

# 8th AIEE Energy Symposium Current and Future Challenges to Energy Security

– the energy crisis, the impact on the transition –

**Padua, 28-30 November, 2024**

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**Long-Duration Energy Storage for power system and industrial heat decarbonization.  
Technology assessment of power-to-heat service applications.**

Federico Santi



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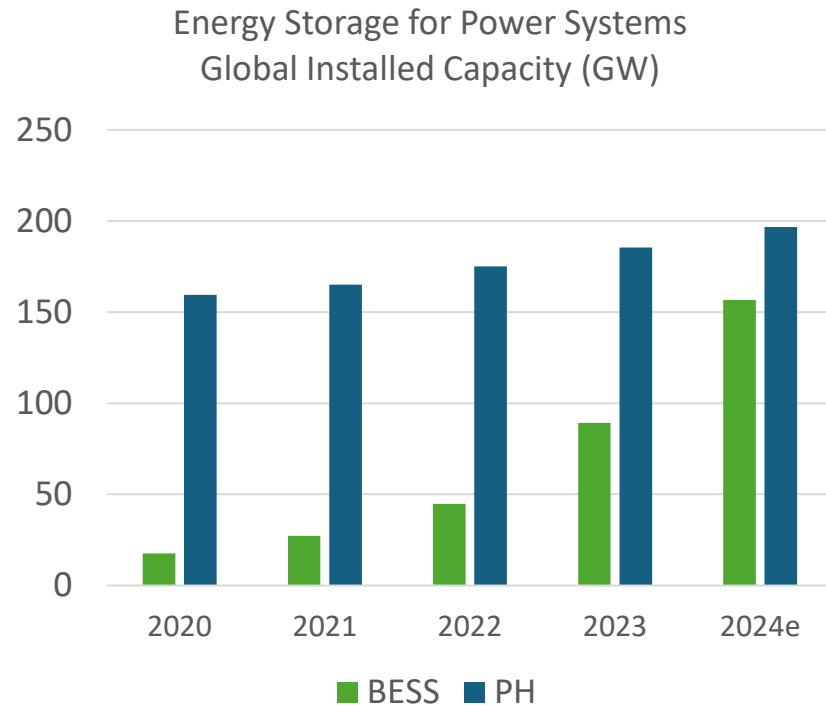


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# Energy Storage Capacity for Power Systems

- ❑ Global Electricity Demand 2024: ~28,000 TWh
- ❑ Energy Storage Global Installed Capacity 2024: **360 GW** | 10.400 GWh (~0.03% of demand)



- ❑ In terms of power (tot 360 GW):  
PH 197 GW (55%), **BESS 157 GW (44%)**, TES&ot. 6 GW (1%)  
BESS capacity growing exponentially (**in 2025 BESS > PH**)
- ❑ In terms of energy (tot 10.400 GWh), PH largely dominant:  
**PH: 96%**, BESS: 4%, TES: 0,2%
- ❑ Today's ES Energy/Power Ratio (global average):  
PH: >50 GWh/GW (50 h "duration")  
BESS: 2,5 GWh/GW (2,5 h "duration")

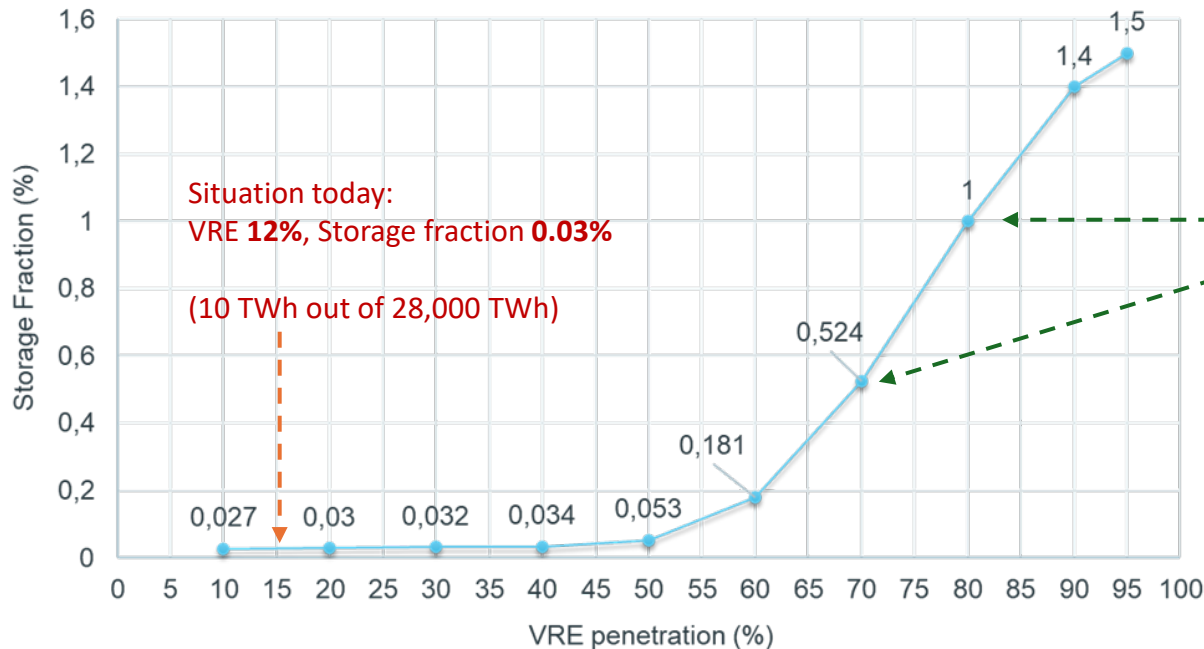


# ES and VRE Penetration in Power Systems

2022/2023 Global Electricity Generation Mix (IEA, IRENA)  
 VRE - Variable Renewable Energy (Wind+Solar) Penetration:

**12% (3,400 TWh)**

Energy Storage Needs vs. VRE Penetration



Typical Zero-Carbon Scenario:  
 VRE 80% → Storage fraction 1.0%  
 VRE 70% → Storage fraction 0.5%  
 e.g. out of 28,000 TWh:

VRE (70%) ~20,000 TWh → x6  
 Storage (0,5%) ~100 TWh → x10

Impossible with BESS only, needs for LDES

Electricity Generation	
<b>8 440 TWh</b>	Renewables in 2022
<b>29.1%</b>   <b>7.2%</b>	Renewables   YoY Growth
<b>11.7%</b>   <b>18.2%</b>	Variable   YoY Growth
Renewables	
Hydro	4 330 TWh
Wind	2 098 TWh
Solar	1 294 TWh
Bioenergy	619 TWh
Geothermal	97 TWh
Marine	1 TWh
Electricity capacity	
<b>3 865 GW</b>	Renewables in 2023
<b>43.0%</b>   <b>14.0%</b>	Renewables   YoY Growth
<b>27.1%</b>   <b>23.4%</b>	Variable   YoY Growth
Renewables	
Solar	1 418 GW
Hydro	1 265 GW
Wind	1 017 GW
Bioenergy	149 GW
Geothermal	15 GW
Marine	1 GW
<b>11.17 TW target by 2030</b>	
Progress	To go
0.47 TW since 2022	7.31 TW to meet target

Modeling simulation results for the EU power system  
 Optimizations are possible



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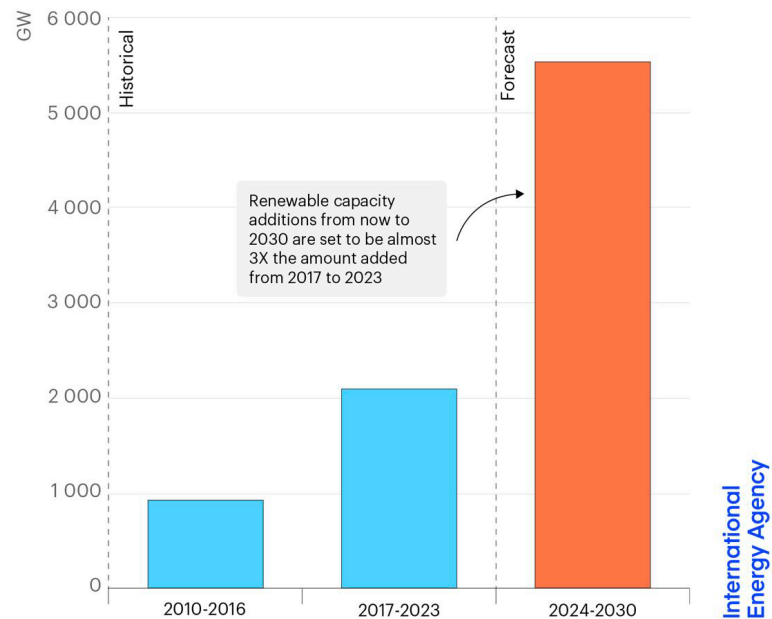


# 2030 Perspective: A Global Race for (V)RES and (B)ESS

- Running towards a 100%-RES power system (RES competitiveness is the new driver)

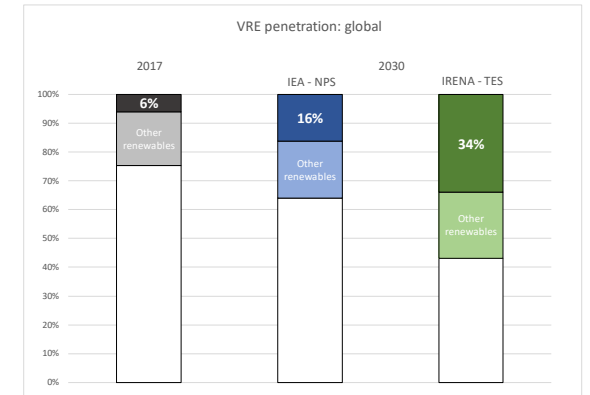
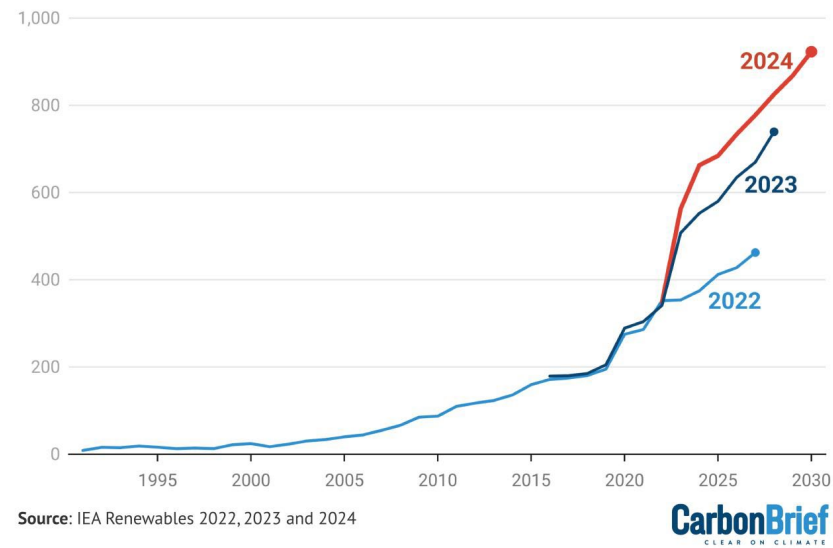
The world is set to add over **5,500 gigawatts of new renewable capacity** between now & 2030

Global renewable capacity growth, historical and main case forecast



The IEA has boosted its latest renewable forecast by another 16%

Annual global additions of renewable capacity, gigawatts



30%÷35% VRE Penetration Expected in 2030 (Worldwide)

→ VRE: x3 ES: x6



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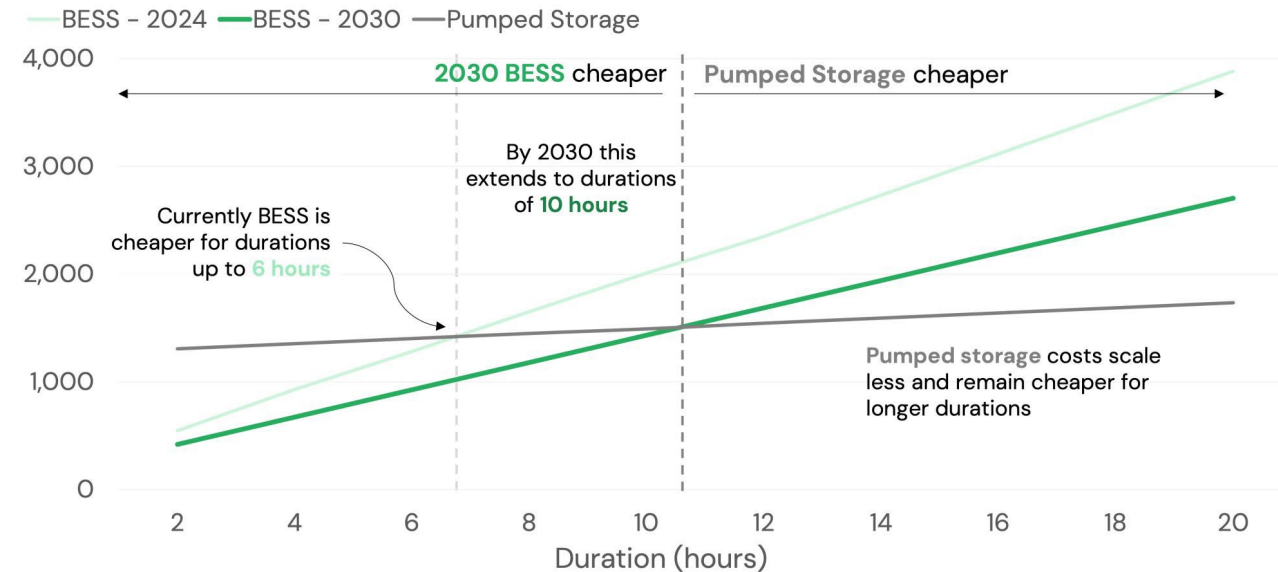


# ES Technology Mix for Future Power Systems

❑ Pumped Hydro Global Potential (Huge. Deployable?): 820,000 sites | **86,000 TWh**

Falling cell costs could make **battery energy storage** cheaper than **pumped storage hydro** for durations up to **10 hours**

Capex (£k/MW)



Source: Modo Energy, SSE, NREL, BNEF, European Association for Storage of Energy  
 Notes: BESS Capex estimates from Modo Energy's central forecast scenario, utilizing data from NREL, BNEF. Pumped storage hydro Capex estimates from NREL and EASE.

**MODOENERGY**

- ❑ **BESS** could conveniently cover the needs for **Short Duration Energy Storage** (up to 10 GWh/GW)
- ❑ **PH** has to remain dominant and cover the needs for **Long Duration Energy Storage**
- ❑ **Heat decarbonization through VRE electrification?** Cross-sectoral benefits of **Power-to-Heat (eTES)** and **Power-to-X** (H2, e-fuels, etc.) energy storage solutions.



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# The Concept of Electric Thermal Energy Storage (ETES)

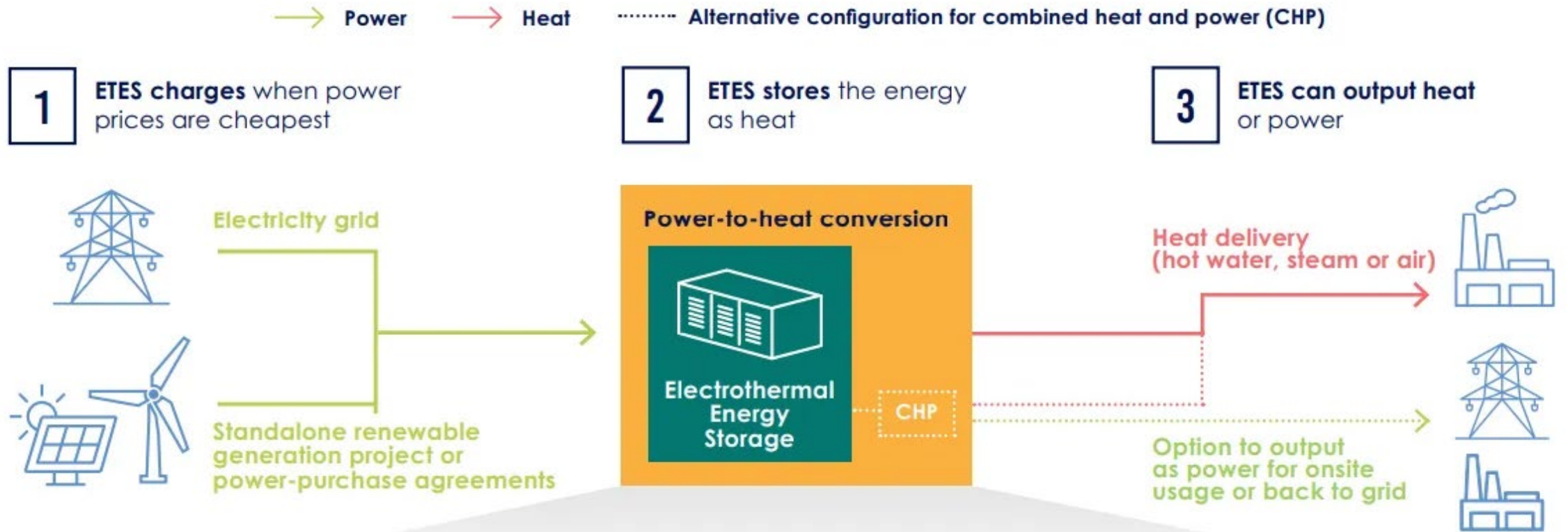


Image credit: Systemiq / Breakthrough Energy



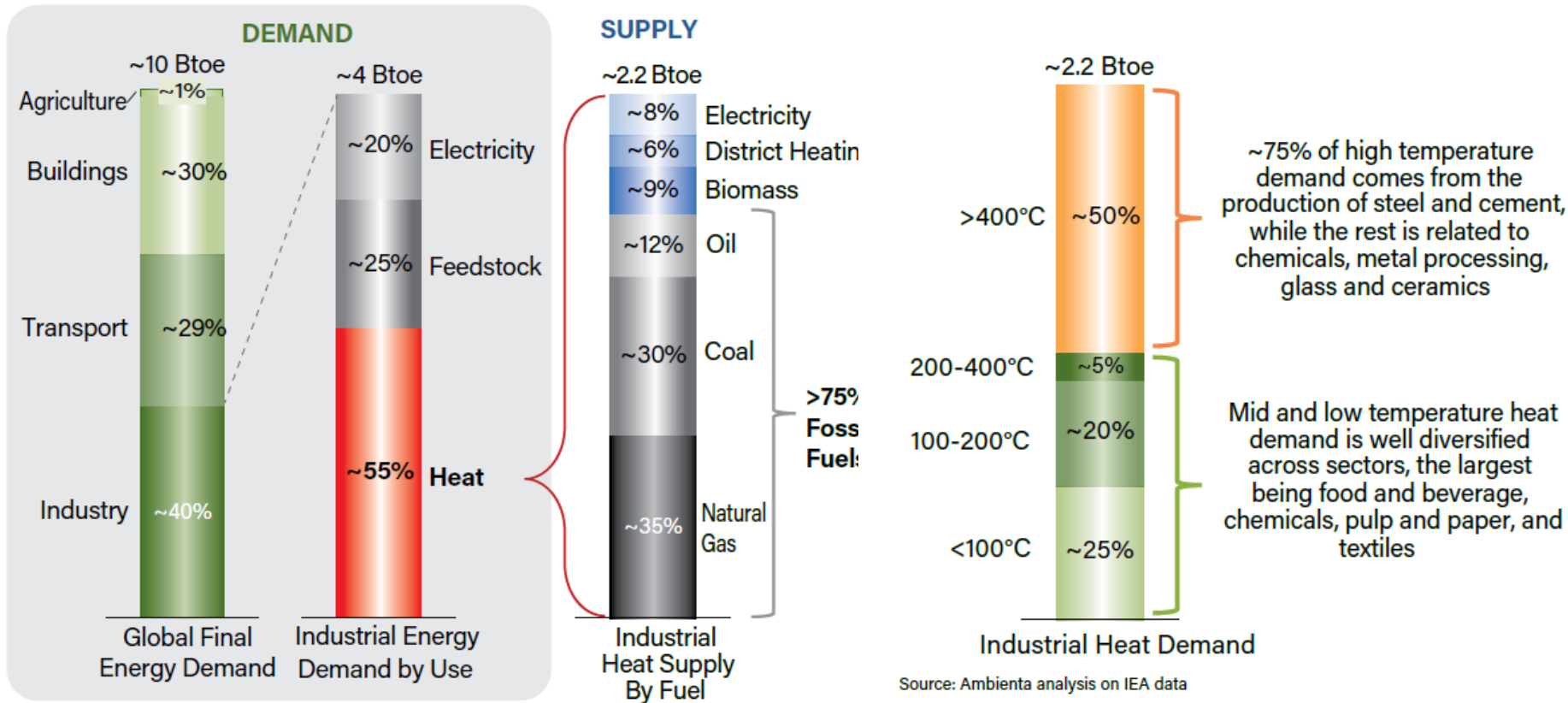
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# Industrial Heat Demand and Supply



Source: Ambianta analysis on IEA and McKinsey Data

The huge impact of the Industrial heat:

- **>20%** of global final energy demand
- **>10%** of the world's CO2 emissions



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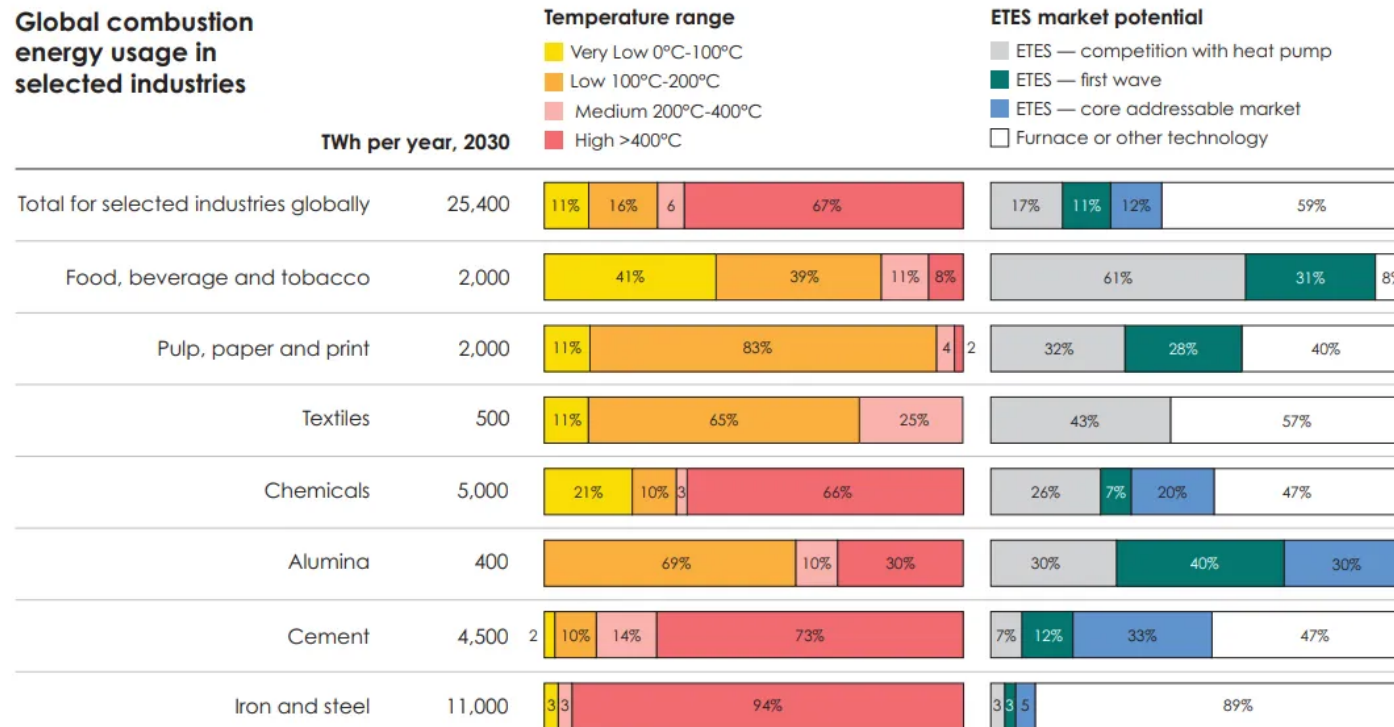


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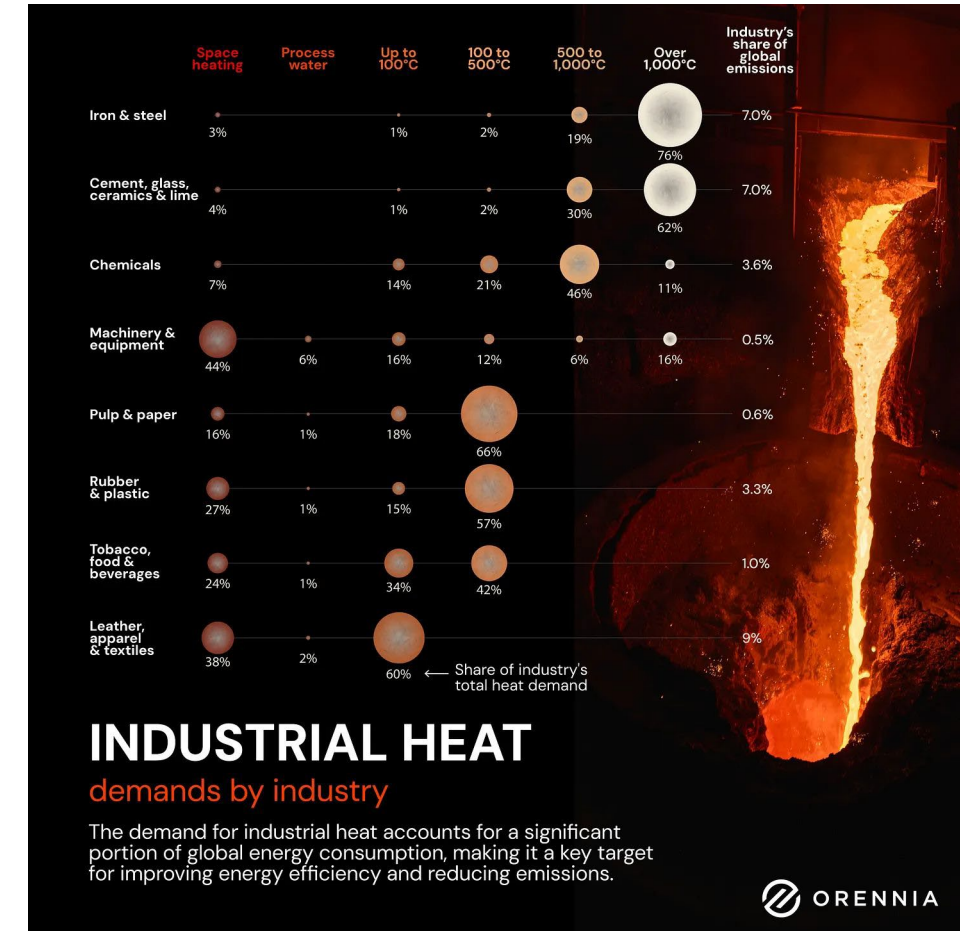
# ETES Application for Industrial Heat Decarbonization

## Global combustion energy usage in selected industries



Note: Only considers energy usage from fuel combustion, not emissions from process, power sector and transportation energy consumption.  
 Source: UNFCCC data set (2021), except for Australia (2019); International Aluminum Institute; World Steel Association; Eurostat; EuraTEX; USGS; Petrochemical Europe; EU heat profile is derived from EU Joint Research Center; US heat profile is derived from Decarbonizing Low-Temperature Industrial Heat in the U.S., Energy Innovations, 2023

Image credit: Systemiq / Breakthrough Energy



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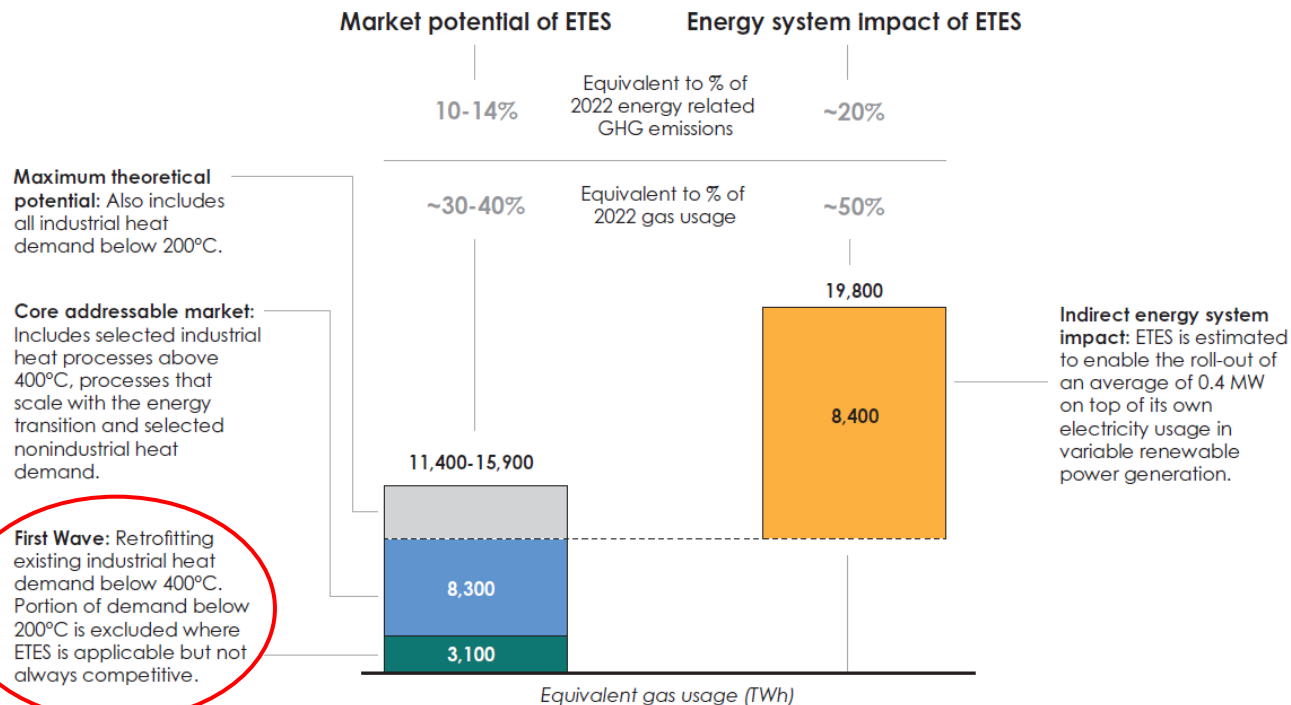


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# ETES Potential Market and Services to Power Systems

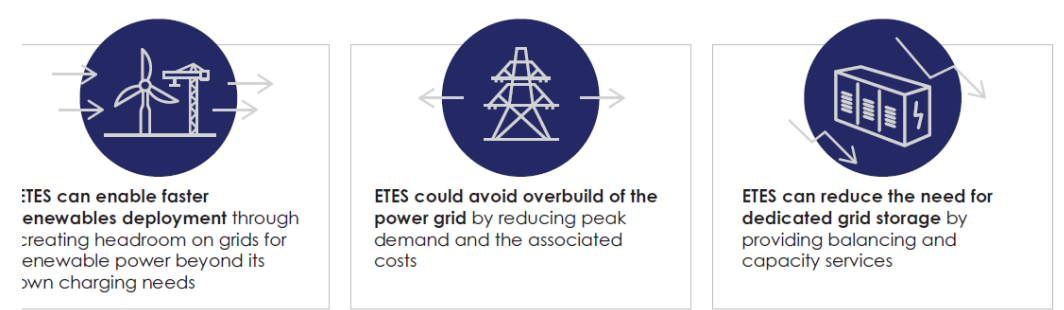


**First Wave:** Retrofitting existing industrial heat demand below 400°C. Portion of demand below 200°C is excluded where ETES is applicable but not always competitive.

An overview of the processes included in the market potential and calculation of the energy system impact can be found in Figure 5 and the Technical Appendix (downloadable from <https://systemiq.info/etes>).

Source: UNFCCC data set (2021) — except for Australia (2019), International Aluminum Institute, World Steel Association, Eurostat, EurATEX, USGS, Petrochemical Europe; Mind the Gap report by ETC, Fossil Fuel Role in Energy Transition report by ETC, EU heat profile is derived from EU Joint Research Center; US Heat Profile is derived from Energy Innovations' Decarbonizing Low-Temperature Industrial Heat in the U.S.; Understanding the Role and Design Space of Demand Sinks in Low-carbon Power Systems (Jenkins, 2021)




## How ETES can support the transition to a net-zero energy system



3: Jenkins and Van der Jagt, Understanding the Role and Design Space of Demand Sinks in Low-carbon Power Systems, 2021; Net-Zero Heat, LDES Council, 20XX, and Driving to Net-Zero Industry through Long Duration Energy Storage, LDES Council, 2023

Electrifying industrial heating systems globally will require investments **above € 1 Tn**

# ETES Technologies and Manufacturers

	SENSIBLE HEAT	LATENT HEAT	THERMOCHEMICAL HEAT
How it works	Increases temperature of a solid or liquid medium	Changing material phase	Endothermic and exothermic chemical reactions
Temperature range	<0 to 700°C <i>In progress to reach more than 1,500°C</i>	<i>In progress to reach 1,600°C</i>	<i>In progress to reach 900°C</i>
Storage duration	Intra day to days (or months at lower temperatures)	Intra day to days	Intra day to months
TRL	Commercially available	R&D to commercial available	Nascent
Providers (non exhaustive)			

Source: Company websites; *Net-zero heat: Long Duration Energy Storage to accelerate energy system decarbonization*, LDES Council, 2023.



# Key Messages

- ❑ **ES is a game changer**, the key enabler of an energy transition based on electrification and VRE (wind, PV). ES and VRE grow up together convergently. By 2030, worldwide, VRE capacity will growth **3x**, ES **6x**.
- ❑ When VRE penetration will overtake **50%**, the needs for ES will growth with a **slope 100 times higher**. Es. VRE penetration of 70% (12x, i.e. **2050**) → ES x28 (!), i.e. **hundreds thousands GWh**. Is BESS+PH enough?
- ❑ **Industrial heat** absorbs **20%** of global final energy demand and **75%** of it is supplied by fossil fuels. **ETES can provide the power system with ES services** (balancing, flexibility, time-shifting, etc.) **absorbing excess VRE production** (VRE penetration >50%) **while decarbonizing industrial heat**.
- ❑ ETES potential market is estimated **3,100 TWh** (electrified heat demand) worldwide in a **1<sup>st</sup> phase (<400 °C)**, about **8,600 TWh** in a **2<sup>nd</sup> phase (>400 °C)** plus **other 8,400 TWh of additional VRE** enabled by ETES itself, for a **total potential of almost 20,000 TWh**, the same order of magnitude of today's global electricity demand.
- ❑ ETES technologies are **ready** (TRL 9), competitive, **free of critical materials**, recyclable/circular, modular, site unconstrained, scalable, easy to install, with long life (>30 years) and long duration storage capacity.
- ❑ The needs for energy storage in power system (VRE >50%) and the excess of (free) renewable electricity are ETES' drivers in the long run.



**THANK YOU**

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# Main Heat Electrification Technologies and Benefits

### Industrial Heat Pumps




**Heat Pump**

- Up to 170 °C
- Up to 300-700% efficiency
- Can use waste heat as input to reach high temperatures and high efficiencies

### Resistive Heating


Metallic Resistance




**Electric Boilers**

- Up to 2,400 °C
- 99% efficiency
- Can generate heat directly in water (electric boilers)


### Electromagnetic Heating




Induction



Microwave




Infrared




Radio Wave

- Up to 3,000 °C
- Up to 90% efficiency
- Is significantly faster than fossil fuel heating

### Electric Arc



**Plasma Torches**

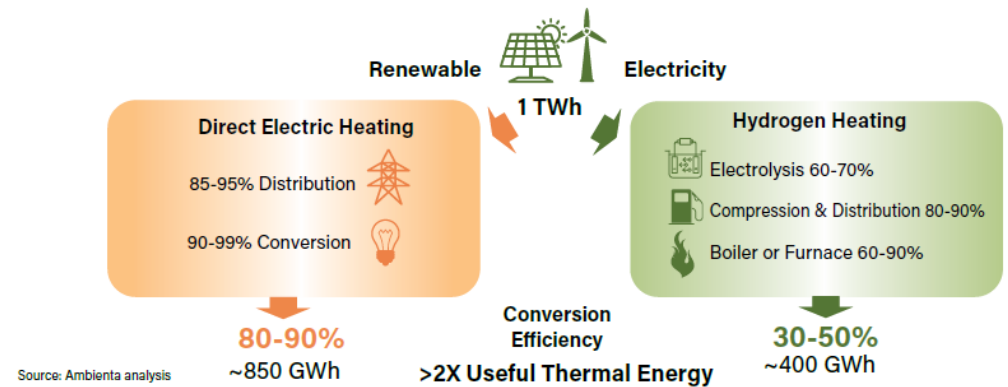


**Electric Arc Furnace**

- Up to 20,000 °C
- Up to 90% efficiency
- Can reach higher temperatures than fossils

Source: Ambienta analysis

## Direct vs. Indirect (Hydrogen) Electrification Efficiency



## Kg CO<sub>2</sub>/kWh of Useful Thermal Energy

