Liquid Air Energy Storage (LAES)

Highview Power Storage
Increasing Space Mission Ground Infrastructure Resiliency through Sustainability

Stuart Nelmes
Head of Engineering
Highview Power Storage
Highview is an award winning designer and developer of utility-scale energy storage and power systems that use liquefied air as the storage medium.

Active since 2005, Highview has secured more than £26 million of private and public funding.

Highview ran a 350kW/2.5MWh pilot plant which was hosted by Scottish and Southern Energy; fully integrated into the local distribution network, and operated from April 2010 to November 2014.

Highview in collaboration with Viridor, has been awarded funding for a Liquid Air Energy Storage (LAES) demonstration project by the UK Government.

The company has signed two licence agreements:

- one with GE Oil & Gas to integrate LAES technology with it’s simple cycle peaker plants and;
- the other with clean coal technology specialists, Advanced Emissions Solutions of Denver Colorado, for grid-connected LAES non-peaker plant energy storage applications covering North America.

The company has a portfolio of patents granted and pending that cover the system.
2005
Research began at University of Leeds.

2008
The power recovery cycle demonstrated in lab-scale tests.

2010
Installation of power recovery cycle in pilot plant.

2011
Installation of complete pilot CryoEnergy Storage plant.

2013
Highview enters into a license agreement with General Electric.

2014
Highview and Advanced Emissions Solutions Inc. of Denver Colorado sign a licence and investment deal for North America.

2015
Frost & Sullivan awards Highview with Global Large-Scale Energy Storage Technology Innovation Award.

Future
The new GigaPlant 1.2GWh/200MW.
Why use large scale long duration storage?

- Storage generally helps manage system during high ramp rate
  - Short duration leaves peak in place
  - Long duration can cover peak (and substitute for thermal plant)
- Moving energy from potential over generation period provides additional benefits of lower CO2 and use of zero marginal cost power
- Ideal system solution is large (many GW) and deep (4 hours or more)
- Can be located at the right place on the network to address constraints

Graph courtesy of CAISO
Demand for energy storage on the grid will grow to $113.5 billion in 2017, from a $2.8 billion market in 2012, reaching more than 185GWh.

**Global Demand for Grid Energy Storage**

- **U.S.**
  - Market value: $26bn
  - Market share: 23%

- **UK**
  - Market value: $10.7bn
  - Market share: 9%

- **China**
  - Market value: $20bn
  - Market share: 18%

- **Germany**
  - Market value: $10bn
  - Market share: 9%

- **Japan**
  - Market value: $20bn
  - Market share: 18%

Source: Lux Research, Grid Storage under the Microscope, 2012.
## Energy Storage – Different Needs

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Time</th>
<th>End user</th>
<th>Distribution</th>
<th>Transmission</th>
<th>Utility System</th>
<th>Independent operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy ($/kWh)</td>
<td>Hours</td>
<td>Energy mng.</td>
<td>T&amp;D Investment Deferral</td>
<td>Energy Arbitrage</td>
<td>Renewable Integration</td>
<td>System Capacity</td>
</tr>
<tr>
<td>Power ($/kW)</td>
<td>Mins</td>
<td>DESS</td>
<td></td>
<td></td>
<td>Renewable Smoothing</td>
<td></td>
</tr>
<tr>
<td>Reliability ($/kW)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations ($/kWh)</td>
<td>Sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ancillary Services</td>
</tr>
</tbody>
</table>

**Energy Storage Applications**

- **10s kW**
  - T&D System Support
- **100s kW**
  - Renewable Integration
  - System Capacity
  - Renewable Smoothing
- **10s MW**
  - Energy Arbitrage
- **100s MW**
  - Ancillary Services
### Energy Storage – Main Technologies

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Time</th>
<th>End user</th>
<th>Distribution</th>
<th>Transmission</th>
<th>Utility System</th>
<th>Independent operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy ($/kWh)</td>
<td>Hours</td>
<td>Energy mng.</td>
<td>T&amp;D Inves.</td>
<td>Energy</td>
<td></td>
<td>Pumped Hydro</td>
</tr>
<tr>
<td>Power ($/kW)</td>
<td>Mins</td>
<td>Reliability</td>
<td>T&amp;D Def.</td>
<td></td>
<td></td>
<td>CAES</td>
</tr>
<tr>
<td>Reliability ($/kW)</td>
<td>Sec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Renewable Smoothing</td>
</tr>
<tr>
<td>Operations ($/kWh)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Ancillary Services</td>
</tr>
</tbody>
</table>

- **10s kW**
- **100s kW**
- **10s MW**
- **100s MW**

- Battery
- Flywheels
- Super Capacitors
- Liquid Air
- CAES
- Renewable Smoothing
- Liquid Air
- Pumped Hydro
Current Solutions

**Expensive**

- Batteries
- Above ground Compressed Air Energy Storage (CAES)

**Geographically limited**

- Compressed Air Energy Storage (CAES) – require caverns
- Pumped Hydro – require mountains

<table>
<thead>
<tr>
<th>Village</th>
<th>Small town</th>
<th>Large town/City</th>
<th>Regional/National</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>Above ground CAES</td>
<td>CAES</td>
<td>Pumped hydro</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>100</td>
<td>1,000</td>
</tr>
</tbody>
</table>
LAES: Technology Benefits

- LAES uses existing mature components (liquefier, liquid air storage, power turbine), with proven performance, cost, lifetime (25 year+).

- Suitable for large energy stores from about 20MWh to >1GWh, not restricted by geography.

- 60% efficiency in stand alone mode.

- Integrates well with other industrial process plant (utilising waste heat/cold) to enhance performance e.g. 70%+.

- Costs/economics improve with scale (50MW/200MWh <£1,000/kW <£250/kWh).

- Can be integrated at renewable site, but more valuable as a system resource for enabling wider renewable deployment.

- The system is ready for deployment at commercial scale (>5MW/15MWh) in industrial or utility applications.
1. **Charge**: Offpeak or excess electricity is used to power an air liquefier, which produces liquid air.

2. **Store**: The liquid air is stored in a tank(s) at low pressure.

3. **Discharge**: To recover power the liquid air is pumped to high pressure, evaporated and heated. The high pressure gas drives a turbine to generate electricity.
LAES – Standard Configuration

- Power In
- Compression
- Refrigeration
- LAIR Storage
- Evaporation
- Expansion
- Power Out

- Air In
- Cleaning
- High Grade Cold Store

- 60% AC/AC

Charge: CHARGE
Store: STORE
Discharge: DISCHARGE

Air Out

© Highview Enterprises Limited, 2015
Peaking Plant Application

- CCGT efficiencies with OCGT Peaking Plant flexibility + LAES
  - *Higher OCGT efficiency & better heat rate*
  - *Higher LAES round trip efficiency using waste heat*
- Faster start-up: 10 minutes for entire plant
- Highly adaptable to network & market conditions
  - *Improved merit order for whole plant*
  - *Access to capacity payment mechanism*
  - *Aligned to AB2514 – Gas Fired generation combined with thermal storage*
- Flexible modular Energy Storage solution at minimal cost

Image courtesy of General Electric
Highview Pilot Plant (completed summer 2011)

Fully operational pilot plant (350kW/2.5MWh) hosted by SSE (Scottish & Southern Energy) at their Slough Heat & Power 80MW biomass plant.

Take a tour of our pilot plant
In collaboration with Viridor, one of the UK’s leading recycling, renewable energy and waste management companies, Highview has been awarded funding for a 5MW energy storage demonstration project by the UK Government.

The funding, valued at more than £8 million ($13.6m), has been awarded as part of the ‘Energy Storage Technology Demonstration Competition’, run by the Department of Energy and Climate Change (DECC).

It will support the design and testing of a pre-commercial demonstration LAES technology system alongside one of Viridor’s landfill gas generation plants in the UK.

In addition to storage, the LAES plant will integrate waste heat to power from the landfill gas engines.
GE Highview Global Licence Agreement

• In March 2014 GE and Highview announced a global licencing and cooperation agreement.

• GE will explore the opportunity to integrate Highview’s LAES technology in peaking power plants where GE’s gas turbines and gas engines are currently or will be installed.

• LAES systems will help to increase power plant efficiency and flexibility, thereby enhancing grid reliability and the distribution of renewable energy.

• Customers will benefit from significant advantages, including improved start up times and efficiency/heat rates, as well as offering waste-heat-to-power and energy storage capabilities.
In December 2014 Highview Power Storage announced a licence and investment deal with leading US clean coal technology provider, Advanced Emissions Solutions, Inc.

Advanced Emission Solutions, Inc. through its subsidiary ADA-ES of Denver, Colorado, signed the licence agreement for North America (US, Canada and Mexico).

The licence agreement is for grid connected LAES non-peaker plant storage applications.

Dr. Michael D. Durham, President and CEO of Advanced Emissions Solutions said, “We are very excited about working with Highview to bring this technology to markets in North America. As we looked for the best technology for large grid-scale energy storage, we concluded that the LAES technology had significant advantages for this market and that Highview was years ahead of anyone else pursuing this approach”
Opportunities for LAES

**Power Generation**
- Managing intermittent renewable generation
- Energy Arbitrage
- Peak shaving

**Transmission**
- Ancillary services
- Transmission constraints
- Inertia services
- Responsive flexibility services

**Distribution**
- Reactive power
- Voltage support
- Local security
- Distribution losses

**End Users**
- Providing power reliability and energy management to commercial and industrial end users.
  - LAES is well suited for energy intensive industries that have low-grade heat or waste cold available, for example steel mills or LNG terminals.
Opportunities for LAES

**Stand alone systems**

**Efficiency:** ~60%

**Application examples:** Managing intermittent renewable generation, energy arbitrage, transmission, power distribution.

**Integration of industrial waste heat**

**Efficiency:** 70%+

**Application examples:** Traditional power generation, data centres, industrial processes e.g. steel mill, peaker plants.

**Integration of waste cold**

**Efficiency:** 70%+

**Application examples:** LNG terminals, industrial gases.
Indicative Layout for a 20MW/80MWh System

1. Compressor house
2. Air cleaner
3. Cold box and cold expanders
4. Liquid air storage
5. Cryo pumps
6. Containerised power turbine and generator (2 x 10MW)
7. Heat exchanger containers
8. High grade cold stores
9. Hot water storage
10. Electrical intake and switch-house
Take a tour of our plant

Gareth Brett - CEO, Gareth.Brett@highview-power.com

Highview Power Storage www.highview-power.com

Matthew Barnett - Head of Business Development, Matthew.Barnett@highview-power.com

Stuart Nelmes - Head of Engineering, Stuart.Nelmes@highview-power.com