32nd Annual INCOSE international symposium

hybrid event

Detroit, MI, USA
June 25 - 30, 2022

Use of Systems Engineering in Repurposing Coal-Fired Power Plants with the Malta Pumped Thermal Energy Storage System

Bao Truong, CSEP
Malta Inc.

MALTA

Outline

- Project Motivation & Background
- Use of Systems Engineering/Thinking
  - Project Management and Planning
  - Host Site Selection
  - Integration Options Down Selection
  - Concept Design & Economic Analysis
- Project Outcomes

Motivation & Background

Overall Context – Why does this work matter?

Cost Challenges and Policy Changes

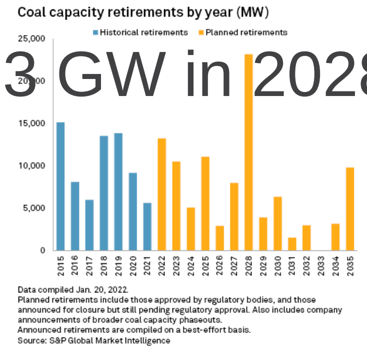
- Massive, earlier than planned retirement of coal plants
- Big energy transition (100 GWs of coal plants retiring)

Challenges for Plant Owners and Communities

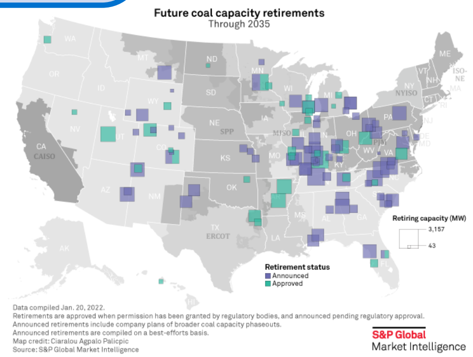
- Stranded assets
- Local communities lose the primary economic engine

What can we do with these retiring coal plants?

- **Allow a Just Transition for local communities**
- Provides benefits to plant owners



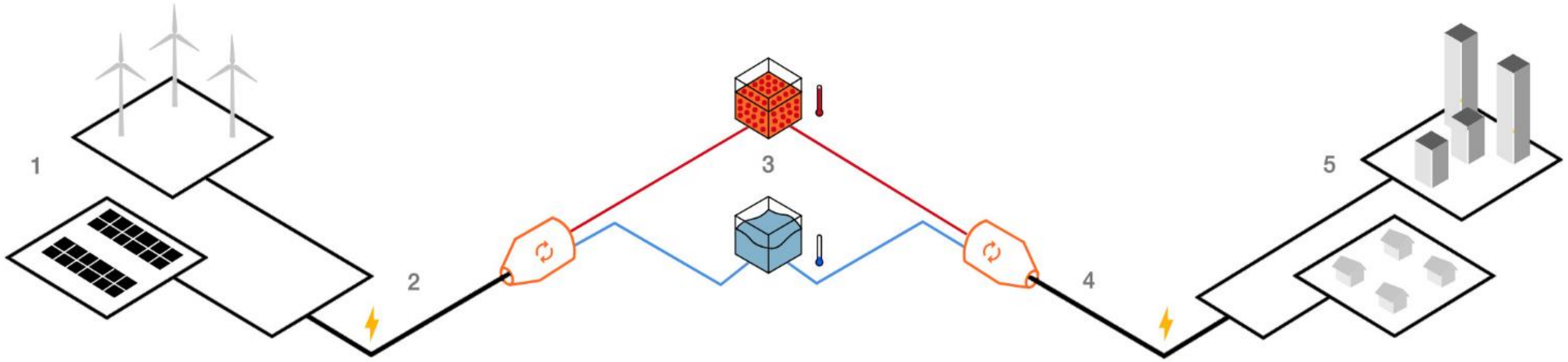
23 GW in 2028



https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/more-than-23-gw-of-coal-capacity-to-retire-in-2028-as-plant-closures-accelerate-68709205

The idea: Integrating a retiring coal plant with a Malta Pumped Thermal Energy Storage (PHES) system could be the solution.

Malta Pumped Thermal Energy Storage System



Grid scale (100MW) long duration (10+ hours) energy storage	→	Firming intermittent wind and solar power
Closed loop air Brayton cycle heat pump (charge) & heat engine (discharge)	→	Similar components to those in thermal power plants (coal, gas)
Energy stored as 565°C heat in solar molten salt	→	Good temperature range for Steam-Rankine cycle in coal plant

Project Objective & Overview

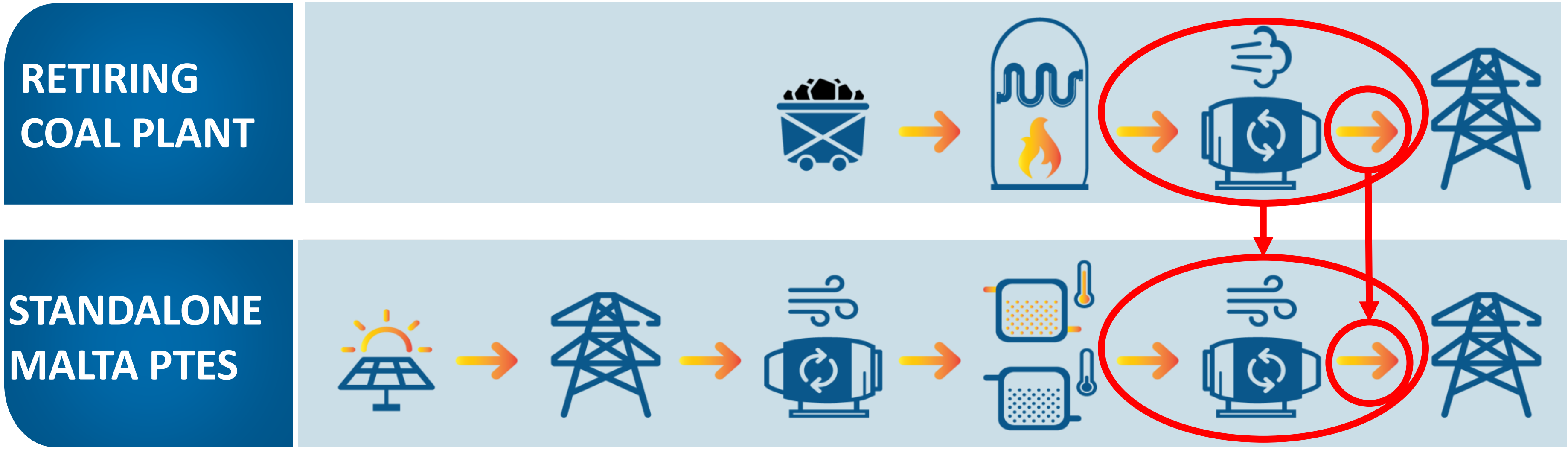
This project evaluated how a Malta Pumped Thermal Energy Storage (PTES) plant could be integrated with a retiring coal plant to achieve benefits to the plant owner and local community.

- Integration options
- Concept Design
- Economic Benefits & Local Impact

MALTA

DUKE ENERGY

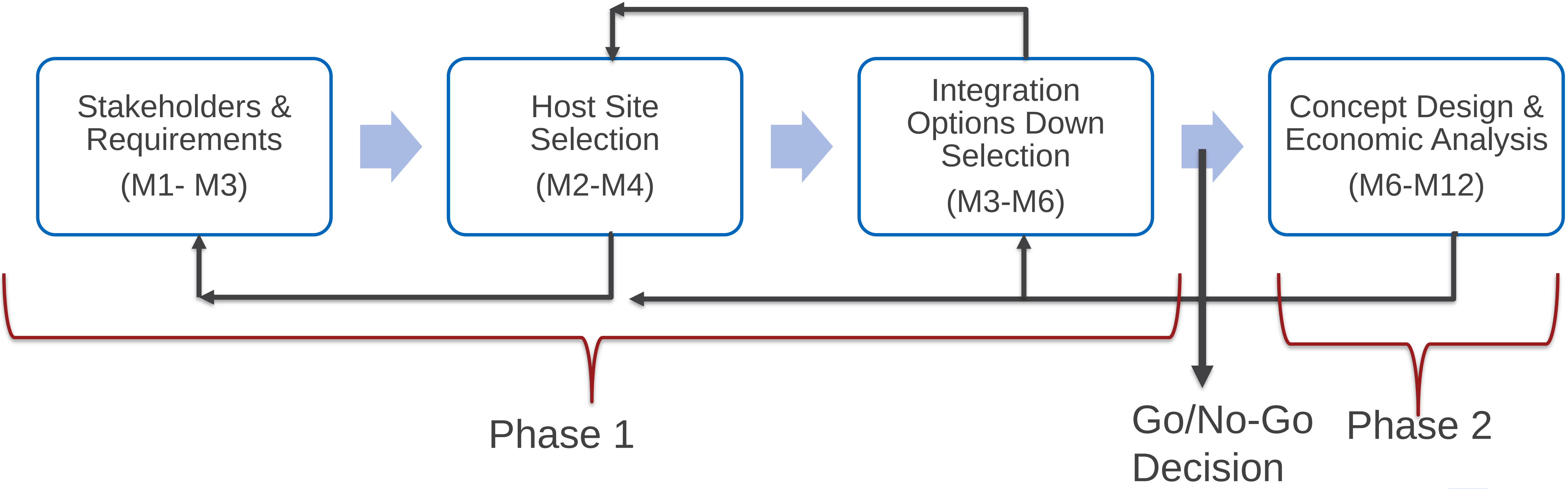
eip energy intelligence partners



Systems Engineering in the Work

Project Planning and Management

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



Stakeholders

U.S. Department of Energy
- Project's findings translatable/applicable to other retiring coal plants

Duke Energy
- 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

Malta
- Development of a potential new product offering
- Cultivate potential customer relationship

Local Communities around Coal Plants
- Can the re-purposed coal plant maintain job and local economy?

Other Utilities
- Can this solution be used for their retiring coal plants?

Host Site Selection Approach

- Duke Energy has many coal plant sites under consideration for retirement.
- How to pick the most optimal host site?

Quick Screening Criteria → 2-3 Finalists → Detailed Comparison → Host Site Selection

Duke Energy's inputs on what is important to them: always part of the process.

Host Site Selection (cont.)

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)

Cliffside 5 was chosen as the host site; part of the reason was access to technical team/data.

Criteria	Importance Ranking	Cliffside	Mayo
Coal Plant Equipment Reusability	3	3	3
Timeline	4	3	3
OPEX Saving	3	3	1
Maintain Coal Plant Capacity	1	2	1
Job maintenance/creation	3	3	3
Reconfiguration capability	4	2	2
Discharge Duration	2	2	3
Footprint Availability	5	2	3
Potential load issue with grid	4	3	2
	Total Score	**75**	**71**

Cliffside 5

Mayo 1

Integration Options Down Selection

Brainstorming integration options → How to compare options? → How much detail to go into each option? → Compare and select one option for 2nd Phase

Entire project team involved, with lot of inputs from different groups within Duke Energy

Plant Engineering
- Technical Feasibility
- What can be re-used?

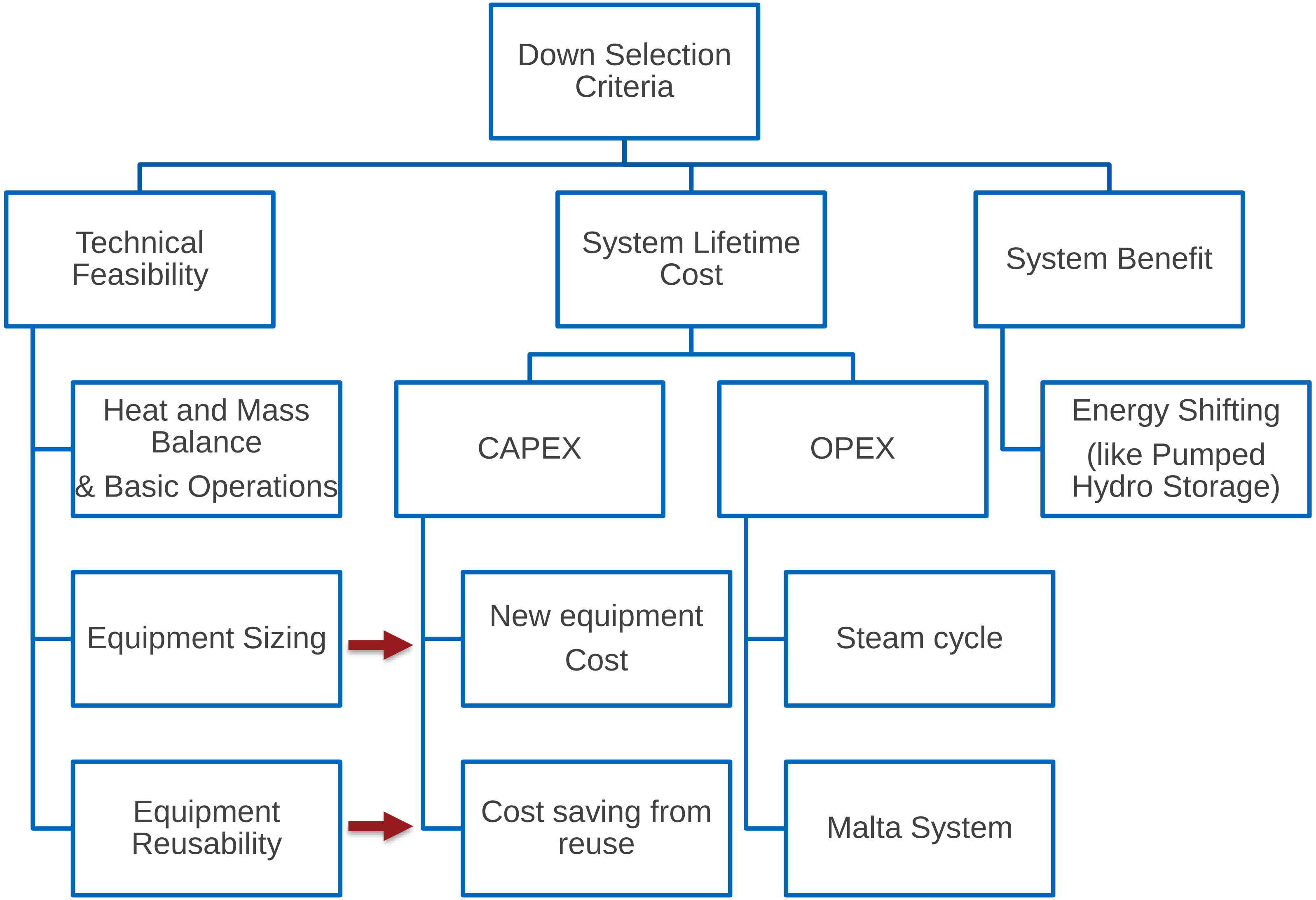
→

Grid System Modeling Team
- Benefits the re-purposed system can provide to the grid

→

Project Team
- Cost/Benefit evaluation and selection

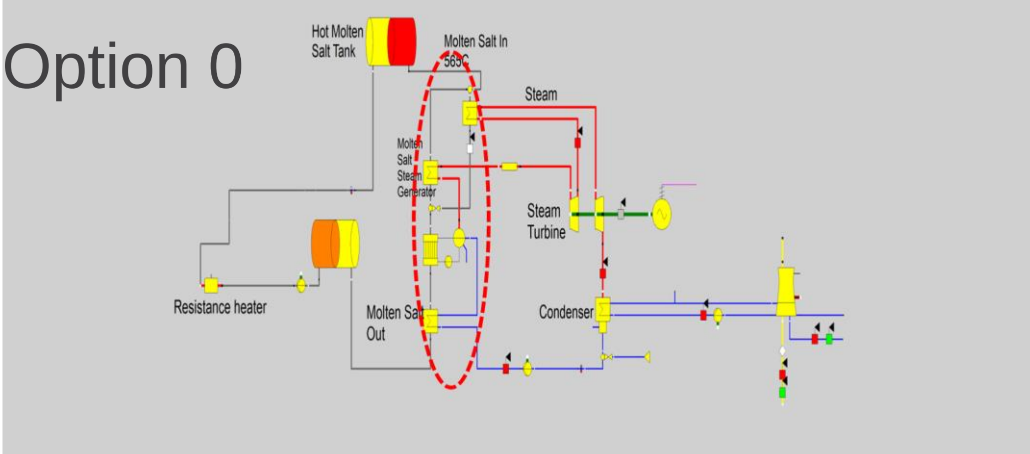
Down Selection Based on Relative Cost/Benefit Analysis

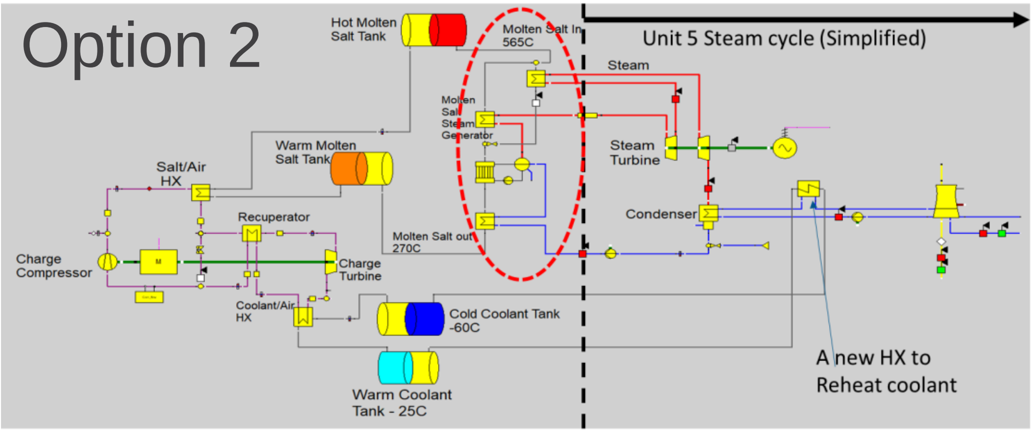


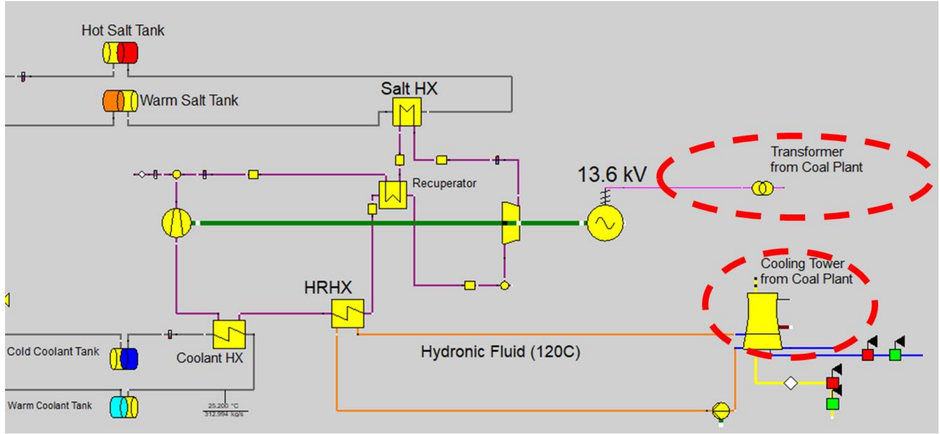
Integration Options

Option	Charging Mechanism	Discharging Mechanism	Major New Equipment	Main Equipment Repurposed	Round Trip Efficiency
0 – Resistance Heater	Resistance Heater	Coal plant's steam cycle	Molten salt Steam Generator (MSSG), resistance heaters	Steam-Rankine cycle	Lowest
1 – Electrical Integration	Malta Heat Pump	Malta Heat Engine		Grid interconnection	Highest
2 – Thermal Integration	Malta Heat Pump	Coal plant's steam cycle	MSSG	Steam-Rankine cycle	3rd Highest
3 – Hybrid Integration	Malta Heat Pump	Malta Heat Engine +Coal plant's steam cycle	MSSG	Steam-Rankine cycle	2nd Highest

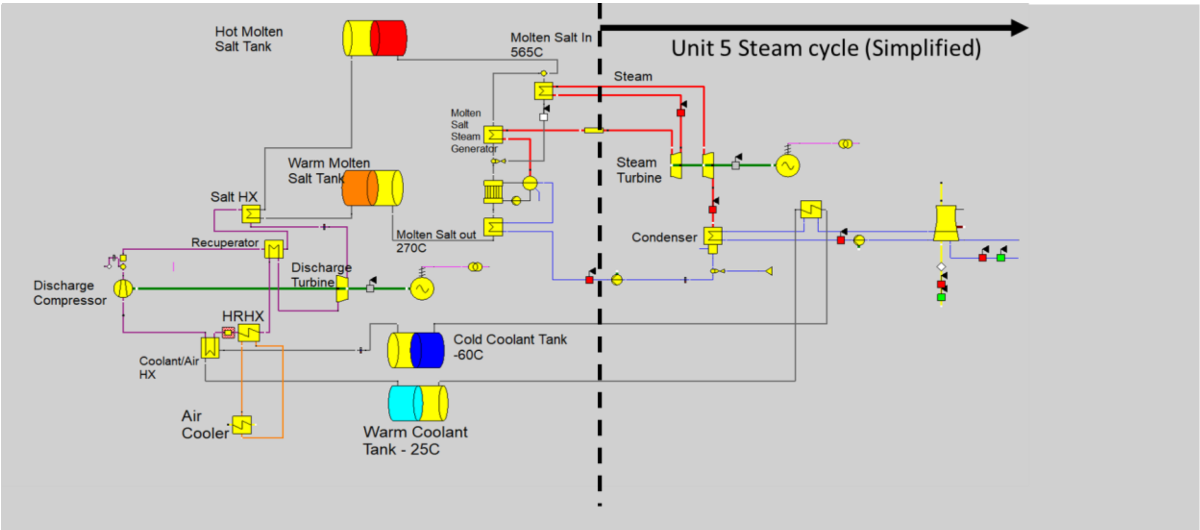
Schematic Diagrams for the Four Integration Options







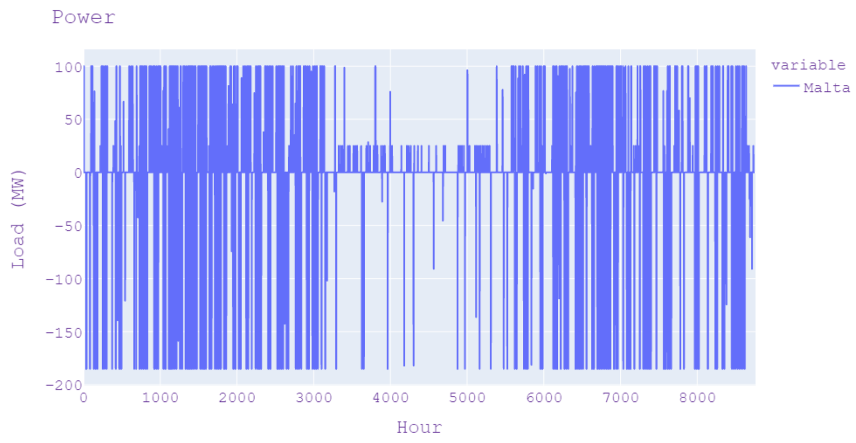
Option 1: Standalone Malta System
(Reuse Grid Interconnection)



Option 3: Hybrid option: Standalone Malta + Steam Cycle

Comparison of Energy Shifting Benefit

Option	2025 Yearly Benefit ($MM)	2030 Yearly Benefits ($MM)	2040 Yearly Benefits ($MM)	Relative Cost
Option 0	-1.58	-1.23	2.89	2nd Lowest
Option 1	**-0.30**	**0.10**	**5.26**	**Lowest**
Option 2	-0.32	0.03	4.37	3rd Lowest
Option 3	**-0.47**	**-.07**	**4.8**	**Highest**



Sample Hourly Dispatch Profile

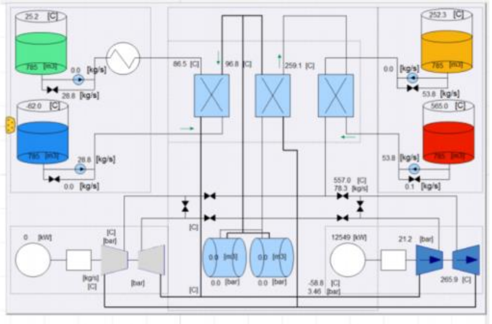
Overall, Option 1 has the best cost/benefit ratio at Cliffside 5.

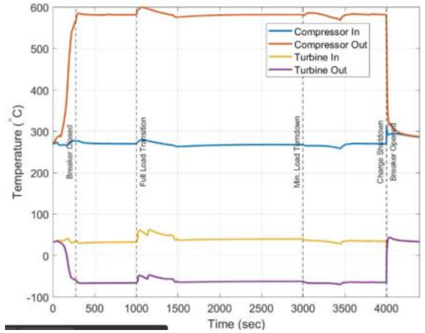
Scenario where Option 3 may be better

- Newer coal plant → lower cost of overhaul of Steam-Rankine cycle; lot of 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 capacity → Use Steam-Rankine cycle to supply the capacity

Concept Design Summary

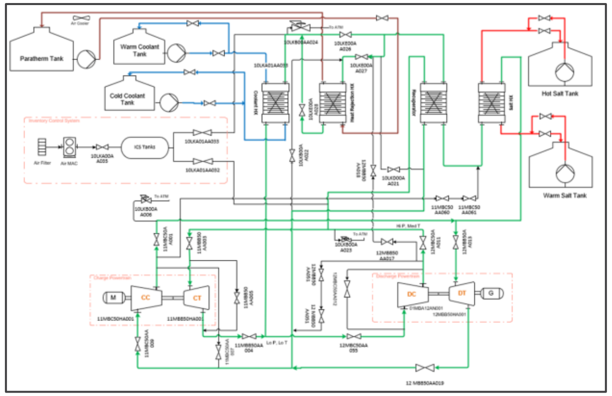
Transient Analyses



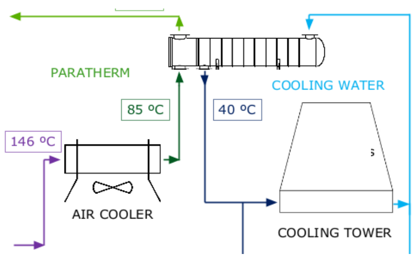


It is feasible to re-use grid interconnection of Cliffside Unit 5 for Malta PTES. There is a large cost saving (~$20M) and project schedule saving.

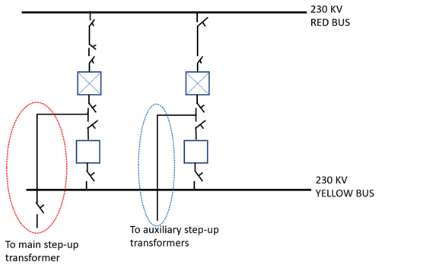
Process Flow Diagrams



Equipment Reusability

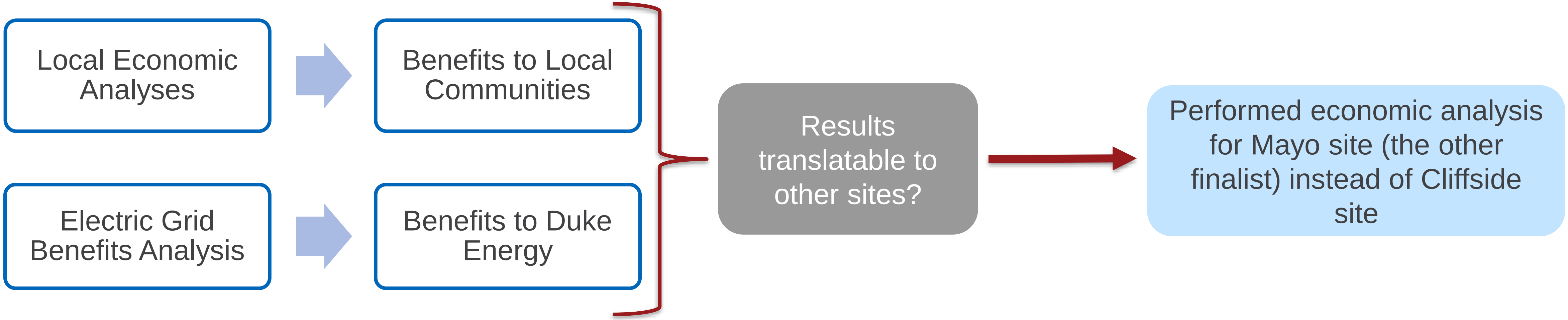


Cooling Tower Re-use Option



Cliffside Unit 5 Grid Interconnection Re-use Option

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

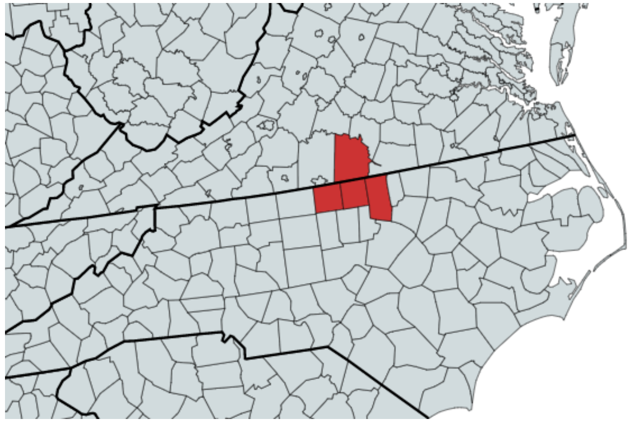
Local Economic Impact Analysis

energy intelligence partners

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

4 Counties around Mayo Site



- 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.

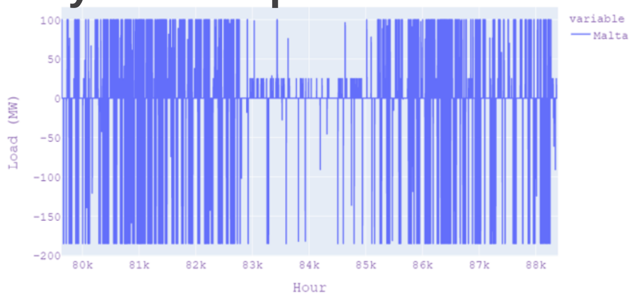
Grid Benefit Analysis

DEP PORTFOLIO RESULTS TABLE

PORTFOLIO	A: Base without Carbon Policy	B: Base with Carbon Policy	C: Earliest Practicable Coal Retirements	D: 70% CO_2 Reduction: High Wind	E: 70% CO_2 Reduction: High SMR	F: No New Gas Generation
System CO_2 Reduction (2030 | 2035)[1]	56% | 53%	59% | 62%	64% | 64%	70% | 73%	71% | 74%	65% | 73%
Average Monthly Residential Bill Impact for a Household Using 1000kWh (by 2030 | by 2035)[2]	$13 | $21	$15 | $27	$16 | $24	$31 | $39	$27 | $36	$49 | $58
Average Annual Percentage Change in Residential Bills (through 2030 | through 2035)[2]	1.2% | 1.2%	1.3% | 1.5%	1.4% | 1.4%	2.7% | 2.1%	2.4% | 1.9%	4.0% | 2.9%
Present Value Revenue Requirement (PVRR) [$B][3]	$35.4	$35.7	$37.3	$44.5	$41.9	$52.1
Estimated Transmission Investment Required [$B][4]	$0.4	$0.8	$0.7	$3.2	$1.0	$6.2
Total Solar [MW][5, 6] by 2035	4,950	6,350	6,450	7,800	7,800	7,950
Incremental Onshore Wind [MW][5] by 2035	0	600	1,350	1,750	1,750	1,750
Incremental Offshore Wind [MW][5] by 2035	0	0	0	1,300	100	2,500
Incremental SMR Capacity [MW][5] by 2035	0	0	0	0	700	0
Incremental Storage [MW][5, 7] by 2035	700	1,600	1,600	2,000	2,000	5,000
Incremental Gas [MW][5] by 2035	5,350	4,300	3,950	2,150	2,150	0
Total Contribution from Energy Efficiency and Demand Response Initiatives [MW][8] by 2035	825	825	825	1,500	1,500	1,500
Remaining Coal Capacity [MW][5] by 2035	0	0	0	0	0	0
Coal Retirements	Most Economic	Most Economic	Earliest Practicable	Earliest Practicable[9]	Earliest Practicable[9]	Most Economic[10]
Dependency on Technology & Policy Advancement						

- 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.

System Dispatch in 2035



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

Project Outcomes

1. This successful project, using systems engineering approach, validated the hypothesis that repurposing a retiring fossil-fuel asset (i.e. coal plant) into energy storage system by integrating it with a Malta PTES system makes sense and provides benefits to the plant owner and local community.
2. Two primary options for integrating a retiring coal plant with a Malta PTES were identified and a guideline for choosing an option was developed.
3. The framework developed for evaluation of repurposing retiring coal plants has received a lot of inquiries and interests from other utilities.
4. Lot of interest from the highest level of government, including the White House.

DOE Director of Integrated Carbon Management visited the project team at Cliffside 5 site.

Malta CEO was invited to the White House to a roundtable discussion hosted by [Working Group on Coal and Power Plant Communities and Economic Revitalization]

Acknowledgement

- This work was done as part of U.S. DOE grant # DE-FE0032004

Thank you!