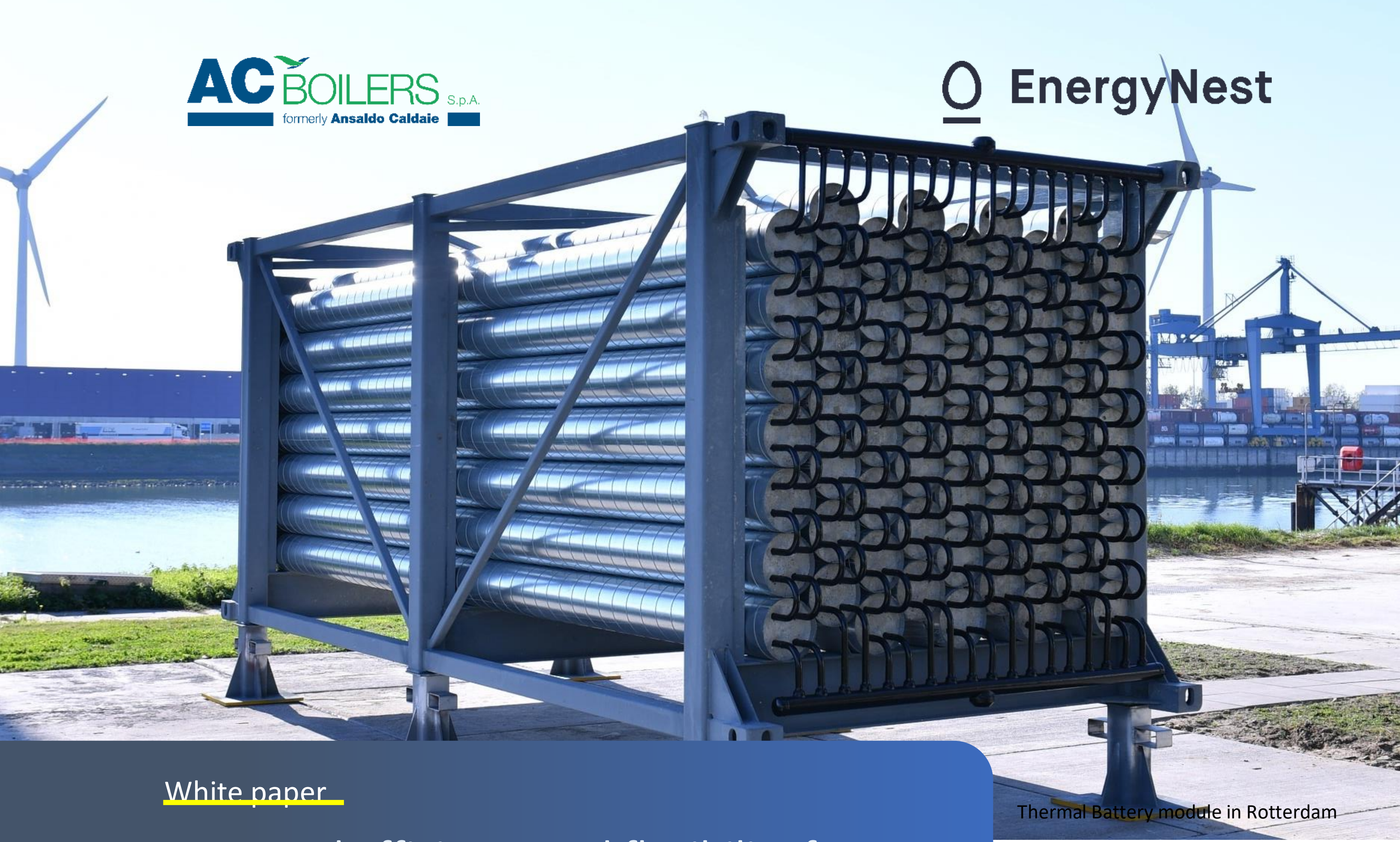
AC BOILERS S.p.A. formerly Ansaldo Caldaie

EnergyNest



Thermal Battery module in Rotterdam

White paper

Increased efficiency and flexibility for combined cycle power plants

SUMMARY

With a growing share of electricity produced from variable renewable energy sources, conventional thermal power plants will have to increasingly shift their role from providing baseload power to providing dispatchable power by ramping up and down.[1] The increasing spread between minimum and maximum electricity prices generates considerable revenue uncertainty. Thermal assets which do not invest in flexibility are at risk of becoming commercially stranded in markets characterized by high price volatility.

EnergyNest's Thermal Battery allows plant operators to decouple the steam boiler from the turbine, thus allowing a much higher degree of flexibility in electric power output, while also storing thermal energy which is otherwise dumped during start/stops and re-use this energy within the plant, reducing fuel costs and CO_2 emissions. The Thermal Battery can provide a range of valuable services for plant owners and managers in an increasingly demanding power market. This paper describes the technoeconomic rationale underlying the technology.

COLLABORATION AGREEMENT

AC Boilers and EnergyNest, in the frame of a collaboration agreement, have been developing over the last years concepts for the implementation of the ThermalBattery™ technology in Steam Power Plants as well as in Industrial Steam grids.

ABOUT ENERGYNEST

EnergyNest AS is a Norwegian technology company specializing in high-temperature thermal energy storage for energy-intensive industries and thermal power plants. The company helps customers across the entire energy system to maximize the value of their energy, from conventional thermal power plants to energy-intensive industries. Thanks to its patented Thermal Battery technology, EnergyNest facilitates the transition towards greater renewable energy generation while helping balance power grids and ensure a clean future.

ABOUT AC BOILERS

AC Boilers SpA, formerly Ansaldo Caldaie, has over 150 years of experience in supply of steam generating plants. From its inception in 1853, the company has continued to lead the development of its technology, and to supply equipment to more than 50 countries around the world. The company also benefits from a long experience in the engineering of Heat Recovery Steam Generator (HRSG) technology. Dating back to 1970 with its first horizontal HRSG for the Dow Chemical Stade 1 Combined Cycle Power Plant in Germany, AC Boilers has supplied more than 140 units globally, including equipment matched with 500 MW gas turbines, confirming AC Boilers' position as one of the leading suppliers in the market.

Project partners realizing first installation at Yara International

The problem we are solving

As modern power grids transition towards cleaner electricity generation, conventional thermal plant owners must rethink how to make their fleets more flexible. Renewables are eating into the load and running time of conventional plants, creating a challenging environment for combined cycle gas turbine (CCGT) power plants. Gas-fired plants are not only more efficient, but also faster and generally less emitting than coal-fired plants, making them preferred candidates for dispatchable generation.[2] Since most coal plants are being phased out in Western Europe,[3] CCGTs can be expected to bear the brunt of future flexibility needs.[4]

This need for flexibility has already been noticed by manufacturers of gas turbines, who accordingly shifted their focus towards flexible turbine design and maintenance.[5] However, this hardly solves the problem faced by existing CCGTs, whose options consist of various marginal improvements,[6] some of which (such as supplementary firing) actually increase fuel consumption.[7] This is where EnergyNest offers an elegant retrofit solution which is perfectly adapted to reduce carbon emissions and increase flexibility, without any change to the existing boiler or turbine.

Its economic value is twofold: minimizing operational expenditure while generating additional revenue in power markets.

The value we provide

OPEX can be optimized in several ways. Most CCGTs dump significant quantities of energy during startup and shutdown by condensing steam. The Thermal Battery can be used to store all this excess energy, and supply it later to replace steam provided by auxiliary gas boilers required to keep the power plant in standby when it has been shut down. This creates savings linked to lower fossil fuel consumption and reduced CO_2 emissions.

The EnergyNest Thermal Battery can also make electricity output more flexible, allowing plant operators to diversify and increase market-based revenues, as it allows the plant to reduce its minimum load when electricity prices are low, while increasing power output during periods of peak demand. There are three types of revenue that flexibility can capture in power markets: wholesale arbitrage, balancing power, and capacity payments.

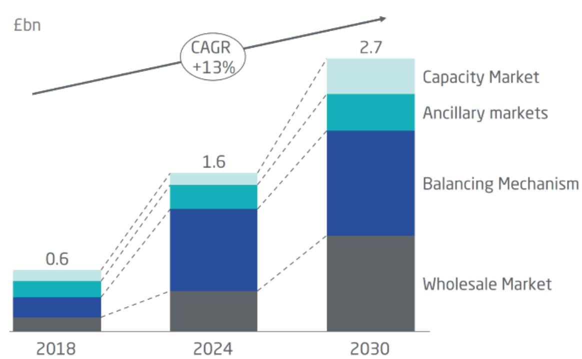


Figure 1. Revenues for flexible generation assets in the UK (Source: Aurora Energy Research/Fluence)

EnergyNest is meeting the requirement for increased efficiency and flexibility with a unique solution.

The Thermal Battery system mostly consists of commodity materials such as steel, concrete and thermal insulation. The fundamental principle of the technology is that energy in the form of heat is transferred to the Thermal Battery using water and steam as a heat transfer fluid. The technology has no moving parts, no degradation due to cycling, and near-zero parasitic costs.[8] This has been validated through demonstration and third-party assessment.

During operation, thermal energy from steam is transferred to/from the solid-state HEATCRETE® storage medium through cast-in “U-shaped” carbon steel heat exchanger pipes. There is no direct contact between the steam and HEATCRETE®; the heat transfer occurs through the heat exchanger steel pipes only.

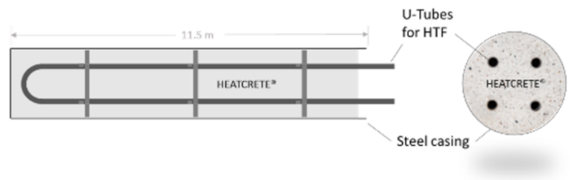


Figure 2. Patented thermal energy storage element.

The Thermal Battery is modular by design since it is made up of a multiplicity of thermal storage elements, the number of which determines the overall Thermal Battery capacity. These elements are combined in modules. The modules are designed for easy transportation, on-site assembly, and for most piping works to be prefabricated and pressure tested before installation.

The Thermal Battery can be directly integrated with combined cycle power plants to provide added flexibility to the existing Rankine cycle. During installation, the modules are combined hydraulically in series (vertical direction) and parallel (horizontal direction), as shown in Figure 3.

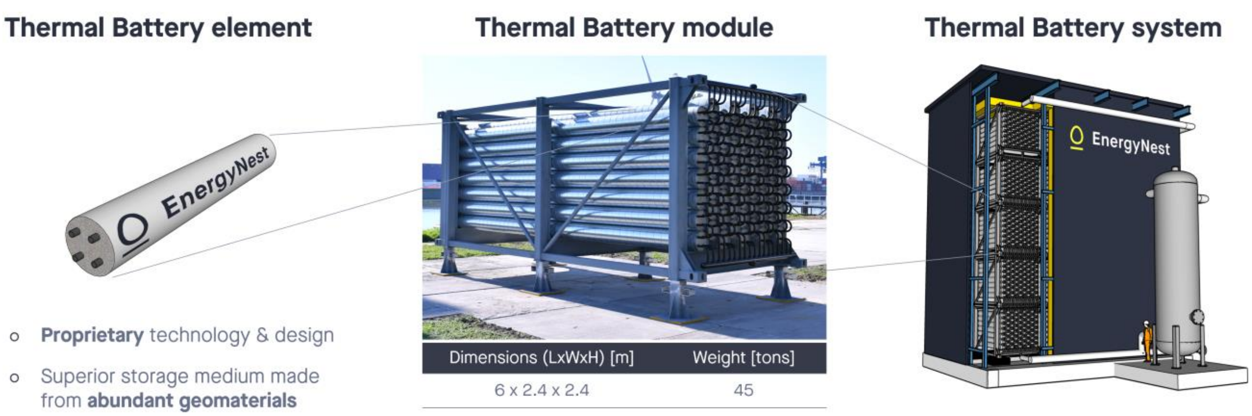


Figure 3. Multiple thermal storage elements are combined in 20-foot container-sized modules. Modules are the basic units that make up the EnergyNest storage system.

OPERATION

The Thermal Battery system consists of an evaporator-condenser (which may include a superheater) and a pressurized storage tank. The system is operated with control valves, which regulate pressure and flow of steam into and out of the system during charge and discharge, as shown in Figure 4.

Charge

During charge, high-pressure steam is directed into the evaporator-condenser, in which the steam condenses as heat is transferred to the storage material. The condensate is collected in a storage tank, where vapor and liquid are separated. Vapor pressure increases as the temperature increases, and more liquid is accumulated. Vapor in the storage tank is recycled back into the evaporator-condenser, where it is finally condensed – thus maximizing the efficiency of the system. Charging continues until the pressure in the storage system reaches that of the external steam supply.

Discharge

During discharge, steam exits the evaporator-condenser from the same point where it entered during charge. Thermal energy is transferred from the condenser-evaporator to generate this steam from the water stored in the pressure vessel. Control valves regulate pressure and temperature in the system to ensure that no liquid exits the outlet of the evaporator-condenser.
Discharge continues until the system reaches minimum operating pressure. Thermal energy

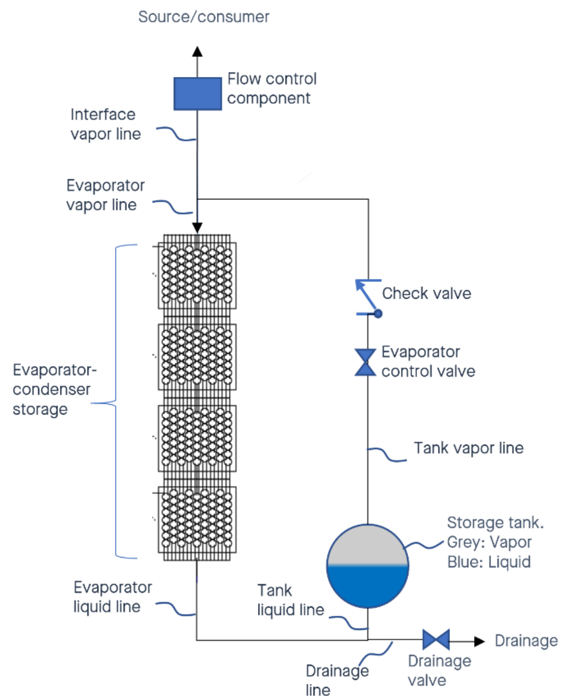


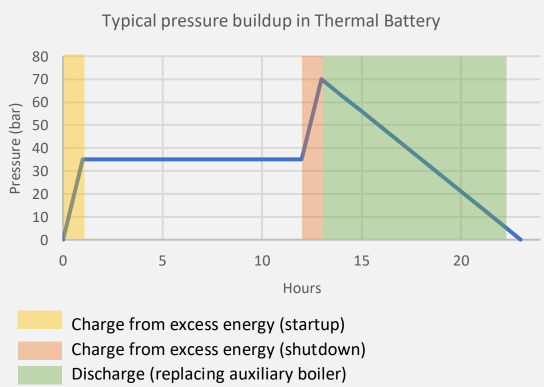
Figure 4. Thermal Battery components.

losses will average 1-2% per 24 hours, depending on the exact system size, configuration, insulation and operation.

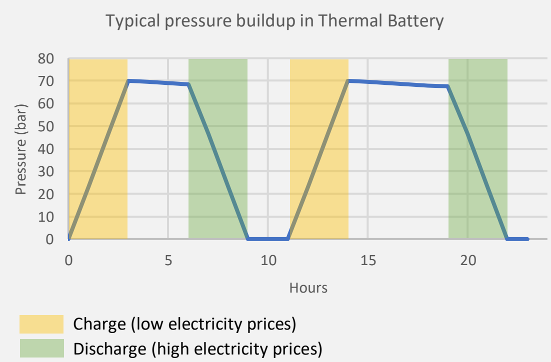
Piping, instruments and valves are the same as those already present in conventional power plants; hence operation and maintenance can be carried out by existing plant staff, and no special spare parts are required. A plant-specific techno-economic analysis and advanced simulation is carried out to identify a Thermal Battery design which optimizes performance and minimizes exergy losses.

Table 1. Example of steam conditions for two different applications: energy efficiency and flexibility.

(1) Startup and shutdown energy recovery		
Charge (with dumped steam)		
Pressure	70	bara
Temperature	420	ºC
Duration	1	hour
Max flow	106	kg/s
Discharge (replacing auxiliary boiler)		
Pressure	9	bara
Temperature	180	ºC
Duration	10	hours
Max flow	12	kg/s
Energy displaced	40	MWh_{th}
Thermal efficiency*	99	%



(2) Reduce minimum load, increase peak output		
Charge (with live steam)		
Pressure	70	bara
Temperature	420	ºC
Duration	3	hours
Max flow	68	kg/s
Discharge (to LP section of steam turbine)		
Pressure	4	bara
Temperature	369	ºC
Duration	3	hours
Max flow	16	kg/s
Energy displaced	154	MWh_{th}
Roundtrip efficiency	45-60	%



* Thermal energy out/thermal energy in.

Depending on the size and type of power plant, the Thermal Battery can be designed for different applications.

Table 1 shows the typical steam parameters for two applications outlined earlier: (1) reducing OPEX related to startup, shutdown, and auxiliary boilers; and (2) reducing minimum load while increasing electricity output during peaks. The same Thermal Battery system can provide both services: market price arbitrage only occurs while the plant is operating, while replacement of auxiliary steam boilers occurs when the plant is shut down. The system has a unique design making it capable of absorbing large quantities of energy over short periods during startup and shutdown, while combining longer charge and discharge durations with a short response time for price arbitrage and balancing power.

GUARANTEED QUALITY

The Thermal Battery system is delivered by experienced partner companies, whose responsibilities are described in Table 2. Our strategic partnerships ensure that the Thermal Battery is delivered with the absolute highest quality. EnergyNest has in addition established relationships with ISO 9000:2015 certified suppliers and partners to ensure best performance throughout its entire supply chain for delivering Thermal Battery systems: Thermal Battery modules are assembled and readied for customers at a central manufacturing hub in Europe. Key products like EnergyNest steel cassettes are fabricated and comprehensively tested to conform to EU regulation together with DNVGL, a global industry certification body. HEATCRETE® manufacture and casting procedures are conducted in compliance with HeidelbergCement and Mebin quality control and strict testing regimes.[9] Detailed engineering is jointly performed by both EnergyNest and AC Boilers, while system integration and interface remains under the responsibility of AC Boilers, benefiting from the company's substantial experience in the construction and maintenance of boiler equipment for thermal power plants.

Table 2. Thermal Battery project consortium partners and respective responsibilities.

• Responsible for delivering core storage technology • Feasibility, basic- and detailed engineering of the Thermal Battery's core storage technology • Detailed simulation of Thermal Battery performance • Facilitates access to grants and public funding	EnergyNest
• Feasibility, basic- and detailed engineering of system interface • Responsible for integration and water/steam interface components • Key role in design/engineering of Thermal Battery system interface • 150 years' experience in power plant engineering • Advanced simulation of complex steam systems	AC BOILERS

1 Fabrication and pressure testing

2 HEATCRETE® casting

3 Shipping to customer site

Figure 5. Illustration of Thermal Battery module fabrication, casting and transport.

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[9] For further information on partners, see: www.heidelbergcement.com, www.mebin.nl, www.dnvgl.com, www.acboilers.com