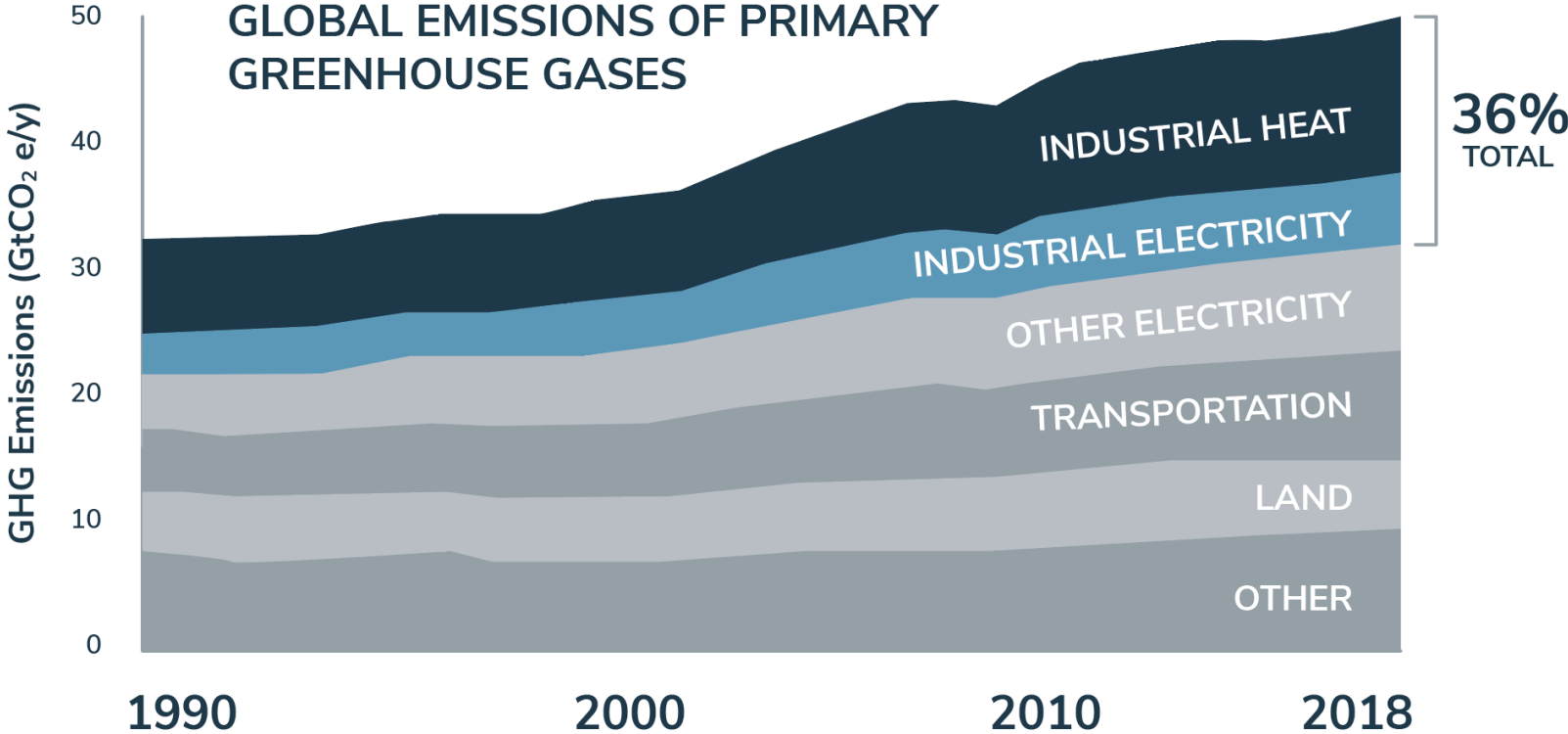




Thermal Energy Storage

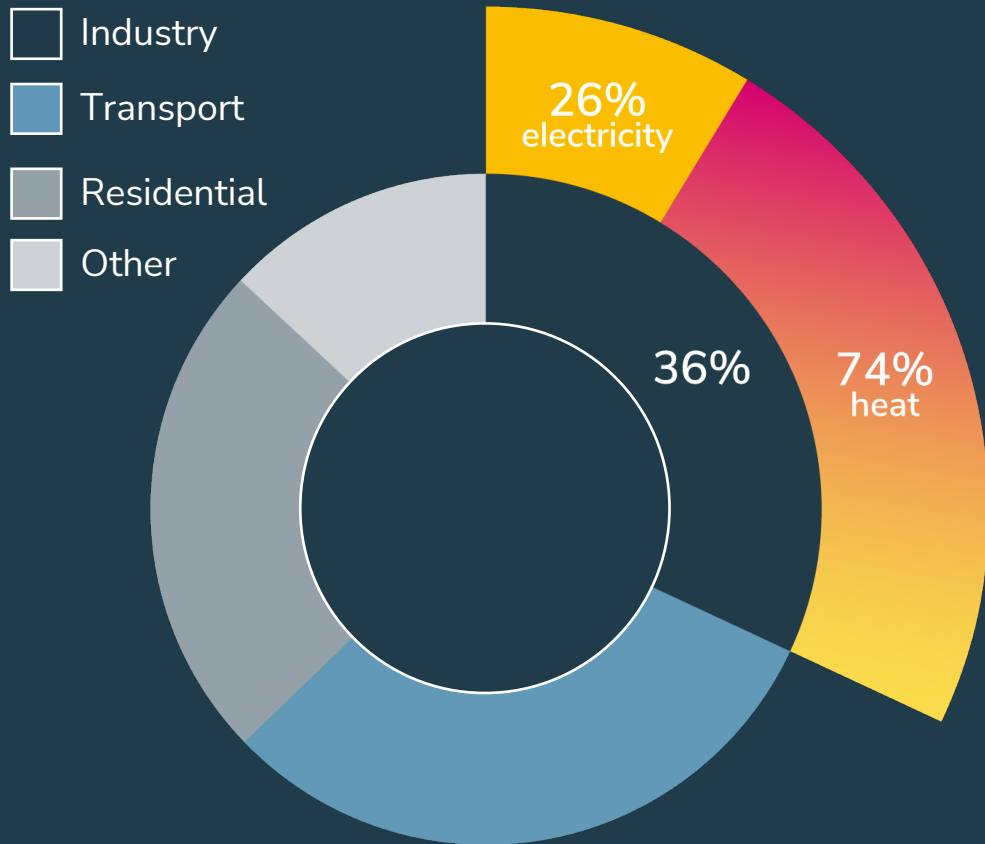
November 1, 2023

Industrial energy is the largest portion of global CO₂



Storage of Intermittent, Renewable Electricity

TOTAL WORLD ENERGY USE



Decarbonizing the world's industrial heat will require 10 TW of new renewables and **46 TWh of heat storage**.

The transition depends upon new developments being economical (e.g. Rondo Heat Battery).

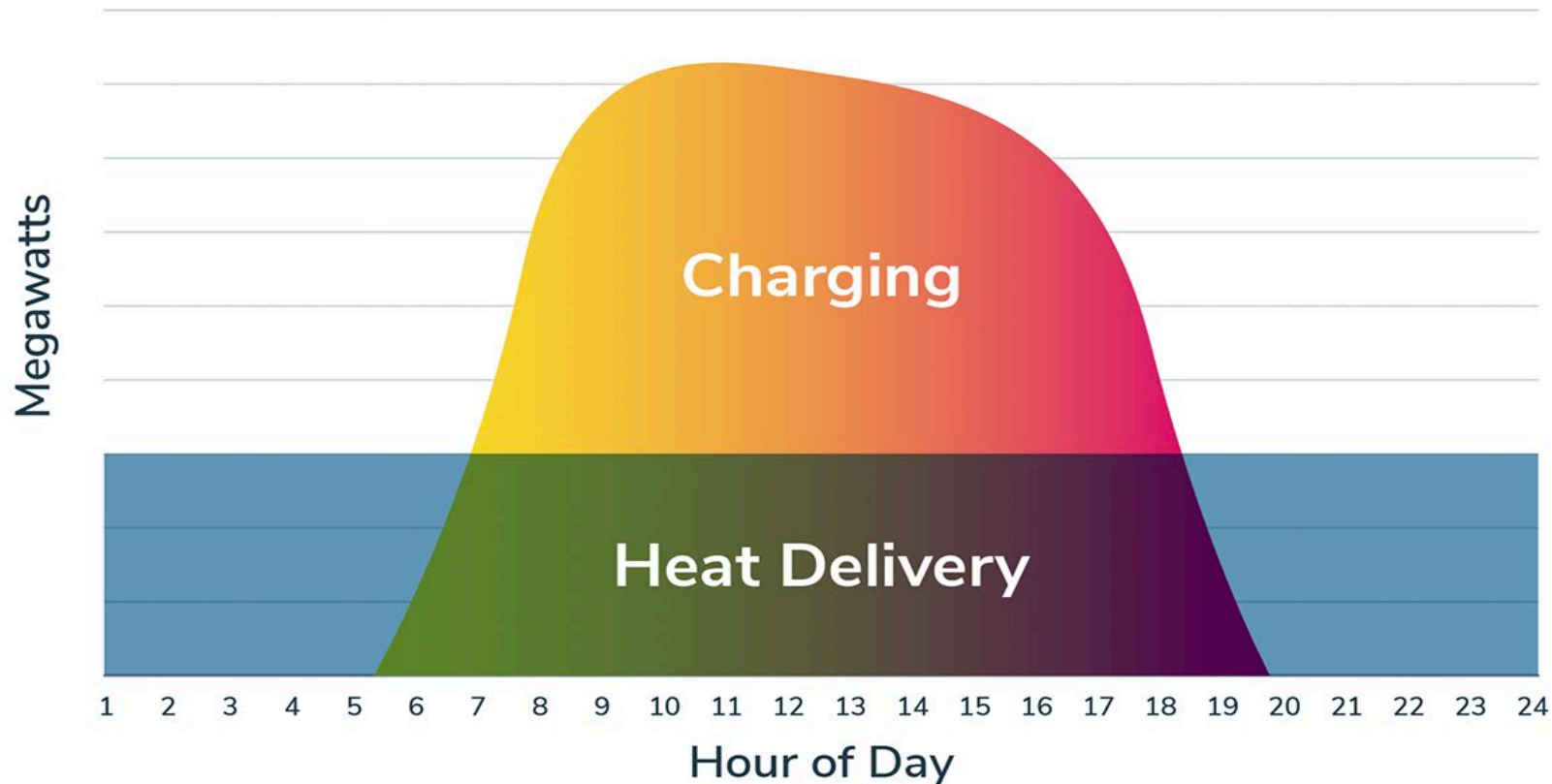
It's likely to be a \$10 trillion industry.

IEA (2017). \$8 trillion in wind/solar, \$2 trillion in energy storage

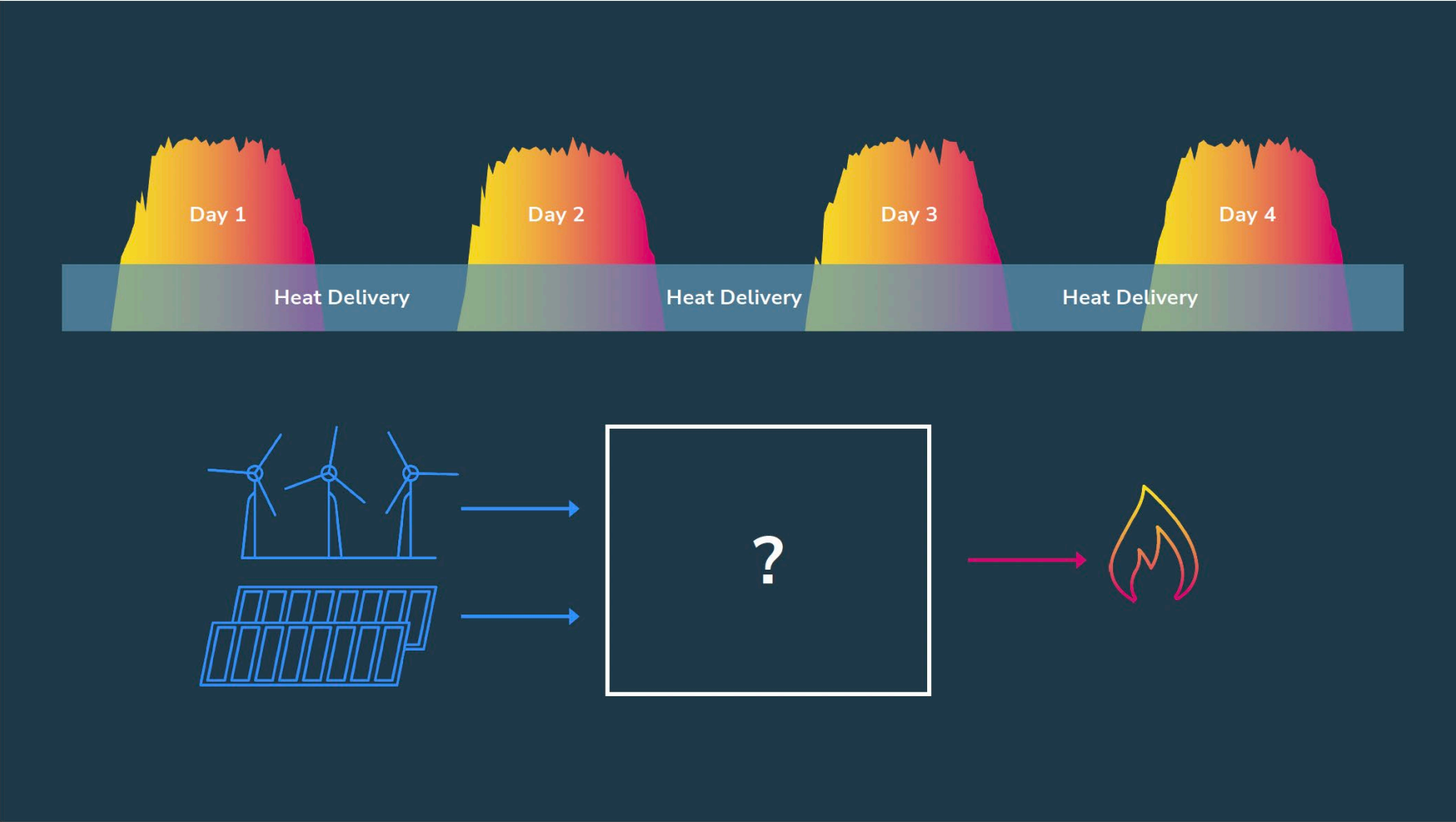


Intermittent wind and solar power now provide the lowest cost energy in history

Intermittent power needs to be **stored as heat** and delivered **continuously** for industrial use



What fills the need for renewable energy storage?



Three criteria for energy storage solutions



(1) SAFETY

Industrial processes have extreme consequences and require total intrinsic safety and/or very high mitigation



(2) HIGH TEMPERATURE

Energy storage is more efficient at high temperatures. Key processes making steel, plastic, cement, minerals, and H₂ require heat at temperatures between 800° - 1500°C



(3) RELIABILITY AND DURABILITY

Factories run continuously (>8500 hours per year) for decades, and any process interruption can take many days to restart

Amounts of storage needed for renewable energy to decarbonize (TWh)

Vehicle & Stationary Batteries (TWh)

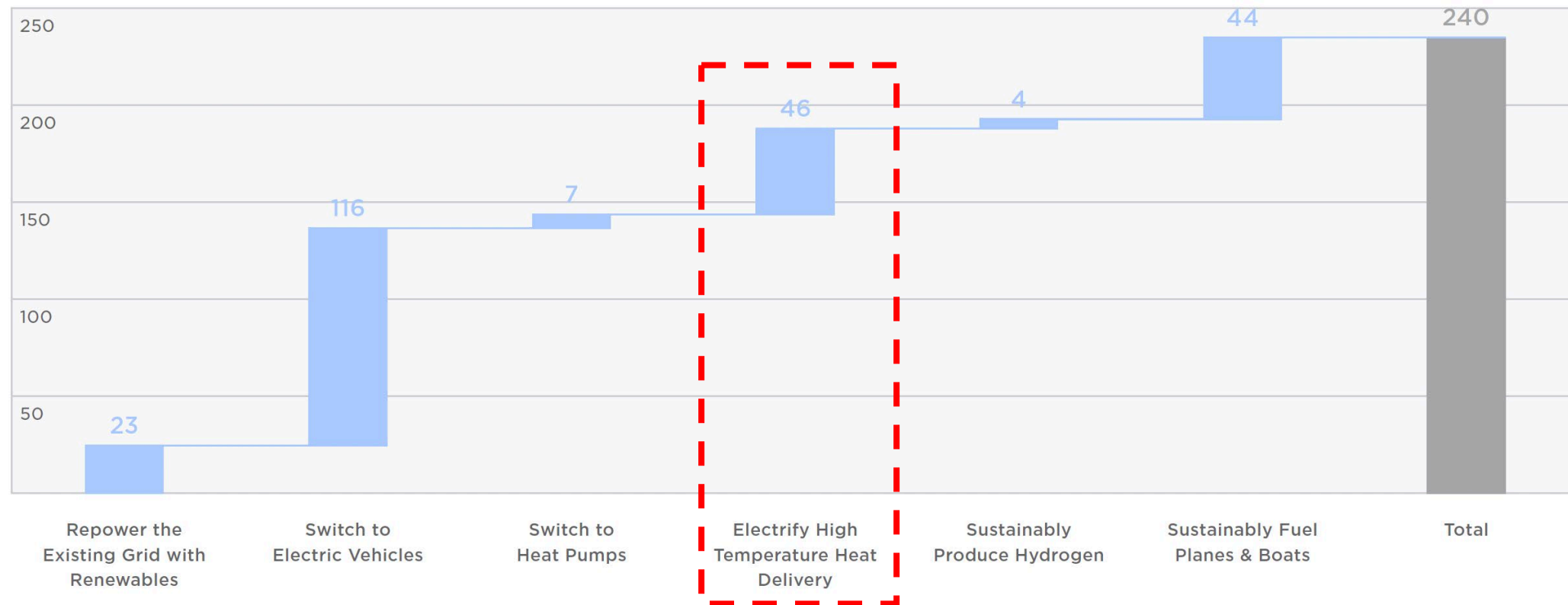


Table 10: Storage Waterfall

Source: Tesla – *Master Plan Part 3 – Sustainable Energy for All of Earth* (2023)

Thermal Energy Storage: a solution for industrial decarbonization

CHALLENGE



Source cheap, 24/7 energy



Cut CO₂ emissions



Meet industrial process requirements



Implement fast

HEAT BATTERIES

Powers continuous operations by charging in the 4-8 hour window when renewable energy is cheapest

Combustion-free technology eliminates process CO₂ emissions

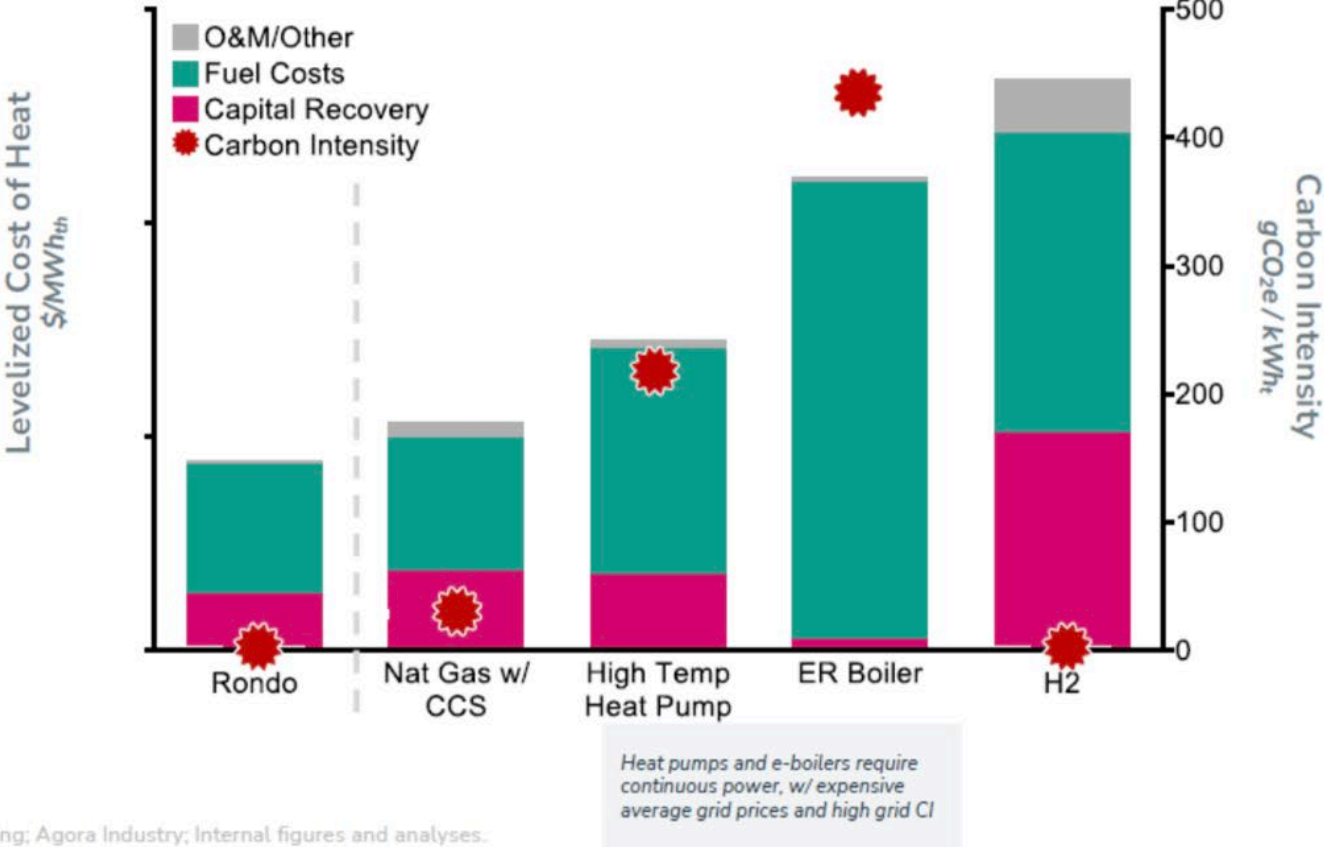
Acts as a drop-in replacement for an industrial boiler, delivering heat, steam, and co-generation at temperatures up to 1000°C

Ready for commissioning due to (a) proven technology, (b) low-cost and readily available materials, and (c) no grid-interconnection requirement

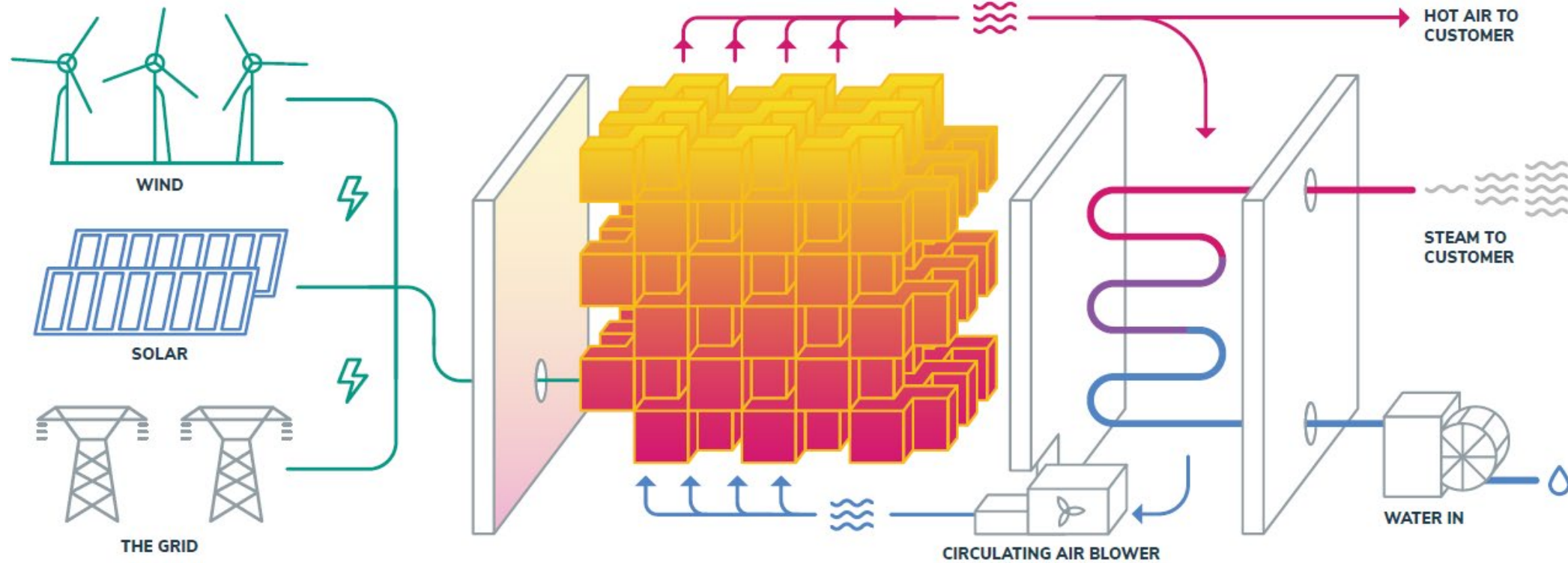
Types of Thermal Energy Storage

- Thermal
 - Sensible Heat
 - Solids (e.g. brick stacks, unstructured rock, graphite)
 - Liquids (e.g. water tanks, aquifer, solar ponds)
 - Latent Heat (e.g. phase change)
 - Solid-Liquid
 - Liquid-Gaseous
 - Solid-Solid
 - Solid-Gas
- Thermochemical (bond energy)

ETES is the lowest-cost option for low-carbon industrial steam



A Heat Battery is a drop-in, zero-carbon replacement for industrial boilers and furnaces



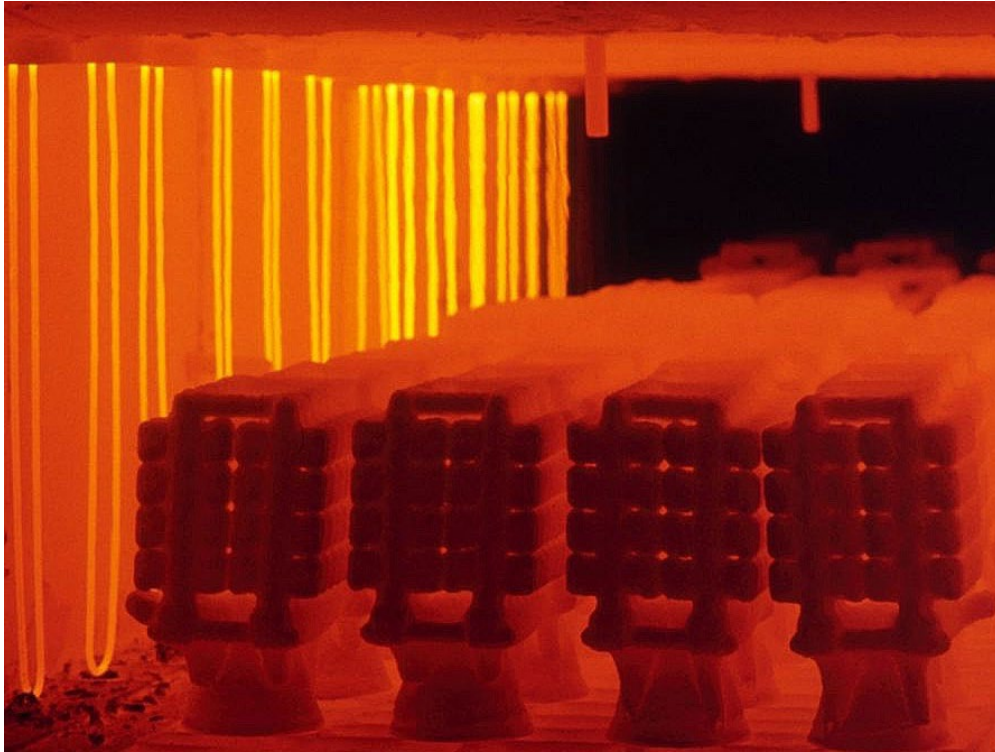
1 The Heat Battery charges with **intermittent electricity** from local wind & solar or from the grid.

2 Electricity powers radiant heaters (100% efficient). Thermal storage medium is rapidly, uniformly heated to **1100 - 1500 °C**, and stores heat for hours or days.

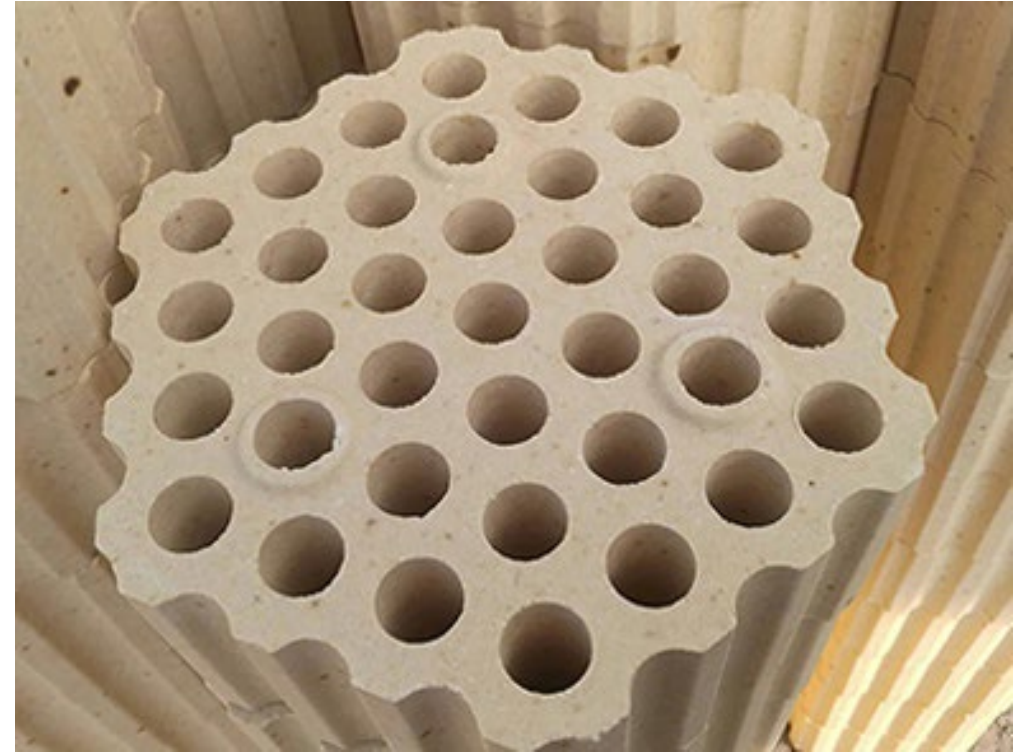
3 The Heat Battery delivers **continuous superheated air** for use as process heat, steam, or electric power at over 98% total efficiency.



Heat Battery materials are low-cost, proven, and large-scale



Rapid **radiant** charging via heavy industry electric **heaters**



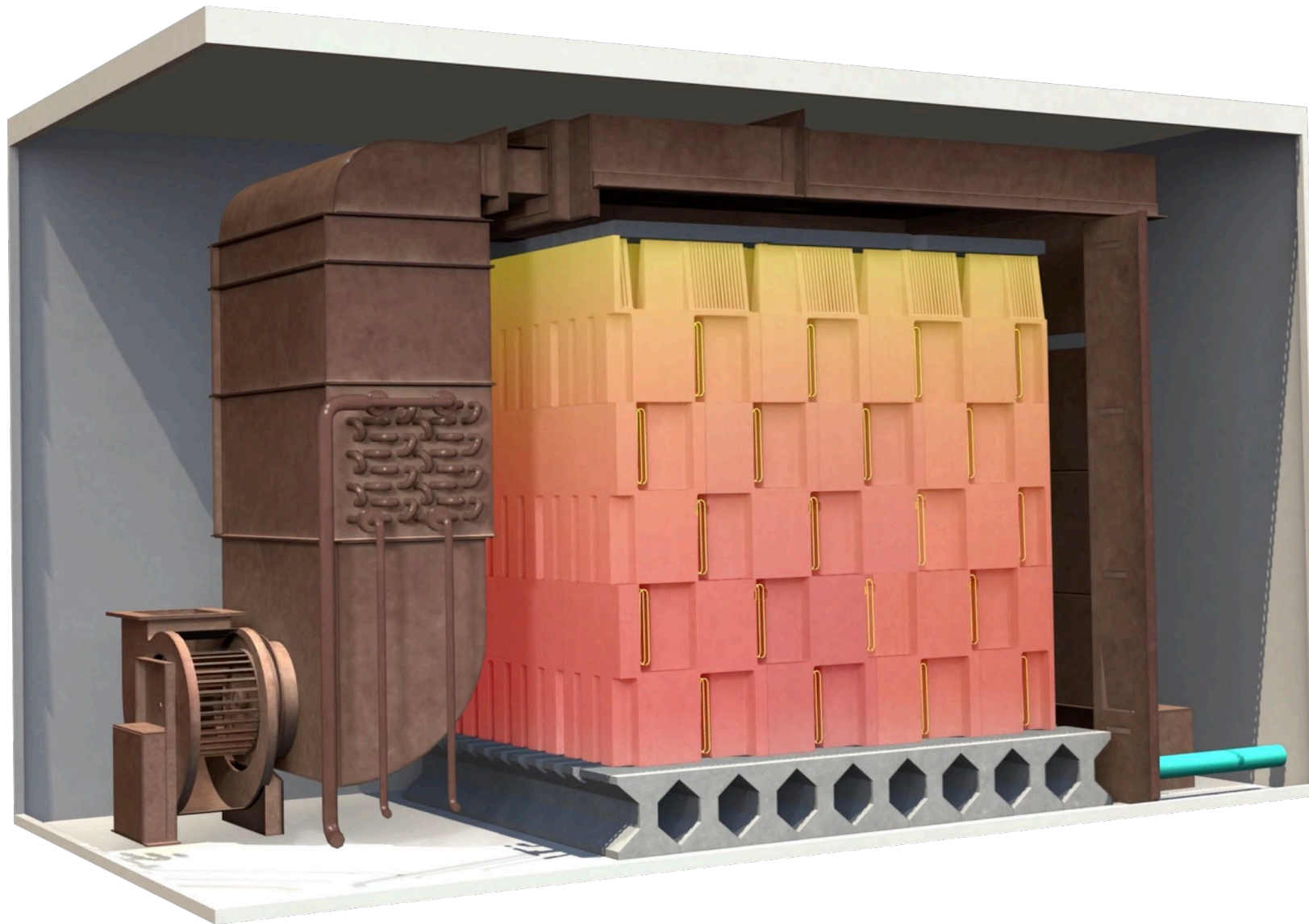
Continuous **heat output** from heat stored in blast furnace **brick**

Thermal Energy Storage (Heat Battery) bricks hold energy for days

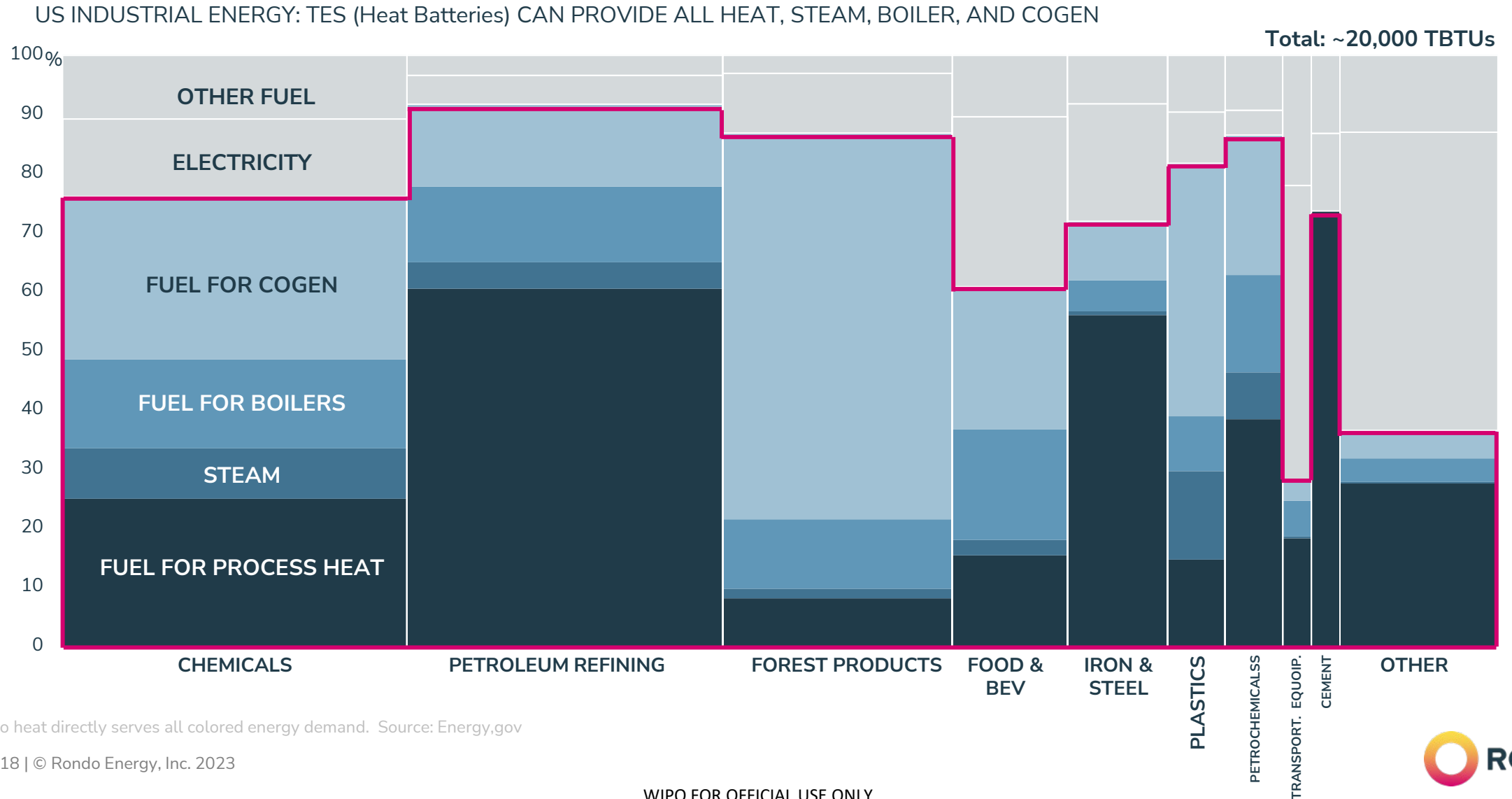
Rondo Heat Battery bricks







Thermal Energy Storage can provide 95% of all industrial heat



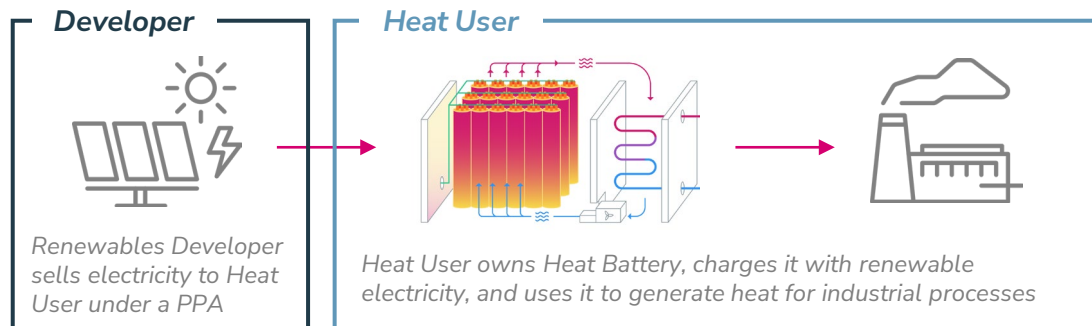
Rondo heat directly serves all colored energy demand. Source: Energy.gov



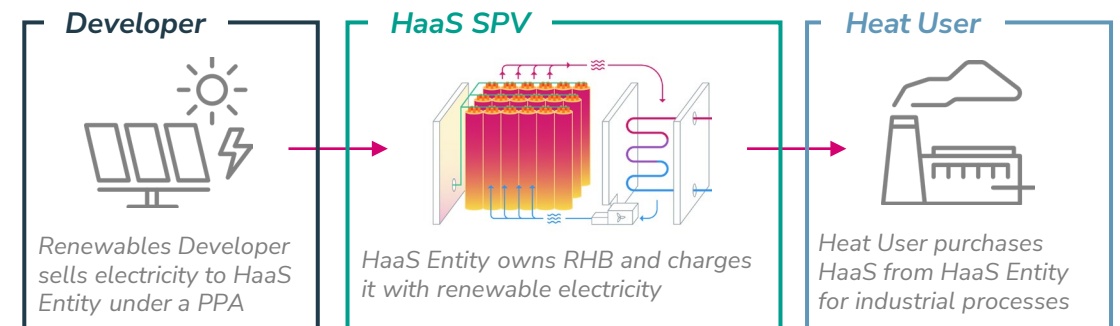
Thermal Energy Storage: Innovation Dissemination

- *Installation into existing or future industrial uses*
- *Collaboration on integration designs*

DIRECT SALE OR LICENSE



HEAT AS A SERVICE (HaaS)





RONDO