"A Like-for-Like Replacement for Natural Gas." What does that mean?

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The Malta team describes our Pumped Heat Energy Storage system (PHES) as a like-for-like replacement for natural gas. What do we mean by that? In a series of memos, we will explain how Malta's PHES is the better alternative to building new natural gas-fueled power plants. Check back regularly so you don't miss the next installment!

First, what is Malta's PHES? It is an innovative, long-duration energy storage technology. It can store clean electricity for 8 hours to as long as 8 days or longer, solving renewable energy's intermittency problem. An industrial-grade heat pump converts electricity from the grid or directly from clean energy plants (e.g., solar farm, wind farms, etc.) into thermal energy – hot and cold. The hot is stored in molten salt, and the cold is stored in an antifreeze-like solution. When called upon, a heat engine uses the stored energy as "fuel," powering industrial turbomachinery that spins utility-scale generators to return the clean power to grid – on-demand, around-the-clock, when it is needed. PHES is built in 100-MWe increments with flexible storage durations, so each plant is tailored to an end-user's specific needs.

It's not exactly like a natural gas power plant. It emits no greenhouse gases, helping to slow climate change. It enables the greater deployment of variable renewable energy, like solar and wind, allowing these technologies to serve customers around the clock and on-demand. Its "green fuel" – clean, renewable energy – is domestically produced, requires no extraction from the subsurface, and is transported on existing power lines while improving grid-stability, avoiding permitting headaches and speeding deployment.

Below are just some of the reasons why Malta's PHES is a better alternative than building new natural gas plants. Periodically, we will update this document, so keep checking back for new information.

FEATURE/BENEFIT	Malta	Natural Gas
No GHG Emissions	✓	✗
Scalable	✓	✓
On-Demand, Around the Clock	✓	✓
Flexible Siting	✓	✓
Well-Established Engineering	✓	✓

Scalability

Natural gas power plants are essentially a combination of compressors, combustors, turbines, and generators. Fuel is delivered to a plant via pipeline, and electricity is dispatched onto the grid via substation. Turbomachinery – the heart of these power plants – has evolved since the first gas-powered plant in 1939, and now manufacturers have dozens of standardized models in production, depending on the end user's need. For example, Tennessee Valley Authority's Colbert power plant was commissioned in 1972 with eight 60-MWe combustion turbine units. In 2023, three 230-MWe units were added, bringing the plant to 1,170-MWe of capacity.[1]

[1] U.S. Energy Information Administration. February 26, 2024. Preliminary Monthly Electric Generator Inventory (based on Form EIA-860M as a supplement to Form EIA-860). https://www.eia.gov/electricity/data/eia860m/

Malta's PHES operates similarly, using compressors, combustors, turbines, and generators. Unlike other storage technologies, PHES's processes do not have any physical limitations for a given set of pressures and temperatures. PHES can be scaled as large as the flow capacity of the system, just like natural gas plants, which is typically determined by turbomachinery throughput and piping elements size. This means that the system can be scaled to >100 MWe without breaking the physics of any of the processes. Many other storage technologies are inherently limited to small-scale, cell-based units (most electrochemical processes), which are great for a lesser capacity storage application (e.g., fewer than 50 MWe), but scale poorly for applications requiring high capacity.

This scalability helps owners deploy storage solutions for not only today's needs but also support future needs that will evolve with the changing energy landscape. A standard design includes a 100-MWe power block that is coupled with an energy block capable of storing between eight hours and eight days of electricity. The power block can be scaled on both charge and discharge sides using multiple units, and the storage durations can flexibly scale with power or independently.

Each customer's needs are unique. Rather than a one-size-fits-all approach that requires the customer to adjust to the limitations of the storage technology, the PHES can be tailored to each customer's needs, just like natural gas technology. Portfolios with solar that generate more electricity than can be used during peak hours require faster charging. PHES can increase its charge power by 2x, 3x, etc., by adding new charge trains and other relevant hardware at a fractional cost of the full system. This doubles, triples, etc., the speed at which electricity can be stored in the system without impacting the discharge speed and duration.

A customer may want to rapidly discharge power from the storage system. Additional discharge trains can be added to double, triple, or further increase the speed of discharge. Duration is proportional to the ratio of charge to discharge, so a 2x discharge train would halve the duration, or additional storage can be added to maintain or extend duration.

If additional capabilities are required in the future, additional power blocks can be added to double, triple, etc. the charging rate and the output capacity, just like with natural gas plants. Additional electrical upgrades would be required but this would have no impact on the energy block (storage hardware). To extend duration, additional storage tanks and media can be added.

On-Demand, Around-the-Clock Generation

Natural gas power plants can run as long as there is fuel flowing through the pipeline to the plant. Malta's "fuel" is clean, renewable energy that is delivered to the plant via the electric grid and stored on-site in the energy block. The duration of storage is independent of capacity of the plant. Whether the power block is 100-MWe or 500-MWe, the duration can be dialed up or down to meet a customer's needs, and it can be extended in the future as necessary.

Let's say that a customer knows that they need six hours of energy storage in the short term, but its needs will grow to 10 hours in the future. Much like buying shoes a little too big for a child at the beginning of the 7th grade, the PHES can be designed and built with an energy block that can store 10 hours of 100-MWe of electricity (1,000 MWh). Storage media (fluids inventory) sufficient for six hours can be purchased initially, reducing the up-front capital cost of the near-term desired duration. When needed, the additional four hours of storage media can be added to the system with no changes to the hardware, including both the power block and the energy block.

If the customer's needs increase from 10 hours to 20 hours, additional storage tanks and fluids inventory can be added to the PHES without impacting output capacity and electrical infrastructure (e.g., GSU, breaker, etc.). This can be accomplished with no operational interruptions.

Flexible Siting

Natural gas power plants can be sited almost anywhere in the world with access to a natural gas pipeline and the bulk power system. Due to combustion-related emissions, there can be "not in my backyard" (NIMBY) and environmental justice concerns about siting new plants. Plants can be collocated with other generation assets or on industrial land if space allows.

Similar to natural gas plants, PHES requires only access to the electric grid for both its charging and discharging needs. The system requires sufficient land area for an optimum installation, which can be reduced by stacking and vertical installation of components. The design calls for a maximum elevation typical for an industrial plant. Beyond that, PHES is incredibly flexible.

It can be sited nearly anywhere in the world:

- It is not dependent on geographic or geologic features (e.g., drastic elevation changes within narrow distances; specific subsurface compositions; etc.).
- It is agnostic to extremely hot and cold environments, unlike many incumbent technologies with underlying technological and/or material limitations.
- It can be cooled with water or air, allowing siting in arid climates.
- It has no inherent safety risks that limit siting, like thermal runaway, large volumes of toxic chemicals, or use of other dangerous materials, like asphyxiating gases.

This gives customers a range of options depending on the specific objectives and available resources at the site to deploy the most optimum solution.

Well-Established Engineering

Simple cycle and combined cycle natural gas power plants have been widely adopted since the 1980s. They have a mature and robust ecosystem of suppliers, OEMs, and EPCs. This gives customers and end users a high degree of confidence. The underlying engineering and mechanics of both are a gas turbine (GT) cycle. It looks like this:

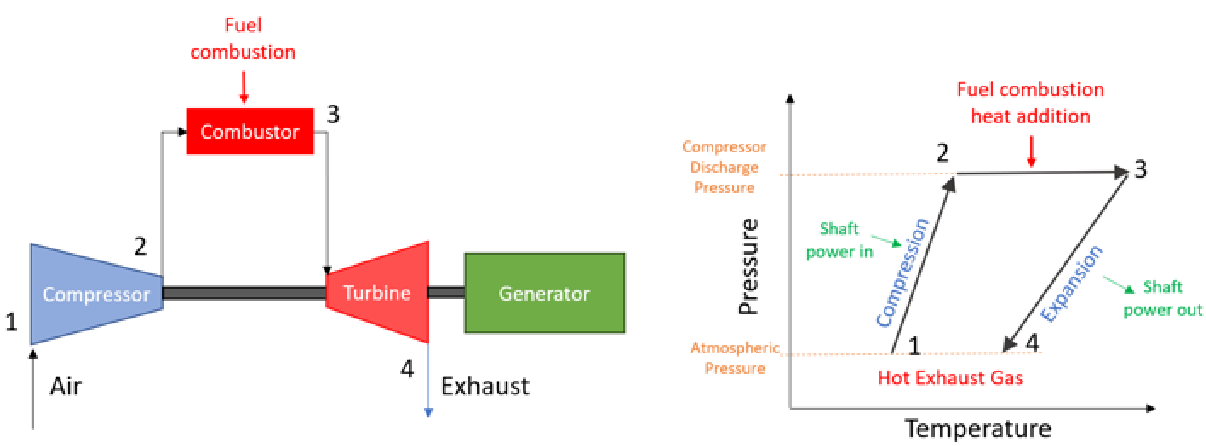

Figure 1. *Open Brayton cycle schematic and Pressure-Temperature diagram*

A typical GT plant (i.e., a simple-cycle plant), predominantly used as a peaker plant, is based on the open Brayton cycle.

1) Compression: Ambient air enters the compressor inlet, is compressed through a series of stages, and exits the compressor. This process pressurizes and heats air to the desired outlet pressure and outlet temperature.

2) Isobaric Heat Addition: High-pressure air then flows to the combustor, where fuel is added for direct combustion, resulting in an elevated temperature.
3) Expansion: The high-temperature, high-pressure air enters the turbine and expands, converting energy into mechanical shaft power that is then converted into electricity by the generator.
4) Isobaric Heat Rejection: The hot exhaust gas is vented to the atmosphere.

This is a simplified version of the GT plant. There are variations of this architecture to improve the efficiency.

Malta's PHES is nearly identical – but without the need for price-volatile fuels and carbon- and NOx-emitting combustion.

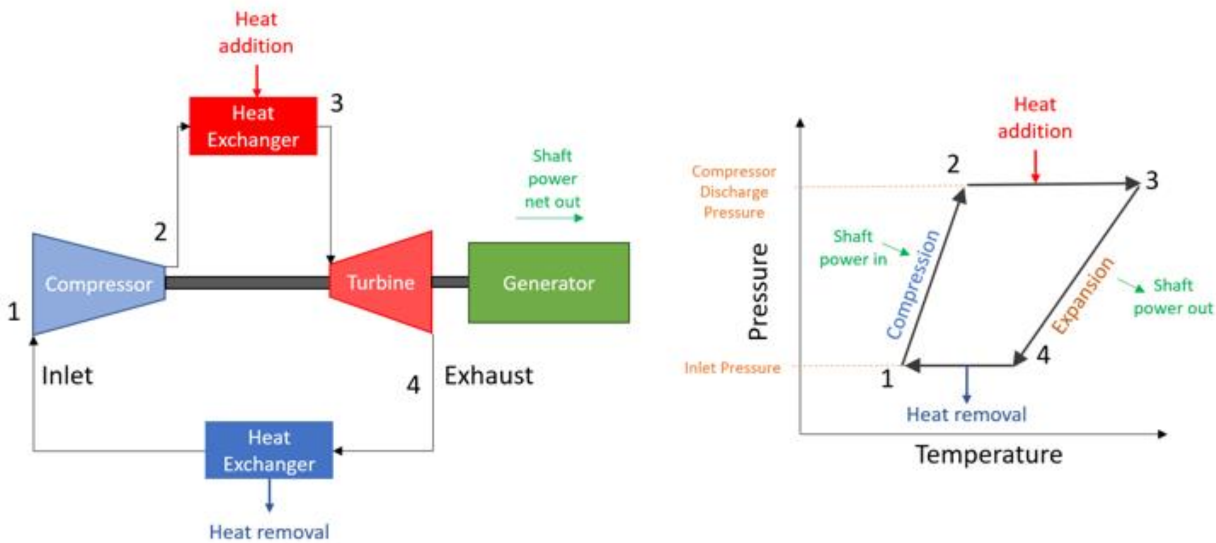

Figure 2. *Closed Brayton cycle schematic and Pressure-Temperature diagram*

Malta's PHES cycle uses a closed Brayton cycle to eliminate the use of combustion. The system uses clean dry air, free of any particulates and flue gases, that is contained and circulated in a closed loop.

1) Compression: Cold, low-pressure air enters the compressor inlet, is compressed through a series of stages, and exits the compressor. This process pressurizes air to a higher pressure and a relatively warmer outlet temperature.
2) Isobaric Heat Addition: The high-pressure air then flows through a series of heat exchangers, where high-temperature molten salt heats up the air. No combustion takes place during this step compared to a simple cycle process.
3) Expansion: The hot, high-pressure air enters the turbine and expands, converting energy into mechanical shaft power that is then converted into electricity by the generator.
4) Isobaric Heat Rejection: The warm, low-pressure air then flows through a series of heat exchangers that a) reject excess heat to the atmosphere and b) further cool the air using a coolant before its return to the compressor inlet. The colder air helps reduce work done by the compressor and improves the generation process efficiency.

There are two major differences between the simple cycle plant and Malta's PHES. First, PHES does not have a combustor or a combustion process, and instead utilizes heat stored in the molten salt storage system (from the charging process), eliminating all emissions related to the combustion process (e.g., CO_2, NOx, etc.)[2]. Second, the turbine outlet is connected to the compressor inlet via the series of heat removal heat exchangers, making PHES a closed-loop system. This configuration improves the generation efficiency (higher than a simple cycle efficiency), similar to a combined cycle gas plant.

The system is divided into three major fluid loops: air (as the working fluid), molten salt, and coolant. The charging process is a closed-loop Reverse Brayton cycle where the system works as a "heat pump" and the airflow is reversed.

The charging cycle is comprised of four main processes:

1) Compression using a compressor on the charge train driven by the synchronous motor;
2) Heat rejection to the storage media at a high temperature;
3) Expansion using a turbine mounted on the same shaft to recover energy from high-pressure air instead of throttling it, discharging air at sub-zero temperatures; and
4) Heat addition from coolant to the air loop, subsequently with the coolant storing energy as a cold storage system.

These types of processes have been in practice for many decades within a range of different industries, including natural gas-fueled electricity generation. The discharging process acts as a "heat engine," and it is comprised of the same four main processes. For example, heat is added from the molten salt, and heat is removed by the coolant. Here, the turbine generates electricity, and the compressor consumes a fraction of this generated output.

Both charging and discharging processes can be visualized using a simple Temperature and Entropy (T-S) diagram, as shown in Figure 3.

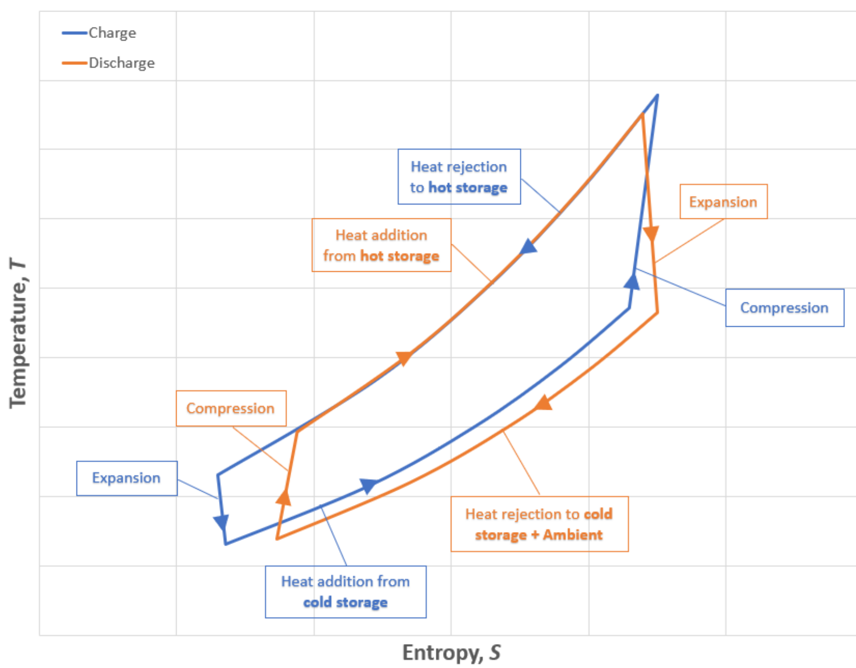

Figure 3. *Malta PHES System Temperature-Entropy Diagram*

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[2] Pavri, Roointon and Moore, Gerald D. Gas Turbine Emissions and Control. *GER-4211 (03/01).* https://www.gevernova.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/resources/reference/ger-4211-gas-turbine-emissions-and-control.pdf

All four main processes of the charging and discharging cycles are based on proven (and boring, frankly) thermodynamic processes, which do not involve novel reactions, exotic materials, sensitive phase-change processes, or novel underground storage methods.

To summarize, Malta's PHES has a lot of similarities with natural gas-based simple cycle or combined cycle plants and leverages decades of learnings from these plants to realize a grid-scale energy storage solution at scale, >100 MWe. Malta's PHES can be viewed as an improved version of GT technology by eliminating emissions, which is considered a major issue in decarbonizing the grid. With this approach, this technology offers the same level of reliability and provides critical rotational inertia for grid stability. By taking a proven technology path, we have been able to avoid introducing new risks that were previously not mitigated and demonstrated at a commercial scale.

Ultimately, customers who understand how natural gas power plants work also understand how PHES works and can appreciate the degree of maturity of the technology with minimum risks.