Rethink energy storage.

EnergyNest

There is no energy problem.

With solar, wind, and hydro power, there is an abundance of energy on our planet. The problem is making this energy available when and where we need it. EnergyNest has developed a revolutionary Thermal Energy Storage solution with unparalleled economics. Our storage technology is the missing link that enables harvesting the full potential of renewable energies.

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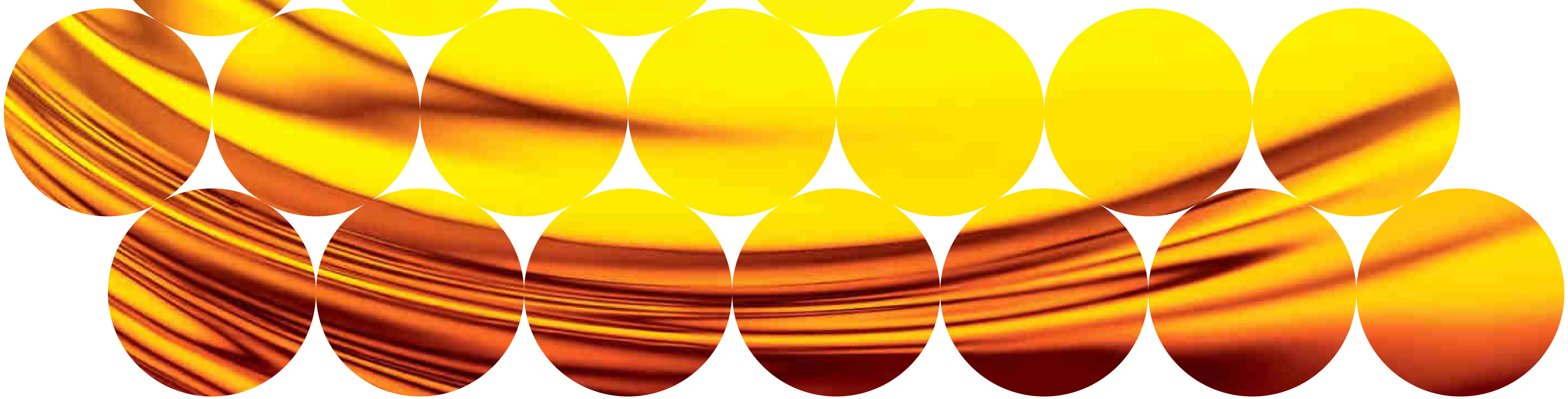
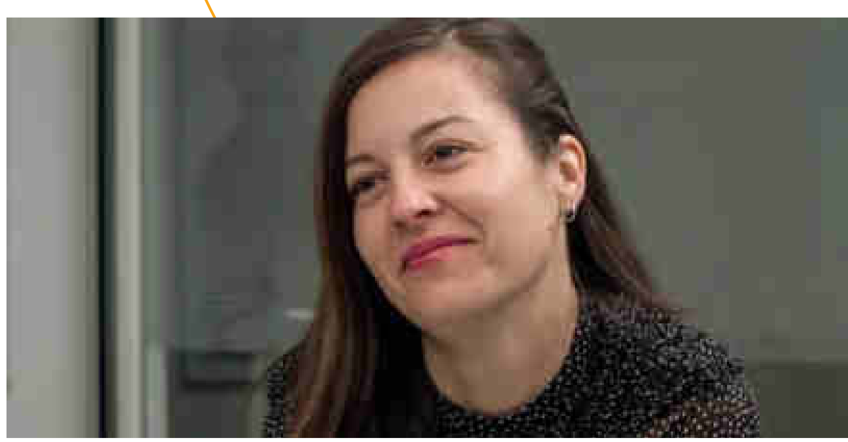


Simple is smart.

How can the world deal with ever-increasing energy demand? When EnergyNest was created in 2011, we started with the bold idea of making this planet a better place. Our efforts began with tackling a problem in need of a solution – not with a technical idea looking for a problem.

Current mainstream approaches to large-scale energy storage rely on the use of complex, cost-intensive, high-tech solutions. At EnergyNest, we went the other way. Instead of trying to fight complexity with complexity, we searched for a response grounded in simplicity.



We spent five years of research, development, and independent third-party validation to finalize our novel Thermal Energy Storage solution.

Ironically, our out-of-the-box thinking led to the development of a box. Today, EnergyNest is changing the game with a system of modular ("LEGO-like") storage elements. This simplicity is what makes it surprisingly smart. EnergyNest Thermal Energy Storage is scalable, durable, easy to install and operate, and over 80% of all materials can be sourced locally.

"We need energy miracles," Bill Gates said at COP21 in Paris. EnergyNest set out to make this happen, and the miracle became a reality – a reality brought forward by a multicultural, international team fully committed to one vision.

EnergyNest is headquartered in Oslo, Norway, with additional offices in Masdar City (Abu Dhabi, UAE) and Seville (Spain). Our company currently has employees of various nationalities, including Norwegian, Spanish, German, Austrian, Canadian, American, Chinese and French. Only five years since our founding, we have already established close cooperations with leading international academic institutions and partnerships with global industrial champions.

Pål G. Bergan

PhD, Dr.h.c., Professor Emeritus
Founder & Chief Technology Officer

With EnergyNest, we have developed a technology that is simple and cost-effective. That means we have found a way to fulfill the vision of making energy available when it is needed.

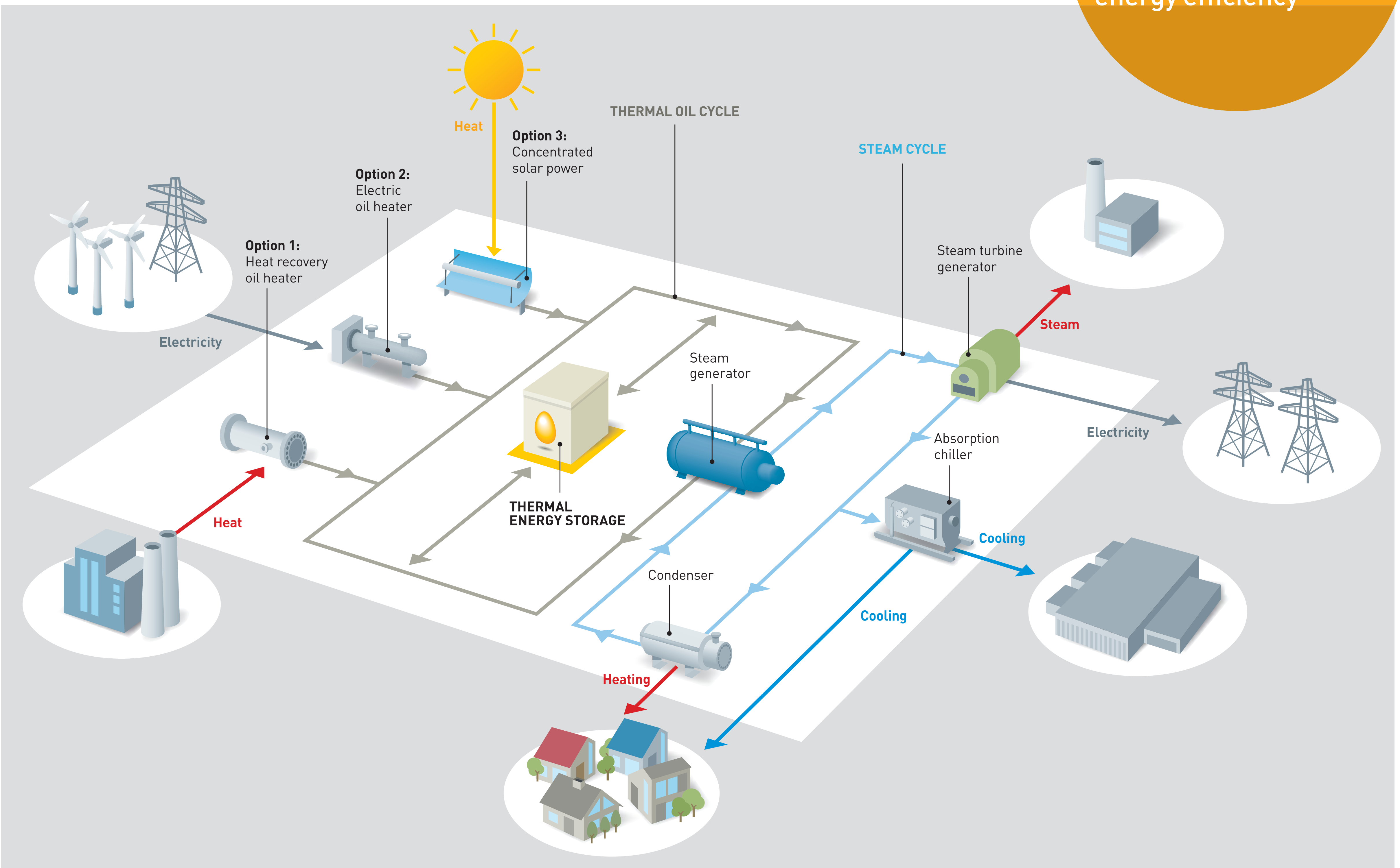
Dr. Christian Thiel

Chief Executive Officer

We now provide the "missing link" that makes it possible to utilize renewable energies more effectively. EnergyNest supports its customers by turning currently wasted energy into **a real** economic value driver – at attractive returns on investment. This is beneficial for business, society, and our planet!

Increase efficiency while reducing costs and emissions.

>90 %
energy efficiency



Our system can deliver four combined or independent energy streams with >90 % round-trip energy efficiency:

- **Electricity.**
- **High quality process steam.**
- **District heating.**
- **Chilling/cooling.**

The EnergyNest technology is applicable to multiple areas in energy and power grid systems. It is based on, and designed around, standard turbomachinery, so it can be easily combined with standard equipment. Our Thermal Energy Storage (TES) can be charged with electricity and/or be heated directly by industrial or solar sources.

The system is simple, robust, and comprises field-proven equipment:

1. **Electric oil heater** (or heat recovery oil heater, or concentrated solar power).
2. **EnergyNest** Thermal Energy Storage (TES).
3. **Steam island** – consisting of:
   - Steam generator.
   - Steam turbine.
   - Option for steam extraction.
   - Condenser with district heating supply.
   - Absorption chiller.

A solid solution.

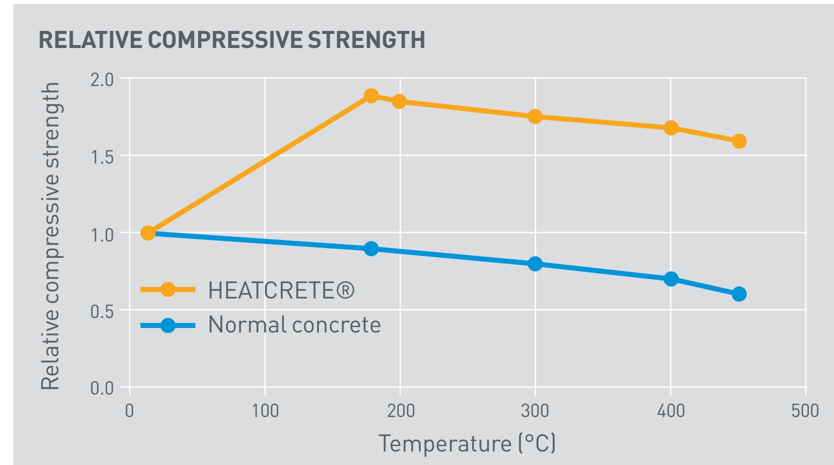
Left: Our partners at HeidelbergCement put a lot of energy into the research and development of concretes with superior properties and innovative functionalities. Image courtesy of HeidelbergCement AG.

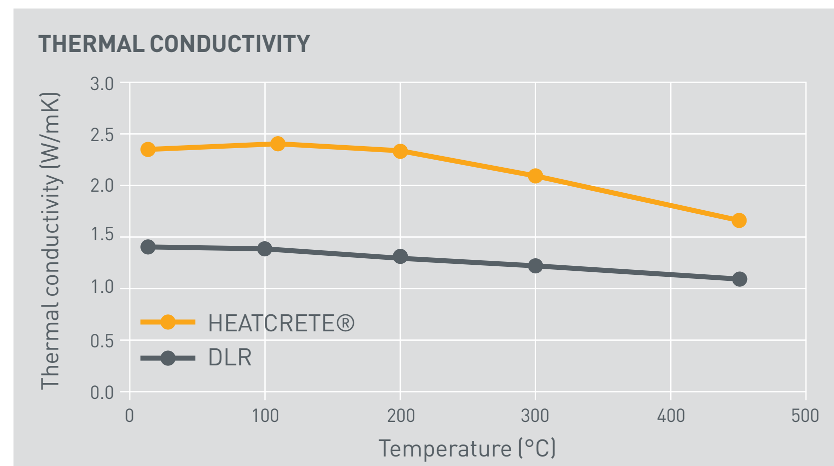
Right: HEATCRETE® is heated, and subsequently cooled, by a heat-transfer fluid flowing inside the embedded steel tube heat exchangers.

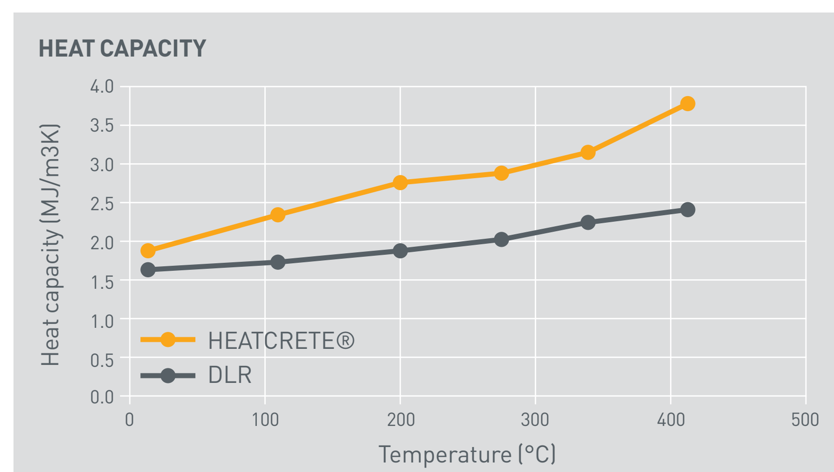
By uncoupling the production from the transmission side, our technology makes it possible to time-shift energy. With Thermal Energy Storage (TES), renewables like solar and wind power become accessible, even when there is no sun or wind. At the core of EnergyNest's technology are heat exchanger tubes integrated into our unique solid-state storage medium: HEATCRETE®.

Due to its smart, simple design, EnergyNest technology is proving to have clear advantages when it comes to stationary, large-scale energy storage solutions – not only for one but multiple applications. Our Thermal Energy Storage system is made up of a large number of individual elements, connected in series and parallel. An integral part of the modules is HEATCRETE®, our innovative high-performance concrete.

We have exclusively developed the HEATCRETE® formula in cooperation with HeidelbergCement, since 2012. HEATCRETE® is a cutting-edge material tested and verified by independent third-party laboratories, such as SP Technical Research Institute of Sweden, the Norwegian University of Science & Technology (NTNU), and Masdar Institute in Abu Dhabi. At EnergyNest, we keep HEATCRETE® a trade secret – it's our very own "Coca-Cola recipe."







This storage medium differs significantly from regular, structural concrete. HEATCRETE® has a higher thermal conductivity resulting in very effective heat transfer. At the same time, it is chemically stable at high temperatures (designed for operation up to 450 °C). The material also has high tensile strength to withstand repeated thermal stress cycling. In fact, HEATCRETE® has twice the strength of normal concrete.

Furthermore, the strength increases significantly after thermal conditioning, and remains high at elevated temperatures. This is important, since it means that HEATCRETE® retains high mechanical integrity at high operational temperatures. Comparing the thermal performance of HEATCRETE® to previous developments of concrete-based TES, such as demonstrated by DLR (German Aerospace Center), HEATCRETE® has both significantly higher thermal conductivity and improved heat capacity.

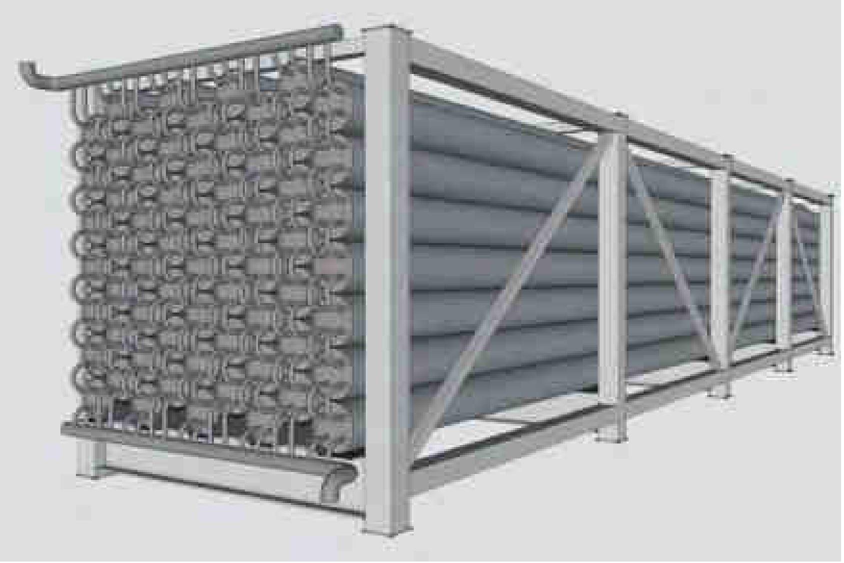
High thermal conductivity is desirable as it provides efficient heat-transfer dynamics to a thermal storage system. Combined with high heat capacity, this reduces the overall storage volume needed – and thus the investment cost. High thermal conductivity also increases performance, and results in higher power output and higher electrical efficiency of steam turbine generators or other thermal power conversion equipment.

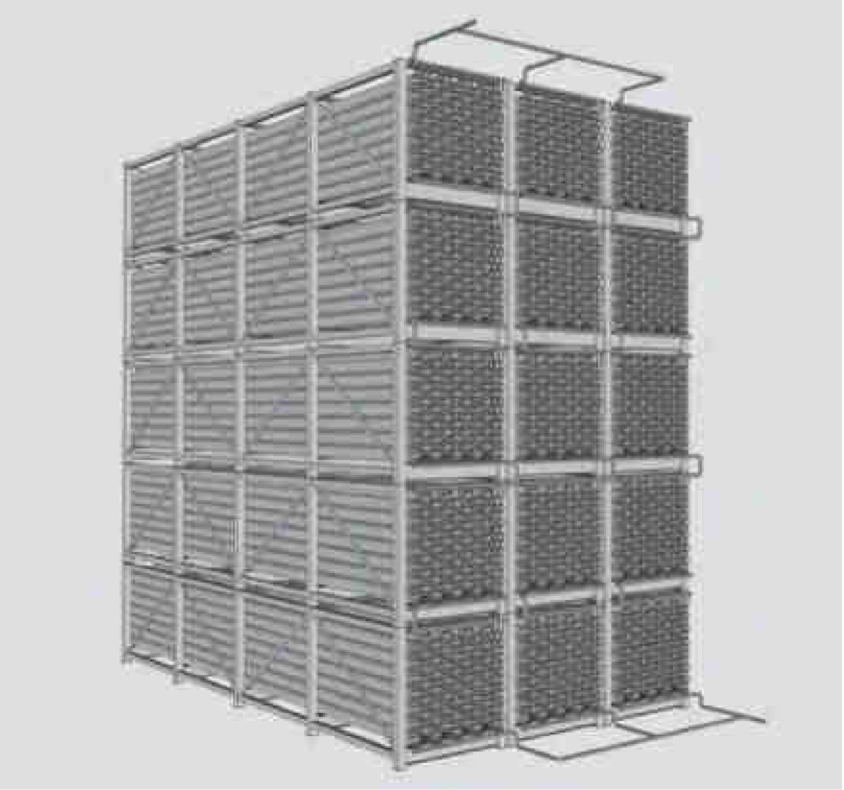
Flexible, scalable, and easy to assemble.

Durable components combined with clever engineering result in a highly robust, flexible system that is easy to assemble. Since the two main materials – concrete and steel – are broadly available and fully recyclable, the technology can be deployed in any geographical area and location.

Our unique modular design enables a "LEGO-like" feature: The number of modules stacked inside the steel structure like building blocks is determined by the required storage capacity and duration. EnergyNest is custom-made to fit your needs and can be scaled from a few MWh_{th} into the GWh range – simply by adding more modules. As such, it can be configured and adapted to a variety of storage applications and requirements.

Thanks to pre-fabricated piping and easy on-site assembly, EnergyNest already saves time and energy in the installation phase. It is also suited for containerized logistics – one module fits into a standard 40-foot container – making multi-module shipping easy.





Above: Our smallest standardized modules are made to fit 40-foot containers (12.03 x 2.35 x 2.34 m).

Below: The "LEGO-like" concept with pre-fabricated elements that are easy to stack and allow great scalability.

ECONOMICAL

Low-cost materials (steel and HEATCRETE®) ensure extreme cost competitiveness.

SCALABLE

Modularity enables high flexibility in scaling; from a few MWh to several GWh.

EASY TO OPERATE

No moving parts, easy to control, near-zero parasitic loads, no special training required.

"LEGO-LIKE" ASSEMBLY

Prefabricated, standardized, stackable modules.

DURABLE

HEATCRETE® withstands millions of stress cycles.

VERSATILE

Adapts to broad temperature range (up to 450 °C) and a variety of heat-transfer fluids.

ASSEMBLY-LINE APPROACH

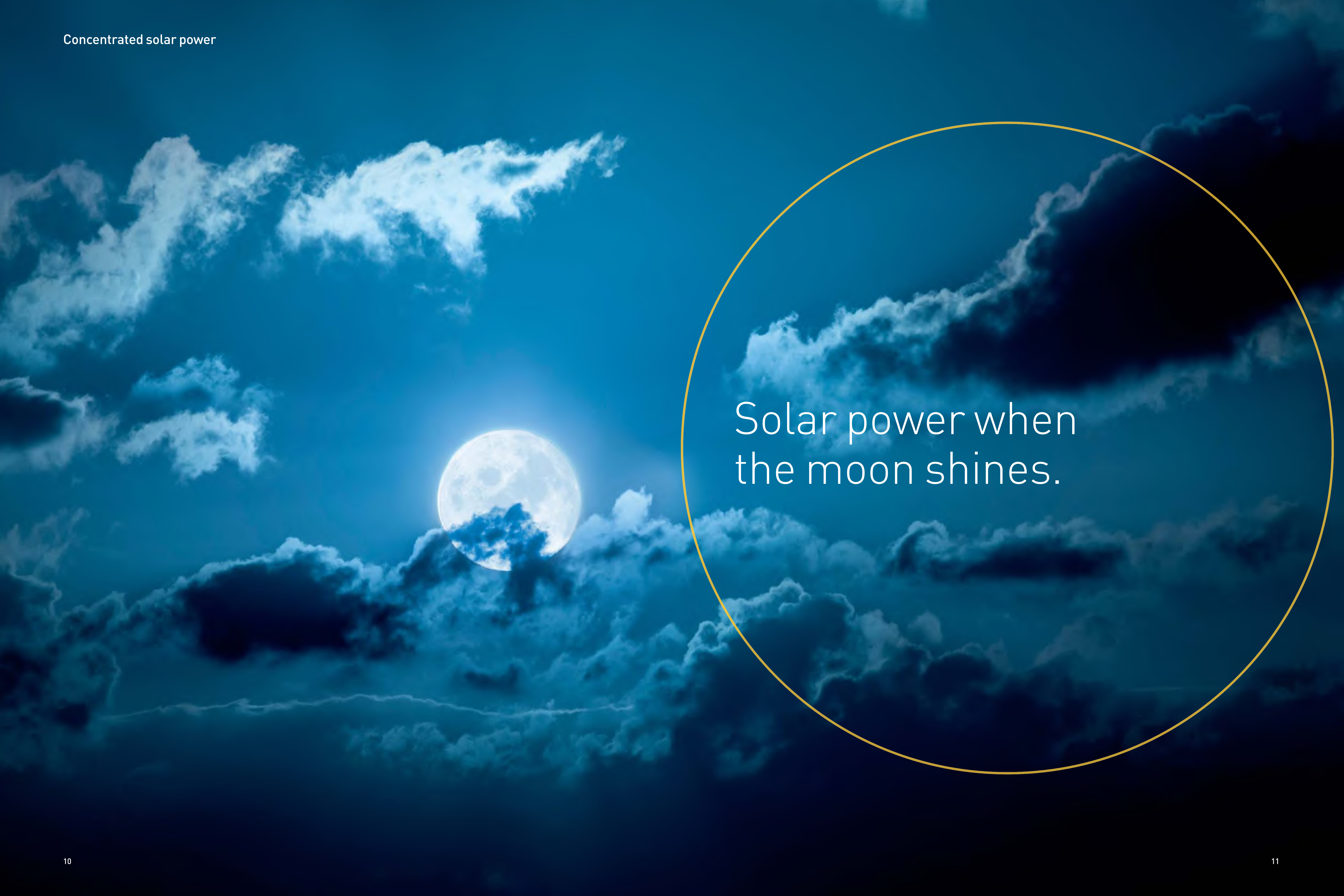
Simple construction process with high degree of parallelization.

LONG DISCHARGE DURATION

Best suited for medium- to long-duration storage (from 4 hours to several days).

SAFE

Solid-state, non-hazardous materials; no special HSE requirements.



Solar power when the moon shines.

Meet real-time energy demands.

EnergyNest's unique Thermal Energy Storage is perfectly tailored to concentrated solar power (CSP) plants using thermal oil or direct steam. It enables storage of surplus heat from the solar field during the day, and subsequent discharge to the steam turbine when the sun is down.

EnergyNest's technology comes at a lower CAPEX and OPEX versus molten salt systems. This is largely due to the use of low-cost materials, simplicity in construction and operation, and very low parasitic energy losses. The technology is based on globally available materials with low technical and environmental risks.

An EnergyNest system also eliminates the need for external loops between different heat-transfer fluids, as well as costly electrical heat tracing and heaters, thus further reducing complexity. CSP plants can be easily retrofitted with EnergyNest technology.

Increasing CSP flexibility

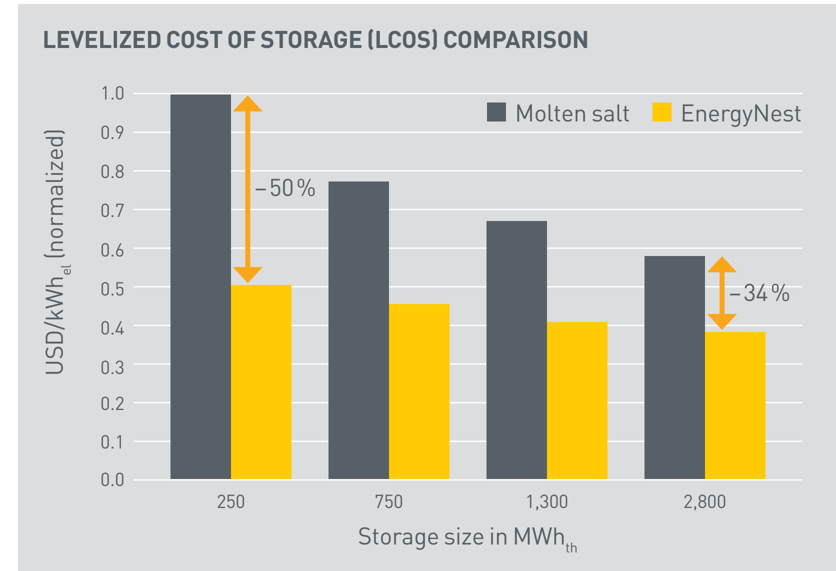
- Fully scalable from a few MWh to several GWh.
- Operates with thermal oil, direct steam or gas.
- Wide temperature range: from ambient to 450 °C.
- Can be retrofitted to existing plants without TES.
- Easy capacity boost for CSP plant expansions.

Lowering CSP cost

- Inexpensive materials that are largely available locally.
- Short lead time for components ensures fast-track installation.
- Simple installation based on proven processes.
- Spare part inventory equal to CSP process plant.
- No special crew required for operation or maintenance.

Increasing CSP output

- Near-zero parasitic energy losses.
- Significant "over-charge" capacity during high DNI conditions.
- In case of maintenance, individual storage units can be isolated with minor impact on total plant performance.



$$LCOS = \frac{NPV_{CAPEX} + NPV_{OPEX}}{NPV_{ENERGY}}$$

Key assumptions:

- Turnkey CAPEX.
- 5 % discount rate.
- 25-year lifetime.
- No residual value at end of lifetime.
- No performance degradation over lifetime.
- 8 % higher annual net production of electricity during discharge of TES with EN vs. MS, as per reference performance simulation.
- OPEX includes operation, spare parts, corrective and preventive maintenance, and training.
- Parasitic energy losses included in annual energy yield.

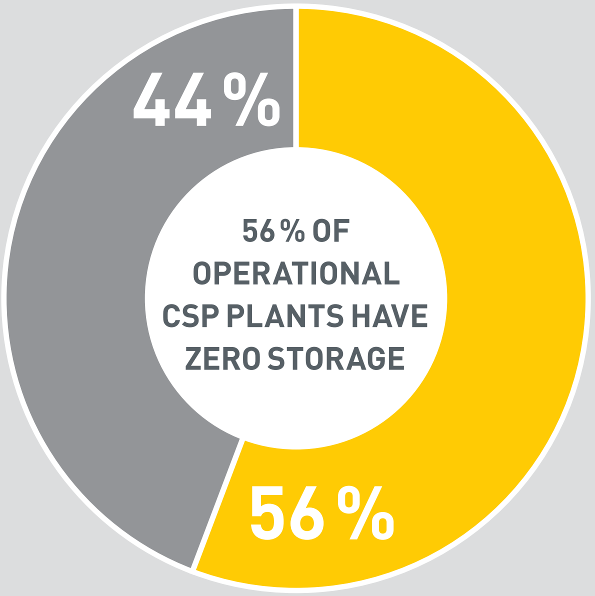
Tune up your plant!

Thanks to its modularity and scalability, EnergyNest represents a unique option for retrofitting existing CSP plants.

Retrofits offer multiple potential benefits:

- The base case is to store excess energy from the solar field that would otherwise be dumped.
- Additional energy can be provided by installing new collector loops or heliostats.
- During the day, the TES can help the plant to ride through cloud transients and avoid a complete shutdown of the turbine.
- During and after sunset, the TES can provide heat to maintain a higher power output and prolong electricity generation.
- During the night, the TES can provide heat to keep the turbine spinning, thus avoiding a shutdown and reducing turbine wear and tear.
- Before sunrise, the TES can provide heat to start up the turbine, thus significantly reducing the time to reach nominal power output.

EnergyNest has developed its own sophisticated simulation software for evaluating the performance of its TES, using parameters from operating plants. This allows EnergyNest to offer customized storage solutions.



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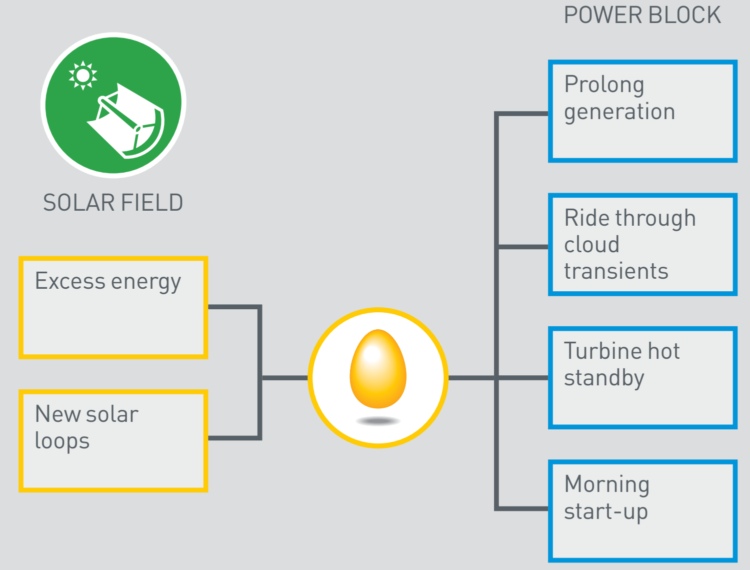
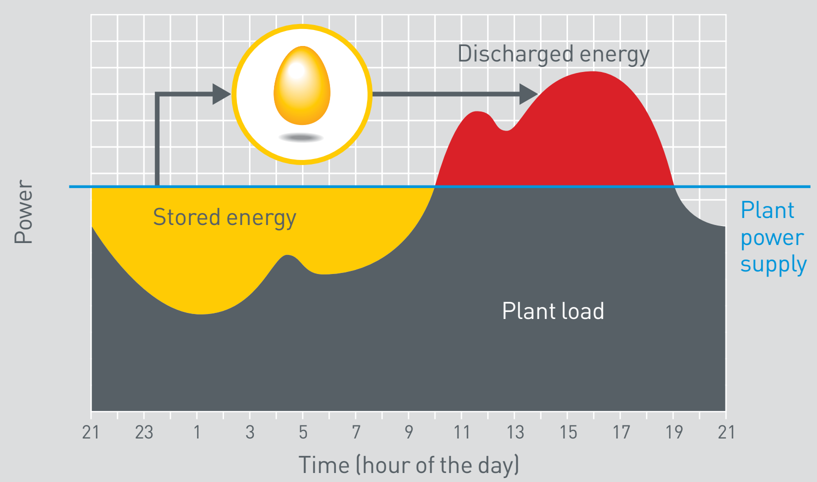
TES RETROFITS OFFER MULTIPLE POTENTIAL BENEFITS



Reclaim your wasted energy.

Keep your balance.

TIME-SHIFTING STEAM TO MEET PRODUCTION REQUIREMENTS



With EnergyNest, industrial facilities optimize their energy production and consumption by storing thermal energy and making it available on demand. At the same time, they can reduce their carbon footprint as demanded by the 2015 United Nations Framework Convention on Climate Change (UNFCCC).

Making use of waste heat is only one way that EnergyNest helps to maximize energy output without increasing resource input. The stored energy can be discharged to cover demand peaks, satisfy backup requirements, and balance cyclic variations in energy consumption. The storage can also take advantage of affordable off-peak grid power to store thermal energy for processes, or store excess heat for power production during peak tariff periods.

Value delivered.

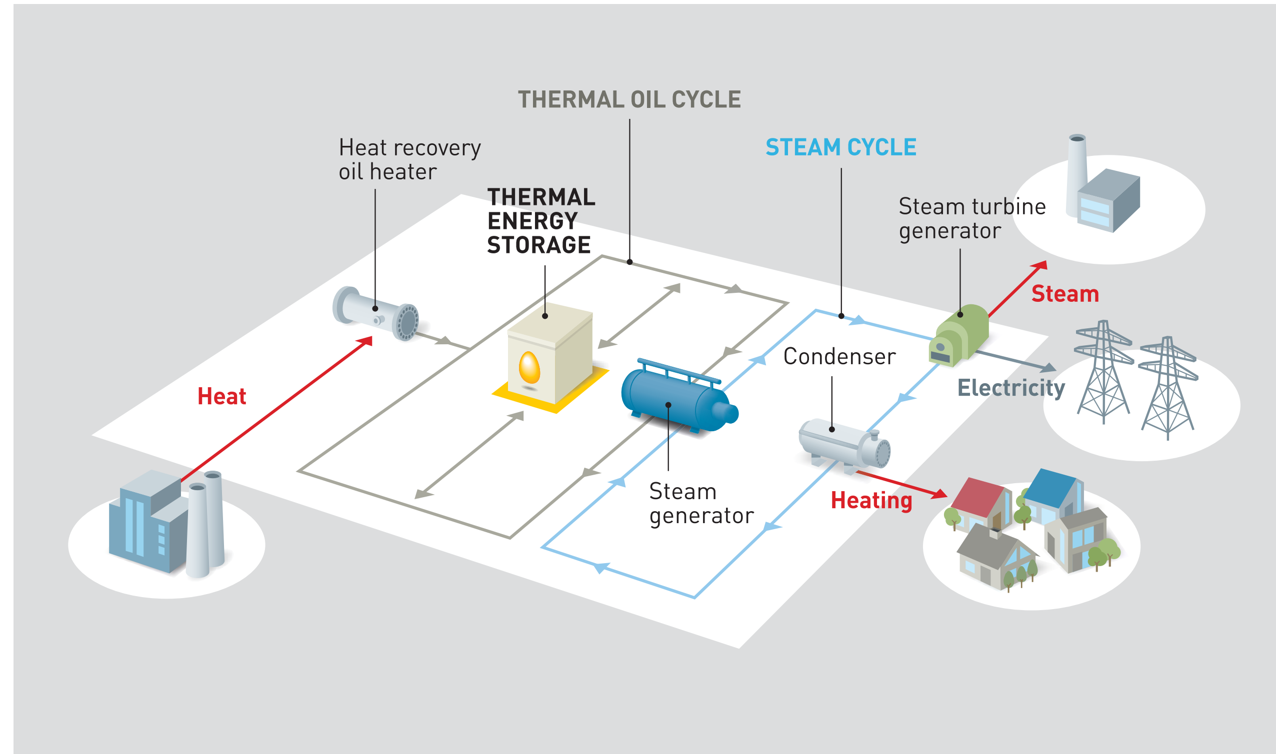
- Efficient use of thermal power on demand.
- Full flexibility in time-shifting energy production to peak price periods.
- Most efficient energy storage solution for long discharge periods.
- Returns excess energy back into a process for electric power generation.
- Storage can supply saturated or superheated steam up to 100 bars.

Integration made easy.

- Compatible with most heat-transfer fluids and processes.
- Our Thermal Energy Storage can drive both organic Rankine and steam cycles.
- Simple implementation as upgrade of existing installations.
- First-class complementary solution.

Temperature up to

450°C



A concrete solution for multiple applications:

- Steel
- Iron
- Silicium/ferrosilicon
- Metal production (Ni, Cr)
- Fabricated metals (casting, rolled products, coating)
- Cement
- Chemical industry
- Petro-chemical industry
- Starch and sugar
- Bioethanol
- Pulp and paper

Why send profits up the chimney?

EnergyNest offers a unique and cost-effective way to temporarily store excess heat – for example in thermal power plants. Especially in natural gas-fired peaker plants, which supply power only during times of highest demand, recovery of waste heat is a unique way to increase energy efficiency.

Open-cycle gas turbines produce exhaust gas flows with temperatures exceeding 400 °C. EnergyNest can store this intermittent thermal energy for continued use in a steam cycle. The Thermal Energy Storage effectively turns open-cycle gas turbines into combined-cycle gas turbines, where the steam turbine is decoupled from the gas turbine, thereby maintaining the gas turbines' flexibility.

Value delivered.

- Efficient use of thermal power on demand.
- Full flexibility in time-shifting energy production to peak price periods.
- Most efficient energy storage solution for long discharge periods.
- Returns excess energy back into a process for electric power generation.
- Storage can supply saturated or superheated steam up to 100 bars.

Integration made easy.

- Compatible with most heat-transfer fluids and processes.
- Our Thermal Energy Storage can drive both organic and Rankine steam cycles.
- Simple implementation to upgrade existing installations.
- First-class complementary solution.

90 %

overall system efficiency

Intermittent production, continuous savings.

The EnergyNest system also makes a good case for the steel industry, where rising energy costs and high levels of power consumption represent a major challenge. The EnergyNest technology allows excess heat produced during peak-heat batch cycles to be stored, and later fed back into the steel production process.

Hours of peak production with extreme heat on the one hand and longer cycles of lower heat on the other – the steel industry is characterized by high intermittency. To balance this out, EnergyNest stores the excess heat (i.e. from flue gases) and makes it available for less energy-intensive applications in the steel mill.

Value delivered.

- Efficient use of excess heat in superhot batch cycles.
- Most efficient energy storage solution for long discharge periods.
- Returns energy back into the steel production process.
- Storage can supply saturated or superheated steam up to 100 bars.

Integration made easy.

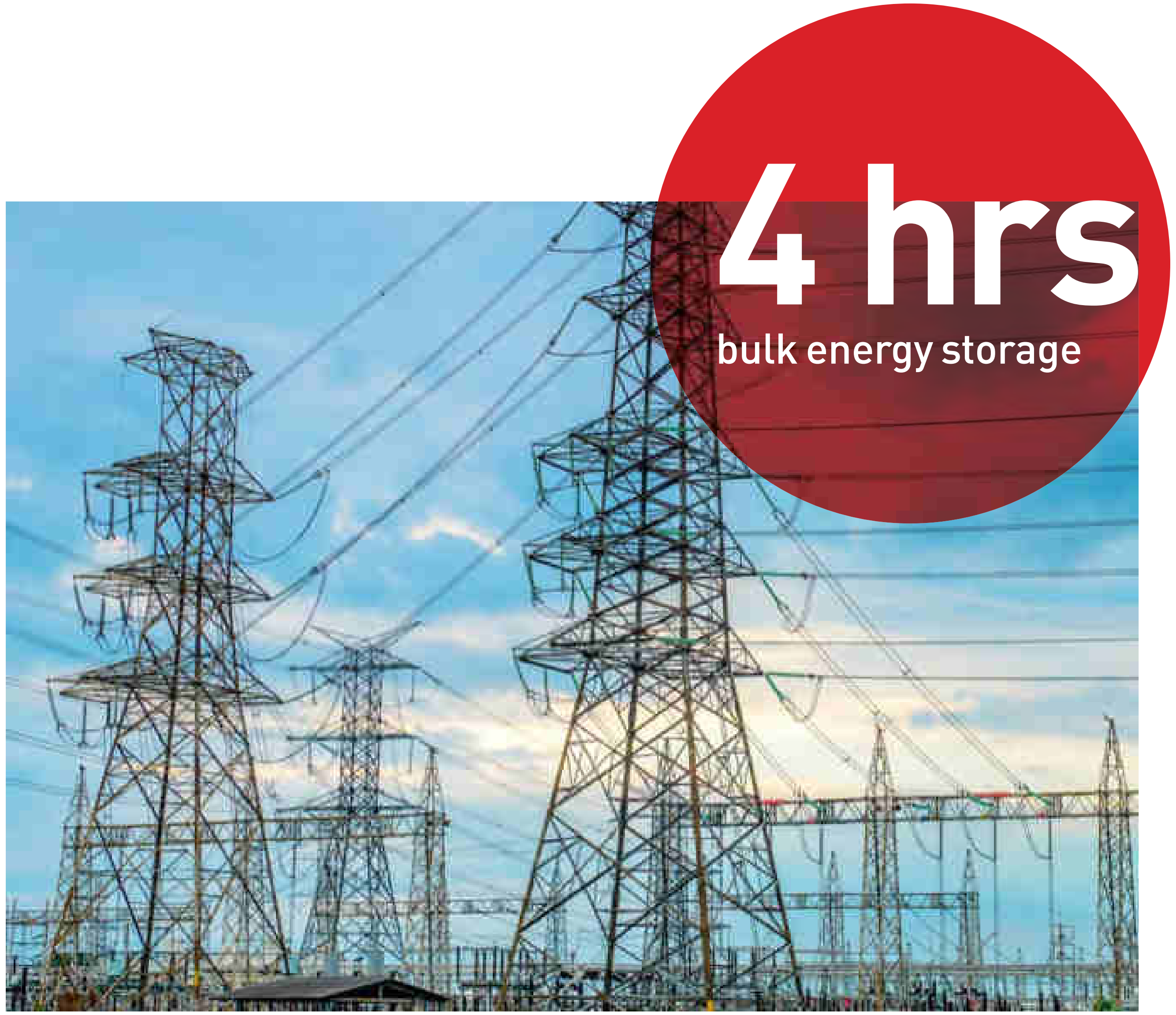
- Compatible with most heat-transfer fluids and types of processes.
- Our Thermal Energy Storage can drive both organic and Rankine steam cycles.
- Simple implementation to upgrade existing installations.
- First-class complementary solution.

A smart grid needs smarter energy storage.

Balancing the grid.

EnergyNest offers a low-cost, scalable, clean, and durable solution to the emerging need for grid-scale storage. Our novel technology enables utilities and grid operators to balance energy production from intermittent renewables with power demand – and can significantly contribute to peak regulation services with its highly flexible operation.

Thermal energy storage has a number of advantages over electrochemical energy storage. It is much less costly and much more durable, has no performance degradation, is made from locally available and recyclable materials, and allows continuous discharge over periods of four hours or more – making it an appealing candidate for bulk storage applications.



Rapid response

Variations in grid frequency are a useful load indicator. TES is charged or discharged according to the actual grid frequency. This allows for a quick response without additional CO_2 emissions.

Spinning reserve

To manage generation and transmission outages, a spinning reserve should be available within milliseconds, and for a substantial amount of time. TES provides this spinning reserve – simple, efficient, and easily scalable.

Reliable renewables

By their very nature, renewable energies are not constantly available. TES smooths the output and provides a reliable level for some time. This avoids rapid voltage changes and prevents potential damages.

Power quality

In environments where power quality is crucial, TES helps stabilize the power load against momentary deviations.

Load leveling

Load leveling balances the load on the grid. In times of reduced load, TES is charged; in periods of heavy demand, additional energy is fed into the system. This way, major investments for grid updates or additional generating capacity can be postponed.

Peak shaving

When power demand is high, peak shaving is used to avoid supply shortages and to relieve power plants, as well as the grid. Instead of reducing the load of selected consumers via load management or demand side management, TES supplies the peaks without costly installation of additional power plants.

Voltage support

If needed, TES injects or absorbs active or reactive power – thus helping to maintain the grid voltage.

CHARGE

An electric oil heater functions as a load bank which can instantaneously absorb and even out fluctuations in the grid:

- Primary, secondary and tertiary regulation.
- Power balancing.
- Instantaneous start/stop and ramping.

A generator (steam turbine) can provide reactive power and voltage control if operated as a synchronous condenser.

DISCHARGE

A steam turbine generator will react much faster than any conventional thermal power plant – but emission-free:

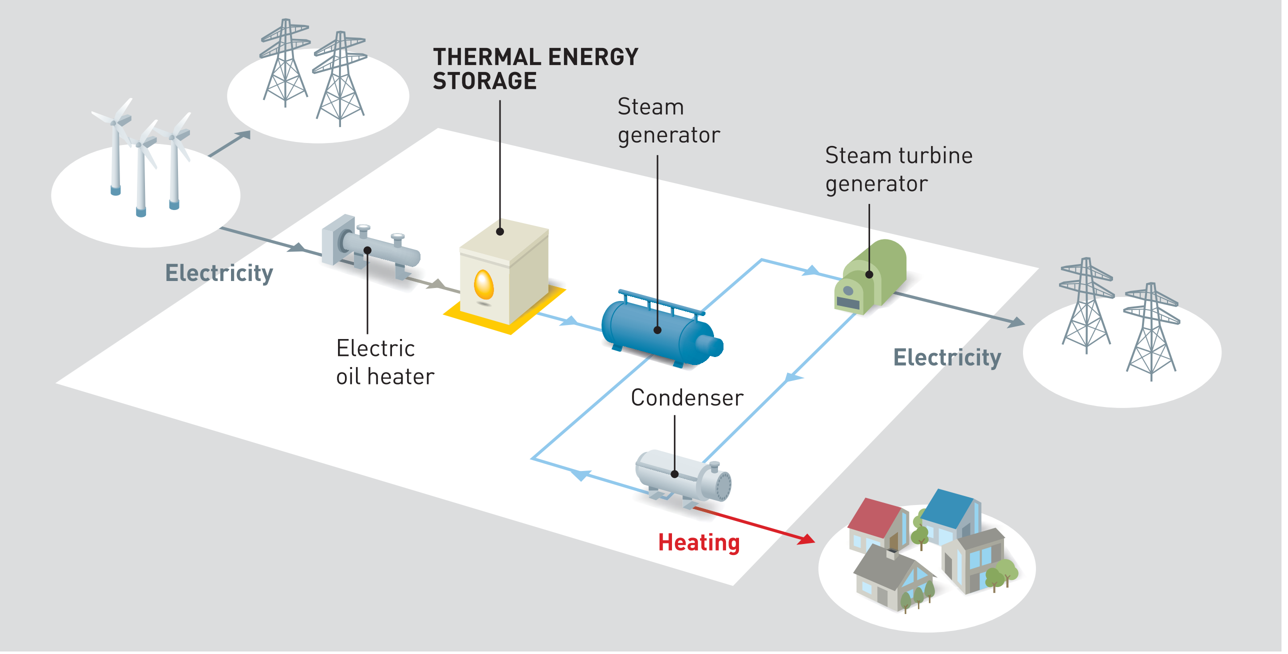
- Primary, secondary and tertiary regulation.
- Power balancing.
- Reactive power and voltage control.
- Start-up time is dependent on size and type of turbine (typically 30 – 60 min for 50 MW_{el}).

Storage now with windfall profits.

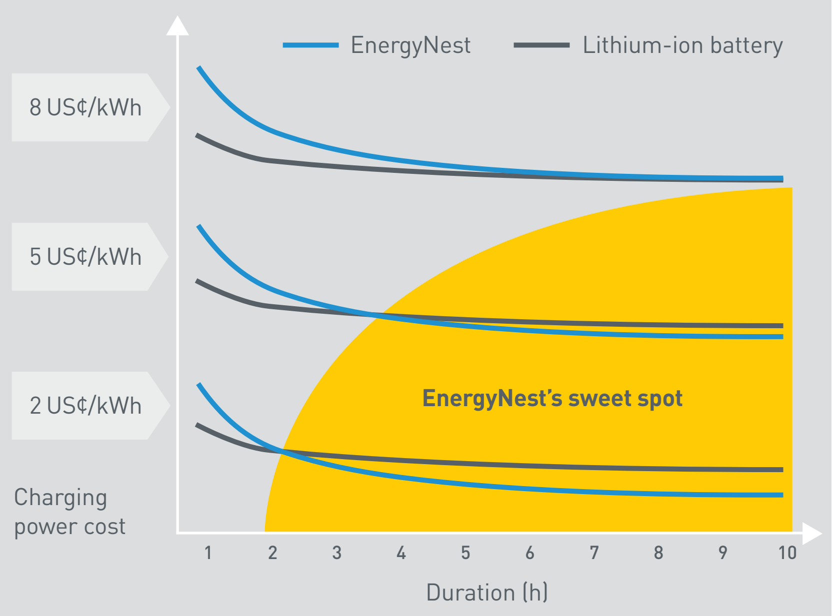
In order to fully harvest their renewable energy and to provide dispatchable power generation, many wind farm projects today rely on Lithium-ion (Li-ion) battery technology. A conversion of electricity to heat storage and back seems costly – a common misconception. EnergyNest's TES proves it is competitive with Li-ion batteries, primarily over long durations in large-scale, grid-tied applications.

For wind farms aiming at balancing out their intermittent power generation, EnergyNest's TES promises a surprisingly low-cost setup. The technical process behind it is easily explained. First, the surplus wind energy is used to power an electric oil heater; the thermal energy generated is then stored in the TES. When there is a need for electricity, the TES is discharged by supplying hot oil to a steam/organic Rankine cycle turbine, which converts thermal and mechanical energy to electric energy via a synchronous generator. EnergyNest's solution can provide both electricity and district heating.

EnergyNest fills an important gap not covered by existing technologies. Our sweet spot lies in long-duration applications with more than three hours of charge/discharge time and low charging power costs. In short: Our technology offers a 40% lower levelized cost of storage for a 10-hour battery charged with electricity for 2 US¢/kWh. This makes the EnergyNest TES an ideal solution for remote or island grids having a high penetration of renewable energy and a combined heat and power demand.



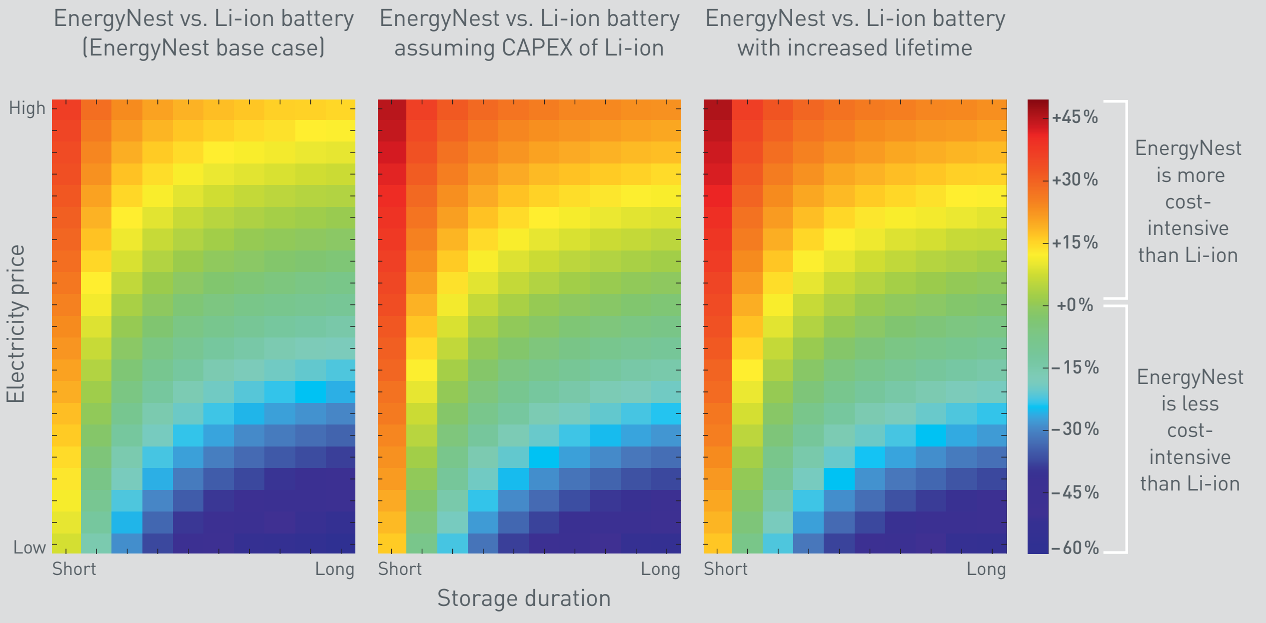
LEVELIZED COST OF STORAGE (LCOS) COMPARISON



- **Competitive with Lithium-ion batteries** – EnergyNest's technology is cost competitive with Lithium-ion batteries in long-duration applications with low charging power costs, yielding significantly lower LCoS.
- **Long duration** is needed for various storage use cases, such as integrating renewable energy generation in island grids.
- **Low charging power costs** are common in large-scale, grid-tied applications, for example:
  - 3 US¢/kWh – price for PV power from the recently tendered 800 MW PV power plant in Dubai.
  - 3.5 US¢/kWh – average spot market price for electricity in Germany (2015).
  - Curtailed wind energy (e.g. 40% on average in China) with zero market value.

Source: EnergyNest; Basic assumptions: 350 cycles per year, 10% discount rate, OPEX 2% of initial CAPEX; Lithium-ion battery assumptions: 12-year and 5,000-cycle lifetime, USD 400/kW CAPEX and USD 500/kWh, 82% efficiency; EnergyNest: 30-year lifetime, no cycle limitations, CAPEX USD 1,500/kW and USD 167/kWh_{el}, 30% efficiency.

SENSITIVITY



Source: EnergyNest; Basic assumptions: 350 cycles per year, 10% discount rate, OPEX 2% of initial CAPEX Lithium-ion battery assumptions (base case): 12-year and 5,000-cycle lifetime, CAPEX USD 400/kW CAPEX and USD 500/kWh, 82% efficiency; EnergyNest: 30-year lifetime, no cycle limitations, CAPEX USD 1,500/kW and USD 167/kWh_{el}, 30% efficiency.

Spot on, even off the grid.

Many utilities in remote areas are fully dependent on local power generation, as they are unable to export or import excess energy from neighboring power grids. In fact, many communities not connected to the main power grid depend solely on diesel to generate power. EnergyNest enables such communities to switch from costly imported diesel to local renewable energy sources.

With its TES technology, EnergyNest provides an effective way to store excess electricity, providing both heat and power to communities during periods of peak demand. Our TES can be connected to the local grid or power generation facility, and charged using excess available electric energy from renewables. The stored thermal energy can then be discharged to provide electricity to local communities, as well as process heat for manufacturing industries, desalination processes, absorption cooling, district heating, and more.

Value delivered.

- Reduce curtailment when renewables produce more power than grid requires.
- Long discharge duration, from several hours to several days, enables uninterrupted supply during long power-deficit periods.
- Avoids the expensive logistics, fluctuating prices, and polluting emissions of fossil fuels.
- High penetration of renewables thanks to low cost, large-scale, long-duration storage.

Integration made easy.

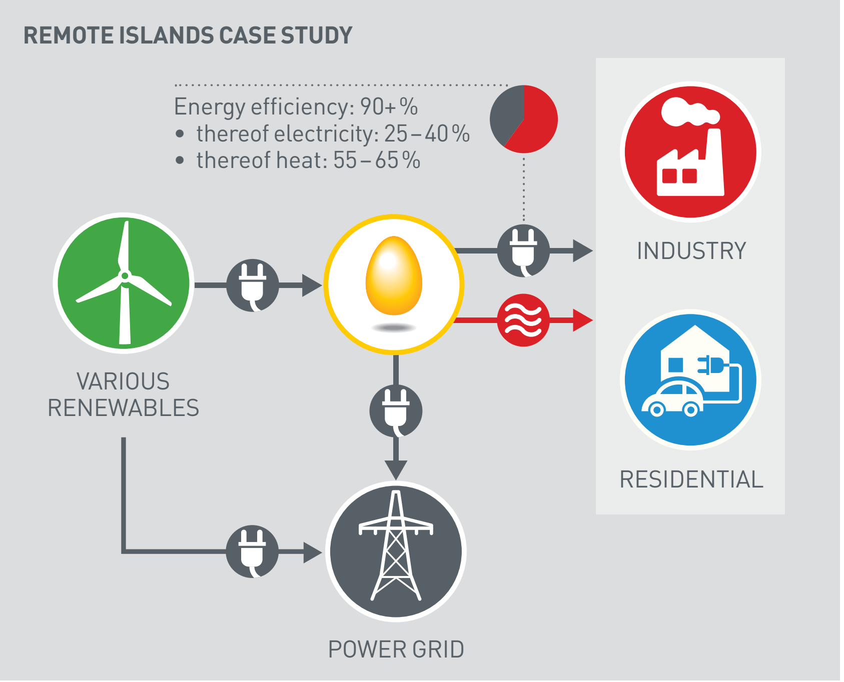
- Integration using off-the-shelf components.
- Simple, robust solution with no moving parts and extremely low maintenance requirements.
- 50-year product lifetime allows long-term operation.
- >90 % round-trip efficiency in combined heat and power mode.

Applications

Island grids not connected to any mainland grid – such as in the Mediterranean or Caribbean, or the Faroe Islands – where local communities and industries can benefit from Thermal Energy Storage to cope with increasing renewable energy generation.

Off-grid mining operations in Sub-Saharan Africa, the Andes, central Australia, northern Canada, and Russia, where there is high demand for electricity and process heat.

Remote areas with poor transmission capacity to the main power grid can store the portion of their excess renewable energy that would otherwise have been wasted.



A big idea – down to the smallest detail.

A hot duo: steam-based storage...

...and oil-based storage.

The high-temperature steam storage jointly developed by EnergyNest and Aalborg CSP avoids intermediary heat-transfer fluids and is charged and discharged directly with steam. The system can comprise one or several storage units, depending on the power/heat cycle it supports.

In a solar plant with direct steam generation, the storage system can include a superheater unit, which stores sensible heat, and an evaporator storage unit, which stores latent heat from condensing steam. The evaporator storage unit relies on natural circulation principles instead of pumps, thus reducing power consumption. The high-temperature steam storage system is ideally suited to providing daily or weekly storage capacity for steam-based systems.

AALBORG CSP
- Changing Energy

Value delivered.

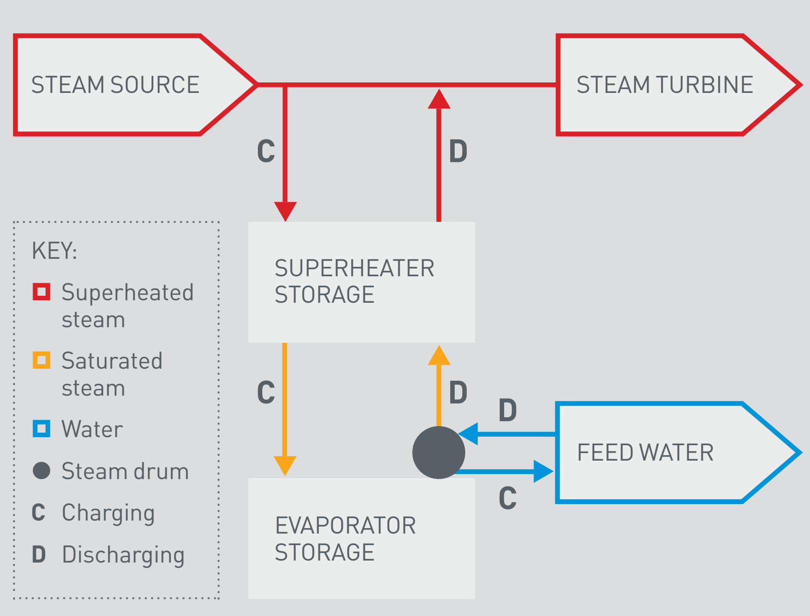
- Reliably supplies high-temperature and high-pressure steam exactly when needed.
- Operating temperature up to 450 °C (HEATCRETE® tested up to 550 °C)
- Operates with saturated or super-heated steam at up to 160 bar.
- Ideal for direct-steam CSP systems (linear Fresnel, tower), as well as CHP power generation or industrial applications.
- Lowest CAPEX and OPEX.
- Boiler unit co-developed with AALBORG CSP.

Integration made easy.

- Low operational costs thanks to simplicity, robustness, and absence of moving parts.
- Highly modular and scalable solution that can be adapted to local space and process requirements.
- Solid storage medium able to withstand thousands of stress cycles without performance degradation; extremely long lifespan.

70 to 100 MWh_{th} EVAPORATOR STORAGE

HIGH-TEMPERATURE STEAM STORAGE PROCESS IN A SOLAR PLANT



OIL-BASED STORAGE APPLICATIONS

Temperature up to

450 °C

Modern tower or linear Fresnel CSP plants rely on direct steam generation and can thus be fitted with a steam-based TES system. For others – like parabolic trough CSP plants – thermal oil is the Thermal Energy Storage medium of choice.

Many of the early parabolic power plants are equipped with a two-tank indirect system where two different fluids are used: mostly mineral oil as the heat-transfer fluid, and molten salt as the storage medium. These plants can be easily retrofitted with a more cost-effective, state-of-the-art storage solution. EnergyNest's TES based on thermal oil is a highly competitive alternative to molten salt storage.

Cost-effective and reliable storage.

- Operating temperature up to 450 °C or the limitation of the HTF.
- Lowest CAPEX and OPEX on the market.
- Cost-effective and reliable by design, a highly competitive alternative to two-tank indirect molten salt storage.
- Ideal for retrofitting older parabolic trough CSP plants, or equipping new ones.
- A first-class solution for power generation and industrial heat recovery.

Tested and proven under extreme conditions.

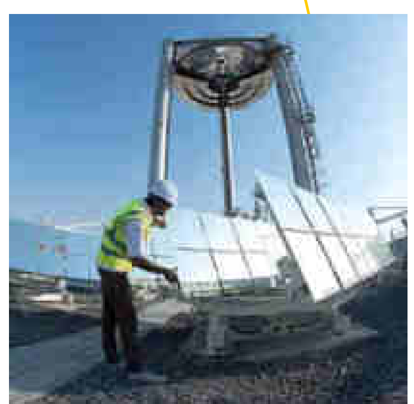
In 2013 Masdar Institute of Science and Technology and EnergyNest initiated a comprehensive joint research project for building and testing a 2x500 kWh_{th} EnergyNest-type Thermal Energy Storage (TES) pilot, emulating CSP plant conditions with thermal oil up to 390 °C.

The pilot was commissioned in 2015, and the R&D setup and performance measurements have been validated by DNV GL, the world's leading classification society. The system is currently operating round-the-clock and has accumulated more than 4,000 hours as at October 2016, with stable and repetitive performance showing no sign of degradation.

Masdar Institute Solar Platform (MISP) provides a full-fledged research platform for testing functionality and validating advantages of the EnergyNest system. More fundamentally, the project will effectively demonstrate the operational and economic feasibility of the EnergyNest technology compared to other TES systems currently on the market.

EnergyNest and Masdar Institute demonstrated that incorporating this new technology into commercial solar thermal projects allows project developers to derive significant benefits and savings, not just in terms of comparative cost of installation (CAPEX), but also in reduced operating expenses over time (OPEX).

Masdar Institute recognized early the potential of EnergyNest's innovative technology to add value to renewable energy segments, as it offers flexible and cost-effective storage. For this extraordinary pilot project, EnergyNest and Masdar Institute were supported by the Research Council of Norway, Siemens, Heidelberg Cement, Dow, and Innovasjon Norge.



DNV·GL

Masdar City: quick facts

In 2008, Masdar City broke ground in Abu Dhabi, United Arab Emirates, and embarked on a daring journey to develop the world's most sustainable, low-carbon eco-city. Its core is being built by Masdar, a company leading the way in renewable energy worldwide.

Masdar City aims to pioneer a "greenprint" for how cities can accommodate rapid urbanization and dramatically reduce energy, water, and waste. Harnessing the sun's rays, Masdar City uses clean energy generated on site from rooftop solar technology and one of the largest photovoltaic installations in the Middle East.

Due to Masdar City's passive and intelligent design features, the temperature within the streets is up to 13 °C cooler than in downtown Abu Dhabi on the same day. The city is growing its neighborhoods around the Masdar Institute of Science and Technology, a research university dedicated to providing real-world, cutting-edge solutions in the fields of energy and sustainability.

A whole new dimension.

Parameter		Unit	Value
HTF[1]			Oil
Module width		mm	2,168
Module height		mm	1,885
Module length		mm	11,800
Module volume		m^3	48.2
Module weight[2]		tons	75
Storage medium[3]			HEATCRETE®
Tube material			A-106 gr B carbon steel
Charging time, hours	Min	Hours	4
	Max	Hours	48+
Discharging time, hours[4]	Min	Hours	4
	Max	Hours	48+
Operating temperature[5]	Min	°C	0
	Max	°C	450
Design pressure[6]	Oil	barg	40
	Steam	barg	160
Modules shipped per 40-foot container			1
HTF fill volume[7]		m^3	1.0
Nominal storage capacity		MWh	1.9
Maximum storage capacity in optimal conditions[8]		MWh	2.4
Thermal losses over 24-hour period[9]		%	<2%
Design lifetime		years	50+

Notes

1. Most specifications in this sheet apply to a system using a single-phase heat-transfer fluid, either liquid or gas, where no phase change will occur. The storage system can be designed for phase-change cycles, but this will directly impact the type of components used. In case of steam, the concrete module can act as the superheater unit in a storage system which also includes a boiler unit. Boiler unit specifications are stated in a separate document.

2. This refers to the approximate total weight of the module with Heatcrete. The shipping weight of the steel components is about 7.5 tons.

3. HEATCRETE® is a special type of concrete tailored for Thermal Energy Storage applications, developed in partnership with Heidelberg Cement. The concrete uses quartzite as the main aggregate.

4. Due to the thermal inertia of HEATCRETE®, long charge and discharge periods are favored, as this will increase the effective storage capacity and thermal performance. Discharge and charge periods can be discontinuous.

5. This refers to the maximum operating temperature range of the storage, irrespective of heat-transfer fluid, based on the upper limit of standard carbon steel used in the heat exchangers. Increasing the temperature up to 550 °C may also be possible by investing in a modified HEATCRETE® formula, as well as appropriate steel grades for higher temperature levels.

6. According to plant requirements. Typically, up to 40 bar for thermal oil and up to 160 bar for water/steam. Higher pressures may affect the choice of steel tubing.

7. Charging at 390 °C and discharging all the way down to 290 °C.

8. Heat-transfer fluid volume will depend on steel tube diameter and wall thickness.

9. This is indicative for larger systems. Thermal losses will depend on size (larger size reduces relative heat losses), temperature, and amount and type of thermal insulation used in the storage.

Knowledge is power.

General questions

How is the EnergyNest TES superior to other storage technologies?

- Fully scalable power and energy storage capacity, from MW/MWh_{th} to GW/GWh_{th}, unlike many other technologies such as molten salt, pumped hydro, and compressed air energy storage, which generally require very large facilities to be economically viable.
- Medium to long discharge duration (from 4 hours up to several days), unlike supercapacitors, flywheels, and most battery technologies, which typically supply power only in the seconds to minutes range.
- Round-trip thermal efficiency, or combined heat and power efficiency, exceeding 90 %, higher than most other technologies including batteries, pumped hydro, and CAES.
- Can be built anywhere, with no geographical or topographical constraints, unlike pumped hydro and CAES.
- Possibility of very high local content with majority of components being manufactured and supplied locally, unlike many other technologies, which require high-tech components manufactured only in certain parts of the world.
- Based on globally available materials, mainly concrete materials and steel, unlike batteries, which require rare earths with limited resource availability.
- Lifetime exceeding 50 years, with no performance degradation and almost unlimited cycling lifetime, unlike battery technologies, which typically degrade over time with a lifetime of 10 years.

Does the EnergyNest system have a sweet spot in terms of temperature and pressure?

Yes, between 300 °C and 427 °C. The higher the temperatures, the better, as a larger temperature differential will allow a more useful heat transfer and utilization of stored energy. However, above 427 °C, higher-grade steel material is required for the steel tubes and piping, and above 450 °C, the composition of the special cement mix used for HEATCRETE® will be different. These additional costs must be traded off against increased storage and energy conversion efficiency. Below 300 °C, alternative TES technologies are available, such as non-pressurized organic oils and pressure vessels with water, which may be more economical depending on the use case, and below 100 – 120 °C low pressure or atmospheric hot water tanks would generally be the preferred option. Our storage system has no pressure limitations.

How are you positioned with regards to other TES technologies?

TES technologies may be summarized as follows:

Technology	Min	Max	Description
Hot water tanks	>0 °C	120 °C	Low-grade heat, typically district heating. >100 °C requires pressure tank
Thermal (mineral) oil storage	40 °C	300 °C	Significant degradation over time
Pressure vessels with water	120 °C	300 °C	Cost increases significantly with temperature (pressure)
EnergyNest	<0 °C	450 °C	Current version of HEATCRETE® limits the upper temperature to 450 °C
Binary molten salt	270 °C	565 °C	Melting point at 220 °C, crystallization can begin at 240 °C, upper limit of 565 °C determined by steel type, limit for salt itself is 593 °C.
Hitec/tertiary molten salt	170 °C	538 °C	Melting point at 142 °C, upper limit of 538 °C determined by salt properties

How can electricity be supplied?

EnergyNest's TES can be used to generate high-grade steam for steam turbines, organic vapor for organic Rankine cycles (ORC), or other heat engines that work within the temperature range of EnergyNest's technology. The components of the power block (turbine-generator, steam generator, etc.) lie outside the company's scope of supply. Such equipment will be the responsibility of other OEMs. EnergyNest has a number of preferred partners who can be recommended for special projects.

Does EnergyNest have a proof of performance?

EnergyNest's TES at the Masdar Institute Solar Platform has been in operation since late October 2015 and will have accumulated around 4,500 operating hours and > 200 cycles by the end of 2016. The R&D setup and initial results have been validated by DNV-GL. A detailed report can be provided on request. The TES is currently operated 24/5 with three shifts to maximize the operating hours and cycles.

Economics

How much does the EnergyNest storage cost?

The material cost for our basic storage module, consisting of HEATCRETE® and steel, is 20 – 25 USD/kWh_{th} of storage capacity. This is the price per kWh_{th} of HEATCRETE® and steel cassettes. In other words, our material cost includes the storage medium, the containment of the medium, and the means to input and extract heat from the medium. This excludes EPC (turnkey) costs, which may vary significantly from project to project, depending on size and location.

What guarantees does EnergyNest provide?

Our performance guarantee may vary depending on the application. Performance guarantees are a combination of discharged energy, temperature profile, and discharging time, as well as quality assurance.

Does the TES affect the operational costs of the process it serves?

For CSP projects, the TES will increase the total HTF volume in the plant, slightly increasing the parasitic loads of pumping the heat-transfer fluids. Compared to molten salts, the overall parasitic loads are significantly reduced, since the storage medium is solid. No pumping power is required to move the medium from one tank to the other. The overall O&M costs are very low, as the TES itself is virtually maintenance-free and there are no moving parts except valves. Moreover, the TES does not require a special crew for operation and maintenance other than what is required for the rest of the plant.

What explains the CAPEX and OPEX difference to molten salt storage?

A combination of lower material costs and significantly reduced complexity, notably;

- The cost of HEATCRETE® and Cassettes is lower than the cost of salts.
- Molten salts require multiple oil/salt heat exchangers. For EnergyNest the heat exchangers are included in the cassettes.
- Molten salts require pumps for cold and hot tanks. With EnergyNest, no pumps are needed, since the storage medium is solid.
- Molten salts require complex and expensive heat tracing, salts drainage, and a back-up heating system to avoid salts freezing (220 – 240 °C). As the freezing point of typical high-temperature thermal oil is 12 °C, such systems are unnecessary for EnergyNest.
- Both salts tanks need nitrogen blanketing to avoid oxidation of salts, adding complexity. No such system is required for EnergyNest.
- Valves and instrumentation are simpler and less costly than for molten salts, as they work with non-corrosive oil instead of highly corrosive molten salts.
- Due to the modularity of EnergyNest's technology, very few circumstances can cause a complete downtime of the TES, and if so, this would mainly be due to a malfunction in a main control valve. If problems arise in a TES block, one can isolate only that block while keeping the rest of the TES in full operation, with a marginal impact on total plant performance. For molten salts, this is very different: a problem will typically shut down the entire TES.
- All in all, the EnergyNest system is much simpler than a molten salt system. It does not add a new fluid with stringent operating requirements, so no additional, specialized crew is required for operation, inspection, and maintenance. For the same reason, there is no need for additional stock of spare parts.

Technical

How does EnergyNest's decreasing output temperature during discharge affect turbine efficiency?

Compared to molten salts, the (net) turbine efficiency with EnergyNest is higher until the oil temperature has dropped to ~365 °C (down from 393 °C); see table below. This is because the salt system consumes around 2 % of gross turbine output, for pumping the salts from the hot tank to the cold tank. So, with EnergyNest, the steam turbine efficiency will be higher for more than half the total discharge duration, and overall electricity output is higher. Moreover, in the first hours of discharge, the net power output will also be higher with EnergyNest than with molten salt, as the oil temperature is close to nominal (>380 °C). For CSP plants that are paid time of day (TOD) tariffs this may be very advantageous as the highest TOD rates are typically in the late evening, when the sun sets and the TES discharge begins.

Oil inlet temperature to steam generator (°C)	EnergyNest relative gross turbine efficiency	Molten salt relative gross turbine efficiency, minus 2 % power for salt pumps
393	1	
380	0.991	0.971
370	0.978	
365	0.971	
350	0.948	
330	0.912	
310	0.870	

We already have a solution for achieving a constant output temperature, by using different oil flows coming from different parts of the TES. But this entails lower initial output temperature and higher cost, due to additional valves and control. In our opinion, the sliding temperature remains the most cost-effective solution.

What is the minimum design duration for charge/discharge?

The TES is designed for charge/discharge durations of at least 4 hours. This means that, from a fully discharged state, one should preferably have at least 4 hours of charge to reach the fully charged state, and vice versa.

Does EnergyNest provide latent heat storage?

Together with its partner Aalborg CSP, EnergyNest has developed a 'latent-sensible' TES system for direct steam applications. The TES stores the latent heat from condensing steam as sensible heat in HEATCRETE®. Later, that heat is transferred to water to boil it to steam. This evaporator TES is based on the principle of natural circulation in a steam boiler, where the lower density of water/steam mix inside the TES (compared to saturated water in external downcomer pipes) drives circulation by gravity. This can be combined with a separate TES unit, referred to as a superheater TES, which enables the combined solution to operate with steam at high temperatures up to 450 °C. Note that the use of a sensible storage medium to store latent heat results in a lower steam pressure during discharge, compared to a TES based on phase change material (PCM).

What kind of heat-transfer fluids can the TES operate with?

Basically all fluids compatible with carbon steel and with sufficient density to allow pumping it through our tubular heat exchangers. This includes but is not limited to: thermal oils, water/steam and pressurized air.

What is the heat capacity of HEATCRETE®?

Temperature (in °C)	Heat capacity (MJ/m3•K)
100 – 450	2.3 – 3.7

What is the thermal conductivity of HEATCRETE®?

Temperature (in °C)	Thermal conductivity (W/m•K)
100 – 450	2.49 – 1.61

Construction

How much local content can be included in the EnergyNest TES?

If HEATCRETE® and Cassettes can be sourced locally, our TES can have close to 100 % local content. 75 % of HEATCRETE® is aggregates, which may be sourced locally if of sufficient quality and volume. However, local fabrication of Cassettes depends on the qualifications (and price competitiveness) of the local steel workshop.

Operation

How is the integrity of the EnergyNest TES monitored?

The only thing we monitor is the thermal performance. Stress and deformation sensors are not practical for systems operated at temperatures up to 400 °C or more. Thermomechanical stresses have been carefully modeled in collaboration with CIMNE in Barcelona and SINTEF in Norway, using advanced simulations of HEATCRETE® columns. Additionally, our design includes a reinforcement – the steel casing – which prevents surface spalling.

How is the TES designed to deal with potential contingencies and damage?

The TES Blocks are equipped with temperature sensors, both on inlet/outlet pipes and inside the Block itself. This allows the operator to monitor the temperature evolution between Blocks and detect if there are any anomalies. In addition, each Block has sensors to detect possible oil leakage. Should a leak occur, the operator will know which Block is affected. This Block can then be cooled, isolated and drained of oil. Next, the insulation layer on the front can be removed and the TES columns and piping system inspected to pinpoint the leak. The affected column can be isolated and by-passed. The remaining Blocks in the total TES system can remain in full operation while the affected Block is repaired.

What basic maintenance does the TES require?

The TES itself requires very low maintenance as there are no moving parts. Maintenance is mainly inspection of valves and instrumentation on the piping interface.

An energetic movement.

EnergyNest has forged partnership networks with world-class research institutions and industry-leading companies.

Our partnerships enable us to continuously improve performance, refine our product, and deliver integrated storage solutions to our customers across the globe. Join the movement!

HEIDELBERGCEMENT

Masdar INSTITUTE

AALBORG CSP - Changing Energy

DOW

SIEMENS

In October 2016, EnergyNest received funding from the European Union's Horizon 2020 Research and Innovation program for their project titled "Reducing carbon footprint by Thermal Energy Storage." The objective of this project, which will run from November 2016 through April 2017, is to identify a partner for demonstrating the feasibility of EnergyNest's Thermal Energy Storage technology.

European Commission

Horizon 2020
European Union funding
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Where do you store your energy?

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