Repowering Coal Plants as Pumped Thermal Energy Storage

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Thermal-Mechanical-Chemical Energy Storage Workshop

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▪ Bao Truong (Malta), project lead

https://www.osti.gov/ Final Report: OSTI # 1874051
Breathing New Life into Coal Communities

Malta offers coal communities and workforces an opportunity to reverse upheaval and economic impacts.

98.3 GW

Coal plants announced for closure

This is just 45% of the existing US coal electricity production

People Impact

- Thousands of coal-fired generation employees are being forced to uproot families
- Replacement jobs are often lower-paying and require new skills
- Closures impact the surrounding communities through shrinking tax revenue, falling property values, a dislocated workforce

How Malta Can Help

- Preserve high-paying jobs for former coal-fired generation employees without new skills
- Reinvigorate or maintain community economic development
Key Takeaways

- Fossil Plant $\rightarrow$ Thermal Storage Plant: **Feasibility**
- Fossil Plant $\rightarrow$ Thermal Storage Plant: **Optionality Guidelines**
- Fossil Plant $\rightarrow$ Thermal Storage Plant: **Asset Owner Economics**
- Fossil Plant $\rightarrow$ Thermal Storage Plant: **Jobs Preservation**
Introduction to Malta

Long Duration (8-200 hr)
Grid Scale (100+ MW)
Thermal Storage using Molten Salt
Discharge Cycle Overview – Generation

**Discharge mode** – system operates as a heat engine:

1. Thermal energy released from hot molten storage tank
2. Salt heat exchanger heats air, maximizing energy to drive turbine
3. Hot air expands across turbine generating electrical energy
4. Anti-freeze heat exchanger cools air for easier compression
5. Compressor increases pressure again to close the cycle
**Charge Cycle Overview – Storage**

**Charge mode** – system operates as a heat pump:

1. Electricity from the grid drives compressor, which compresses warm air into higher pressure, very hot air
2. Salt heat exchanger stores the heat in molten salt
3. Warm air expands efficiently across a turbine, making it very cold
4. Anti-freeze heat exchanger “stores the cold”
5. Warmed air circulates back to the compressor
Malta M100 Site Layout - 100 MW, 10 hrs

- ~12 acres total footprint, expectations to reduce
- System modular design can accommodate irregular land sizes (tanks, ICS, power island can be arranged independently)
- No geographic limitations
- 2X duration increase (10 h → 20 h) adds 4 additional tanks, ~15% land increase

Standard Layout readily scaled to meet increased capacity and storage duration needs
Malta’s ownership represents a unique balance of bold visionaries and world-class execution experience: financial investors and strategic investors.

The company recognizes the value of technical partnerships and has aligned itself with the best:
- Alfa Laval – Heat Exchangers
- Siemens – Turbomachinery
- Proman – Project Engineering & Delivery

Additional commercial partners:

Research Partners:
Project Objective & Overview

This project evaluated how a Malta PHES plant can be integrated with a retiring coal plant to achieve benefits to the plant owner and local community.

- Four integration options evaluated
- Concept Design for selected option
- Economic Benefits & Local Impact

**Step ①**: Evaluate integration options, benefits

**Step ②**: Advance design of integration

**Step ③**: Outline gaps and future work
Project Stages

One-year study funded by U.S. Department of Energy (DOE)

Stakeholders & Requirements (M1-M3) → Host Site Selection (M2-M4) → Integration Options Down Selection (M3-M6) → Concept Design & Economic Analysis (M6-M12)

Phase 1

Go/No-Go Decision

Phase 2
Stakeholders

- Project’s findings translatable/applicable to other retiring coal plants
  - Does it make techno-economical sense to repurpose a Duke Energy’s retiring coal plant with a Malta PTES?
  - More detailed technical/due diligence assessment of Malta PTES technology
- Development of a potential new product offering
  - Cultivate potential customer relationship
- Can the re-purposed coal plant maintain job and local economy?
- Can this solution be used for their retiring coal plants?

Local Communities around Coal Plants

Other Utilities
Host Site Selection

Quick screening criteria
- Retirement date
- Co-location with operating unit(s)
- Power level range
- Potential load issue during charging

Detailed Comparison
- Importance ranking of different criteria (provided by Duke Energy)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Importance Ranking</th>
<th>Cliffside</th>
<th>Mayo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Plant Equipment Reusability</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Timeline</td>
<td>4</td>
<td>3</td>
<td>3</td>
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<tr>
<td>OPEX Saving</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Maintain Coal Plant Capacity</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Job maintenance/creation</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Reconfiguration capability</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Discharge Duration</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Footprint Availability</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Potential load issue with grid</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Total Score: 75 (Cliffside) 71 (Mayo)

Cliffside 5 was chosen as the host site; part of the reason was access to technical team/data.
0: BASE CASE
RESISTIVE HEATER +
SALT STORAGE +
STEAM CYCLE

Reuses:
Steam Rankine Cycle
Grid Interconnection
New: Resistance Htr, MSSG
0: BASE CASE
RESISTIVE HEATER + SALT STORAGE + STEAM CYCLE

Reuses:
Steam Rankine Cycle
Grid Interconnection
New: Resistance Htr, MSSG

1: STANDALONE MALTA
AIR HEAT-PUMP + SALT STORAGE + AIR HEAT-ENGINE

Reuses:
Grid Interconnection
New: Malta Heat Pump, Malta Heat Engine
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- Steam Rankine Cycle
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Reuses:
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2: BASE w/ HEAT PUMP
AIR HEAT-PUMP + SALT STORAGE + STEAM CYCLE

Reuses:
- Steam Rankine Cycle
- Grid Interconnection
- New: Malta Heat Pump, MSSG
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
<th>Reuses:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0: BASE CASE</strong></td>
<td>RESISTIVE HEATER + SALT STORAGE + STEAM CYCLE</td>
<td>Steam Rankine Cycle, Grid Interconnection, New: Resistance Htr, MSSG</td>
</tr>
<tr>
<td><strong>1: STANDALONE MALTA</strong></td>
<td>AIR HEAT-PUMP + SALT STORAGE + AIR HEAT-ENGINE</td>
<td>Grid Interconnection, New: Malta Heat Pump, Malta Heat Engine</td>
</tr>
<tr>
<td><strong>2: BASE w/ HEAT PUMP</strong></td>
<td>AIR HEAT-PUMP + SALT STORAGE + + STEAM CYCLE</td>
<td>Steam Rankine Cycle, Grid Interconnection, New: Malta Heat Pump, MSSG</td>
</tr>
<tr>
<td><strong>3: HYBRID INTEGRATION</strong></td>
<td>AIR HEAT-PUMP + SALT STORAGE + + AIR &amp; STEAM CYCLE</td>
<td>Steam Rankine Cycle, Grid Interconnection, New: Malta Heat Pump, MSSG, Malta Heat Engine</td>
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</tbody>
</table>
Down Selection Based on Relative Cost Benefit Analysis

1. Developed schematic and HMB for each option
2. Sizing of major equipment such as resistance heaters, molten salt steam generator
3. Estimation of Capex of each option and relative OPEX for each option
   - Cost of new equipment (such as MSSG, resistance heaters)
   - Cost saving based on potential re-use of certain equipment (such as cooling tower, generator, etc.)
   - Cost of major overhaul of repurposed equipment (such as steam turbine, heaters, cooling tower, etc.)
   - Relative OPEX: Steam-Rankine cycle and/or Malta PHES stand-alone
4. Benefit is based on energy shifting following similar dispatch to what pumped hydro storage does

Acknowledgement: Special thanks to Rick Roy and Robert Dorroh of Cliffside 5 Engineering Team for providing lot of Unit 5 technical inputs and discussions on the different integration options.
HMB evaluated in Ebsilon → RTE

Option 0: Resistance Heaters + Salt + Steam Cycle

Option 1: Standalone Malta System (Reuse Grid Interconnection)

Option 2: Heat Pump + Salt + Steam Cycle

Option 3: Hybrid option: Standalone Malta + Steam Cycle
### Hourly Dispatching → Energy Shifting Benefit

<table>
<thead>
<tr>
<th>Option</th>
<th>2025 Yearly Benefit ($MM)</th>
<th>2030 Yearly Benefits ($MM)</th>
<th>2040 Yearly Benefits ($MM)</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 0</td>
<td>-1.58</td>
<td>-1.23</td>
<td>2.89</td>
<td>2nd Lowest</td>
</tr>
<tr>
<td>Option 1</td>
<td>-0.30</td>
<td>0.10</td>
<td>5.26</td>
<td>Lowest</td>
</tr>
<tr>
<td>Option 2</td>
<td>-0.32</td>
<td>0.03</td>
<td>4.37</td>
<td>3rd Lowest</td>
</tr>
<tr>
<td>Option 3</td>
<td>-0.47</td>
<td>-.07</td>
<td>4.8</td>
<td>Highest</td>
</tr>
</tbody>
</table>

Sample Hourly Dispatch Profile

Overall, Option 1 has the best cost/benefit ratio at Cliffside 5.
1: STANDALONE MALTA
AIR HEAT-PUMP + SALT STORAGE + AIR HEAT-ENGINE

- Older coal plant → high cost of overhaul of Steam-Rankine cycle and generator
- Plant located in the grid where the followings are expected:
  - Daily shifting of energy is the primary use case

Reuses:
- Grid Interconnection
- New: Malta Heat Pump, Malta Heat Engine

3: HYBRID INTEGRATION
AIR HEAT-PUMP + SALT STORAGE + + AIR & STEAM CYCLE

- Newer coal plant → lower cost of overhaul of Steam-Rankine cycle; substantial remaining life
- Plant located in the grid where the followings are expected:
  - Daily shifting of energy is required → Use Malta system to get better round-trip efficiency
  - Occasional need for additional high capacity → Use Steam-Rankine cycle to supply the capacity

Reuses:
- Steam Rankine Cycle
- Grid Interconnection
- New: Malta Heat Pump, MSSG, Malta Heat Engine
It is feasible to re-use grid interconnection of Cliffside Unit 5 for Malta PTES. There is a large cost saving (≈$20M) and project schedule saving.
Economic Benefit Analyses

- Mayo site: Once Unit 1 retires, there is nothing left. Large local economic impact → Most other coal sites are like this
- Cliffside site: Once Unit 5 retires, there is still Unit 6 operating (does not lose all the jobs)
- The technical work done at Cliffside: translatable to Mayo
- Mayo is in the grid where higher renewable (wind + solar) is likely to happen first → similar reason why other coal plants are being retired early
Local Economic Impact Analysis

Local economic impact was measured for 4 activities

1. Decommissioning of the Mayo plant – One time
2. Ceasing of operations of the Mayo plant – On-going
3. Construction of the Malta plant – One time
4. Operations of the Malta plant - Lifetime

- Construction of a new Malta PTES can bring more than 200 construction jobs
- On a per MW basis, on-going O&M on the new Malta PTES system maintains similar number of jobs compared to the retiring coal plant.
Grid Benefit Analysis

- Analyzed by the Duke Energy ISOP team
- Chose a base case portfolio that could reduce CO$_2$ emission by 70% of the 2005 level (IRP 2020) → Realistic scenario
- Results:
  - A Malta 100MW-10 hour system can provide significant saving compared to a 100 MW-10 hour battery system.
  - A Malta 100MW-10 hour system can provide saving compared to a 100 MW-4 hour battery system.

The results here validated the value/benefit of the Malta long-duration energy storage system(s) in a highly decarbonized grid.
Project Outcomes

Heat and Mass Balances verified feasibility, quantified performance of integrated concepts.

Standalone and hybrid options each are attractive in certain grid and retirement scenarios.

In a high-renewables, low-carbon grid, long-duration energy storage is more advantageous than yet another 4h battery.

On a per MW basis, a Malta PHES plant maintains similar numbers and types of jobs as retiring coal plants.
Long-duration energy storage is needed now

- Yesterday’s problem: short-duration intermittency
  - Solution: Gas Peakers
  - Solution: Batteries (Primarily Li+)

- The Grid of Tomorrow will be different

Yesterday...  

<table>
<thead>
<tr>
<th>Gas Plant</th>
<th>Energy</th>
<th>Load following</th>
<th>Frequency Support (inertia)</th>
<th>Resilience</th>
</tr>
</thead>
</table>

Today and the future...  

- Utilities are asking today: how do we get there
- Solution: Malta LDES

Growing need for long-duration energy storage

Annotated version from Electric Power Research Institute “Bulk Energy Storage Costs and Performance, Overview for Technology Developers”
Thank You