bGen™ Brenmiller Energy

Industrial Waste Heat

BRENMILLER ENERGY

Industrial Waste Heat - The Potential

Vast amounts of thermal energy from various process industries (in the form of flue-gas exhausts, cooling streams, etc.) are currently being wasted by disposal into the environment. The recovery and reuse of these waste-heat streams can significantly improve the overall energy and economic efficiencies of many process plants across a broad range of industries.

Looking at the steel industry, which is one of the highest energy and emissions intensive sectors, there are multiple options for waste heat recovery in ore smelting furnaces.

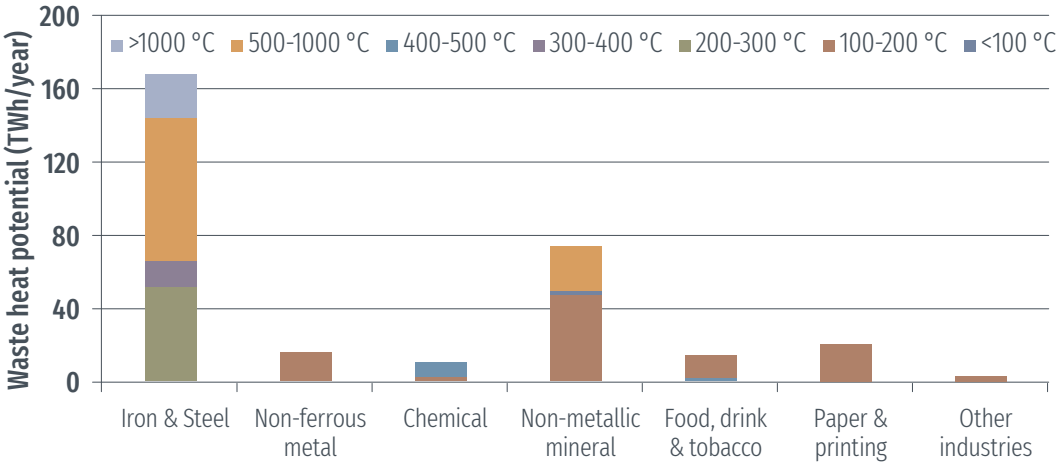
Electric arc furnaces (EAF) are considered as important and highly suitable candidates for waste heat recovery projects. The off-gas (i.e., flue-gas) has a high potential for energy recovery.

Brenmiller Energy's thermal storage system, named - The bGen™, is used to collect and store waste heat from the furnace flue gas output. The System can discharge the energy upon demand to generate electricity and steam. Heat is being to be used at time periods that maximize the overall savings.

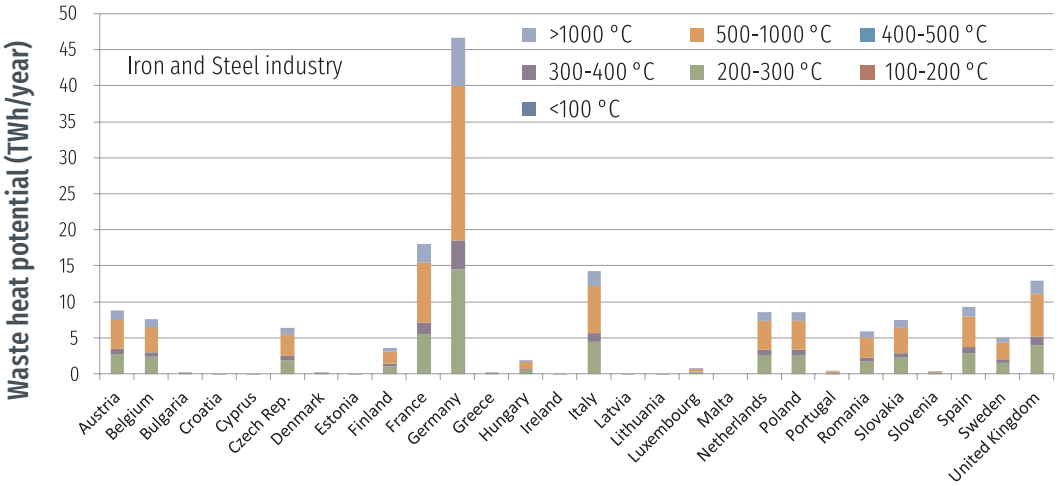
Market overview

The heat recovery market reached 53.12$ billion in 2018. Europe dominates this market and accounted for 38% of the global heat recovery equipment market.

The countries with the highest industrial energy consumption are Germany, Italy, France, UK, and Spain.
These five countries represent about 60% of the total industry energy consumption in EU.



Waste heat potential per industrial sector and temperature level for EU industry in 2015



Waste heat potential in each EU country per temperature level in iron and steel industry

System Description

A basic factory system is comprised of 3 subsystems:

- Charging subsystem - Typically an insulated ducting system harvesting the waste heat from the factory's chimney system and returning cooled gases back to the chimney with sufficient pressure for an easy disposal
- Storage subsystem - A modular solid-state rock based thermal energy storage with 1-1,000MWh thermal capacity for each storage unit
- Discharging subsystem - A state of the art steam turbine system with high efficiency and compact design, converts the stored energy into electricity on demand with startup times as short as 5 min

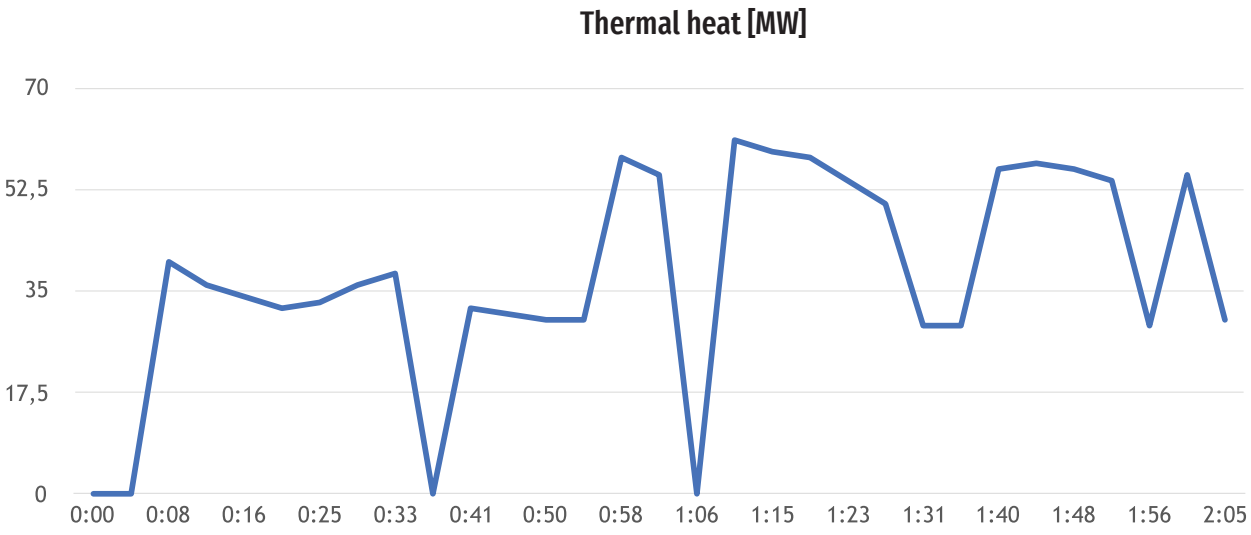
The bGen™- Key Advantages

- The bGen™ system can work with a **wide temperature range** from 350° to 750° and pressure range of up to 120 bar for electricity production and even wider temperature range for energy recovered for air conditioning usage – heating and cooling
- The storage media has been tested for **thousands of charge/discharge cycles** with no performance degradation
- The bGen™ system doesn't only save money on energy consumption and electricity but also **save money on the operational cost** handling the waste heat **cooling systems** etc.
- As a default, the bGen™ system is installed on a **bypass** from the original heat evacuation system, to prevent even the smallest disturbance with the facility's normal operation. That way we can insure the facility's continuous operation
- The bGen™ system enables **energy consumption shifting** – saving cost on tariff difference and lowering the facility's maximum loads
- The bGen™ as a thermal battery is **un-effected by an intermittent production processes.** The heat is cultivated whenever it is available and released **steadily and continuously** according to the customers demand.
- Different unit sizes can be built using the **modular elements.** System losses are minimized through the completely covered and insulated block. The modular structure enables simple shipment, short installation time and an easy final testing
- Thermal losses from the storage over 24h period is **less than 3%**
- Lifespan of system is **over 30 years** with no degradation
- The bGen™ system will **lower the CO_2 emissions** because waste heat is converted into energy

Case Study - Waste Heat Recovery Iron & Steel Industry

The case chosen for this study is a smelter using electric arc furnace (EAF) located in South Africa. The particular issue of the EAF technology is selected due its increasing implementation worldwide on steel mills. This productive methodology requires a high electric energy input, which afterwards around 50% is lost as waste heat, combustion products and others.

In this kind of plants, it is crucial to consider the heat profile variation of the typical batch process of an EAF (see figure below). An integration of a storage is necessary to handle the fluctuations.



Example of available thermal heat from an EAF

Calculation of the potential hourly amount of energy is as follows:

Outlet waste gas Volume (Nm3/h)	403,846
Air density @0°c (kg/m3)	1.29
Mass (Kg/h)	520,962
CP- Air @700°c (kJ/kg*K)	1.136
Gas temperature - Charging storage (°C)	700
Gas temperature - Exit to chimney (°C)	180
ΔT (°C)	520
Recovered energy from waste heat (KWt/h)	**85,484**

Brenmiller Energy's solution:

Our system allows to exploit the maximum potential from the waste heat, 748,840 MWth/year, in order to produce 267,500 MWe/year. The system will shift energy production to hours when economic savings will be most significant.

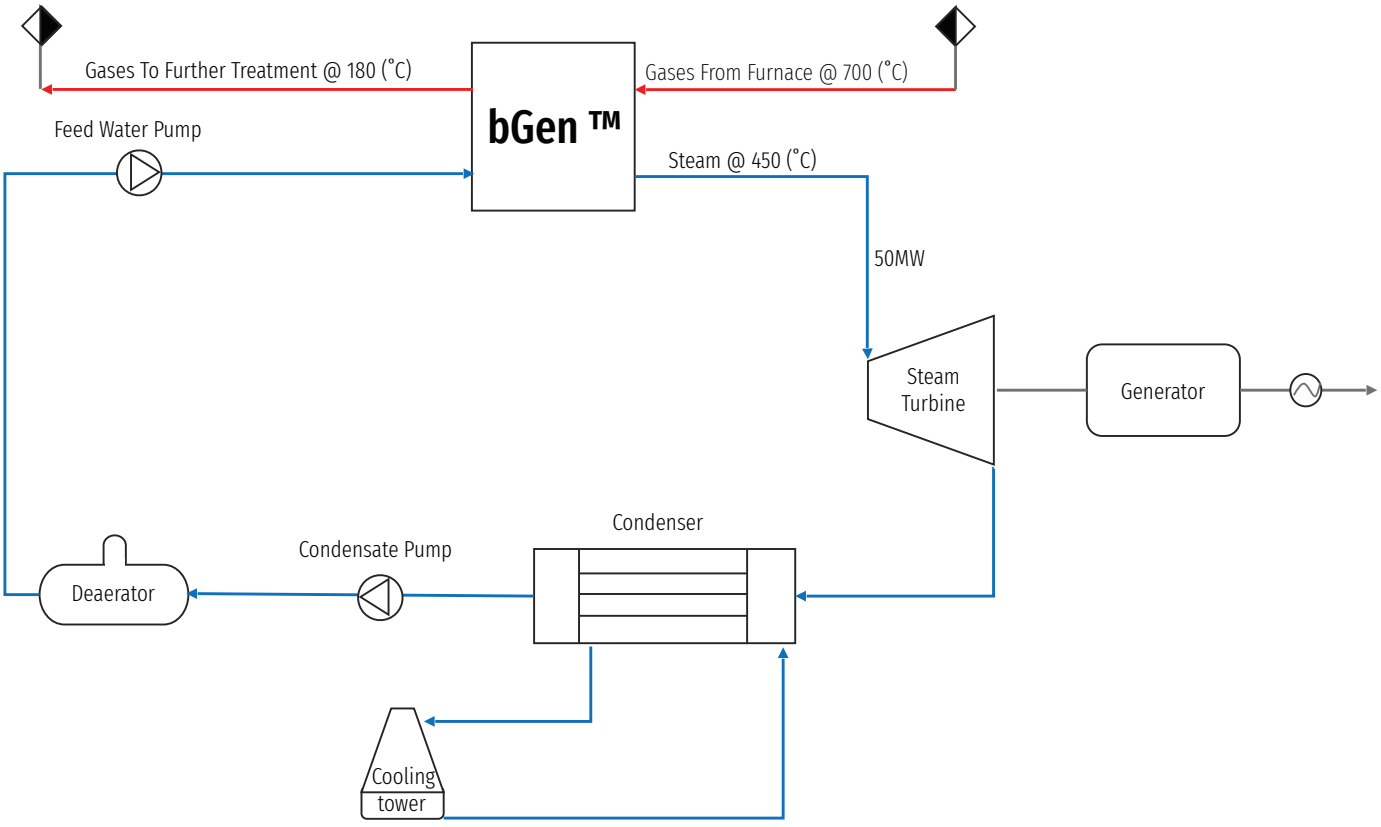
Our solution will provide return on investment of up to 5 years, without taking in account savings in cooling or 25% decrease in electricity cost.

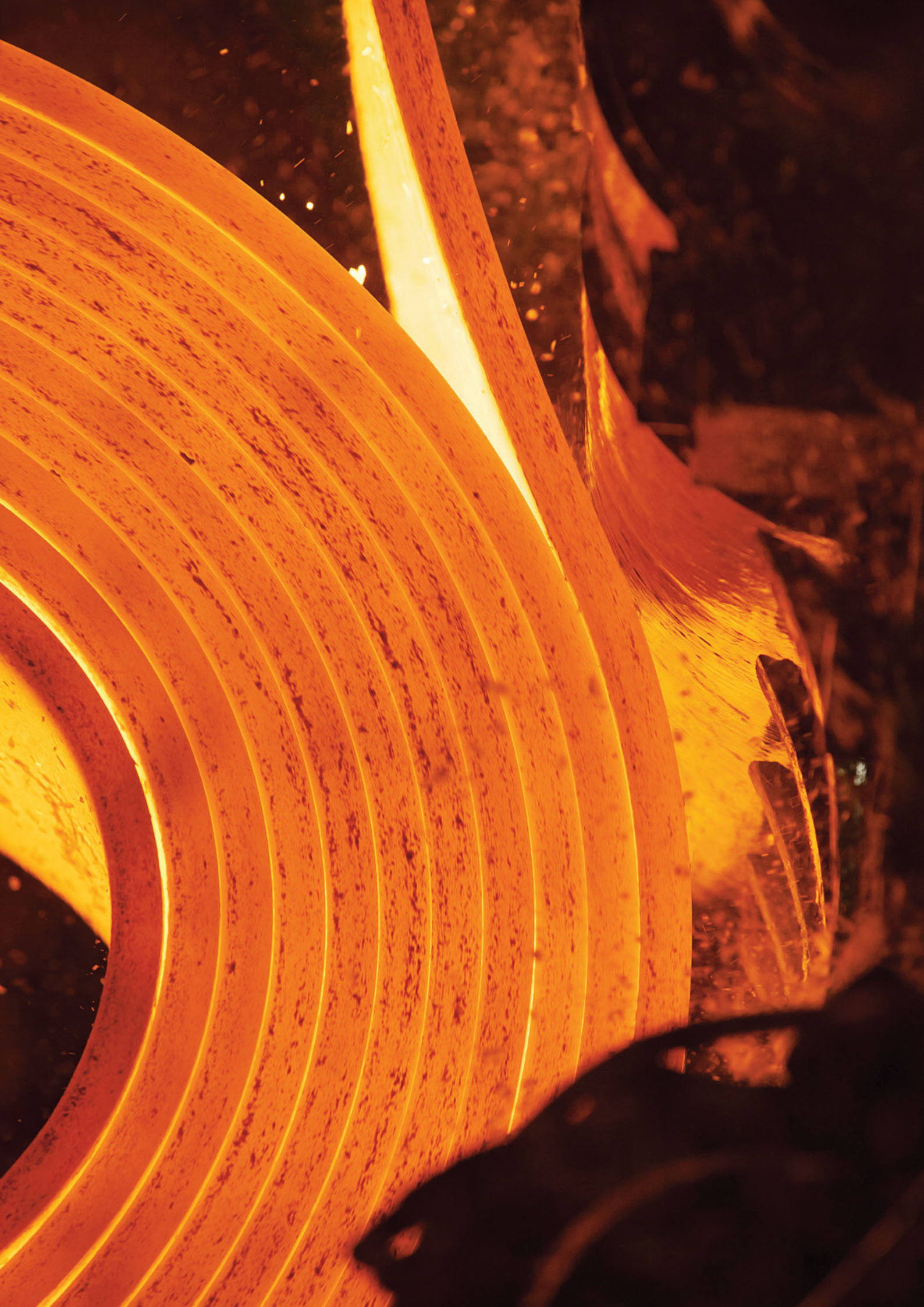
The system is comprised of an integrated heat exchanger, thermal storage, as well as a power production system, all as follows:

- A flue-gas delivering system carries hot flue gas at temperatures of 700°C into the storage system and charging it. The gases then exit the bGen™ system at a temperature of 180°C and are delivered back to further treatment and disposal. The high temp of the process flue-gas enables the operation of a high efficiency steam cycle, using the thermal energy storage.
- The bGen™ thermal energy storage collects the excess heat from the exhaust gas and converting this excess energy to thermal energy stored in a solid state thermal storage media.
- When electrical power is in demand, the bGen™ releases its stored thermal energy by producing superheated steam, which is fed downstream to a steam turbine for power production.
- A steam turbine and adjoined steam cycle, including water cooled condenser, pumping system, auxiliary filtering and BOP systems, uses steam produced by the bGen™ to produce electricity.

The bGen™ system is added to existing interconnection and therefore improves reliability and stability and will easily replace it on demand.

A process flow diagram of the bGen™ unit, as integrated within the Smelter, is presented here in:





Technical Information

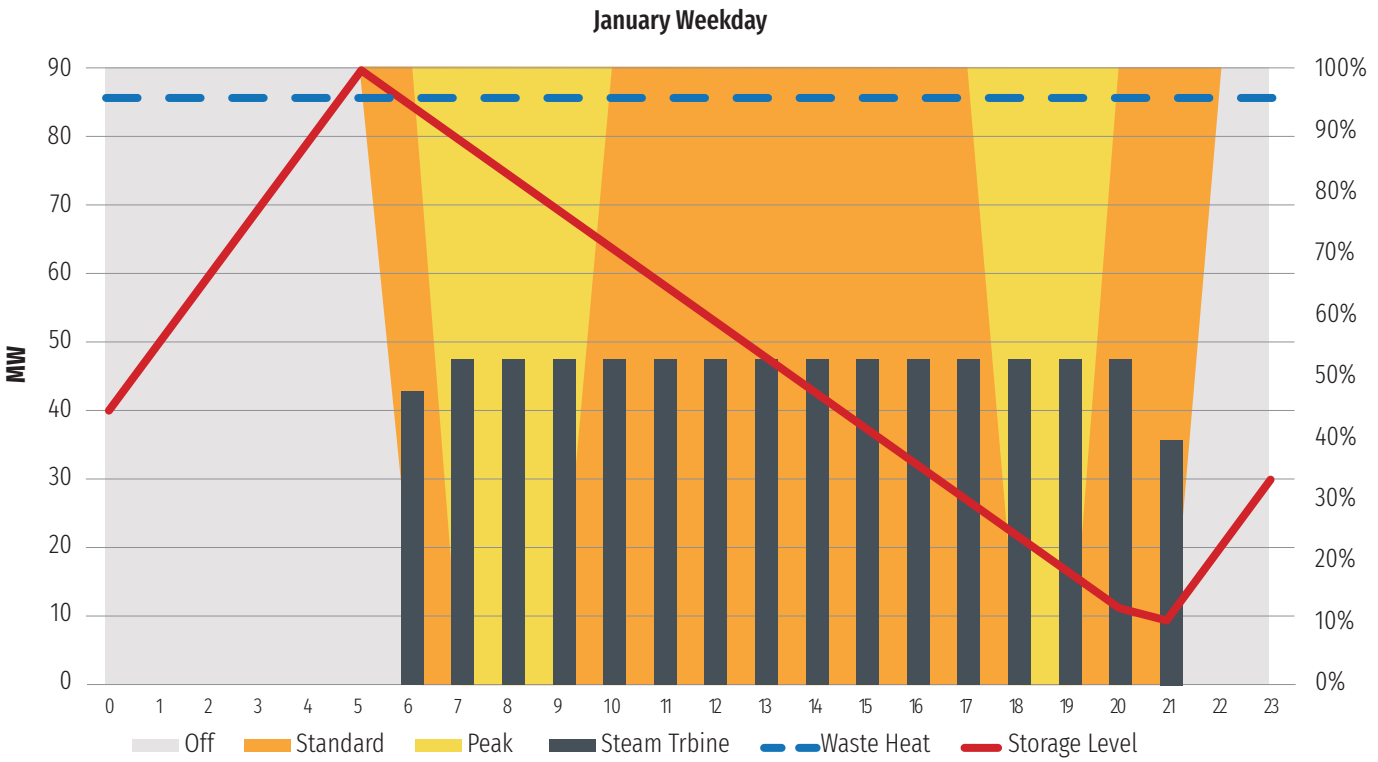
Heat recovery [MWt/h]	85.5
Steam turbine gross capacity [MW]	50
Steam turbine Cycle efficiency	40%
bGen™ net dimensions (m) L x W x H (2 units- One unit for a chimney)	12 x 12 x 15.5
Thermal storage capacity [MWh]	750
Round trip efficiency- Thermal to electricity	35.7%

Electricity production by the bGen™ system

Annually net production [MWh]	**267,500**

Typical production profiles at low demand season:

Showing the saving by shifting energy to standard and peak time.



Business Model

Brenmiller Energy offer two models:

1. Sale of Turn-Key project

2. PPA- Brenmiller as energy utility

1. Sale of Turn-Key project

Indicative system price ($ '000):

Power plant & bGen™	52,500
Infrastructure and construction	3,500
EPC	10%
Total	**61,600**
OPEX (annual)	2,875

ROI Analysis ($ '000):

Annual electricity production (MW)	267,500
Average tariff to kW ($ cent)	5.46
Annual saving in electricity cost- Gross ($)	14,605
Annual OPEX	2,875
Annual saving in electricity cost- Net ($)	11,730
ROI	**5.25**

2. PPA- Brenmiller Energy will finance, build and operate the system, and will sell the electricity at a 25% discount of the tariff that is paid today.

Annual electricity production (MW)	267,500
Average tariff to kW ($ cent)	5.46
Cost of electricity without system	14,605
Annual saving - 25% discount on produced electricity from the system	3,651

Company Profile

Brenmiller Energy, based on its unique storage technology, provides sustainable energy solutions to the distributed generation market.

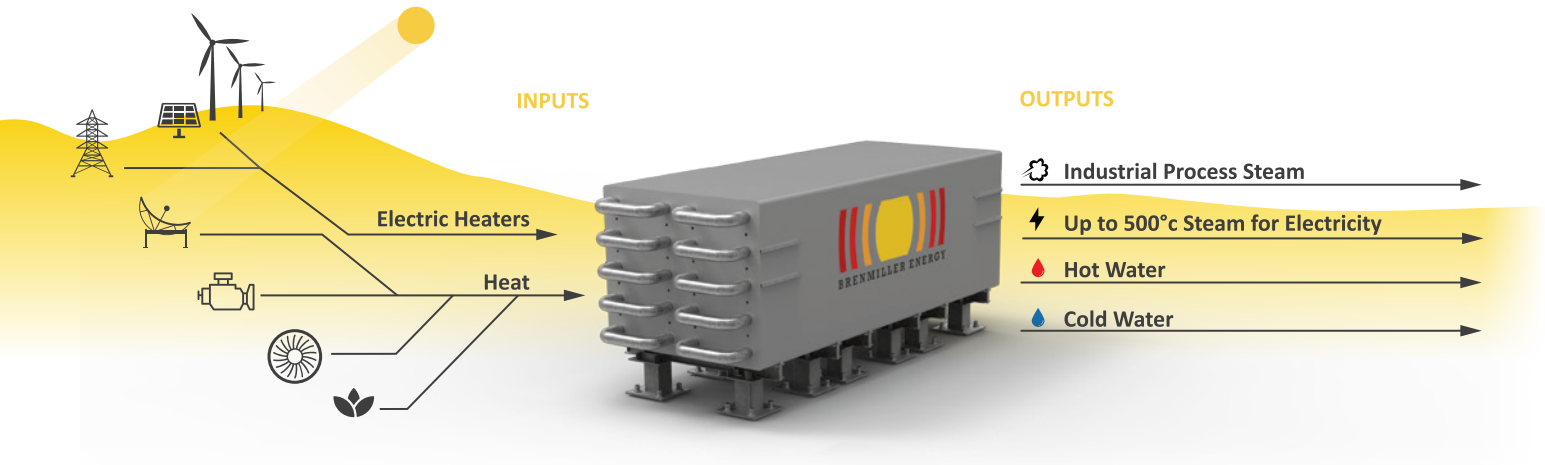
The company was founded in 2012 by Avi Brenmiller, former CEO of Siemens CSP and Solel, and a team of experts in the field of renewable energy. Brenmiller Energy's knowledge and expertise are well-grounded and are based on years of field experience in designing, building and operating solar power plants in Spain and in US of over 500MW.

Recent accomplishments include being awarded a $1M grant for a joint project with the New York Power Authority, where the company will supply electricity and heating to a university within New York, as well as being awarded a grant by the Ministry of Defence for an energy storage project, where the company will provide a mobile-based CHP unit for the Israel Defence Forces.

The company completed a successful IPO in August 2017 and is now being traded on the Tel Aviv Stock Exchange.

Company Projects:

- **Rotem 1, Israel** a Hybrid power plant, using solar collectors and 90 MWh storage combined with natural gas to generate clean energy throughout the day. This will enable baseload operation and continuous generation of electricity to the national grid under a 20-years PPA. The project is guaranteed by the European Investment Bank and to be grid connected in the second quarter of 2019.
- **Rotem 2, Israel** a Hybrid power plant of Solar PV plus 2—MWh storage. The project is expected to be grid connected by second quarter of 2020.
- **Storage Based CHP Project, NY** a joint project between New York Power Authority (NYPA) and Brenmiller Energy at Purchase College, State University of New York (SUNY). The bGen™ will increase the efficiency of a standard combined heat and power system and specifically will take the designed building off the college's main central heating system. This project is expected to provide an annual energy saving of 10,000 MMBtu and an annual greenhouse gas reduction of 550 MTCO2e (metric tons of CO2 equivalent emissions). This project is expected to be commissioned in Q3 2019.
- **Mobile Storage based CHP, IDF** a mobile thermal storage unit integrated with a diesel generator to provide electricity and thermal energy to an army base.



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