Solar Energy and Storage Technology Economics

Ardeth Barnhart and Dr. Joseph Simmons
Co-Directors, Arizona Research Institute for Solar Energy (AzRISE)
University of Arizona – www.azrise.org
AzRISE
Research, Development, Outreach

- Formed September 2007 at the University of Arizona
  - Funding – ABOR, University of Phoenix, TEP, APS, DOE, SFAz
- Solar Energy Systems Development
  - Storage
  - Smart Grid
  - Demonstration Sites
  - Solar House, Solar Car, Desalination
- Basic Research
  - Seed Projects
  - New Photovoltaic Materials/ Solar Concentrators
- Testing – PV Test Site
- Economic and Policy analysis
- Education and Outreach
U.S. Primary Energy Production by Major Source (2008)

Source: Energy Information Administration, *Annual Energy Review 2008*, Table 1.2. (June 2009)
Solar has short-term intermittency due to weather

Rated Power
2,640 Watts peak

Data from TEP Test Yard – Alexander Cronin
Energy Storage Technologies must be able to provide energy and power combinations:

- Wholesale markets
- Upgrade deferral
- Retail markets
- Operating reserves
Benefits of Energy Storage

- **Generation**
  - Arbitrage
  - Renewable energy integration
- **Delivery**
  - Capacity upgrade deferral
- **End Use**
  - Renewable energy integration
  - Energy management
  - Backup power
  - Power quality

  - Peak Demand Reductions
  - Improved asset utilization
  - Air emission reductions
  - Improved reliability
## A New Day: energy storage price & performance comparisons

### Storage Technologies Primarily for Energy (kWh) Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>$/kWh</th>
<th>Rater Power (MW)</th>
<th>Efficiency</th>
<th>Lifetime</th>
<th>Discharge Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped Hydro</td>
<td>250 – 260</td>
<td>20 – 2,400</td>
<td>78 – 83%</td>
<td>11,000+</td>
<td>10</td>
</tr>
<tr>
<td>CAES</td>
<td>550 – 650</td>
<td>110 – 290</td>
<td>50 – 75%</td>
<td>11,000+</td>
<td>10</td>
</tr>
<tr>
<td>Flow batteries</td>
<td>500 – 1,000</td>
<td>0.05 – 8</td>
<td>65 – 80%</td>
<td>500+</td>
<td>8</td>
</tr>
<tr>
<td>NaS batteries</td>
<td>2,500 – 3,750</td>
<td>0.05 – 50</td>
<td>70 – 80%</td>
<td>3,000+</td>
<td>7</td>
</tr>
<tr>
<td>NiCad batteries</td>
<td>610 – 1,700</td>
<td>0.01 – 27</td>
<td>60 – 65%</td>
<td>1,000+</td>
<td>4</td>
</tr>
</tbody>
</table>

### Storage Technologies Primarily for Power (kW) Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>$/kW</th>
<th>Rater Power (MW)</th>
<th>Efficiency</th>
<th>Lifetime</th>
<th>Max Discharge Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaS batteries</td>
<td>3,000 – 4,000</td>
<td>0.05 – 50</td>
<td>70 – 80%</td>
<td>3,000+</td>
<td>300</td>
</tr>
<tr>
<td>Li-Ion batteries</td>
<td>1,000 – 4,500</td>
<td>0.005 – 1</td>
<td>90 – 95%</td>
<td>20,000+</td>
<td>15</td>
</tr>
<tr>
<td>NiCad batteries</td>
<td>1,560 – 3,780</td>
<td>0.01 – 27</td>
<td>60 – 65%</td>
<td>1,000+</td>
<td>15</td>
</tr>
<tr>
<td>Lead acid</td>
<td>1,050 – 1,890</td>
<td>0.01 – 10</td>
<td>70 – 75%</td>
<td>250+</td>
<td>15</td>
</tr>
<tr>
<td>Flywheels</td>
<td>2,500 – 4,000</td>
<td>0.5 – 1</td>
<td>90 – 95%</td>
<td>500,000+</td>
<td>15</td>
</tr>
<tr>
<td>Super capacitors</td>
<td>N/A</td>
<td>0.003 – 0.01</td>
<td>90 – 98%</td>
<td>500,000+</td>
<td>seconds</td>
</tr>
</tbody>
</table>
Peak Shaving Function of Solar Energy

1/1,000 TEP System Load

PV + Batt + CAES + Grid

Grid Energy (1.27MWh/h)

1.5 MW PV Array
Single-axis tracking

1 MW Battery

CAES Storage Energy

Time of Day (August 15, 2007)
PV and CAES Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV capacity</td>
<td>1.5 MW</td>
</tr>
<tr>
<td>PV conversion efficiency</td>
<td>15%</td>
</tr>
<tr>
<td>CAES natural gas heat rate</td>
<td>4300 Btu/kWh</td>
</tr>
<tr>
<td>CAES storage capacity</td>
<td>3.5 MWh/1 MW</td>
</tr>
<tr>
<td>Roundtrip efficiency</td>
<td>80%</td>
</tr>
<tr>
<td>Hours of storage</td>
<td>3</td>
</tr>
</tbody>
</table>

(SOLON Single Axis – www.solon.com)
<table>
<thead>
<tr>
<th>PV/CAES Cost Estimates</th>
<th>$/kW</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAES Equipment</td>
<td>$750</td>
<td>$1,800,000</td>
</tr>
<tr>
<td>1 MW/ 250 kWh Battery</td>
<td>$2000</td>
<td>$2,000,000</td>
</tr>
<tr>
<td>Photovoltaic system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installed cost</td>
<td>$4000</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>O &amp; M</td>
<td>$6</td>
<td>$9,000</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>$/MMBtu</td>
<td>$/kWh</td>
</tr>
<tr>
<td>Natural gas</td>
<td>$6</td>
<td>$0.0258</td>
</tr>
<tr>
<td>Total Capital Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV and CAES</td>
<td></td>
<td>$9,809,000</td>
</tr>
<tr>
<td>Federal ITC</td>
<td></td>
<td>$1,803,150</td>
</tr>
<tr>
<td>AZ State Rebates</td>
<td></td>
<td>$25,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$7,386,850</td>
</tr>
</tbody>
</table>

*All costs are estimates derived from published reports*
Energy Arbitrage Revenues

Cumulative revenue over 20-year period

* Includes inflation rate for natural gas and discount rate of 9%
Energy Arbitrage Revenues

Cumulative Net Revenues (3hr)

- $0
- $100,000
- $200,000
- $300,000
- $400,000
- $500,000
- $600,000

Year

Addition of CAES
sell direct to grid
LCOE Projections

- Parabolic Trough CSP
- PV and CAES Storage
- Silicon PV
- Nuclear: capital costs only
  Fuel costs could add 7 cents
Seasonal Mismatch Between Demand and Production

![Graph showing the seasonal mismatch between PV production and TEP consumption.]

- **PV Production 5.2 GW**
- **TEP Consumption**

*Months of the Year*

*MegaWatt-hours*
Solar Base-load Utility Scale Capability

MegaWatt - hours

Months of the Year

PV Production 5.2 GW
CAES Produced Electricity
TEP Consumption
CAES Stored Energy

Arizona Research Institute for Solar Energy
Conclusions

- Energy storage technologies have no emissions with the exception of CAES.

Constraints

- Current technologies have demonstrated capabilities for limited storage
- Cost is perceived as high
- Need to develop long-term models to enable project financing
- Lack of targeted credits
- Cost recovery – valuing efficiency
- Ownership uncertainties
Energy storage technologies enable renewable energy integration

- **Goals**
  - Reduce cost of deployment
  - Support R&D
  - Accelerate market entry

- **Direct support**
  - Current DOE Programs to fund R&D and deployment
  - Needs to receive direct R&D support (CCS)
    - Development of energy storage and renewable energy generation as a baseload generation option
  - Storage-integrated renewable energy needs to receive direct support
    - Production tax multiplier
    - Climate legislation needs to reflect storage technologies
    - Dedicated incentive for dispatchable renewable energy
Conclusions

- Solar energy technologies integrated with Energy Storage can match peak demand and base-load requirements
  - Experts agree with this and calculations show feasibility
  - Critical need is a demonstration facility that can give utilities technical and economic assessments of performance of various components.

- Cost of solar energy technologies, especially PV, is driven down by increased manufacturing capacity and open competition and will soon (2012) fall below the minimum capital cost of building a coal or nuclear power plant before they become operational.
Ardeth Barnhart
ardethb@email.arizona.edu

Dr. Joseph Simmons
simmonsj@email.arizona.edu

www.azrise.org
Comparison of water use by energy technology for the same energy production

![Graph showing comparisons of water use by energy technology.](attachment:image.png)