MO	**High energy, low cost planar liquid sodium beta batteries for grid scale electrical power storage. Could enable continuous power from renewable resources, like wind and solar, and could support a highly stable and reliable grid.**
Envia Systems Argonne National Laboratory **$4,000,000** Hayward, CA	**High energy density Lithium-ion batteries with 3x better energy density than current batteries. Based on novel nano silicon-carbon composite anodes and manganese composite cathodes discovered at Argonne National Laboratory. Could lower the cost and speed the adoption of plug-in hybrids and electric vehicles.**
FastCAP Systems Corp. Mass. Inst. of Technology **$5,349,932** Cambridge, MA	**A nanotube enhanced ultracapacitor with energy density approaching that of standard batteries, but with many times greater power density and thousands of times the cycle life. Could greatly reduce the cost of hybrid and electric vehicles and of grid-scale storage.**
Inorganic Specialists, Inc. Ultramet, Inc; EaglePicher; Southeast Nonwovens; EMTEC **$1,999,447** Miamisburg, OH	**A silicon-coated carbon nanofiber paper for the anode of next generation Lithium-ion batteries. These low cost, manufacturable batteries could accelerate the deployment of plug-in hybrids and electric vehicles, shifting U.S. transportation energy from imported oil to the grid.**
Massachusetts Institute of Technology **$6,949,624** Cambridge, MA	**An all liquid metal grid-scale battery for low-cost, large-scale storage of electrical energy. This new class of batteries could enable continuous power supply from renewable energy sources, such as wind and solar, and a more stable, reliable grid.**