Thermal Storage

Renewable Thermal Technology

RENEWABLE
THERMAL
COLLABORATIVE

Thermal energy storage balances the mismatch in supply and demand for heating by offsetting differences in time and quantity of heat production

Source of thermal energy

Low-cost intermittent electricity or waste heat sources supply thermal energy

Thermal energy storage

Thermal battery stores heat at elevated temperatures for several hours to days

Thermal energy release

Thermal storage releases heat for useful industrial processes

Several forms of thermal energy storage are currently commercially available or under development

Sensible

Solid

- **Materials:** rock, sand, ceramic, metals
- **Temperature:** Up to 1,500ºC delivered
- **Cost:** Low
- **Applicability:** Large utility or industrial scale thermal storage
- **Maturity:** High

Focus of this fact base

Liquid

- **Materials:** water-based, thermal oils, molten salt, molten metal
- **Temperature:** Up to 1,600ºC delivered
- **Cost:** Medium
- **Applicability:** Space and water heating for buildings or concentrated solar power
- **Maturity:** Medium high

Latent (phase change)

Solid-Liquid

- **Materials:** organic solutions, inorganic solutions
- **Temperature:** Up to 120ºC delivered
- **Cost:** High
- **Applicability:** High heat storage in limited volume or rapid heat transfer required
- **Maturity:** Medium low

Others

- **Materials:** liquid-gas, solid-gas, solid-solid crystal
- **Temperature:** Up to 175ºC delivered
- **Cost:** High
- **Applicability:** High heat storage in limited volume or rapid heat transfer required
- **Maturity:** Low

Source: Advanced cooling technologies

Heating using stored thermal energy is applicable to all but the highest temperature applications

Key properties of electric resistance plus thermal energy storage heating include:

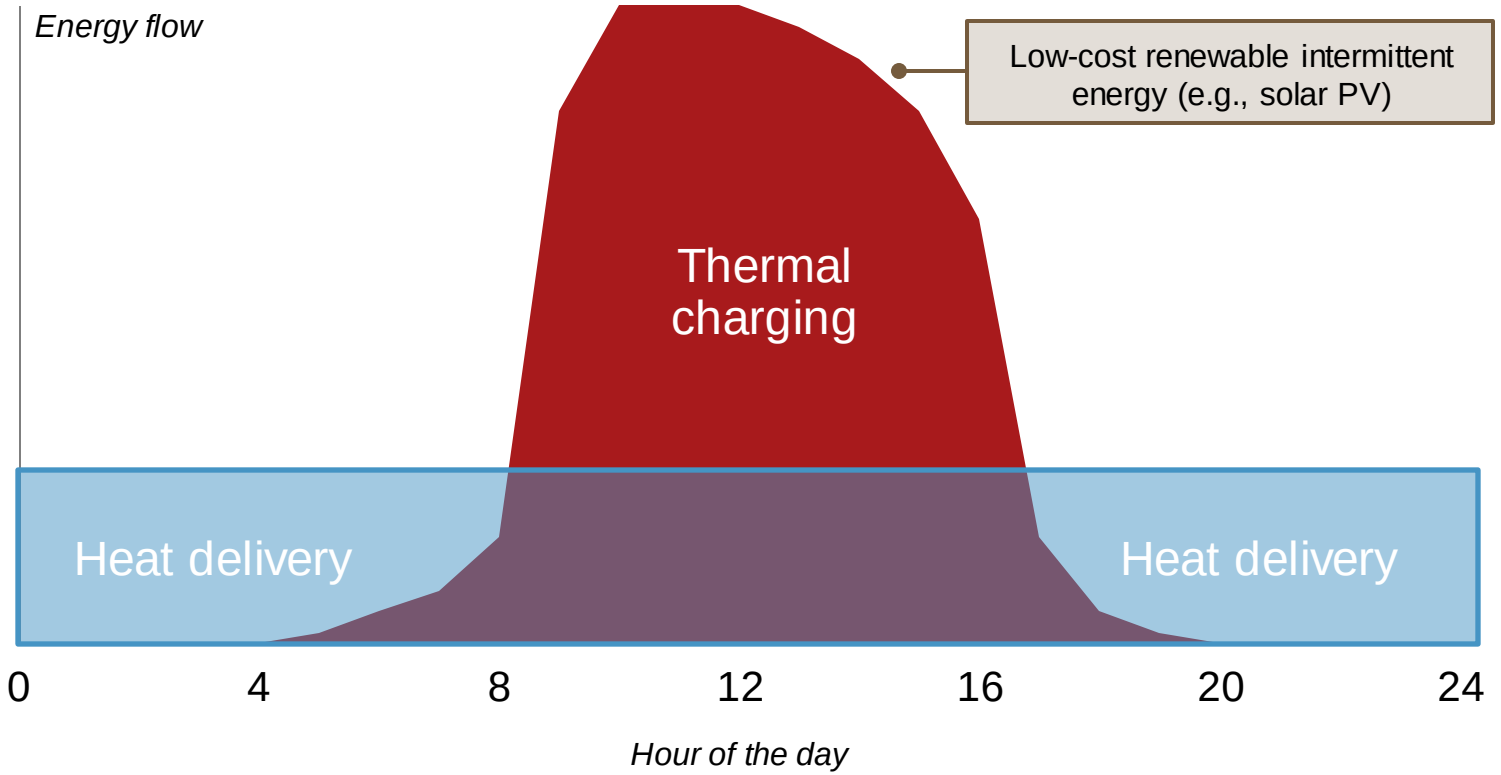
- 1,500 ºC max. temp. delivered
- High heat flux
- Heats all materials

These properties align with requirements for several process heating applications.

Industry Sector	Process Heating Applications						Relevant Equipment
Refineries	Distillation	Reactors					Boiler, process heater
Chemicals	Distillation	Drying	Reactors				Boiler, process heater, furnace, air heater
Iron & steel	Pelletization	Hot rolling	Basic oxygen furnace	Blast furnace			Boiler, furnace
Food	Drying	Pasteurizing	Boiling	Sterilizing	Washing	Cooking	Air heater, boiler, oven
Paper	Stock steaming	Drying	Wood processing	Evap. & chem. prep.	Lime calcination		Air heater, boiler, oven, furnace
Cement	Pre-heating & treating	Melting furnace	Forming	Annealing	Kiln combustion		Furnace

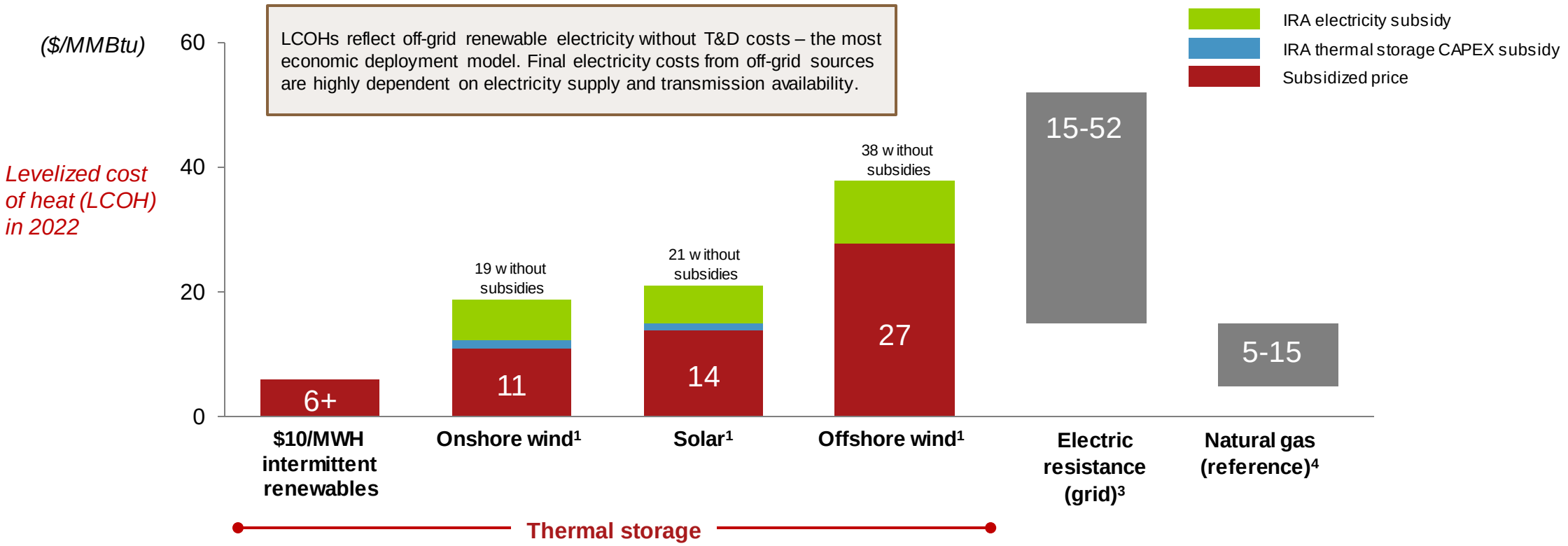
Not applicable | Potentially applicable | Currently deployed

Intermittency of low-cost renewable or waste energy is the primary driver of thermal energy storage



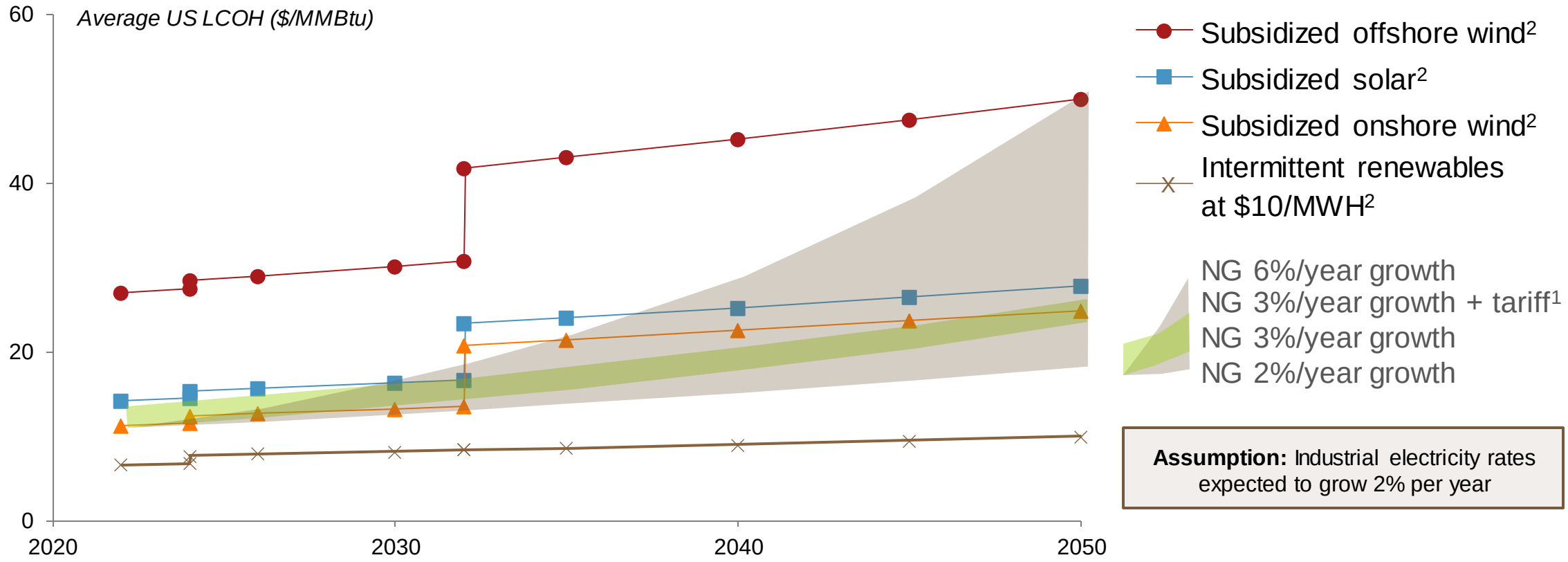
Time-of-use tariffs and other time shifting electricity price signals are likely required to drive the economic viability of thermal energy storage

Thermal energy storage using low-cost intermittent electricity has potential to be cost competitive with natural gas heating in many circumstances



1. Thermal storage combined with electric resistance without T&D costs and with 30% IRA investment tax credits; 2. Thermal storage combined with grid electricity at industrial retail prices in May 2022 from EIA; 3. Range of industrial electricity prices in May 2022 from EIA; 4. Range of industrial natural gas prices in May 2022 from EIA

Thermal storage with electric resistance can by economically competitive with natural gas depending on source and cost of renewable electricity



Assumption: Industrial electricity rates expected to grow 2% per year

1. Based on $51/tonne CO2 social cost of carbon; 2. Thermal storage combined with electric resistance without T&D costs and with 30% IRA investment tax credits

Renewable thermal collaborative (RTC) includes three thermal storage sponsor companies

BRENMILLER ENERGY

- Based in Israel, with projects worldwide include the US
- Charges thermal battery using electricity, biomass, flue-gas, heat recovery, or a combination of these inputs
- Reaches temperature up to 750ºC
- System is modular and is fully integrated with heat exchangers and a steam generator

ANTORA

- Based in California
- Uses intermittent low-cost power to charge thermal energy storage, provides on-demand industrial heat and power
- Reaches temperature up to 1,500ºC
- Rapid charging modular system

RONDO

- Based in California, with first operational customer in August 2022
- Uses intermittent low-cost power to charge thermal battery, provides on-demand industrial heat and power
- Reaches temperature up to 1,500ºC
- Achieves 98% efficiency with common insulation materials, and loses 2% energy per day

Thermal energy storage for industrial heating has many advantages, but faces several major barriers to adoption

Advantages

Bridges gap during periods of low intermittent energy supply

Utilizes low-cost zero-emissions intermittent energy

Can reach most temperatures required for industrial processes

Provides grid service as dispatchable demand source

Barriers

Potentially high capital costs

Not a standalone heating technology, requires heating input

Integration of energy storage into industrial processes required

Current low awareness and maturity of technology

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