Repowering Coal Plants as Pumped Thermal Energy Storage

Ben Bollinger, Malta Inc.

Thermal-Mechanical-Chemical Energy Storage Workshop

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Acknowledgements

- This work was funded under U.S. DOE grant # DE-FE0032004
- Many thanks to the folks at NETL, in particular program mangers Vito Cedro and Sarah Nathan, for their support throughout the project
- Many thanks to Duke Energy, in particular Jared Troyer, Rick Roy, and the folks at the Cliffside Plant
- Thank you to Edward May and Ron DeFelice of Energy Intelligence Partners for their support with the local benefits analysis
- 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 → Thermal Storage Plant : **Feasibility**

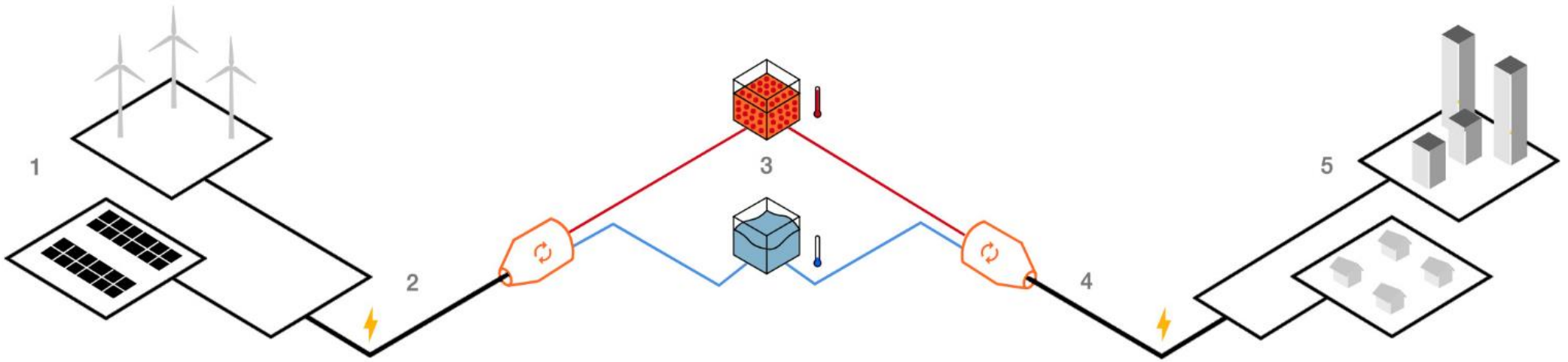
Fossil Plant → Thermal Storage Plant : **Optionality Guidelines**

Fossil Plant → Thermal Storage Plant : **Asset Owner Economics**

Fossil Plant → Thermal Storage Plant : **Jobs Preservation**

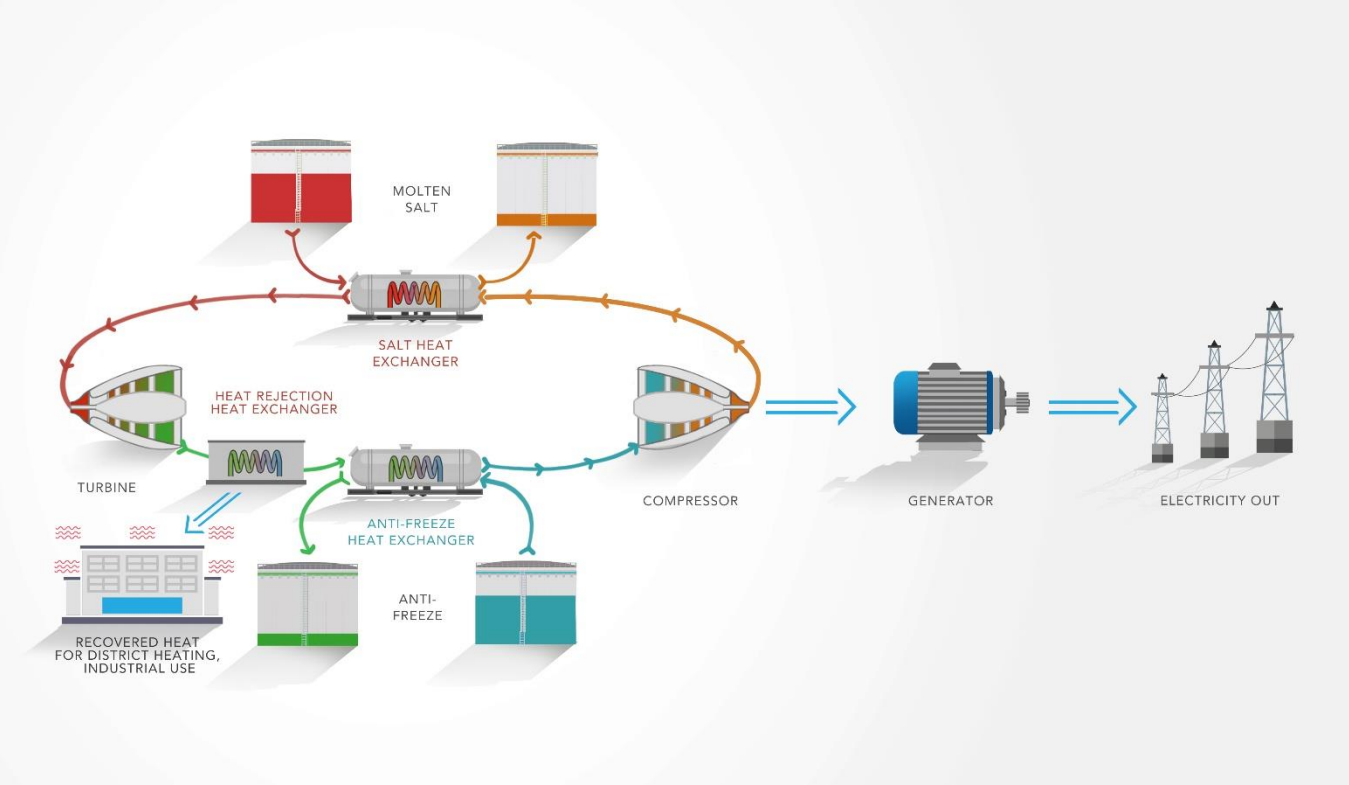
Introduction to Malta

Long Duration (8-200 hr)
Grid Scale (100+ MW)
Thermal Storage using Molten Salt



Discharge Cycle Overview – Generation

Malta Discharge Cycle



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

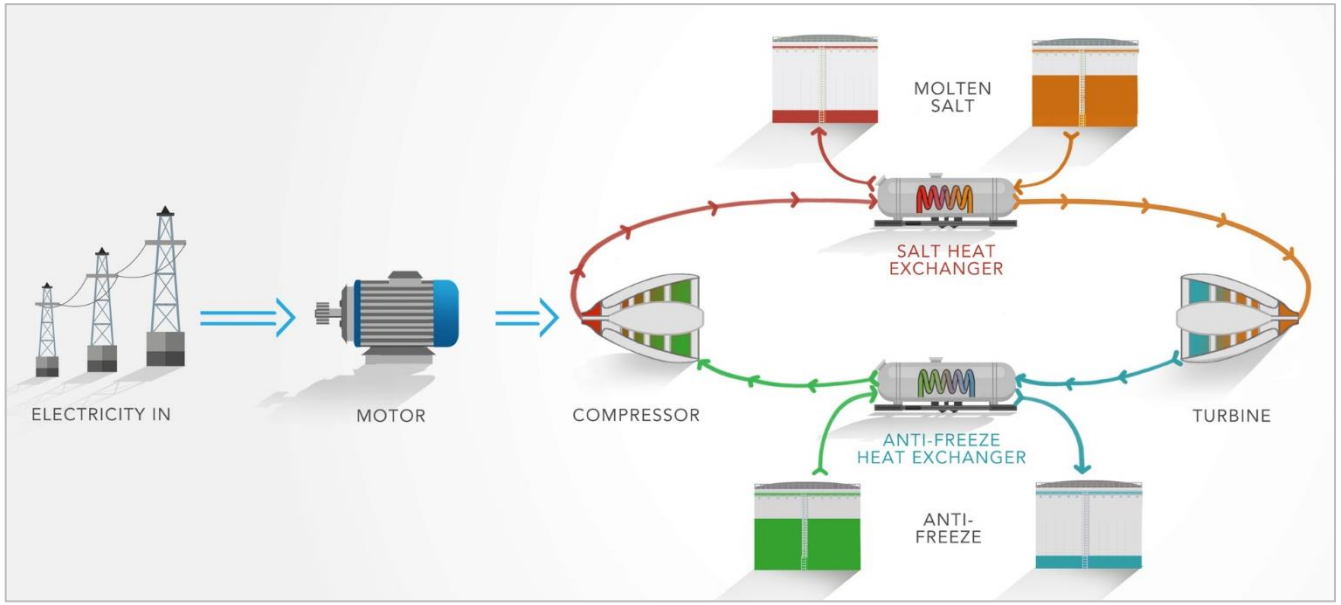
Proprietary—Malta Owned Information

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

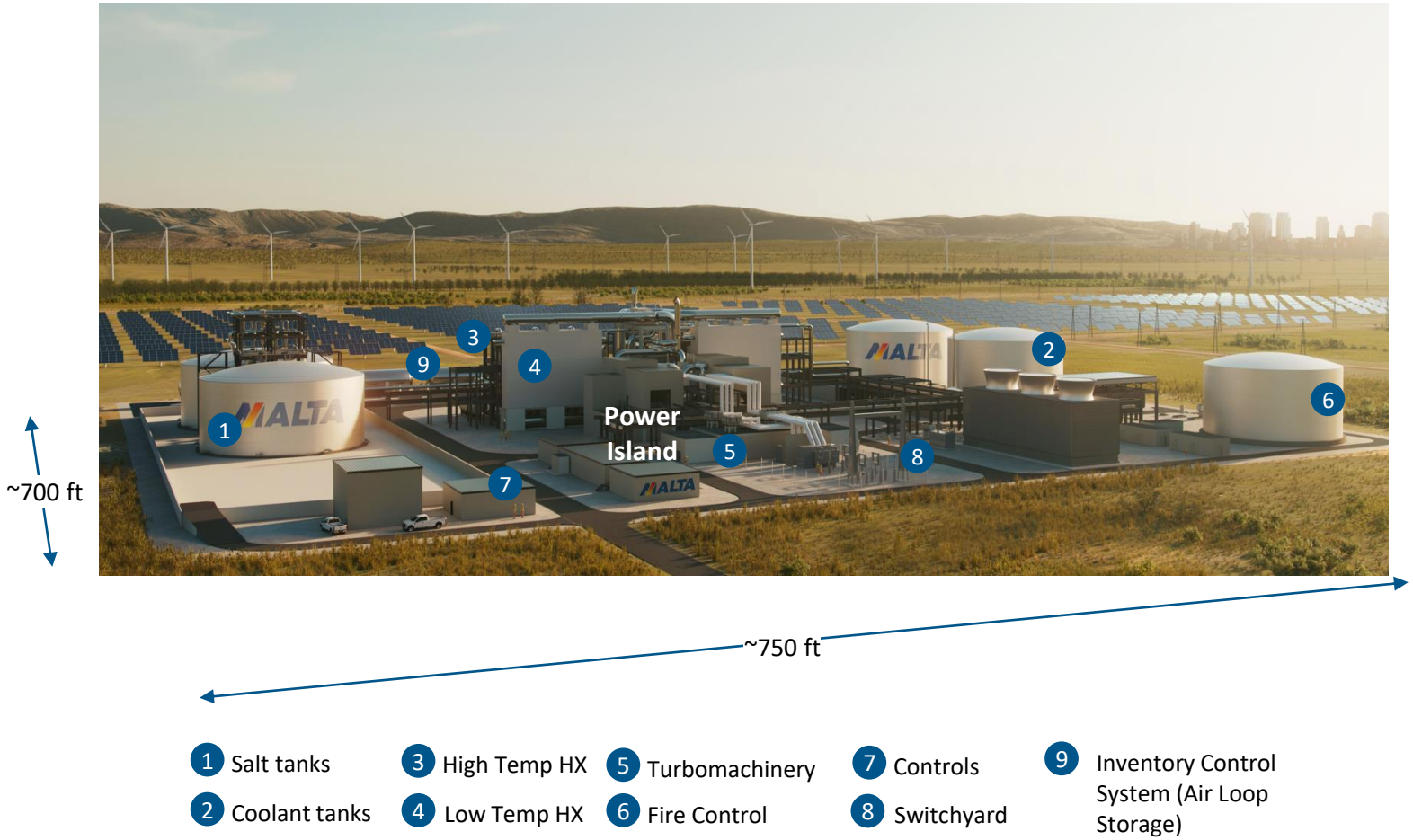
Malta Charge Cycle



Proprietary—Malta Owned Information

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

Proprietary—Malta Owned Information

World-Class Partners

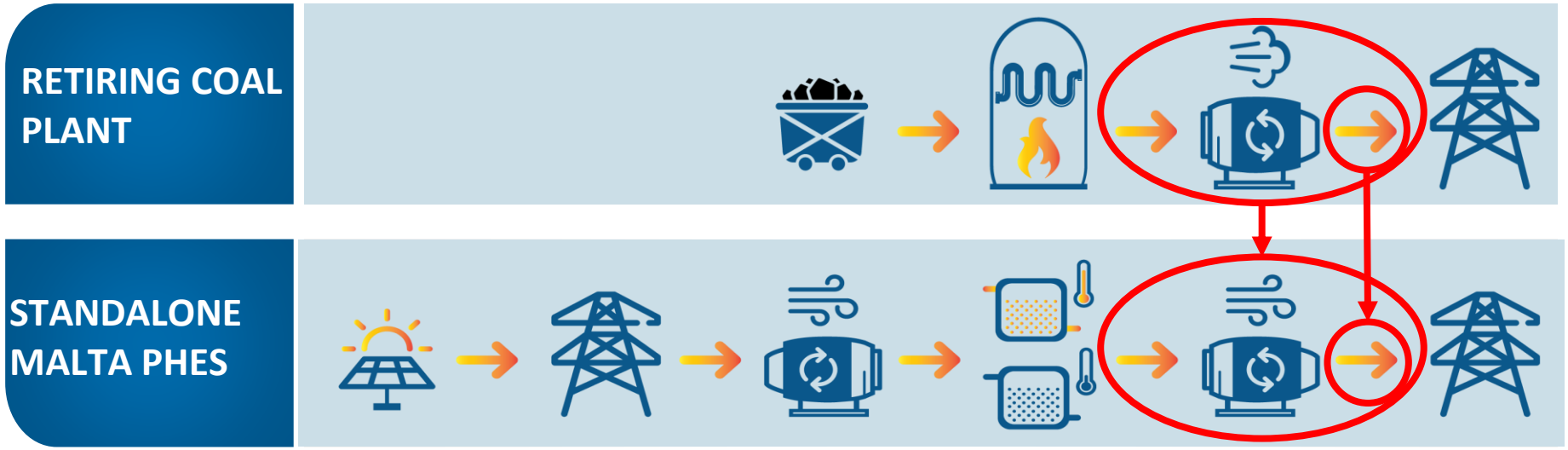
- Malta's ownership represents a unique balance of bold visionaries and world-class execution experience: financial investors and strategic investors
- The company recognizes the value of technical partnerships and has aligned itself with the best
  - Alfa Laval – Heat Exchangers
  - Siemens – Turbomachinery
  - Proman – Project Engineering & Delivery
- Additional commercial partners: Bechtel, Magtel
- Research Partners: Duke Energy, Luminant, SwRI, SolarDynamics, EPRI, UNB

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

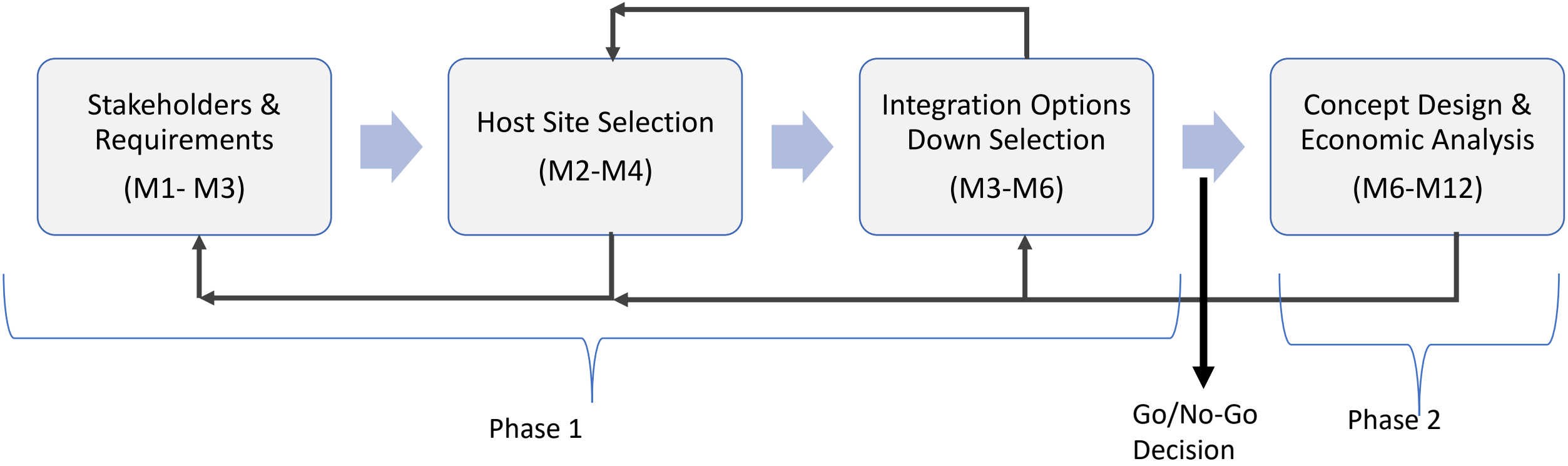


Step ②: Advance design of integration

Step ③: Outline gaps and future work

Project Stages

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



Stakeholders

- 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

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)

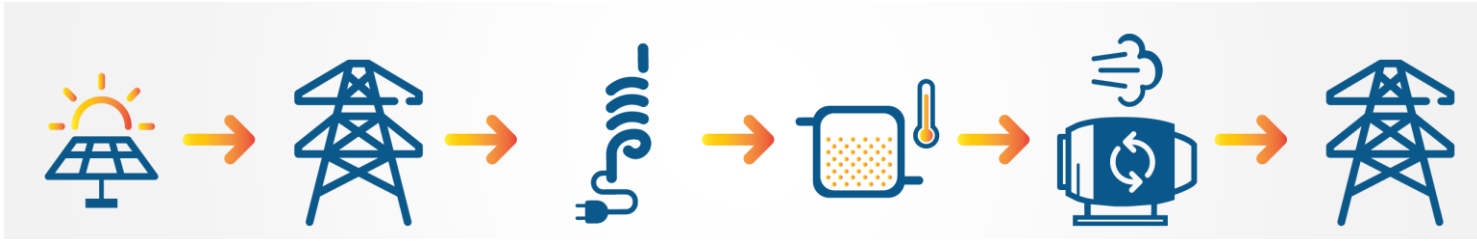
Cliffside 5 was chosen as the host site; part of the reason was access to technical team/data.

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

0: BASE CASE
RESISTIVE HEATER +
SALT STORAGE +
STEAM CYCLE



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

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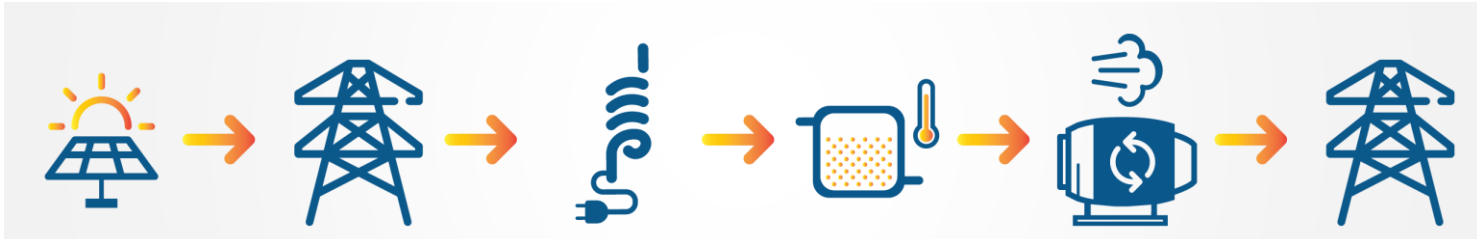

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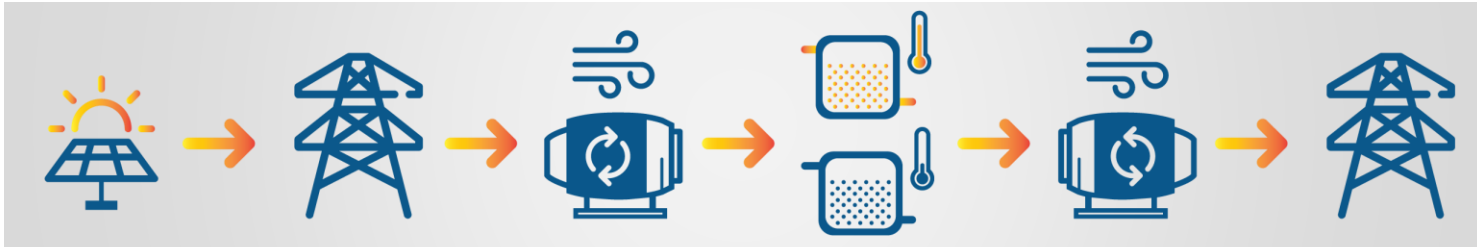
AIR HEAT-PUMP +
SALT STORAGE +
AIR HEAT-ENGINE



Reuses:
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New: Malta Heat Pump,
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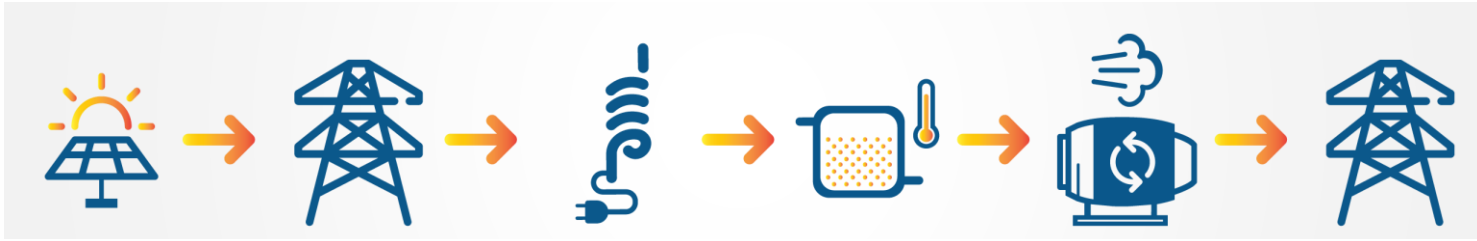

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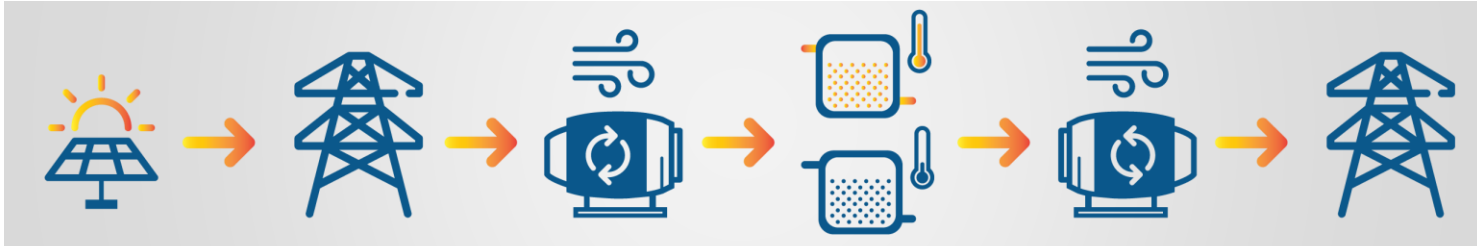

Reuses:
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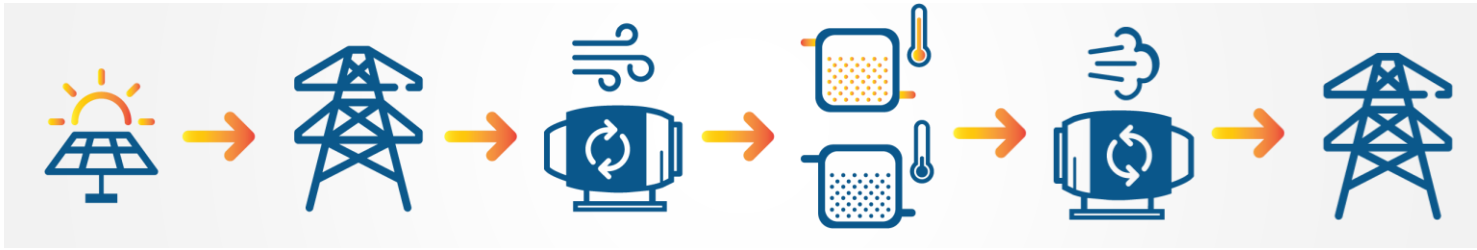
New: Malta Heat Pump,
Malta Heat Engine

2: BASE w/ HEAT PUMP
AIR HEAT-PUMP +
SALT STORAGE +
+ STEAM CYCLE



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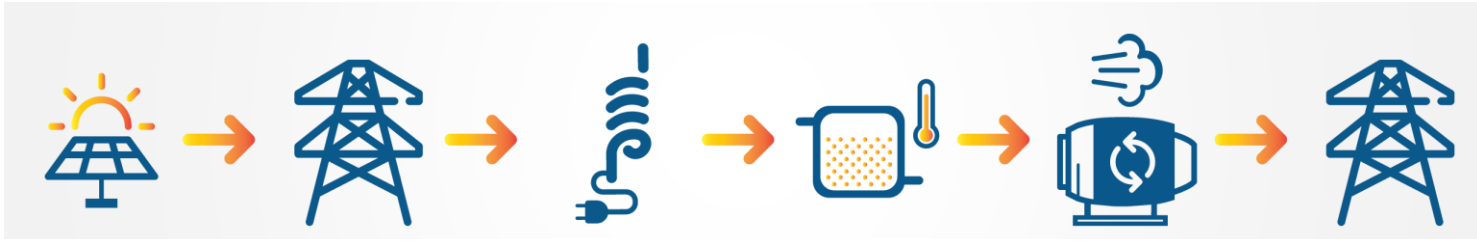

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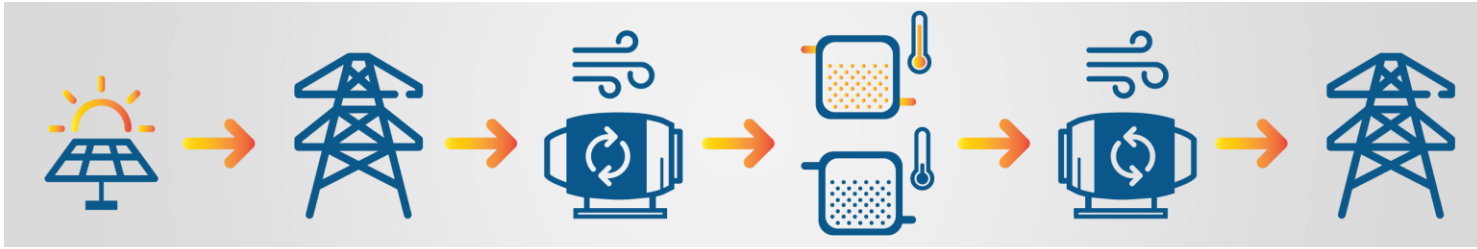

Reuses:
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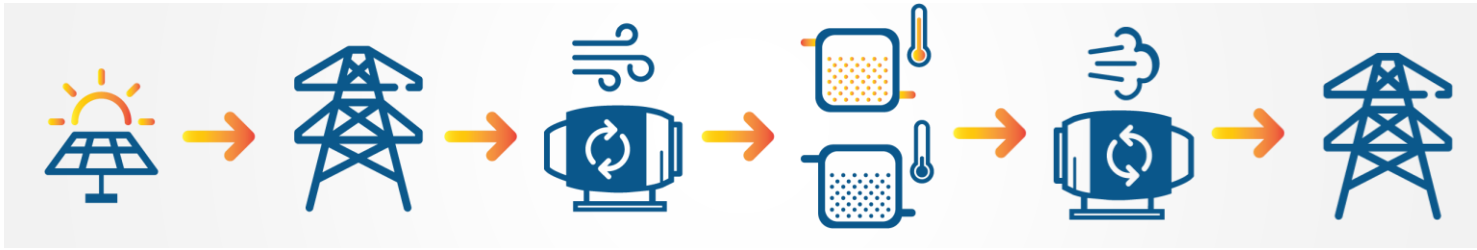
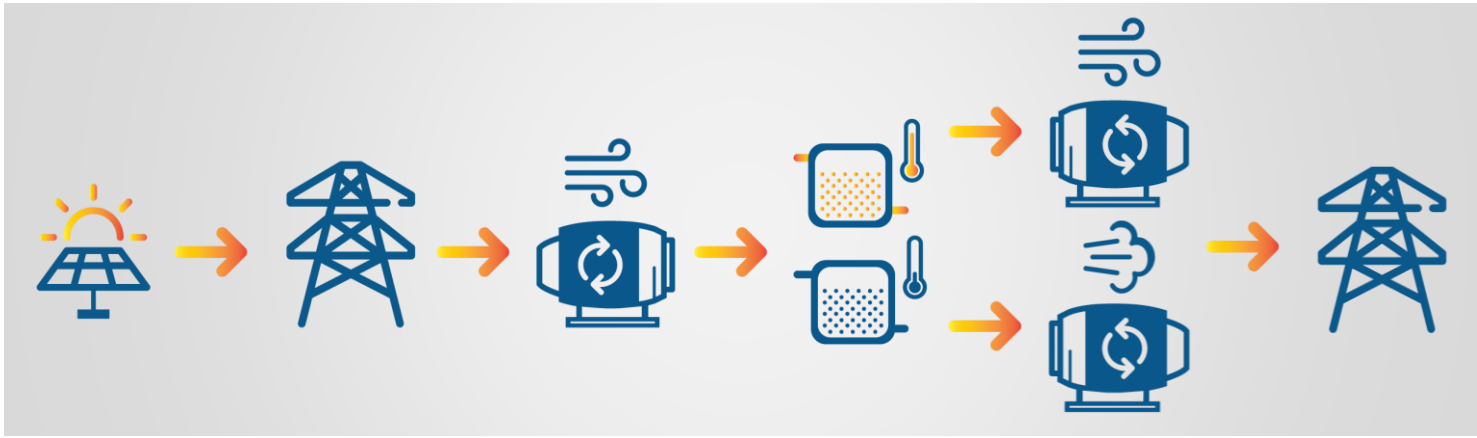


Reuses:
Steam Rankine Cycle
Grid Interconnection
New: Malta Heat Pump,
MSSG

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



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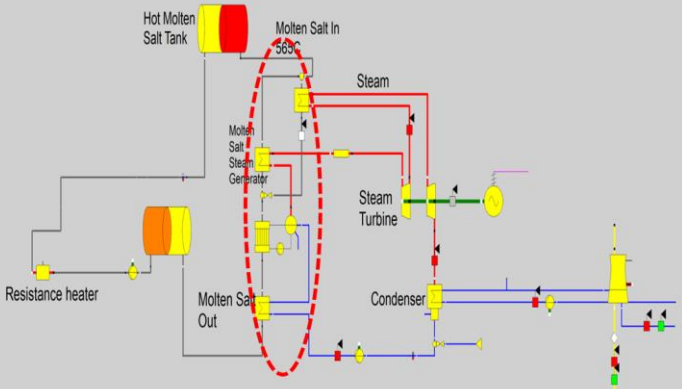
Grid Interconnection
New: Malta Heat Pump,
MSSG, Malta Heat Engine

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

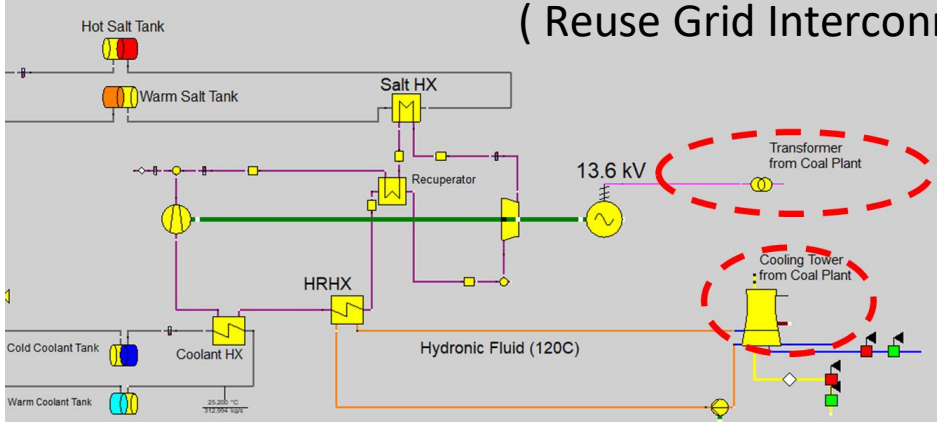
Acknowledgement: Special thanks to Rick Roy and Robert Dorroh of Cliffside 5 Engineering Team for providing lot of Unit 5 technical inputs and discussions on the different integration options.

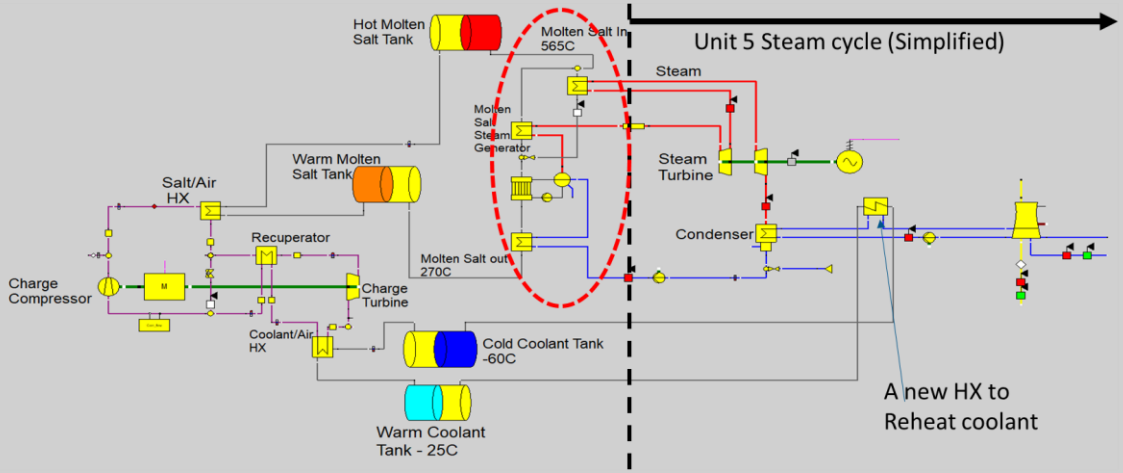
HMB evaluated in Ebsilon → RTE



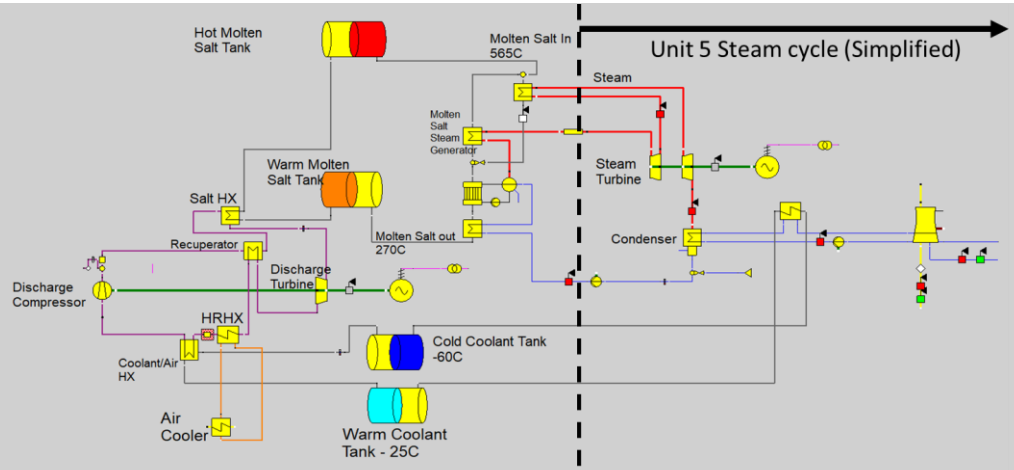
Option 0: Resistance Heaters + Salt + Steam Cycle

Option 1: Standalone Malta System
(Reuse Grid Interconnection)





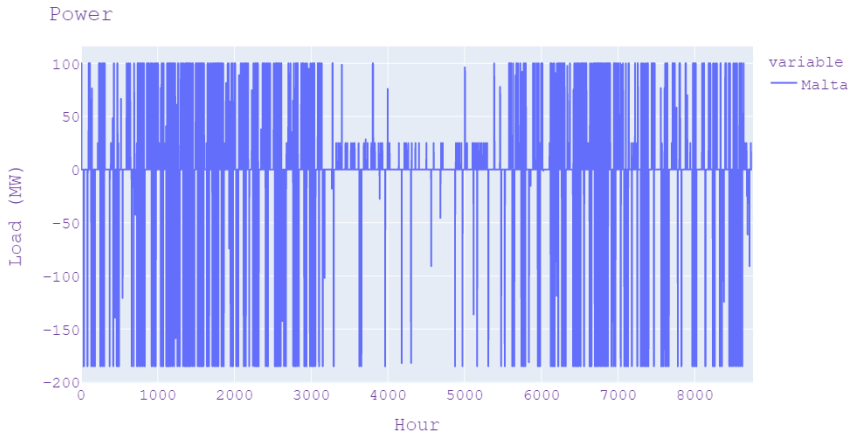
Option 2: Heat Pump + Salt + Steam Cycle



Option 3: Hybrid option: Standalone Malta + Steam Cycle

Hourly Dispatching → Energy Shifting Benefit

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**

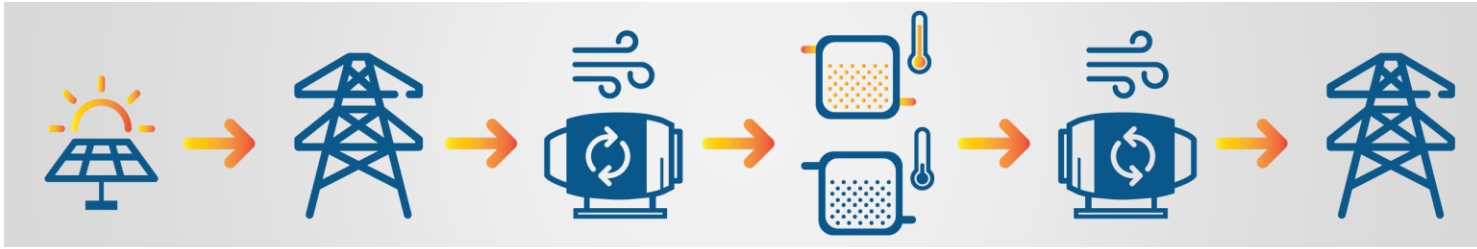


Sample Hourly Dispatch Profile

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

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

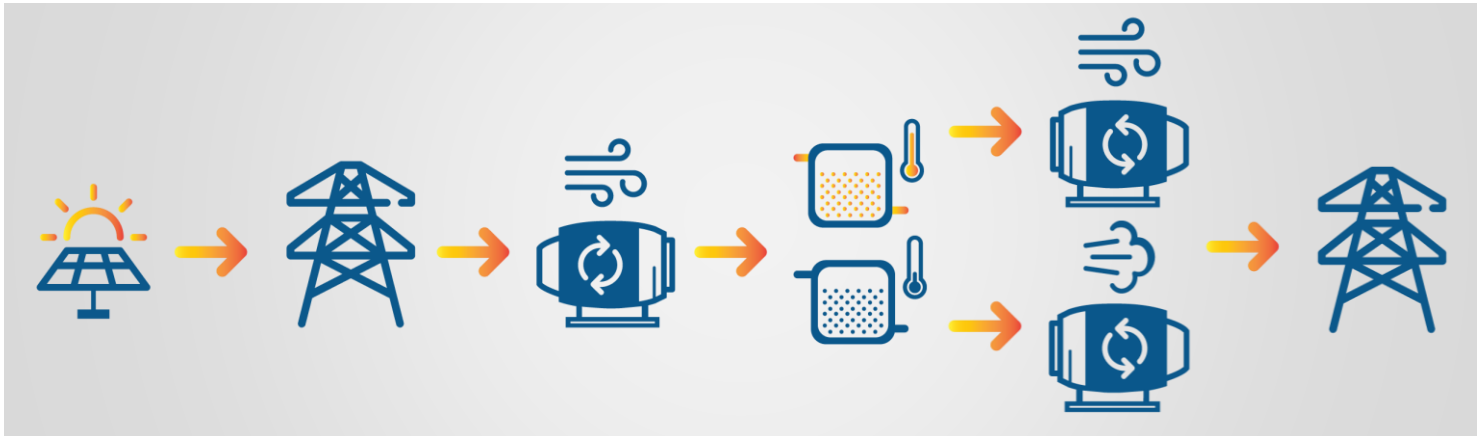
- Older coal plant → high cost of overhaul of Steam-Rankine cycle and generator
- Plant located in the grid where the followings are expected:
  - Daily shifting of energy is the primary use case



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:
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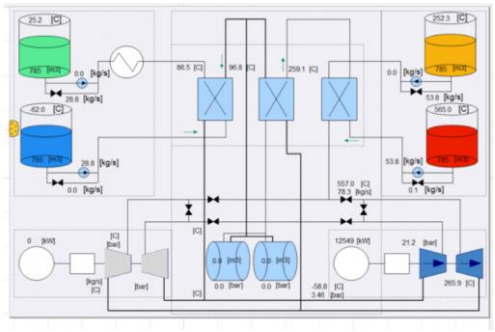
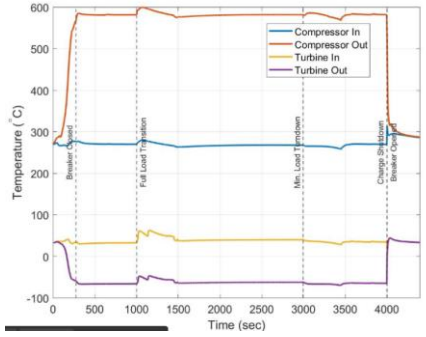
Concept Design Summary

Location on Site

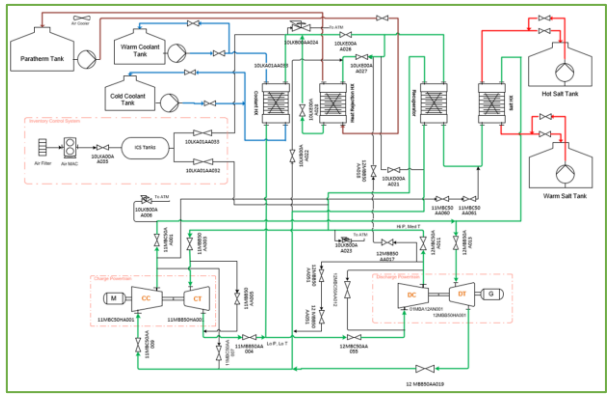
Transient Analyses



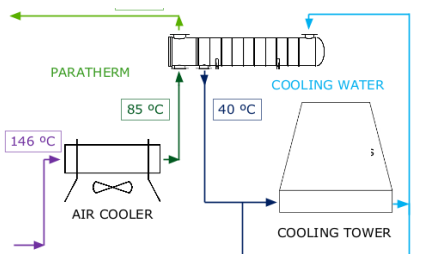


It is feasible to re-use grid interconnection of Cliffside Unit 5 for Malta PTES. There is a large cost saving (~$20M) and project schedule saving.

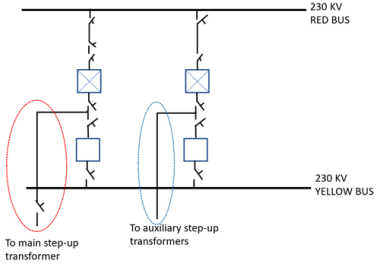
Process Flow Diagrams



Equipment Reusability

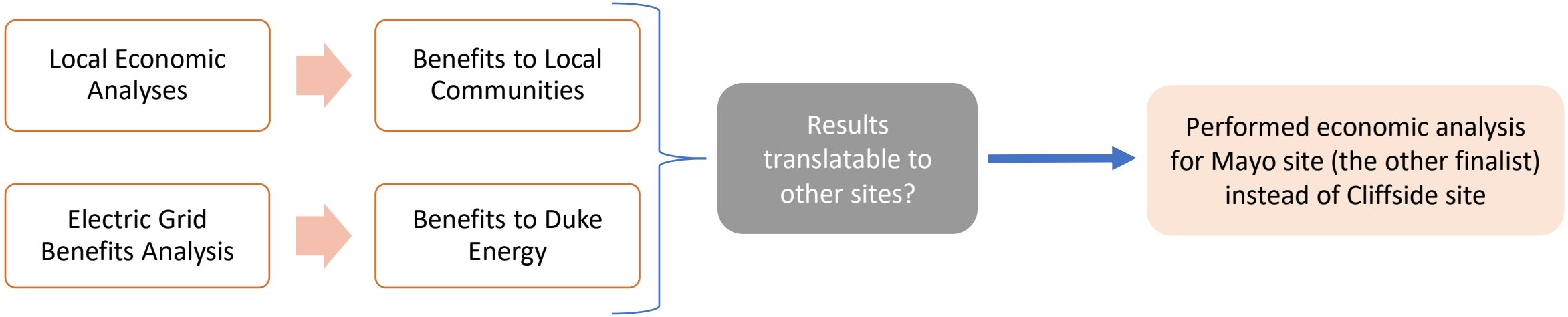


Cooling Tower Re-use Option



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

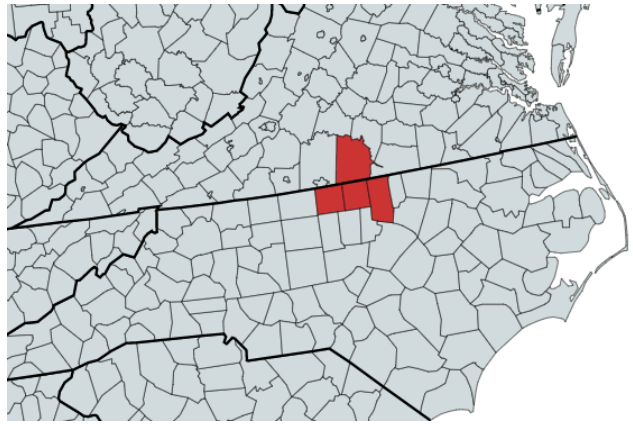
Local Economic Impact Analysis

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.

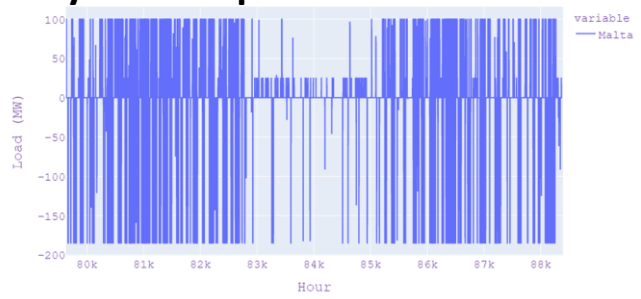
Grid Benefit Analysis

DEP PORTFOLIO RESULTS TABLE

PORTFOLIO	Base without Carbon Policy		Base with Carbon Policy		Earliest Practicable Coal Retirements		70% CO_2 Reduction: High Wind		70% CO_2 Reduction: High SMR		No New Gas Generation	
	A		B		C		D		E		F	
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

Fossil Plant → Thermal Storage Plant : **Feasibility**

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

Fossil Plant → Thermal Storage Plant : **Optionality Guidelines**

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

Fossil Plant → Thermal Storage Plant : **Asset Owner Economics**

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

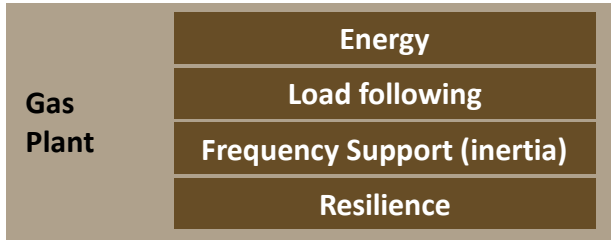
Fossil Plant → Thermal Storage Plant : **Jobs Preservation**

On a per MW basis, a Malta PHES plant maintains similar numbers and types of jobs as retiring coal plants.

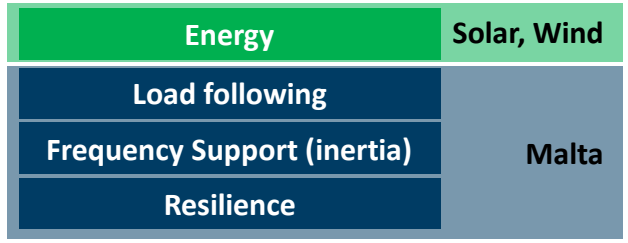
Long-duration energy storage is needed now

- Yesterday's problem: short-duration intermittency
  - Solution: Gas Peakers
  - Solution: Batteries (Primarily Li+)
- The Grid of Tomorrow will be different

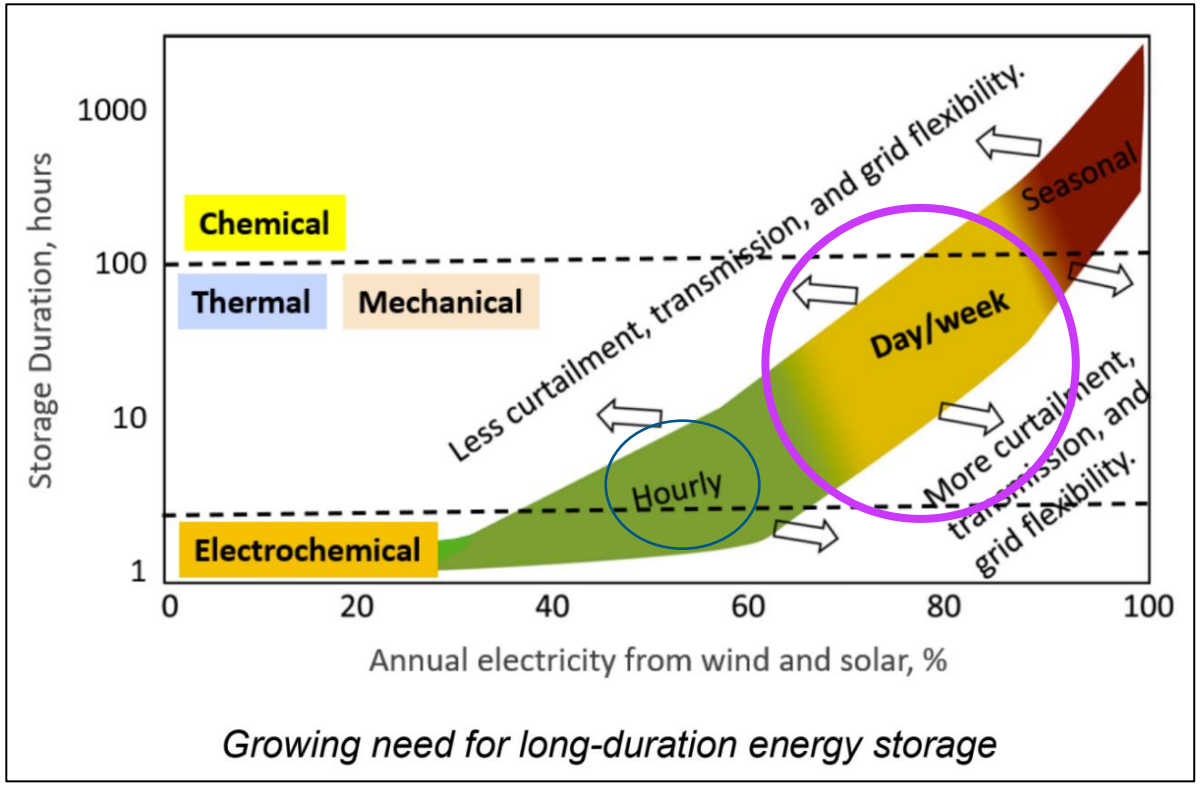
Yesterday…



Today and the future…



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



Annotated version from Electric Power Research Institute "Bulk Energy Storage Costs and Performance, Overview for Technology Developers"
Original figure from Albertus, P., Manser, J.S., Litzelman, S., "Long-Duration Electricity Storage Applications, Economics, and Technologies," *Joule* 4, 21 – 32, Jan. 2020

Thank You