Energy Storage: Insights from Explorer

November 2015

Susan Leiby
Senior Consultant
sleiby@sbi-i.com

www.strategicbusinessinsights.com
SBI’s Services and Programs: Syndicated Research and Consulting Synergies

Addressing Markets and Technology

Consulting Services

Scenario Planning/Strategy
- Opportunity Discovery
- Roadmapping
Scanning, Monitoring, and Other Intelligence Solutions
- Commercialization
- Consumer Demand
- Technology and Market Assessment

Syndicated Research Programs

Explorer
- Scan™
- VALS™
- Consumer Financial Decisions

Representative Clients

Auto Mfrs: US, Japan, Europe
Biotechnology: US, Europe, Asia
Chemicals: Global
Consumer Electronics and IT: Global
Consumer Products: Global
Government Agencies: Global
Materials: Global
Medical Sector: US
National Laboratories
Oil Industry and Related Services: Global
Telecommunications: North America
Utilities: North America

Syndicated Research:
Over 300 Clients worldwide

Over 300 Clients worldwide
Technology Monitoring Overview

SBI recently introduced Energy Storage in the Explorer program. At its core is a comprehensive “Technology Map” covering emerging developments and opportunities.
Energy Storage Monitoring and Reporting: Disruptive Emerging Trends

Just looking at five of these topics reveals the scope and magnitude of recent disruptive changes.

- **Advanced batteries**
  - Fuel cells
  - Self-generation
  - Photovoltaic prices
  - Feed-in tariffs

- **Electric vehicles**
  - Microgrids
  - Smart energy management
  - Carbon taxes

- **Advanced manufacturing**
  - Grid energy management

- **New energy storage technologies**
  - Renewables
  - Demand for clean energy
  - Volatile fossil fuel prices
  - Net metering

- **Utility and Regulatory Actions**
  - New energy business models
  - Carbon nanomaterials
  - Hydrogen production
  - Demand for portable electronics
  - Efficient building practices
**Disruptive Emerging Trends: Advanced Batteries**

Advanced batteries, particularly Li-ion cells, are improving in energy density and decreasing in cost at a gradual but steady rate.

- US DOE tracking of battery cost and energy density reveals continuous improvements.
- Developers continue to modify anodes, cathodes, electrolytes, and packaging.
- Manufacturing at high volumes has allowed cells to become affordable.
- Advanced batteries are increasingly seeing use in stationary storage.

- Major manufacturers—such as BYD, GS Yuasa, LG Chem, Panasonic, Samsung SDI, and Sony—supply huge volumes of Li-ion batteries and make regular small performance improvements and cost cuts.
- Smaller startups are working to produce new battery designs that represent high-risk but high-reward opportunities.
Disruptive Emerging Trends: Advanced Batteries

New battery designs are appearing all the time… most do not make it to commercial production, but some do show promise

- Some developers are using nanostructured silicon anodes and/or sulfur cathodes to increase performance

- Others are working on solid-state electrolytes to make batteries thinner and more durable/safer

- Developers are now producing advanced battery systems that store power at distributed locations for record-low costs

Companies mentioned:
- Nexeon
- Amprius
- GS Yuasa
- Sakti
- Seeo/Bosch
- SolidEnergy Systems
- Tesla Motors
- Aquion Energy
- Eos Energy Storage
Disruptive Emerging Trends: Electric Vehicles

Electric vehicles are becoming a reality as carmakers make compelling plug-in cars that consumers actually want to buy

• **2006:** Tesla begins selling its Roadster for over $100,000, demonstrating that EVs can have long ranges and be luxurious

• **2010:** Nissan and General Motors began selling the Leaf and Volt, bringing lower-cost and mass-produced EVs to consumers

• **2012:** Tesla begins selling its Model S, an in-demand luxury sedan with high performance, fast charging, and long range

• **2015:** Numerous automakers, including early entrants like Mitsubishi, Nissan, General Motors, and Tesla as well as newer players to the EV market like BMW, Mercedes, Ford, and VW are now planning a variety of EVs in a range of sizes and market segments
Disruptive Emerging Trends: Electric Vehicles

Better batteries and lower costs → improve EV range and charge speed

Rising EV sales → increase battery market size, encourage further R&D and cost reduction

• Currently hybrid and start-stop vehicles dominate sales volumes in automotive energy storage market

• Full electric vehicles are increasing in popularity and use much larger batteries than hybrids, and therefore exert more influence per vehicle on the battery market

• EV manufacturers are using their battery system expertise to begin selling products for distributed generation
  — Tesla is now selling lower-cost battery-based energy storage for homes, small businesses, and utility-scale applications
  — Daimler is also producing home battery systems based on vehicle batteries that will launch in fall 2015
  — Other automakers, such as GM and Nissan, have built systems that use car batteries to power homes
Disruptive Emerging Trends: Advanced Manufacturing

New manufacturing techniques and automation are driving cost reductions in energy-storage and distributed energy products

• Printed battery technologies enable the manufacture of thin, flexible, and inexpensive batteries

• Huge automated production facilities create strong downward price trends
  — Tesla says its high-volume grid batteries (100 kWh Powerpack units) will sell for $250 per kWh

• Some manufacturers are taking the opposite approach by establishing small or modular assembly lines to bring costs down
  — 24M believes it can lower the cost of Li-ion cells to below $100 per kWh by 2020
Disruptive Emerging Trends: New Energy Storage Technologies

Novel technologies are emerging to enable better or less expensive stationary energy storage across all scales and applications.
Disruptive Emerging Trends: New Energy Storage Technologies

Every energy-storage technology has unique advantages and disadvantages.

### Comparison of Selected Energy-Storage Technologies

<table>
<thead>
<tr>
<th>Energy-Storage Technology</th>
<th>Typical Power Capacity</th>
<th>Energy Density (Watt-hours per Kilogram)</th>
<th>Power Density (Kilowatts per Kilogram)</th>
<th>Roundtrip Efficiency (Percent)</th>
<th>One-Half Storage Time</th>
<th>Lifetime</th>
<th>Installation Cost (Dollars per Kilowatt-hour)</th>
<th>Installation Cost (Dollars per Kilowatt-hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead acid</td>
<td>1 W to 35 MW</td>
<td>30 to 40</td>
<td>0.3</td>
<td>70 to 92</td>
<td>4 to 25 months</td>
<td>1000 cycles</td>
<td>175</td>
<td>125</td>
</tr>
<tr>
<td>Lithium-ion</td>
<td>&lt;1 W to 100 MW</td>
<td>150 to 250</td>
<td>0.18</td>
<td>93 to 97</td>
<td>7 to 14 months</td>
<td>10 000 cycles</td>
<td>200 to 360</td>
<td>1000</td>
</tr>
<tr>
<td>Zinc-air</td>
<td>&lt;1 W to 1 MW</td>
<td>375</td>
<td>0.175</td>
<td>40 to 50</td>
<td>Years (sealed)</td>
<td>300 cycles</td>
<td>400 to 900</td>
<td>3000</td>
</tr>
<tr>
<td>Flow batteries</td>
<td>0.2 to 10 MW</td>
<td>40 to 70</td>
<td>0.05 to 0.1</td>
<td>60 to 85</td>
<td>5 to 10 days*</td>
<td>20 years</td>
<td>400 to 000</td>
<td>4000 to 8000</td>
</tr>
<tr>
<td>PSH</td>
<td>5 to 2700 MW</td>
<td>0.28 per 100 m height</td>
<td></td>
<td>70 to 85</td>
<td>To years</td>
<td>10 to 50 years</td>
<td>100</td>
<td>1000 to 1600</td>
</tr>
<tr>
<td>CAES</td>
<td>100 to 300 MW</td>
<td>75 (20 bar)</td>
<td></td>
<td>42 to 55</td>
<td>4 to 10 hours</td>
<td>&gt;10 years</td>
<td>50</td>
<td>425</td>
</tr>
<tr>
<td>Ultracapctor</td>
<td>&lt;1 W to 15 MW</td>
<td>1 to 12</td>
<td>0.01 to 15</td>
<td>90 to 98</td>
<td>1.3 months</td>
<td>10⁶ cycles or 10 to 15 years</td>
<td>9000</td>
<td>300</td>
</tr>
<tr>
<td>Flywheel</td>
<td>0.002 to 2 MW</td>
<td>10 to 100</td>
<td>1 to 10</td>
<td>90 to 95</td>
<td>From day to month</td>
<td>10⁶ to 10⁷ cycles or 20 years</td>
<td>4000</td>
<td>400 to 300</td>
</tr>
<tr>
<td>SMES</td>
<td>1 to 100 MW</td>
<td>50</td>
<td>0.3 to 1</td>
<td>95</td>
<td>&gt; 4 years</td>
<td>10 to 20 years</td>
<td>30 000 to 630</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>10 to 500+ MW</td>
<td>40 000 (compressed)</td>
<td></td>
<td>30 to 40</td>
<td>Up to a year</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Molten salt</td>
<td>100 to 500 MW</td>
<td>30 to 50</td>
<td></td>
<td>80 to 90</td>
<td>1 week</td>
<td>20 years</td>
<td>25 to 40</td>
<td>—</td>
</tr>
</tbody>
</table>

Source: Ricardo plc; SBI

### Positioning of Electricity Storage Technologies

Source: DOE/EPRI 2013 Electricity Storage Handbook; SBI
Disruptive Emerging Trends: Utility and Regulatory Actions

Governments around the world are incentivizing clean energy and distributed energy systems through different subsidies, for example:

California offers generous support for clean vehicles and renewable energy

- Up to $2500 rebate on hydrogen and electric cars on top of $7500 federal rebate
- Mandated energy storage for all large utilities
- Clean-vehicle credits for cars makers
- Self-generation and solar incentives

Japan is also a leader, although it supports different technologies

- Up to ¥2 million for fuel cell vehicles, more from local governments
- Varying incentives for Ene-Farm fuel cells distributed generation
- Smaller incentives for EVs and other efficient vehicles
- Feed-in tariffs for renewable energy
- New 2015 rebates for energy efficiency and storage
Uncertainties

• Potential markets for distributed energy products like solar panels, batteries, and home energy systems could be worth billions of dollars.
• Horizontal synergies could emerge between energy distribution and dozens of related fields, ranging from information technology to automobiles.
• Regulators could continue to subsidize renewable energy sources, or they could begin to draw back support for financial or political reasons.
• Utilities may move from being power producers to grid managers, or even become obsolete if people begin to move off the grid.
• Fossil fuel prices remain highly unpredictable and could dramatically affect the cost of electricity and attractiveness of alternative power sources.
• Advanced energy technologies may emerge, creating new paradigms in production, distribution, or usage.
• Work and home lifestyles could transform if environmental concerns, branding, or financial motivators completely change the way people manage their energy use and transportation.
Uncertainties

The Energy Storage Map discusses issues for each application category and rates them according to impact and uncertainty.

Source: SBI
Uncertainties

The Technology Map organizes these issues into tables that suggest developments to watch for in different segments.

<table>
<thead>
<tr>
<th>Area to Monitor</th>
<th>Key Application Segments</th>
<th>Why It Is Important</th>
<th>What to Watch For</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging Speed and Infrastructure</td>
<td>Transportation, portable power</td>
<td>Conventional Li-ion batteries in portable and transportation applications typically take more than an hour to recharge fully. Manufacturers are making significant strides in developing fast-charging technologies, which could improve the attractiveness and competitiveness of advanced battery systems. For plug-in EVs, limited operating range, limited charging-station availability, and the time necessary for recharging continue to limit popularity. Standards to ensure compatibility across charging infrastructures (including those in different countries) and to ensure that batteries are compliant with such charging rates are also an issue.</td>
<td>Development of fast-charging technologies such as a prototype cell from Boston Power (Westborough, Massachusetts) that recharges to 80% capacity in 30 minutes, an organic radical battery from NEC that the company claims will recharge to 96% capacity in less than 1 minute, and a version of Toshiba’s Super Charge ion battery for a laptop computer that can recharge up to 90% of full capacity in ten minutes. Efforts by EV automakers such as BMW and Tesla to develop seamless charging infrastructures to help broaden the appeal of EVs in both urban and nonurban areas. Inclusion of integrated power-management electronic hardware, including fast chargers and battery-management systems, that maximize charge speed in vehicles and portable devices.</td>
</tr>
<tr>
<td>Cost of Commercial Technologies</td>
<td>Stationary power, transportation</td>
<td>The high costs of essentially all energy-storage technologies are a major deterrent to their commercial success, especially in transportation and stationary-power markets. Less proven technologies (such as SMES, high-energy flywheels, and flow batteries) are at a disadvantage relative to more mature technologies because of the significant expense and time necessary to conduct large-scale demonstration programs.</td>
<td>Battery makers’ planning very large-scale manufacturing facilities to scale up production volumes and reduce the cost of their technologies. Tesla Motors has partnered with Panasonic to construct a “gigafactory” in Nevada to make lower-cost battery modules and packs for EV and stationary applications. Recent announcements from both Boston Power and Foxconn of plans to build large new Li-ion battery facilities in China.</td>
</tr>
</tbody>
</table>

Source: SBI
Implications of Commercialization

The Energy Storage Technology map outlines three plausible but distinct mini-scenarios describing outcomes of these uncertainties.

Source: SBI
Opportunities

Although the future of energy storage is uncertain, numerous opportunities exist and players are working to capture these.

### Opportunities Timeline: Stationary Power

<table>
<thead>
<tr>
<th>Current Applications</th>
<th>Emerging Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Utility-Scale</strong></td>
<td></td>
</tr>
<tr>
<td>PSH/CAES in Bulk Energy Management</td>
<td>Hydrogen in Bulk Energy Management</td>
</tr>
<tr>
<td>Grid Ancillary Services—PSH, CAES, Batteries, SMES, Flywheels (Frequency Regulation, Reserves, Voltage Support, Load Following)</td>
<td></td>
</tr>
<tr>
<td>Transmission and Distribution Services—Batteries (Congestion Relief, Investment Deferral)</td>
<td></td>
</tr>
<tr>
<td>Customer Energy Management—Batteries, Flywheels (Power Quality and Reliability, Demand Shifting, Peak Reduction)</td>
<td></td>
</tr>
<tr>
<td>Renewables Integration—PSH, CAES, Batteries, Flywheels, Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Residential and Commercial PV Integration—Batteries, Flywheels, Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Community Energy Storage—Batteries, Flywheels</td>
<td></td>
</tr>
<tr>
<td>Distributed-Power Quality and Reliability Systems</td>
<td></td>
</tr>
<tr>
<td>Microgrids—Batteries, Flywheels, Ultracapacitors</td>
<td></td>
</tr>
<tr>
<td>Rooftop Air Conditioning—Thermal-Energy Storage</td>
<td></td>
</tr>
<tr>
<td>Off-Grid Applications—Batteries, Flywheels, Hydrogen</td>
<td></td>
</tr>
<tr>
<td>Second-Life Batteries</td>
<td></td>
</tr>
<tr>
<td><strong>Distributed</strong></td>
<td></td>
</tr>
<tr>
<td>Waste-Heat Utilization</td>
<td>Combined Heat and Power</td>
</tr>
</tbody>
</table>

### Value Chain for Stationary-Energy Storage

#### Enabling Components
- Lithium-Battery Electrode Materials
  - Hitachi Chemical
  - Mitsubishi Chem.
  - Nippon Carbon
  - Umicore
- Community Energy Storage—Batteries, Flywheels
- Distributed-Power Quality and Reliability Systems
- Microgrids—Batteries, Flywheels, Ultracapacitors
- Rooftop Air Conditioning—Thermal-Energy Storage
- Off-Grid Applications—Batteries, Flywheels, Hydrogen
- Second-Life Batteries

#### Systems and Integration
- **Energy-Storage Systems**
  - Lithium Batteries
    - AES Energy Storage
    - LG Chem
    - Johnson Controls
    - NEC
    - Sakti
    - Samsung SDI
    - SK Innovation
    - Tesla/Panasonic
    - Toshiba
  - Other Batteries
    - Aquion Energy (Na-ion)
    - EcouteC (hybrid battery/ultracap)
    - Eos Energy Storage (Zn-air)
    - GE (Na-NiCl2)
    - NGK Insulators (NaS)
- **Grid-Battery Software and Integration**
  - ABB
  - Advanced Microgrid Solutions
  - Alevo
  - Demand Energy
  - Greensmith
  - Gridtico Systems
  - NEC
  - S&C Electric Co.

#### Applications
- **Stationary-Energy Storage (Utilities and Distributed)**
  - PSH Operation
    - Alstom
    - Rushydro
    - SN Power
    - Utilities (Many Worldwide)
  - CAES Process Design
    - General Compression
    - LightSail Energy
  - CAES Process Design, Equipment, Construction, and Operation
    - Dresser Rand
    - Apex
- **Battery Applications (Utilities)**
  - E.ON
  - NextEra Energy
  - Pacific Gas and Electric
  - PJM
  - Kyushu Electric Power
  - Southern California Edison
  - Terna S.p.A
  - PJM
  - RWE
  - San Diego Gas and Electric
  - Vattenfall
  - Wegman
  - Xcel Energy

### Source: SBI
Interest in the energy-storage industry has soared due to the confluence of better and less-expensive energy storage technologies, demand in multiple markets, lower costs, and regulatory changes.

Potential for significant disruptions exist.

Although the future of energy-storage markets remains uncertain, activity in all market areas suggests that momentum has reached a tipping point where many established methods of energy utilization and distribution could begin to see rapid changes.

The future of energy storage and distribution holds many uncertainties that could affect an enormous range of industries and players.
SBI’s Consulting Services Can Help Make Sense of Future Uncertainties

- SBI structures many highly uncertain forces and drivers into distinct but plausible **scenarios**

- Scenarios build strategic awareness and provide a platform to identify multiple potential strategy options and then **strategic roadmaps** describe future paths that companies can follow