Liquid Air Combined Cycle
Hybrid Energy Storage

TMCES Workshop
10-11 Aug 2021
San Antonio, TX
CHALLENGE: 
Bridge renewable and conventional generation

Low-cost, long-duration, large scale, low-carbon HYBRID ENERGY STORAGE
Why Hybrid Generation + Storage?

SYNERGY

• Capital cost
• Siting
• Technical
• Scalability
• Operating cost
• Operating flexibility
• Resilience
• Risk reduction
• Efficient use of clean fuels
Energy Storage Trade Offs

Charging Process
- Charging duration (power & efficiency)
- Cost per unit of power in
- Efficiency per unit of energy in

Storage Medium
- Safety
- Duration (quantity of energy)
- Density (Volume, acreage)
- Cost and availability of container
- Media cost per ton/gallon
- Mass/energy/exergy leakage rate
- Standby energy needs

Discharging Process
- Power output
- Cost per unit of power output
- Efficiency (electricity per unit of stored energy and fuel energy)
## ASME PTC-53 Metrics: Both Hybrid and Pure-play

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Technical Factor</th>
<th>Economic Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P_D</strong></td>
<td>Discharge power (MW)</td>
<td>CAPEX of discharge process ($/kW)</td>
</tr>
<tr>
<td><strong>t_D</strong></td>
<td>Discharge duration (h)</td>
<td></td>
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<tr>
<td><strong>P_C</strong></td>
<td>Charge electric power (MW)</td>
<td>CAPEX of charge process ($/kW)</td>
</tr>
<tr>
<td><strong>t_C</strong></td>
<td>Charge duration (h)</td>
<td></td>
</tr>
<tr>
<td><strong>E_C=P_Ct_C</strong></td>
<td>Charge electric energy (MWh)</td>
<td>CAPEX of storage reservoir ($/kWh)</td>
</tr>
<tr>
<td><strong>E_D=P_Dt_D</strong></td>
<td>Discharge electric energy (MWh)</td>
<td></td>
</tr>
<tr>
<td><strong>FHR = Q_D/E_D</strong></td>
<td>Fuel Heat Rate (MMBtu/MWh)</td>
<td>Marginal Cost of Energy ($/MWh) = ( FHR \times Fuel \ Cost + \ PER \times Power \ Cost )</td>
</tr>
<tr>
<td><strong>PER = E_C/E_D</strong></td>
<td>Primary Energy Rate (MWh/MWh) (inverse Round Trip Efficiency)</td>
<td>PER impacts CAPEX of charge process and storage reservoir</td>
</tr>
<tr>
<td><strong>TR = t_C/t_D = PER P_D/P_C</strong></td>
<td>Time Rate (h/h)</td>
<td>Low TR increases Capacity Factor ≤ (1-TR)</td>
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<td>Low TR increases Park Spread (lowers Power Cost)</td>
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10 August 2021
DOE and Industry Support for Hybrids

DE-FE0032016
Liquid Salt Combined Cycle
Pilot Plant Design

DE-FE0032002
Liquid Air Combined Cycle
Design Optimization

Electric Power Research Institute
Pintail Power LLC
Southern Company
NexantECA

Southwest Research Institute
Pintail Power LLC
Wood
Liquid Air Combined Cycle (LACC™) Hybrid

- Safe high-density storage
- Daily/weekly/monthly/seasonal
- Standard cryogenic refrigeration plant
- Bullet or above/in-ground storage tanks
- Couples to any gas turbine or high-grade heat source
- Condensate recovery
  - Uses Higher Heating Value
  - Potential closed-loop electrolysis

30,000 MWh/acre
LACC Thermal Performance (Epsilon)

Gross LHV Heat Rate: 4477.82 kJ/kWh
Gross LHV Heat Rate: 4244.16 Btu/kWh

Net LHV Heat Rate: 4550.45 kJ/kWh
Net LHV Heat Rate: 4313.00 Btu/kWh

Electricity to Produce Liquid Air at 400 kW/kg: 112320.00 kW

Net Primary Energy Rate: 1.00 kWh(m)/kWh(out)
Net Specific Air Consumption: 2.50 kg/kWh

Gross Power: 114056.1 kW
Net Power: 112235.6 kW
Gross LHV Fuel: 510.72 MJ/h
Gross LHV Fuel: 484.07 MMBtu/h
Liquid Salt Combined Cycle™ (LSCC) Hybrid

- **Compact, Low-cost Storage**
  - $20-$30/kWh-AC marginal CAPEX
  - >700 MWh/acre
  - Intra/Inter-day (8 to 24 hours)

- **Superior Grid Coupling**
  - Fast charging + ancillary services
  - No rate/state of charge constraints
  - Fast discharge startup

- **Deployable now**
  - Add to existing gas turbines
  - Proven equipment, modest pressure & temperature conditions

U.S. Patents 9,816,490; 10,113,535; 10,808,685, 10,982,570; others pending in US, Europe
Hybrids: Cheapest Way to Decarbonize

Hydrogen @ $1.5/kg ($11/MMBtu); N.G. @ $3/MMBtu; + CCUS

Cyclic duty challenges
• 3P+ RH CC?
• CCUS?

Sources: EIA 2020 S&L Cost and Performance Report, Pintail Power
• Low technical risk
• Equipment vendor and fuel neutral
• Deploy broadly with top EPCs
• Existing or new installations
• Retain good jobs and asset value
• Ready today to meet tomorrow’s needs