Evaluating the Underwater Compressed Air Energy Storage Potential in the Gulf of Maine

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Introduction – Why Storage?

High Penetration Levels of Renewable Generation may be a problem

Utility-scale storage maybe a potential solution...

Project Goals:
1) Analyze and compare ideal CAES/PHS models
2) Integrate into ArcGIS to estimate potential resource
Introduction – Why CAES?

- Utility-Scale
- High efficiency 70-80%
- Shifting power
- Transmission utilization
- Firm wind capacity
- Reduce spinning reserve
- Aids in BOS
- TES and UWCAES

Source: Energy Storage Association
Analysis – Storage Density of Idealized Cases

Three CAES Models & One PHS:
1) Adiabatic CAES
2) NO TES CAES
3) Isothermal CAES
4) Underwater PHS
Results – Thermodynamic Analysis

Energy density of stored air from CV analysis:

1) Adiabatic CAES
\[
\frac{\Delta U}{\Delta V_{\text{Adiabatic}}} = \frac{\gamma P_0}{\gamma - 1} \left( \frac{P_{\text{abs}}}{P_0} \right) \left( \frac{P_{\text{abs}}}{P_0} \right)^{\gamma / \gamma} - 1 \]
with...\(P_{\text{abs}} = P_0 + \rho gd\)

2) NO TES CAES
\[
\frac{\Delta U}{\Delta V_{\text{NO-TES}}} = \frac{\gamma P_0}{\gamma - 1} \left( \frac{P_{\text{abs}}}{P_0} \right)^{1 / \gamma} - \left( \frac{P_{\text{abs}}}{P_0} \right)
\]

3) Isothermal CAES
\[
\frac{\Delta U}{\Delta V_{\text{ISO}}} = P_0 \left( \frac{P_{\text{abs}}}{P_0} \right) \ln \left( \frac{P_{\text{abs}}}{P_0} \right)
\]

4) Underwater PHS
\[
\frac{\Delta U}{\Delta V_{\text{PHS}}} = \rho g H \eta
\]

Assume:
- Ideal System (reversible)
- Ideal Gas Law
- Constant Cv & Cp
- 100% Efficiency
- Density of Water
Results – Storage Density Comparison

\[
\frac{\Delta U}{\Delta V_{\text{Adiabatic}}} = \frac{1 \text{kwh}}{m^3} \rightarrow Z = 99m
\]

\[
\text{NO TES} \rightarrow Z = 130m
\]

\[
\text{ISO} \rightarrow Z = 176m
\]

\[
\text{PHS} \rightarrow Z = 367m
\]

Adiabatic

NO TES
Case Study – Gulf of Maine

- GoM Area = 170,000 sq.km
- Excellent offshore wind Resource
- 156GW capacity within 90km, 80% in waters >60m
- ArcGIS used with NOAA Bathymetry data
- Integrated Storage density equation in ArcGIS
Results – GoM Storage Density Map

### Storage Density

<table>
<thead>
<tr>
<th>Class</th>
<th>Depth</th>
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<tbody>
<tr>
<td>1</td>
<td>0-50m</td>
</tr>
<tr>
<td>2</td>
<td>50-100m</td>
</tr>
<tr>
<td>3</td>
<td>100-150m</td>
</tr>
<tr>
<td>4</td>
<td>150-200m</td>
</tr>
<tr>
<td>5</td>
<td>200-250m</td>
</tr>
<tr>
<td>6</td>
<td>250-300m</td>
</tr>
<tr>
<td>7</td>
<td>&gt;300m (max 375)</td>
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</table>

### Region Distance

<table>
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<tr>
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<th>Distance</th>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>50-100km</td>
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<td>3</td>
<td>100-150km</td>
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<tr>
<td>4</td>
<td>150-200km</td>
</tr>
<tr>
<td>5</td>
<td>200-250km</td>
</tr>
</tbody>
</table>

AREA = 75,775 sq.km

Source: Esri, GECO, NOAA, National Geographics, Osprey, HERE, Geoservices.org, and other contributions.
### Results – Storage Resource Adiabatic Model

<table>
<thead>
<tr>
<th>Region</th>
<th>(1) 0-50km</th>
<th>(2) 50-100km</th>
<th>(3) 100-150km</th>
<th>(4) 150-200km</th>
<th>(5) 200-250km</th>
<th>TOTAL</th>
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<td>Capacity TWh</td>
<td>Area $m^2$</td>
<td>Capacity TWh</td>
<td>Area $m^2$</td>
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<td>Class</td>
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<td>0</td>
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Conclusions and Future Work

- 1\textsuperscript{st} law analysis shows Adiabatic model has the highest storage density followed by the Isothermal case. The PHS had the lowest storage density.
- Case study analysis show great resource potential less than 100km from shore. Several “hotspots” near load centers like Boston.
- Future work will look at integrating CAES models with offshore wind and load data for New England. More work with GIS to assess potential environmental implications and site assessment issues.
Acknowledgements

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https://windenergyigert.umass.edu/