NWE Electricity Supply Resource Technology Forum

Liquid Air Energy Storage (LAES)

Gene Larson, SNC Lavalin  
VP, Project Development

Matthew Barnett, Highview  
Business Development Dir.

Charlie Ricker, MADA Power  
President

November 29, 2017
The REAL Problem – Intermittent RE, Wind & Solar PV

Wind BLUE

Solar Yellow

Demand Red

BPA
30 Days
April 2010
Liquid Air Energy Storage - LAES
Conventional Equipment Used in an Unconventional Manner

1. Charge
Off Peak or Curtailed RE produces Liquid Air.

2. Store
Liquid Air stored in tanks
# of Tanks = discharge duration

3. Discharge
Pressurized Liquid Air is evaporated and heated to power the expansion turbine

Industrial Gas Industry

Industrial Gas & LNG Industries

O&G Refineries Worldwide
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
Major Equipment Suppliers for LAES

- GE
- Heatric
- Nikkiiso Cryo
- Atlas Copco
- MAN

Equipment:
- 4 x 2,500 tpd liquefiers
- 2 x 7,000 tonne liquid air tanks
- 8 x 25MW turbines
- Cryo pumps
- Evaporators
- Heat storage
- High grade cold storage
## Integrated Energy Storage

<table>
<thead>
<tr>
<th>State of the Art</th>
<th>• 5 MW, 15 MWH commercial demonstration unit at Pilsworth, N. Manchester in the UK, commissioning now, COD Feb 2018</th>
</tr>
</thead>
</table>
| Size, Scope and Penetration | • 10 – 200 MW  
• 40 MWH – 1.2 GWH  
• Firm wind, transmission deferral |
| How would you use it in MT? | • Working in MT for 2 years  
• Bid on Colstrip 1 & 2, repurposing  
• Tendered Hybrid Peaker to NWE – 67 MW firm, 4 hrs |
| What is the lead time? | • Today - Early units 18-22 months, NTP to COD  
• Near future - Modular 6-8 months, NTP to COD |
### Integrated Energy Storage

| Specific Products? | • Energy & Capacity – Behaves just like a rotating machinery asset  
|                    | • Frequency Response – Combined with short term BESS (ramp hider)  
|                    | • Voltage Regulation and KVAR Support – Utility scale rotating generator  
|                    | • Spinning Reserve – Standalone using “SpinGen” technology  
|                    | • Resource Adequacy – Firms wind and solar, time shifts power delivery |
| Benefits to MT Customers? | • Remove intermittency from Wind  
|                           | • Time shift MT wind to winter & summer peaks |
| How would you use it in MT? | • Fully dispatchable even while charging  
|                             | • Operates just like a spinning asset  
|                             | • Can provide regulation up & down  
|                             | • Congestion relief and transmission deferral  
|                             | • Handle over-generation of solar PV based on number of interconnect requests in 2015-16 |
## Integrated Energy Storage

<table>
<thead>
<tr>
<th>Cost of Ancillary Services?</th>
<th>These need to be modeled and vary between standalone LAES and Integrated Energy Storage systems (co-located with a gas peaker unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed costs per MW-month</td>
<td>These need to be modeled and depend on site specifics such as charging rate, discharge rate and hours of discharge at full load</td>
</tr>
<tr>
<td>Variable cost per MWH</td>
<td>Generally run at 3 – 6 $/MWH depending on the configuration of the system as noted above. This includes 1.5% of capex per annum for O&amp;M. High charging rates (MW/hr) have a significant impact.</td>
</tr>
<tr>
<td>Expected Life</td>
<td>Based on standard equipment from the air separation and petroleum industries, we expect 30 years of useful life. Major maintenance is at 20 years with minor overhauls every 8 years. Lots of operating data to confirm long term performance and O&amp;M costs.</td>
</tr>
</tbody>
</table>
## Integrated Energy Storage

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated reliability/availability?</td>
<td>• Based on significant historical data on the key components, we estimate 18 days per year off line to perform maintenance which implies 95% availability. Again, years of operational data exists on all major components.</td>
</tr>
<tr>
<td>Estimated capacity factor?</td>
<td>• Based on significant historical data, we estimate the capacity factor to be 98%.</td>
</tr>
<tr>
<td>What determines hourly capacity factor?</td>
<td>• Hourly capacity factor is dependent upon the charging rate, duration of charging and duration of discharge and includes liquid air storage tank volume reserves.</td>
</tr>
<tr>
<td>Is there a daily, monthly, seasonal or yearly shape to output?</td>
<td>• The most common benefit of LAES systems is to time shift RE from when it is generated to when it is needed. The charging cycle has a shape based on the source of power but the discharge can be shaped to meet a customer’s needs.</td>
</tr>
</tbody>
</table>
Benefit Summary – NorthWestern Energy

- NWE’s wind RE from 8% of nameplate capacity to 35%
- Delivers wind RE on demand, no curtailment
- Effective NHR
  - 8500 Btu/kWh typical Peaker
  - 3400 Btu/kWh Hybrid
  - 60% reduction in gas consumption

YES WE CAN!
But only with utility scale storage
How do you do that?

<table>
<thead>
<tr>
<th>Heat Rate Model:</th>
<th>MWH</th>
<th>Weighting</th>
<th>Component HR, HHV Btu/kWh</th>
<th>Implied HR combined system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total MWH Generated</td>
<td>195,700</td>
<td>100%</td>
<td></td>
<td>3,404</td>
</tr>
<tr>
<td>Total MWH Generated from LM6000</td>
<td>69,900</td>
<td>36%</td>
<td>8,500</td>
<td></td>
</tr>
<tr>
<td>Total MWH Generated from gas firing of PRU</td>
<td>6,000</td>
<td>3%</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td>Total MWH Generated from LAES - direct bypass or stored wind energy</td>
<td>119,800</td>
<td>61%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BESS Rapid Response + LM6000 & LAES Ramp Rates