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Energy Storage Outlook: SVB Observations

OBSERVATIONS

• Incumbent Dominance
  — The large established battery manufacturers continue to dominate, making breakouts for new entrants challenging. Incumbents bring financial stability, manufacturing scalability and reliability which win favor over the technical advantages of new battery players. Batteries are often integrated into the end user product, and established OEMs are often reluctant to purchase from startups due to supply and quality concerns.

• Long on Promise, Short on Results
  — Advanced energy storage is still in its early stages. Even companies that have been around for years are only in early commercialization. This is both good and bad: the sector has a lot of potential but it will be awhile until we see any breakout companies. Some new breakout technologies, such as supercapacitors/ultracapacitors show promise, but they all seem far on the horizon in terms of leapfrog technical advances and market adoption is ever further out.

• New Entrants Few and Far Between
  — Startup activity is muted due to the lack of strong exits and the long time to market for existing energy storage companies.

• Contract Manufacturing and Service Models Attract Investor Interest
  — Achieving attractive economics in battery manufacturing requires significant scale and massive investment in plant assets. Following the broader cleantech trend, investors favor capital efficient models. Typically, these models are faster to commercialization, although gaining access to contract manufacturing resources may be challenging.

• Sales Cycles Long
  — Some energy storage markets, such as the grid-storage sector, are characterized by long sales cycles to utilities. Safety concerns linger, too, as consumer-oriented companies contemplate new battery technologies.
OBSERVATIONS

• Current Regulations Inhibit Adoption
  — Current regulatory bodies, such as FERC and the PUCs in the U.S., are still operating under legacy policies that were not written for, and consequently inhibit, new storage technologies for grid scale and distributed energy storage. These regulations are slowly changing and, as those regulations are updated and ISOs and utilities implement them, market adoption of the new technologies could accelerate.

• Lithium-ion Will Continue to Dominate
  — Relative to new technologies, it appears that lithium-ion will continue to dominate in terms of ubiquity of application. Relative to newer technologies, lithium ion has superior price and performance metrics. Advances in chemistry and manufacturing processes continue to provide improvements in efficacy, indicating likely continued dominance absent significant breakthroughs in other technologies.

• Transportation Market Slow to Develop
  — EVs growth may be strong on a percentage basis but the absolute penetration is still modest. Drivers of broader adoption include cost reductions, range improvements, and development of an adequate charging infrastructure.

• Large-Scale Energy Storage Solutions Not Yet Cost Competitive
  — Large scale energy storage has yet to win over customers on a cost basis relative to incumbent diesel generators and lead acid batteries in commercial and industrial applications, and to pump hydro and natural gas peakers in grid scale applications.

• Exits Elusive
  — Most energy storage startups are simply too early to attract strong M&A activity and are even further away from having enough revenue traction to be IPO candidates.
Cleantech Ecosystem

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Application Benefits

Commercial

Industrial

Utilities, Government and Others

Energy Generation

• Solar / Thermal
• Wind
• Hydro
• Alternative fuels
• Fuel Cells

Energy Storage

• Consumer Devices
• Electric Transport
• Large-scale Storage

Energy Efficiency

• Building materials
• Lighting
• Demand response systems
• Energy Management

Energy Infrastructure

• Smart Grid
• Hardware
• Smart meters
• Transmission

Recycling & Waste Management

• Waste to energy
• Waste repurposing

Agriculture, Air & Water

• Agriculture
• Air
• Water

Materials & Manufacturing

End User

Residential

Commercial

Industrial

Application Benefits

• Improved and economical source of energy
• Less pressure on non-renewable resources (oil and gas)
• Energy security
• Grid/Off Grid

• Improved power reliability
• Intermittency Management
• Increased cycles/longer storage
• Efficiency

• Reduced operating costs
• Lower maintenance costs
• Extended equipment lives

• Reduction in wastage
• Reduce outage frequency / duration
• Reduce distribution loss

• Economic in nature - well-run recycling programs cost less to operate than waste collection and landfilling

• Organic pesticides / fertilizers
• Water purification
• Water remediation
• Purification
• Management
VC Investments and Government Funding in Energy Storage

Overview

VC Investments:

- In 2011, VC investments in global energy storage was US$618 million, a 40% increase over the US$443 million investment in FY2010.

- For 3Q 2012, VC investments in Energy Storage was 7% of total VC funding in clean technology.
  - Energy Storage VC funding was down to US$80.3 million in 3Q 2012, as compared to US$84.9 million in 2Q 2012.

Government participation – new programs:

- In August 2012, Advanced Research Projects Agency-Energy (ARPA-E) announced funding for 19 new projects in two new program areas. The new programs, Advanced Management and Protection of Energy Storage Devices (AMPED) and Small Business Innovation Research (SBIR), will focus on battery management and storage to advance electric vehicle technologies, help improve the efficiency and reliability of the electrical grid and provide important energy security benefits.
  - 12 research projects are received $30 million in funding under the AMPED program, aiming to develop advanced sensing and control technologies that might improve the safety, performance and longevity for grid-scale and vehicle batteries. Unlike other Energy Department efforts to push the frontiers of battery chemistry, AMPED is focused on maximizing the potential of existing battery chemistries.
  - Under the SBIR program, a total of $13 million will fund seven projects for enterprising small businesses pursuing cutting-edge energy storage developments for stationary power and electric vehicles.

- The 19 new ARPA-E projects span 14 states and will receive a total of $43 million in funding.

Source: 1,2Cleantech Group.
Note: * For cumulative investments, Energy Storage includes Transport.
Top VC Investments in Energy Storage and Transportation

Select Deals Over Last Five Years

<table>
<thead>
<tr>
<th>Company</th>
<th>Key Sector</th>
<th>Key Venture Capital Firm</th>
<th>VC Rounds</th>
<th>Recent Round to Date (US$M)</th>
<th>Total VC Amount Raised (US$M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better Place</td>
<td>Electric Transport</td>
<td>Vantage Point, Israel Corp.</td>
<td>3</td>
<td>Dec 2011 $201.01M</td>
<td>$750.0M</td>
</tr>
<tr>
<td>Coda Automotive</td>
<td>Electric Transport</td>
<td>Aeris Capital, Harbinger Capital, New World</td>
<td>5</td>
<td>Feb 2012 $21.50M</td>
<td>$275.5M</td>
</tr>
<tr>
<td>Lilliputian Systems</td>
<td>Consumer Devices</td>
<td>KPCB, Atlas, Rockport, Rusano</td>
<td>8</td>
<td>Sep 2012 $40.0M</td>
<td>$154.2M</td>
</tr>
<tr>
<td>Protean Electric</td>
<td>Electric Transport</td>
<td>Oak, GSR Ventures</td>
<td>2</td>
<td>Jun 2012 $84.0M</td>
<td>$84.0M</td>
</tr>
<tr>
<td>ChargePoint Inc.</td>
<td>Consumer Devices</td>
<td>KPCB, Braemar, Voyager</td>
<td>4</td>
<td>Apr 2012 $51.01M</td>
<td>$83.7M</td>
</tr>
<tr>
<td>Deeya Energy</td>
<td>Consumer Devices</td>
<td>DFJ, NEA, Element</td>
<td>5</td>
<td>Sep 2012 $10.0M</td>
<td>$78.0M</td>
</tr>
<tr>
<td>Xtreme Power Inc.</td>
<td>Large Scale Storage</td>
<td>Bessemer, DOW, Sail</td>
<td>5</td>
<td>May 2012 $10.0M</td>
<td>$75.5M</td>
</tr>
<tr>
<td>LightSail Energy Inc.</td>
<td>Large Scale Storage</td>
<td>Khosla, Triplepoint</td>
<td>2</td>
<td>Aug 2012 $37.0M</td>
<td>$52.9M</td>
</tr>
<tr>
<td>QuantumScape Corp.</td>
<td>Large Scale Storage</td>
<td>Khosla, KPCB</td>
<td>2</td>
<td>Aug 2012 $22.7M</td>
<td>$50.0M</td>
</tr>
</tbody>
</table>

Key Investors Since 2001

<table>
<thead>
<tr>
<th>Venture Capital Firm</th>
<th># Deals</th>
<th>First Investment in Energy Storage / Transportation</th>
<th>Amount (US$mM)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFJ (Draper Fisher Jurvetson)</td>
<td>26</td>
<td>2001</td>
<td>$223.2M</td>
</tr>
<tr>
<td>KPCB (Kleiner Perkins Caufield &amp; Byers)</td>
<td>22</td>
<td>2005</td>
<td>$1,414.3M</td>
</tr>
<tr>
<td>New Enterprise Associates (NEA)</td>
<td>17</td>
<td>2007</td>
<td>$1,026.0M</td>
</tr>
<tr>
<td>Braemar Energy Ventures</td>
<td>13</td>
<td>2003</td>
<td>$379.7M</td>
</tr>
<tr>
<td>Khosla Ventures</td>
<td>13</td>
<td>2006</td>
<td>$212.5M</td>
</tr>
<tr>
<td>VantagePoint Capital Partners</td>
<td>12</td>
<td>2006</td>
<td>$1,000.0M</td>
</tr>
<tr>
<td>Technology Partners</td>
<td>12</td>
<td>2003</td>
<td>$136.6M</td>
</tr>
</tbody>
</table>

Source: Silicon Valley Bank

¹Amount represents cumulative investments (through a consortium of investors) and not the particular VC’s contribution in a deal(s).
Energy Storage: Analysis and Trends
Energy Storage Overview

Overview

- Electric energy storage systems are technologies that allow energy to be stored and used at a later time when and where it is needed.
- Storage enables energy to be moved across time, similar to transmission and distribution where energy moves across distances to end users.
- Small scale energy storage is currently dominated by batteries. Batteries are devices that convert stored chemical energy into useful electrical energy, and is one of the oldest and widely used forms of energy storage.
- Non-battery storage type includes flywheels, compressed air energy and pumped hydro.
- The global battery market for 2011 by type was distributed amongst Non-rechargeable (37%), Transport (30%), Industrial (17%) and Portable (16%).

The Segments

- **Consumer electronics**: The most mature market segment is consumer electronics, which needs lower power requirement and is used in portable devices such as computers, mobile phones, and GPS devices. These devices have been in the market for over 20 years.
- **Electric transport**: Electric transport involves batteries for fully electric vehicles (EV’s), plug-in hybrid electric vehicles (PHEV’s) and other mass electric transit (trains). EVs run on electric motors and require charging of their electric batteries, while PHEVs (like traditional hybrids) contain both an internal combustion engine and an electric motor.
- **Large-scale storage**: Large-scale storage is used by utilities and other power industry participants for several purposes. This segment has, by far, the most demanding technical requirements in terms of power, energy, and sheer scale. Large scale storage is generally used by power plants, transmission lines and energy units (useful for integrating intermittent energy sources like solar, wind, etc).

Source: 1EAC, California Energy Storage Alliance & Electric Power Research Institute.
Defining the Energy Storage Landscape

Energy Storage Market Segmentation

**Mobile**
- **Consumer Devices**
  - Mobile Phones, Smartphones
  - Laptops
  - Power tools
  - Video gaming machines
  - Mobile games

**Electric Transport**
- Batteries for plug-in electric vehicles
- Batteries for hybrid vehicles
- Batteries for other electric vehicles (buses, trains etc)

**Stationary**
- **Large-Scale Storage**
  - Storage for utilities
  - Used to shift energy produced
  - Useful for integrating intermittent energy sources
  - Provide grid stability and range of other benefits

**Energy Requirements (kW or MW)**
- Low
- High

**Technology & Market Maturity**
- High
- Low

Source: Cleantech Group.
Energy Storage: Common Tradeoffs and Key Metrics

Common Tradeoffs with Energy Storage

• **Energy capacity vs. Power capability**: More energy in a battery means the addition of more active materials to engage in a electrochemical reaction. However, this additional active material creates more resistance to electricity flow in the battery and reduces its power capability.

• **Capital Expenditures (Capex) vs. Operating Expenditures (Opex)**: Some technologies are more expensive initially but require less ongoing cash outlays to maintain the ability to store the same amount of energy.

• **Cost vs. Performance**: In all energy storage systems, there are costly high performance versions and less costly low performance versions.

• **Core Energy Storage Device vs. Energy Storage System/Pack**: There is a good deal of value to be added at the system level, and a good energy storage device (battery, flywheel etc) becomes useless if it is a part of a bad system (power converters / cooling / safety / reliability).

### Key Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Capacity</td>
<td>MWh, kWh</td>
<td>Maximum amount of energy stored in a device when fully charged</td>
</tr>
<tr>
<td>Power</td>
<td>MW, kW</td>
<td>Rate at which energy is transferred (charged or discharged). In electrical battery systems, there is a balance between power and energy; increasing the power of a system will reduce its energy</td>
</tr>
<tr>
<td>Power Density</td>
<td>Wh/L for energy, W/L for power</td>
<td>Amount of energy or power per unit of volume. Most relevant for mobile applications where physical space is often a more important limitation</td>
</tr>
<tr>
<td>Discharge Time</td>
<td>Seconds / Minutes / Hours</td>
<td>Time required to discharge a device</td>
</tr>
<tr>
<td>Cost per kWh</td>
<td>Currency / kWh</td>
<td>Measure cost per unit of energy capacity and power</td>
</tr>
<tr>
<td>Calendar life</td>
<td>Months / Years</td>
<td>Time before a battery becomes unusable whether it is in active use or inactive. Almost all devices degrade over time regardless of their cycling regime</td>
</tr>
<tr>
<td>Cycle life</td>
<td># number</td>
<td>Represents the number of cycles that a battery can provide. If the battery degrades before its calendar life, it is often because it has reached the end of its cycle life</td>
</tr>
<tr>
<td>Round-trip efficiency</td>
<td>Percentage</td>
<td>Percentage of energy stored that is lost in one cycle</td>
</tr>
</tbody>
</table>
Battery Basics

Battery Timeline

250BC – 224 AD: 'Baghdad Batteries'

1899: Nickel-cadmium (NiCd) battery (first alkaline battery) invented

1903: Nickel-iron battery invented; promoted by Thomas Edison for use in electric cars

1880s: First dry cell battery (zinc-carbon battery) invented by Carl Gassner

1899: Lead-acid battery invented (the first secondary or rechargeable battery)

1970s: Introduction of sealed valve regulated lead acid battery (VRLA)

1859: Lead-acid battery invented

1898: Nickel-metal-hydride (NiMH) batteries are used in mobile phones and portable electronics

1800s: Invention of Voltaic pile

Mid1990s: Lithium-ion polymer battery (higher energy density than standard Li-ion battery)

1899: Nickel metal-hydride (NiMH) battery invented

2010s: Thin film batteries for applications from smart cards to medical implants

1981: Sony launches first commercial, rechargeable, stable, lithium-ion battery

1903: Nickel-iron battery invented; promoted by Thomas Edison for use in electric cars

1989: NiMH overtaken by lithium and then lithium-ion

1898: Nickel-metal-hydride (NiMH) batteries are used in mobile phones and portable electronics

1990s: NiMH overtaken by lithium and then lithium-ion

1981: Sony launches first commercial, rechargeable, stable, lithium-ion battery

1981: Sony launches first commercial, rechargeable, stable, lithium-ion battery

2000s: Arrival of Lithium-ion as the predominant battery for transportation

1970s: Introduction of sealed valve regulated lead acid battery (VRLA)

1989: Nickel metal-hydride (NiMH) battery invented

Primary Batteries

Primary batteries are non-rechargeable. In terms of volume, they account for c.90% of all batteries in the world – mainly small, disposable batteries for consumers

Zinc-carbon primary batteries
Non-rechargeable manganese zinc alkaline
Non-rechargeable lithium
Specialty non-rechargeable (including zinc-air, silver oxide and magnesium)

Secondary Batteries

The chemical reaction in a secondary battery can be reversed, which means that the battery can be recharged. Rechargeable battery types, although accounting for only c.10% of all batteries by volume, represent more than 60% of the global battery market in terms of value

Lead-acid
Nickel-Cadmium (NiCd)
Nickel Metal-Hydride (NiMH)
Lithium batteries
Flow batteries
Sodium Sulfur

Source: Broker Research and websites.
Battery Basics: Key Technologies

<table>
<thead>
<tr>
<th>Technology / Characteristics</th>
<th>Lithium based</th>
<th>Lead Acid</th>
<th>Sodium Sulfur (NaS)</th>
<th>Flow Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging. Li-ion batteries use lithium compound as the electrode material, compared to the metallic lithium used in the non-rechargeable lithium battery.</td>
<td>Oldest type of rechargeable battery. Has a very low energy-to-weight ratio and a low energy-to-volume ratio. Capable of supplying high surge currents.</td>
<td>Molten-metal battery constructed from sodium (Na) and sulfur (S). NaS has a high energy density, high efficiency of charge/discharge and long cycle life, and is made from inexpensive materials.</td>
<td>Rechargeable fuel cell in which electrolyte containing one or more dissolved electroactive species flows through an electrochemical cell that reversibly converts chemical energy directly to electricity.</td>
</tr>
<tr>
<td>Commonly used in consumer devices</td>
<td>Suitable for use in motor vehicles to provide the high current required by automobile starter motors.</td>
<td>Used primarily for large-scale non-mobile applications such as grid energy storage.</td>
<td>Primarily used in load balancing, electric vehicles, UPS, power conversion and storage.</td>
<td></td>
</tr>
</tbody>
</table>

| Market Application Characteristics | | | | |
| Consumer electronics and electric transport users have adopted lithium due to favorable energy density, plus minimal operational and maintenance (O&M) needs. | Power to energy ratios for these batteries can be configured to match users’ specific needs. Till date, there has been limited commercialization at a grid-scale. | These batteries are more “power-centric”, with a lower energy density, than lithium-ion. | Flow batteries have the advantage of flexibility and scalability since they can be configured to different specifications of power and energy capacity. |
| | | | They tend to have a long cycle life. |
Lithium-ion Trends

- **U.S. and European players enter the fray in automotive battery market**
  - Companies based out of U.S. and Europe are emerging as strong players in the emerging automotive LiB battery segment, along with the Chinese, who are now becoming more active.

- **China’s growth**
  - Chinese domestic market is setting the tone for growth in the midsize and large LiBs market and growth in smartphones, thus offsetting the decline in feature phones.

- **Asian dominance to be broken for automotive LiBs?**
  - U.S. and European automakers are looking at local companies (in their home countries) to source the key components so that they do not have to rely on imports from Asia in the future.

- **Japan losing steam in small LiBs**
  - In small LiBs, Japanese usually produce cylindrical cells domestically because production is easily automated. Prismatic batteries (used in mobile phones) are manufactured overseas as production is more labor-intensive.
  - But with domestic production margins slim, companies like Panasonic and Sony are increasingly shifting production overseas to cut costs.

- **New battleground for battery materials makers**
  - Korean and Chinese manufacturers are now emerging as a threat to the long-dominated battery materials suppliers from Japan.
  - Deep pocket chemical conglomerates from U.S. and Europe (BASF, DuPont, 3M etc) and Korea (Samsung, LG etc) promise to change the level playing field.

- **Influx of non-chemical makers in Korea**
  - Chemical companies are not the only players to enter the market. Companies including steelmaker POSCO (through subsidiary POSCO Chemtech) and GS Group (GS Caltex), have recently entered the materials business.

- In recent years, for small LiB’s, low-cost battery manufacturers from China have entered the market, and the Korean makers’ share has been rising, while low-cost makers in China have also begun to emerge in a trend that has been particularly pronounced for small LiB materials. U.S. and European chemical makers have entered this market and it is turning highly competitive.

- Technological capacities are narrowing and production is decentralized (spreading to the U.S. and Europe, instead of being concentrated in Asia), making it more challenging for Japanese firms to maintain their competitiveness.
Lithium-ion will dominate the consumer and automotive markets for a long time into the future due to their high efficiency, long cycle and calendar life, high energy density and manageable safety.

Further increase in energy density is possible with lithium metal systems. But intrinsic problems with reversibility, cyclability and safety of lithium metal needs to be overcome to make the systems more viable.

<table>
<thead>
<tr>
<th>Battery System</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-metal / Sulfur</td>
<td>Low cost</td>
<td>Low cycle life, safety issues</td>
</tr>
<tr>
<td>Li-metal/Air</td>
<td>Low cost</td>
<td>Low cycle life, low efficiency, safety issues</td>
</tr>
<tr>
<td>Li-ion / Flow Battery (Cambridge Crude)</td>
<td>Separation of energy storage from energy conversion</td>
<td>Pumping of liquids containing dispersed nano particles</td>
</tr>
<tr>
<td>Li / Metal polymer (60 C)</td>
<td>No liquids</td>
<td>Heating required, low power output, safety issues</td>
</tr>
<tr>
<td>Li-metal / Multi electron chemistry</td>
<td>High energy density</td>
<td>Low cycle life, low efficiency, safety issues</td>
</tr>
<tr>
<td>Sodium / Sulfur (Na/S)</td>
<td>Good cycle life, low cost</td>
<td>Works at 300 C</td>
</tr>
<tr>
<td>Sodium / Nickel Chloride</td>
<td>Good cycle life, reasonable cost</td>
<td>Works at 350 C</td>
</tr>
<tr>
<td>Redox flow batteries</td>
<td>Low cost</td>
<td>Low power output, pumping of liquids</td>
</tr>
<tr>
<td>Sodium and Magnesium-ion batteries</td>
<td>Low cost</td>
<td>Low reversibility, low power output</td>
</tr>
<tr>
<td>Supercapacitors / Ultracapacitors</td>
<td>High power &amp; fast discharge</td>
<td>Low energy capacity</td>
</tr>
</tbody>
</table>
Overview

- Ultracapacitors are energy storage devices that can charge and discharge rapidly (in milliseconds) and generate short bursts of power while having extremely limited (less than a few seconds) energy storage capacity.
- Supercapacitors represent a step change from capacitors, improving upon the traditional capacitor in ways including:
  - Increasing the amount of charge that the plates can store. This is achieved through coating the plates with a porous material (e.g., activated carbon) which gives them a much higher surface area to store charge.
  - A thin physical separator is introduced in place of a conventional separator, eliminating the need for a bulky dielectric. This greatly reduces the separation and the actual physical size of the capacitor.
- Supercapacitors have remained a niche market. The key disadvantages are energy density and cost.
- The size of the current global market for ultracapacitors is estimated at approximately US$300 million and growing ~20%–30% annually.
- Ultracapacitors / supercapacitors are predominantly used in heavy and public transport and motor racing.

Ultracapacitors vs. Batteries

- Despite the current generation of supercapacitors having larger than normal capacitors, their storage capacity is very limited compared to a battery (~5%).
- On the performance front, an ultracapacitor can release energy much faster and with much more power than a battery, which relies on a slow chemical reaction. The charge/discharge cycle of supercapacitors is measured in seconds vs. hours for batteries.
- Ultracapacitors have low cost per cycle and good reversibility compared to batteries.
- Compared to a battery, there is no danger of overcharging in an ultracapacitor.
- In an ultracapacitor, the self discharge rate is very high compared to a battery.
- Unlike batteries, ultracapacitors have low maximum voltage, hence series connections are needed to obtain higher voltages.
- Ultracapacitors are more environment friendly due to non-usage of electrolytes and less toxic materials.
- Effective storage and recovery of energy requires complex electronic control and switching equipment, with consequent energy loss. The voltage across any capacitor drops significantly as it discharges.
- Capacitors have a long life, with little degradation over hundreds of thousands of charge cycles. This is because they have a high number of charge-discharge cycles (millions or more compared to 200 to 1,000 for most commercially available rechargeable batteries).

Key players¹

Maxwell Technologies  APowerCap Technologies  NESSCAP  PrimeEarth EV Energy Co., Ltd

Source: ¹Company data.
Energy Storage for Consumer Devices
**Consumer Devices**

**Overview**

- According to Global Industry Analysts (GIA), the global market for consumer batteries is forecast to reach US$55.4 billion by the year 2017.
- The secondary/rechargeable batteries segment would see lithium-ion (LiB) rechargeable batteries display the maximum growth opportunities, driven by the widespread popularity of consumer electronic devices, including smartphones and tablet PC’s. However, laptop demand, the main driver until now, is likely to decline as a result of market erosion from tablets and a downturn in battery capacity per unit.
- The strong demand for electronic devices would also support the demand for Nickel-Metal Hydride (NiMH) batteries to a certain extent (commonly available as AAA and AA, used as small rechargeable batteries).
- The small LiB market (predominantly the consumer electronics batteries) is expected to continue to grow at an annual rate of about 10% by capacity volume.
- In terms of technology, a shift in the shape of batteries used in laptops is being witnessed [from cylindrical types (the “18650”) to polymer types].

**Key Challenges**

| Manufacturing reliability at a global scale | • Massive capital buildup is required to set up manufacturing units and this can be achieved only by bigger firms  
• Manufacturers also need to be adaptive to changing technology and be able to produce and deliver the desired goods within a set timeframe |
| Hazardous Materials | • Batteries, especially ones which include mercury, are hazardous for the environment. The U.S. government enacted the Mercury-Containing and Rechargeable Battery Management Act in 1996. The purpose of the law was to formalize, with legal requirements, the phase-out of the use of mercury in batteries, provide for the efficient and cost-effective collection and recycling or proper disposal of certain used battery types. This has considerably reduced the effects on the environment, although not completely eliminated |
| Recycling | • Currently, the battery industries in the U.S., Europe, and Japan are working to develop improved recycling technologies. Technical feasibility of recycling alkaline and zinc carbon batteries in existing metal smelting furnaces and kilns have been demonstrated by European and U.S. battery industries. Environmentally beneficial and cost-effective recycling technologies are not universally available despite considerable progress |

**Small (consumer-use) LiB volume share (2011)**

- Panasonic (inc. Sanyo) 24%  
- Samsung 23%  
- LG Chem. 16%  
- Sony 8%  
- BYD 5%  
- Tianjin Lishen 4%  
- BAK 4%  
- Maxell 3%  
- Others 8%
# Energy Storage for Consumer Devices: Value Chain

## Lithium-ion

### Lithium Mining
- Chemtall
- FMC
- SQM

### Anode materials
- ShanshanTech
- Mitsubishi Chemical*
- TianJiao
- Hitachi Chemical*
- Amprus
- Pulead

### Cathode materials
- ShanShanTech
- NICHIA
- Mitsubishi Chemical*
- TianJiao
- TODA America
- Stella Chemifa*
- 3M*
- Umicore*
- Tanaka Chemical Corporation
- Phostech Lithium
- Pulead

### Electrolyte
- Samsung
- Cheil Industries
- Stella Chemifa*
- Tian Jiao

### Separator / membrane
- Asahikasei*
- Sumitomo Chemical*
- Polypore International, Inc*
- Celgard

### Battery cells
- Boston Power
- Eamex
- Enovix
- Johnson Controls*
- Valence*
- Electrovaya*
- Hitachi*
- NEC*
- Toshiba*
- Sanyo*
- LG Chem*
- Leyden Energy
- Gsyu USA*

### Production
- Local
- Global
- Regional
- Local

### Cost Drivers
- Material purity (ton/m³)
- Specific Energy (kWh/kg)
- Production efficiency (m²/sec)
- Volume (n/hrs)

### Other Drivers
- Mining capacity
- Sulphatization
- Materials
- Process
- Manufacturing technology
- Technology in assembly
- Labor and components

---

*Public Company
## Energy Storage for Consumer Devices: Value Chain (cont’d)

<table>
<thead>
<tr>
<th>Lithium-ion</th>
<th>Lithium Mining</th>
<th>Anode materials</th>
<th>Cathode materials</th>
<th>Electrolyte</th>
<th>Separator / membrane</th>
<th>Battery cells</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Present</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>In-house manufacture by OEM’s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Limited suppliers</td>
</tr>
<tr>
<td>The future…</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Limited outsourcing, mainly led by in-house assembly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cell manufacturers to take on the role of larger system delivery (including electronics)</td>
</tr>
</tbody>
</table>

**Present**
- Oligopoly
- Dominated by Japanese players, entry of Korean and Chinese manufacturers
- Partially specialized precursors sources
- Certain cathode materials still manufactured by cell manufacturer
- Joint Venture (JV) strategy to enter the market
- Independent Asian Li-battery manufacturers
- Research spin-offs

**The future…**
- Select new players
- Recycling companies
- Business models integrating recycling
- New players from specialty sectors
- More integration of precursor manufacturer
- Consolidation and downstream integration
- Minimal upstream integration
- In-house manufacture by OEM’s
- Limited suppliers
Energy Storage for Transport
Electric Transport

Overview

- Electric transport applications have four main battery types of interest:
  - **Nickel-based aqueous**: Nickel-cadmium and nickel-metal hydride are the two main nickel-based aqueous (liquid electrolyte) battery types. Cost and toxicity of cadmium are the main concerns for nickel-cadmium batteries (EU has imposed bans in most cases)
  - **Lithium-ion**: The most popular and commonly used battery type for portable consumer electronics, displaying favorable characteristics like durability, high specific energy, correspondingly light weight, and reasonably fast-charge/discharge capability
  - **Lithium metal and Metal-air**: Currently under development with a promise of up to a tenfold increase in energy. Full-fledged deployment in transportation sector has not been made as it is in the R&D stage, though these technologies have demonstrated basic performance and energy density potential in niche applications
- The EV battery market is expected to grow to US$8.4 billion by 2015 and nearly US$33 billion by 2020, from just US$1.5 billion in 2011.

Electric Transport Market

- Traditionally the industry is broken down into three main categories:
  - **Hybrid Electric Vehicles (HEVs)**: Vehicle that uses both an internal combustion engine (using conventional gasoline, diesel, or biodiesel) in tandem with either an electric motor powered by a rechargeable battery
  - **Plug-in Hybrid Electric Vehicles (PHEVs)**: Refers to an all-electric range which can be plugged into an electric outlet to charge their primary battery
  - **Electric Vehicles (EVs)**: Purest form of electrified vehicle in that it relies solely on an electrical motor as its source of propulsion
- According to Jeffries, rapid growth is expected from 2012-2014 in PHEVs and EVs, and they are expected to grow at 30%+ annually from 2014-2020, while the HEVs expected to increase market share from 2.5% in 2011 to 3.0% in 2020.
- By 2020, over 1 million vehicles sold per year will be an alternative vehicle, or 6.1% of U.S. market and ~500k+ vehicles will be PHEV/EV, or 3.1% of U.S. market by 2020.

Key Challenges

- **Higher upfront cost**
  - A primary barrier to deployment is their cost and availability. After the discontinuation of commercially produced electric passenger vehicles in the early 1990s, and before the introduction of the Nissan Leaf and Chevrolet Volt in late 2010, there were no mass produced electric passenger vehicles available in the U.S.
  - The costs of the current generation of EVs and PHEVs are high, with fossil fuels cheaper as of now

- **Range / Infrastructure**
  - Lack of existing infrastructure for vehicle fueling and charging, combined with limited range of pure electric vehicles presents a barrier to large-scale adoption, especially for those who do not have access to secure charging at home. Even with the fastest level three charging, a full charge would still take 30-45 minutes

- **Technology and service risk**
  - Consumers may tend towards the “tried and true” rather than take a risk on new technology, new products, and even entirely new companies while making such a heavy investment
  - EVs are likely to require service from OEMs that have the specific expertise, parts, and tools. New EVs currently do not have lengthy track records in terms of maintenance issues, battery life, motor wear etc
Electric Transport: Trends and Drivers

Federal, state, and local governments have an array of policy incentives for the purchase of EVs and greener vehicles, and also for the development of the energy storage and alternative vehicle technologies. One of the most crucial incentives is a federal tax credit of $7,500, designed to phase out once a manufacturer has sold 200,000 qualifying vehicles.

### Trends

- **HEV’s plying on Ni-MH batteries dominate the EV market**
  - Toyota vehicles still make up the vast majority of HEVs, and most of these models use Ni-MH batteries produced by PEVE (Primearth EV Energy). Relying on deep experience and know-how, PEVE has an annual in-house production capacity of c.1mn units. Toyota thus has a cost advantage over other automobile manufacturers which are relying on external procurement.

- **LiB transition (from Ni-MH) expected to continue in HEVs**
  - Ongoing shift in demand to LiBs is expected to accelerate going forward, evident from large automakers. Ford has already completely switched over from Ni-MH to LiB in all its models, and Honda is expected to boost its procurement volume following establishment of its joint venture with GS Yuasa (Blue Energy).

- **LiB to dominate as mainstream of current battery technology**
  - With automakers other than Toyota gradually shifting to LiBs for HEVs and all automakers adopting LiBs for their PHEVs and EVs from the beginning, LiBs are expected to be the mainstream battery type atleast in the foreseeable future.
  - Development of next-generation battery technology is underway (to resolve various issues associated with LiBs including boosting operating range).

### Drivers

- **Policy drivers: The Corporate Average Fuel Economy (CAFE) standard**
  - Established in 1975 in response to the oil crisis, the standard is defined as the sales-weighted harmonic mean in miles per gallon (MPG) of a manufacturer’s fleet of passenger vehicles or light trucks weighing 8,500lbs or less.
  - In July 2011 President Obama announced a new 54.5mpg CAFE standard by 2025.

- **Economic drivers**
  - The fundamental EV economic equation is higher upfront costs in the form of a battery in exchange for lower fuel costs. As the price of gasoline rises and the cost of batteries decrease, the lower operating cost of EVs will more quickly pay off the additional upfront cost.

- **Environmental drivers: Consumer preferences**
  - Primary motivation for buyers has been more environmental (opposition to oil) than economic.
Governments around the world and the global automakers are starting to take meaningful action to help reduce the world off its addiction to oil while at the same time mitigating the environmental impact of ever increasing vehicles on the road. A key part of this movement is the introduction of more battery-powered vehicles from the ground-breaking Toyota Prius hybrid (HEV) to the plug-in Chevrolet Volt (PHEV) to the all-electric Nissan Leaf (EV).

Future designs in automotive batteries include high power, high energy lithium-ion and high energy metallic lithium.

### Present designs

<table>
<thead>
<tr>
<th>Battery System</th>
<th>Potential</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead acid</td>
<td>2.0 V</td>
<td>High power, low cost</td>
</tr>
<tr>
<td>Nickel / Metal Hydride</td>
<td>1.2 V</td>
<td>Long life, durability</td>
</tr>
<tr>
<td>Lithium-ion</td>
<td>3.6 V, 2.4 V</td>
<td>High energy, design flexibility</td>
</tr>
<tr>
<td>Lithium-polymer</td>
<td>3.6 V, 2.4 V</td>
<td>High energy, planar design</td>
</tr>
</tbody>
</table>

### Automotive adoption metrics

**Hierarchy of Needs:**

- Performance / work
  - Performance, life and robustness
- Fitness & safety
  - Package without compromising crash performance and expected interiors
- Cost effective
  - Life of vehicle performance
  - Cost of fuel influence
  - Cost of carbon influence
  - Value based on power and/or energy density
  - Value based on degree of uniformity
- Mass effective (Wh/kg and W/kg)
Compelling Market Opportunity

- A BMS is an electronic system that manages a rechargeable battery by monitoring its state, calculating and reporting data, protecting the battery, and balancing & controlling its environment
- The key function of BMS is safety and reliability, making it an important value-add in the battery equation. Companies who can design and manufacturer cells, packs and overall systems are better able to differentiate themselves by adding more value than component manufacturing
- For an Electric Vehicle, BMS accounts for c.11% of manufacturing costs
- BMS topologies fall in 3 categories: Centralized (a single controller is connected to the battery cells through a multitude of wires), Distributed (a BMS board is installed at each cell, with single communication cable between battery and controller) and Modular (a few controllers, each handing a certain number of cells)

### Key Players

<table>
<thead>
<tr>
<th>Key Players</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash Woods Energy</td>
<td>Supplier of BMS and Battery Pack integration for EVs</td>
</tr>
<tr>
<td>APC by Schneider Electronic</td>
<td>Offers smart-charging and remote battery management for stationary batteries</td>
</tr>
<tr>
<td>CODA</td>
<td>Provides BMS, through its acquisition of EnergyCS – a leading developer of BMS</td>
</tr>
<tr>
<td>Mission Motors</td>
<td>Offers electric racing motorcycles, energy storage systems, electric drive systems and software intelligence</td>
</tr>
<tr>
<td>NOVO</td>
<td>Develops and markets electronic management systems for lithium ion batteries</td>
</tr>
</tbody>
</table>

### Key Functions

| Monitor and control | • BMS monitors the state of the battery through items such as Voltage, Temperature, State-Of-Charge (SOC), State-Of-Health (SOH), Coolant Flow & Current |
| Demand management & energy recovery | • In an EV, the BMS will also control the recharging of the battery by redirecting the recovered energy (i.e.- from regenerative braking) back into the battery packs (a pack is typically composed of a few cells) |
| Computation and log book function | • BMS also calculates and computed values for maximum charge / discharge current as a charge / discharge current limit (CCL / DCL), energy delivered since last charge or charge cycle and total energy delivered since first use and total operating time since first use |
| Communication | • Reports data to an external device, using communication links including direct wiring, wireless communication, DC-bus (serial communication over power-line) and CAN-bus (controller area network - a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer) |
| Cell protection and charge control | • BMS protects its battery by preventing it from operating outside its safe operating areas like over-current, over-voltage (during charging), under-voltage (during discharging), over-temperature, under-temperature and over-pressure |
| Cell balancing & optimization | • BMS ensures that all the cells that compose the battery are kept at the same SOC, through balancing. Balancing is usually accomplished through modular charging, shuffling energy, wasting energy and reducing the charging current |

Source: ¹Company sources.
## Electric Transport: Landscape (Automakers and Battery Suppliers)

<table>
<thead>
<tr>
<th>Key Manufacturers</th>
<th>Key Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primearth EV Energy Co., Ltd</td>
<td>TOYOTA, RENAULT NISSAN, GM, HYUNDAI, CHRYSLER</td>
</tr>
<tr>
<td>SANYO</td>
<td>BMW, HONDA, Ford, VOLKSWAGEN, SUZUKI, TOYOTA, TESLA, DAIMLER</td>
</tr>
<tr>
<td>LG Chem</td>
<td>GM, Ford, RENAULT, VOLVO, CHANA, Volkswagen, HYUNDAI</td>
</tr>
<tr>
<td>Johnson Controls</td>
<td>GM, Ford, BMW, DAIMLER</td>
</tr>
<tr>
<td>SB LiMotive</td>
<td>GM, Volkswagen, HYUNDAI, TESLA</td>
</tr>
<tr>
<td>Nissan + NEC = AESC</td>
<td>RENAULT NISSAN, MAZDA, SUBARU, SUZUKI</td>
</tr>
</tbody>
</table>

Source: Company data, list not exhaustive.

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Nickel-metal hydride batteries
Large-Scale Energy Storage
Large-Scale Energy Storage: Overview

Overview

- Large-scale energy storage (also called grid-scale energy storage) refers to the methods used to store electricity on a large scale within an electrical power grid.
- As of March 2012, pumped-storage hydroelectricity (PSH) was the largest-capacity form of large-scale energy storage available. PSH accounted for more than 98% of bulk storage capacity globally and its energy efficiency varies in practice between 70% to 75%.
- GTM Research and Azure International’s forecast, states that pumped hydro storage capacity will double or triple by 2016 to reach 40-60 GW. Other storage technologies are expected to rise to over 700 MW of installed capacity by 2016.
- The addressable market is over US$90 billion globally, growing at over 12% annually over the next four years to become a US$150 billion market by 2015.

Opportunities

- Substantial growth in renewables is driving the need for grid-storage with existing mandates set to deliver tremendous growth in renewable energy worldwide
- Enable a better utilized grid
- Defer significant T&D investment: If storage were able to offset or defer some small part of this T&D investment, the scale of the opportunity is tremendously large
- Storage has global potential of over US$100 billion: Several geographies outside of U.S., especially Asia is expected to drive the storage market and is mainly fueled by:
  - Faster economic growth
  - Growth in electricity demand
  - Greater use of renewable energy
  - Need for Transmission & Distribution (T&D) investments

Key Challenges

Technical

- Developing a safe and effective storage device at such a low price point is tremendously difficult. No vendor has yet built a substantial grid storage business (around the $300/kWh price point)

Regulatory

- There are a host of government funding programs around the world for storage projects, but cost recovery from the rate-payer is an obstacle
- Decrease in cost of storage or rate-payer funding of storage investments will drive mass adoption, mainly through a sustained regulatory system

Marketing and sales

- Lack of product standardization and established sales process is an obstacle to scale
- Slow and resource intensive sales cycle of the utility market hits the vendors hard. This is compounded by the industry’s lack of clarity about quantifying energy storage’s value

Non-storage alternatives

- Competition between various electrochemical solutions (i.e., batteries), thermal and mechanical approaches
- There is still no clarity on whether grid-storage is a viable alternative to other, non-storage technologies that address the same problems. For instance, gas-fired peaker plants can help with shifting load and meeting peak demand. These plants are relatively easy to build, simple and cheap to operate (assuming low natural gas prices)
Large-Scale Energy Storage (cont’d)

Large-Scale Energy Storage Global Market

- Japan (23 GW) and Western Europe (13 GW) lead the deployment of pumped hydropower.
- In 2012, China’s electric grid is expected to become the largest in the world in terms of both installed generation capacity and electricity produced. China also possesses the world’s largest installed wind power base and the world’s largest declared investment in renewable energy.
  - China currently has just 4% of the worldwide energy storage.
  - With strong government support and steadily improving technology, China’s energy storage market is expected to grow to a US$500 million per year market by 2016.
- 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, also allowing for less greenhouse gas emissions.

Source: 1,2 Cleantech Group.

Installed Capacity of Grid Energy Storage by Geography (2011)

<table>
<thead>
<tr>
<th>Geography</th>
<th>Capacity (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>42%</td>
</tr>
<tr>
<td>Japan</td>
<td>35%</td>
</tr>
<tr>
<td>Europe</td>
<td>15%</td>
</tr>
<tr>
<td>China</td>
<td>4%</td>
</tr>
<tr>
<td>Others</td>
<td>4%</td>
</tr>
</tbody>
</table>

Large-Scale Addressable Energy Storage Market Size

<table>
<thead>
<tr>
<th>Year</th>
<th>US$ billion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>75.0</td>
</tr>
<tr>
<td>2012</td>
<td>81.8</td>
</tr>
<tr>
<td>2013</td>
<td>91.6</td>
</tr>
<tr>
<td>2014</td>
<td>105.4</td>
</tr>
<tr>
<td>2015</td>
<td>123.3</td>
</tr>
</tbody>
</table>

Source: 1,2 Cleantech Group.
Large-Scale Energy Storage

U.S. Large-Scale Energy Storage Overview

- Energy storage in the U.S. electric power grid totals just over 23 GW, with 96% provided by existing pumped hydro systems.
- U.S. energy storage technology investments are expected to grow at an annual average rate of between 20% - 30% over the next five years. Public and private sector investments, mainstream adoption of EVs, and the pace of smart grid deployment will all play a role in the development of the U.S. energy storage market.
- Through the American Recovery and Reinvestment Act (ARRA), the U.S. Department of Energy (DOE) launched its significant energy storage program in 2009.
  - ARRA funded US$185 million to support energy storage projects with a total value of US$772 million.
  - 537 MW of new storage systems to be added to the grid with these projects.

Federal Energy Regulatory Commission (FERC) Ruling

- FERC ruled that wholesale power market operators are required to pay more for faster response energy storage than they currently do for slower response systems (like gas turbines).
- Batteries, as well as other technologies like flywheels, are classified as ‘faster’ response and will therefore ultimately benefit from the pay-for-performance decision.
- The FERC ruling has spurred increased utility interest in batteries for frequency regulation and comes at a favorable time, as depressed natural gas prices have made the economics more challenging as of late.
- Depending on how the program is implemented, pay-for-performance could provide a 25-100% premium for faster response time which would make them much more valuable to grid operators.

Note: Ice Storage - Thermal energy storage using ice, which makes use of the large heat of fusion of water.
### Large-Scale Energy Storage: Key Technologies and Landscape

#### Non-Electrochemical

<table>
<thead>
<tr>
<th>Technology</th>
<th>Characteristics</th>
<th>Key Bets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pumped Hydro-Storage</strong></td>
<td>• Electricity pumps water uphill into an upper reservoir when there is excess power and water is released back to generate power when it is needed</td>
<td>• Low price per kWh cycle, bigger scale and long lasting life</td>
</tr>
<tr>
<td><strong>Compressed Air Energy Storage (CAES)</strong></td>
<td>• Energy is stored in form of compressed air, into a cavity underground and then later use that compressed air as the input air to a gas fueled turbine</td>
<td>• Low price per kWh cycle, bigger scale and long lasting life</td>
</tr>
<tr>
<td><strong>Flywheel</strong></td>
<td>• Flywheels store energy in the angular momentum of a spinning mass. During charge, the flywheel is spun up by a motor with the input of electrical energy; during discharge, the same motor acts as a generator, producing electricity from the rotational energy of the flywheel</td>
<td>• High speed flywheel: High power density, strong cycle life involving low maintenance</td>
</tr>
<tr>
<td><strong>Ultra-Capacitor</strong></td>
<td>• Ultracapacitors are energy storage devices which can charge and discharge rapidly (in milliseconds) and generate short bursts of power while having extremely limited (less than a few seconds) energy storage capacity</td>
<td>• High power density combined with strong cycle life</td>
</tr>
<tr>
<td><strong>Superconducting Magnetic Energy Storage (SMES)</strong></td>
<td>• Systems store energy in the magnetic field created by the flow of current in a superconducting coil. This coil has been cooled to a temperature below its superconducting critical temperature</td>
<td>• Very high power and high ramp rate</td>
</tr>
</tbody>
</table>

#### Key Technologies

- Exelon*
- Toshiba*
- River Bank Power
- GridFlex
- Ridge Energy Storage & Grid Services LP
- General Compression
- Energy Storage and Power
- Sustain Energy Storage
- LightSail Energy
- ESPC
- Terrajoule
- Amber Kinetics
- Beacon Power
- Williams Hybridpower
- Vycon
- Storener02
- Bruker

**Source:** Silicon Valley Bank

**Note:** In October 2011, Beacon Power filed for bankruptcy protection under Chapter 11. As part of the bankruptcy court proceedings, Beacon Power agreed to sell its Stephentown facility to repay the DOE loan. In February 2012, Rockland Capital, bought the plant and most of the company’s other assets for US$30.5 million.
Large-Scale Energy Storage: Key Technologies and Landscape (cont’d)

<table>
<thead>
<tr>
<th>Technology / Characteristics</th>
<th>Electrochemical</th>
<th>Advanced Lead Acid Batteries</th>
<th>Fuel Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium-ion</td>
<td>• Lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging</td>
<td>• Ashlaw Energy</td>
<td>• Ballard*</td>
</tr>
<tr>
<td></td>
<td>• Altair Nano*</td>
<td>• Deeya Energy</td>
<td>• Ceramic Fuel Cells*</td>
</tr>
<tr>
<td></td>
<td>• Amprius</td>
<td>• Enervault</td>
<td>• Fuelcell Energy*</td>
</tr>
<tr>
<td></td>
<td>• Byd*</td>
<td>• Primus Power</td>
<td>• Heliocentris*</td>
</tr>
<tr>
<td></td>
<td>• ABSL Power Solutions</td>
<td>• Prudent Energy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Enovia</td>
<td>• Redflow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Envia</td>
<td>• ZBB Energy Corp*</td>
<td></td>
</tr>
</tbody>
</table>

Lithium-ion Batteries: • Leyden Energy, • Lishen, • QuantumScape, • Seeo, • Stem

Sodium Sulfur Batteries: • NGK*

Flow Batteries: • Ashlaw Energy, • Deeya Energy, • Enervault, • Primus Power, • Prudent Energy, • Redflow, • ZBB Energy Corp*

Advanced Lead Acid Batteries: • EXIDE Technologies*, • EnerSys*, • Johnson Controls*

Fuel Cells: • Ballard*, • Ceramic Fuel Cells*, • Fuelcell Energy*, • Heliocentris*

Technology / Characteristics:
- Lithium ions move from the negative electrode to the positive electrode during discharge, and back when charging.
- Liquid metal battery that has a high energy density, charge/discharge efficiency, and long cycle life.
- Corrosive materials are used and has a high operating temperature in the range of 300 to 350 degrees Celsius.
- Electrochemical energy storage, similar to a rechargeable fuel cell. It pumps two different liquid electrolytes across opposite sides of a membrane in a reaction chamber to produce or sink electrical current.
- The amount of power a flow battery can produce is defined by the area of the membrane it flows past and the amount of energy it can produce is defined by the size of its electrolyte tanks.
- A step up / improvisations from the traditional lead acid batteries.

Key bets:
- Improve grid responsiveness. It can pair up with renewable sources (like wind) to help smooth their output.
- Best suited for combined power quality and peak demand shaving duties.
- High energy density, high efficiency (up to 90%) and high power density.
- Long lasting, low maintenance and environmentally friendly batteries.
- Carbon electrodes will extend the cycle life and charge elasticity of lead acid batteries, allowing this already commercialized technology to be used in applications such as HEVs and grid storage.
- Targeting cycle life improvement from 1,000 cycles at 80% DoD to 2,000 cycles at 80% DoD.
- Fuel cells do not burn fuel, making the process quiet, pollution free (for hydrogen types) and 2-3 times more efficient than combustion.

Source: Silicon Valley Bank.

* Public Company
Appendix
## Select Players in Energy Storage

<table>
<thead>
<tr>
<th>Company</th>
<th>Business Description</th>
<th>Energy Storage Focus Area</th>
</tr>
</thead>
</table>
| Altair Nano   | • Engaged in the business of developing, manufacturing and selling batteries and systems  
• Operates in three segments: electric grid, transportation (commercial vehicles), and industrial                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Nano lithium titanate batteries and battery systems                                                                                                                                                                                              |
| BYD           | • Principally engaged in the research, development, manufacture and distribution of automobiles, secondary rechargeable batteries and mobile phone components  
• Operates primarily through secondary rechargeable battery business, which provides lithium-ion batteries and nickel batteries                                                                                                                                                                                                                                                                                                                                                                                                           | Rechargeable lithium-ion batteries and nickel batteries                                                                                                                                                                                          |
| Exide Technologies | • Provider of stored electrical energy solutions, and is a manufacturer and supplier of lead-acid batteries for transportation and industrial applications worldwide  
• Operates in four segments: Transportation Americas, Transportation Europe and Rest of World (ROW), Industrial Energy Americas, and Industrial Energy Europe and ROW                                                                                                                                                                                                                                                                                                                                                   | Lead-acid batteries                                                                                                                                                                                                                              |
| Electrovaya   | • Designs, develops and manufactures advanced battery and battery systems for the transportation, electric grid stationary storage and mobile computing end-markets  
• Its products include battery electric vehicle (BEV) battery system, battery bank, powerpad, scribbler and plug-in hybrid electric vehicle (PHEV) battery system                                                                                                                                                                                                                                                                                                                                                                                                   | Automotive batteries                                                                                                                                                                                                                             |
| GSYUASA       | • Japan-based company mainly engaged in the manufacture and sale of batteries and power supply devices  
• Provides automotive and motorcycle batteries, industrial batteries, power supply devices, alkali batteries for EV’s, small lead batteries and LIB’s                                                                                                                                                                                                                                                                                                                                                                                              | Automotive & other batteries                                                                                                                                                                                                                    |
| Hitachi       | • Manufactures and sells electronic and electrical products  
• Its Components & Devices segment offers LCDs, information storage media, and batteries  
• Provides automotive interiors and batteries for automobiles and hybrid electric vehicles  
• Also provides related systems engineering, marketing and service expertise                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Lithium-ion batteries  
Automotive batteries                                                                                                                                                                                                                           |
## Select Players in Energy Storage (cont’d)

<table>
<thead>
<tr>
<th><strong>LG Chem</strong></th>
<th><strong>Panasonic</strong></th>
<th><strong>Sanyo</strong></th>
<th><strong>Sony</strong></th>
<th><strong>Toshiba</strong></th>
<th><strong>ZBB Energy Corporation</strong></th>
</tr>
</thead>
</table>
| • Korea-based company engaged in the manufacture of petrochemicals and electronic materials  
• Operates two business segments, of which its electronic material segment produces rechargeable batteries, printed circuit materials, toner products and others | • Japan-based electronics manufacturer operating in eight segments  
• Energy segment provides solar system and lithium-ion batteries | • Designs and produces televisions, solar power generating systems, batteries, multimedia projectors, and electronic components  
• Sanyo has the largest global production capacity for manufacturing batteries and accessories offering the most extensive OEM (Original Equipment Management) capabilities | • Primarily focused on the electronics, game, entertainment and financial services  
• Operates in seven business segments of which the Professional Device Solution (PDS) segment provides audio, videos and monitors, image sensors and other semiconductors, optical pickups, batteries, data recording media and systems | • Manufactures and markets electronic and electrical products worldwide  
• Its electronic device segment provides general logic integrated circuits (ICs), optical semiconductors, power devices, logic large-scale integrated (LSI) circuits, image sensors and others | • Engaged in designing, developing, and manufacturing energy storage and power electronic systems to solve a range of electrical system challenges in global markets for utility, governmental, commercial, industrial and residential customers |

| **Energy Storage Focus Area** | **Lithium-ion batteries and lithium-ion polymer rechargeable batteries** | **Lithium-ion batteries** | **Battery appliances, batteries, battery chargers** | **Lithium batteries** | **Batteries** | **Flow batteries** |

*Source: Company data.*
## Select Players in Energy Storage (cont’d)

<table>
<thead>
<tr>
<th>Company</th>
<th>Business Description</th>
<th>Energy Storage Focus Area</th>
</tr>
</thead>
</table>
| Amprius       | • Founded in 2008 and is based in Sunnyvale, California  
• Manufactures and distributes batteries for electric vehicles and consumer electronics. The company’s products include lithium-ion batteries | Lithium-ion batteries    |
| Better Place  | • Founded in 2007 and is based in Palo Alto, California with operations in Israel, Denmark, and Australia  
• Builds and operates an infrastructure and intelligent network to deliver services to drivers for the adoption of electric vehicles and optimization of energy | Energy storage network for vehicles and optimization |
| Chargepoint   | • Founded in 2007 and is based in Campbell, California  
• Operates as an online global charging network that connects electric vehicle drivers to charging stations worldwide. Provides cloud-based service plans as annual subscriptions for providing tools, data, payment processing, and driver support | Charging stations         |
| Deeya Energy  | • Founded in 2004 and is based in Fremont, California with operations facilities in India  
• Engaged in developing and manufacturing stationary electrical energy storage solutions for telecommunications backup, renewable energy, defense, and grid power applications | Energy storage for large scale |
| EnerVault     | • Founded in 2008 to develop highly flexible, very large electric energy storage systems for cost-effective use in commercial and industrial facilities, renewables support, and utility grids  
• Owns a patented Engineered Cascade technology for Redox flow battery | Energy storage for large scale |
| Enovix        | • Founded in 2006 and is based in Fremont, California  
• Develops energy storage cells used in lithium-ion and lithium polymer rechargeable batteries. Offers 3D wave array based silicon lithium-ion rechargeable cells | Lithium-ion batteries    |
| Envia         | • Founded in 2007 and is based in Newark, California  
• It has offices in Detroit, Michigan with manufacturing facilities in China  
• Develops and manufactures lithium-ion energy storage systems for manufacturers of hybrid, plug-in, and pure electric vehicles | Lithium-ion storage      |

Source: Company data.
## Select Players in Energy Storage (cont’d)

<table>
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<tr>
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</tr>
</thead>
</table>
| **Leyden Energy** | • Founded in 2007 and is based in Fremont, California with manufacturing facilities in China  
                     • Manufactures and sells lithium-ion batteries for the consumer electronics, energy storage, and electric vehicle markets | Lithium-ion batteries                    |
| **LightSail Energy** | • Founded in 2008 and is based in Berkeley, California  
                        • Provides air energy storage systems | Air-energy storage systems                |
| **PRIMUS POWER** | • Incorporated in 2009 and is based in Hayward, California  
                        • Designs and develops energy storage systems  
                        • Solutions include power grid flexibility, renewables integration and demand management | Energy storage systems                    |
| **QuantumScape**  | • Incorporated in 2010 and is based in San Jose, California  
                        • Focuses on fundamental disruption in the energy storage sector | Lithium batteries                        |
| **SEEO**         | • Founded in 2007 and is headquartered in Hayward, California  
                        • Develops and manufactures rechargeable lithium batteries in the U.S.  
                        • Seeo was established with initial funding from Khosla Ventures, one of Silicon Valley’s top venture capital firms | Lithium-ion batteries                    |
| **Stem**         | • Headquartered in Millbrae, California  
                        • Stem’s services include energy insight, energy optimization and solar optimization | Energy administration                    |
| **Terrajoule**   | • Founded in 2009 and is based in Redwood City, California  
                        • Develops a technology that reduces energy costs for industry and agriculture. This technology has introduced a category in industrial power - Distributed Generation with Storage (DG-S) | Energy storage for large scale            |

*Source: Company data.*
Cell Types and Battery Terminology

**Cell Types**

- Cells are the basic electrodes which provide energy. They are then bundled together into modules to form usable mechanical devices.
- In addition to different chemistries, there are also different battery formats:
  - **Cylindrical cell**: One of the most widely used packaging styles for primary and secondary batteries. Ease of manufacture and good mechanical stability are the positives while the tubular cylinder has the ability to withstand internal pressures without deforming.
  - **Prismatic cell**: Introduced in the early 1990s, the prismatic cell is widely used in applications which need thinner sizes and lower manufacturing costs. Prismatic cells make use of the layered approach to maximize space usage.
  - **Button cell**: Cells are stacked into a tube to achieve a desired voltage, predominantly used in smaller devices needing compact cell design.
  - **Pouch Cell**: Conductive foil tabs are welded to the electrode and sealed to the pouch carry the positive and negative terminals to the outside rather than using a metallic cylinder and glass-to-metal electrical feed-through for insulation.

**Battery Terminology**

- **Gravimetric Energy Density**: Amount of energy stored in a given system or region of space per unit mass. Often only the useful or extractable energy is quantified, which is to say that chemically inaccessible energy such as rest mass energy is ignored.
- **Cycle Life**: Represents the number of cycles a battery can provide. If the battery degrades before its calendar life, it is often because it has reached the end of its life cycle.
- **Fast Charge Time**: Amount of time required to charge an equipment, usually the opposite of slow charging (typically associated with overnight charging, usually 6-8 hours).
- **Self-discharge**: Phenomenon in batteries in which internal chemical reactions reduce the stored charge of the battery without any connection between the electrodes. Self-discharge decreases the shelf-life of batteries and causes them to initially have less than a full charge when actually put to use.
- **Operating Temperature**: The temperature at which an electrical or mechanical device operates. The device will operate effectively within a specified temperature range which varies based on the device function and application context, and ranges from the minimum operating temperature to the maximum operating temperature (or peak operating temperature).
- **Cost per Cycle**: Measure cost per unit of cycle.
- **Toxicity**: The degree to which a substance can damage an organism.
# Large-Scale Energy Storage: Technical Benefits

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Stabilization</td>
<td>Transmission grids need to be returned to their normal operation after a disturbance and this is where Electrical Energy Storage (EES) comes handy. Instability in the grid occurs mainly in three forms - rotor angle instability, voltage instability and frequency excursions.</td>
</tr>
<tr>
<td>Operational Support</td>
<td></td>
</tr>
<tr>
<td>Frequency Regulation Services</td>
<td>Fluctuations in generation and load is handled by EES through injection and power absorption.</td>
</tr>
<tr>
<td>Contingency Reserves</td>
<td>At the transmission level, during a sudden loss of generation or a transmission outage, EES acts as a contingency reserve includes spinning (or synchronous) and supplemental (non-synchronous) for providing power.</td>
</tr>
<tr>
<td>Voltage Support</td>
<td>Voltage support involves the injection or absorption of reactive power (VARs) into the grid to maintain system voltage within the optimal range.</td>
</tr>
<tr>
<td>Black Start</td>
<td>From a shutdown condition without support from the grid, and then energize the grid to allow other units to start up, EES units act as black start units.</td>
</tr>
<tr>
<td>Power Quality and Reliability</td>
<td>Voltage sags and interruptions (with durations less than 2 seconds) are the two main reasons for grid-related power quality, and EES is often used to improve power quality and reliability.</td>
</tr>
<tr>
<td>Load Shifting</td>
<td>Load shifting is achieved by utilizing EES for storage of energy during periods of low demand and releasing the stored energy during periods of high demand. Peak shaving is one common form of load shifting, mainly the use of energy storage to reduce peak demand in an area.</td>
</tr>
<tr>
<td>Supporting the Integration of Other Renewable Resources (like wind)</td>
<td></td>
</tr>
<tr>
<td>Frequency and Synchronous Spinning Reserve Support</td>
<td>Shifts in grid frequency occur when sudden shifts in wind patterns lead to significant imbalances between generation and load. EES can provide prompt response to such imbalances without the emissions related to most conventional solutions.</td>
</tr>
<tr>
<td>Transmission Curtailment Reduction</td>
<td>Excess energy to be stored and then delivered at times when the transmission system is not congested if an EES unit is located close to the wind generation.</td>
</tr>
<tr>
<td>Time Shifting</td>
<td>EES can be used to store energy generated during periods of low demand and deliver it during periods of high demand.</td>
</tr>
</tbody>
</table>

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Matt Maloney is Head of Silicon Valley Bank’s national Cleantech Practice. He has over 20 years of experience investing in and lending to the technology industry. Prior to joining Silicon Valley Bank in 2002, Maloney co-founded Enflexion Capital, a specialty debt provider for alternative communications companies. From 1989 to 2000, Maloney held several business development and senior management positions in GATX Capital’s Technology Services group that grew from zero to more than $500 million during his tenure. Among other roles, he developed, structured and managed numerous technology investment joint ventures, spearheaded strategic acquisitions and founded the company’s Telecom Investments group.

Prior work experience includes investment banking and money center commercial banking. Maloney earned a bachelor’s degree from Guilford College and a master’s of business administration from Kellogg Graduate School of Management.

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As National Cleantech Coordinator, Quentin Falconer leads the business development efforts for the cleantech industry at Silicon Valley Bank. Formerly an engineer with Bechtel Corporation, Falconer began his commercial banking career in 1990 and has been with Silicon Valley Bank since 1999 working with emerging and mid-stage technology companies. He provides and oversees commercial and merchant banking, investment management and global treasury services for his portfolio of clients.

Falconer sits on the Advisory Council for the Berkeley Entrepreneurs Forum and is a member of Financial Executives International. He earned bachelor’s degrees in mechanical engineering and music from Tufts University and a master’s of business administration from UC Berkeley's Haas School of Business. He is also a Chartered Financial Analyst (CFA).

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Dan Baldi is a Deal Team Leader in Silicon Valley Bank’s Cleantech Practice. He manages numerous client relationships across the Bay Area and beyond. Dan and his team have primary responsibility for banking and lending activity to venture-backed cleantech companies.

He is experienced in many aspects of early stage and middle market financing including growth capital lending, working capital lending, asset based lending, EXIM finance, USDA lending, utility rebate finance, cash flow lending, international credit products and trade finance. Prior to joining Silicon Valley Bank Dan spent four years in middle market banking at commercial banks. He also has experience in technology leasing focused on the early stage technology market, partnering and syndications, and public and private accounting.

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Rob Tompkins is a director and Cleantech Sector Lead with SVB Analytics, responsible for overseeing valuation analysis and overall engagement execution for venture-backed companies and venture capital firms, with a primary focus on companies within the cleantech sector.

Prior to joining SVB Analytics in 2008, Tompkins worked with Huron Consulting Group in the firm's San Francisco valuation practice. While at Huron, Tompkins focused primarily on valuing start-up companies in the life science, internet, technology and cleantech sectors and led the group’s cleantech initiatives.

Before Huron, Tompkins spent 18 months in Santiago, Chile, where he worked in sales and marketing for an Internet news organization and later as an analyst for a venture capital and private equity firm focusing on Latin American markets. Tompkins began his career with PricewaterhouseCoopers’ Healthcare Consulting Practice where he was responsible for modeling and forecasting multi-billion dollar budgets for state-sponsored health programs.

Tompkins earned a bachelor’s degree in government from the University of Virginia, and a master’s in business administration and a master’s of science in international development from Tulane University.
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