EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Thermal Energy Storage

Cost-effective avoidance of plant cycling to enable economic carbon capture

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ARPA-e Flexible Carbon Capture Technologies for a Renewable-Heavy Grid

Today's Fossil Plants Are Being Run Flexibly

- Intermittent renewables are driving fossil plants to provide grid support
  - Damage from startup, shutdown, and cycling operations can occur
  - Shorter lifetimes, higher emissions per kWh, and lower profitability
  - More difficult for carbon capture operations
- If substantial energy can be stored:
  - Plants can operate during low/negative pricing periods without exporting power
  - Electro-chemical battery technology can be used; however, the cost of storage can be prohibitive at **$1300–2100/kW** for a 4-hour system*
  - Due to the high cost relative to incremental value, battery technology is more challenging for longer durations (e.g., 10+ hour storage)

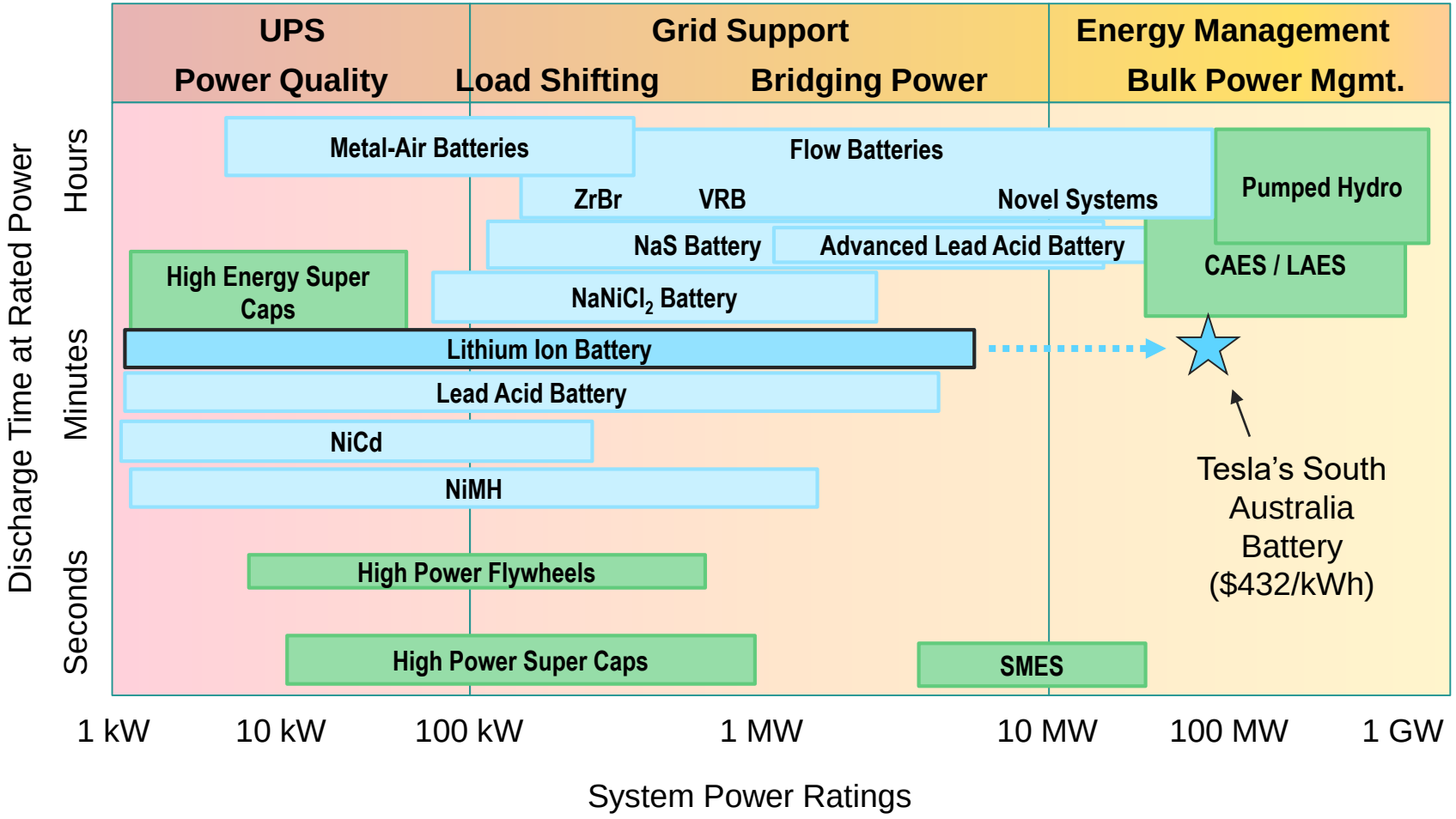
**Energy Storage Technology and Cost Assessment. EPRI, Palo Alto, CA: 2018. 3002013957*

Non-battery bulk energy storage may deliver lower-cost options

Energy Storage Options – Power vs. Discharge Duration

Battery

Non-Battery



Energy Storage Options – Power vs. Discharge Duration

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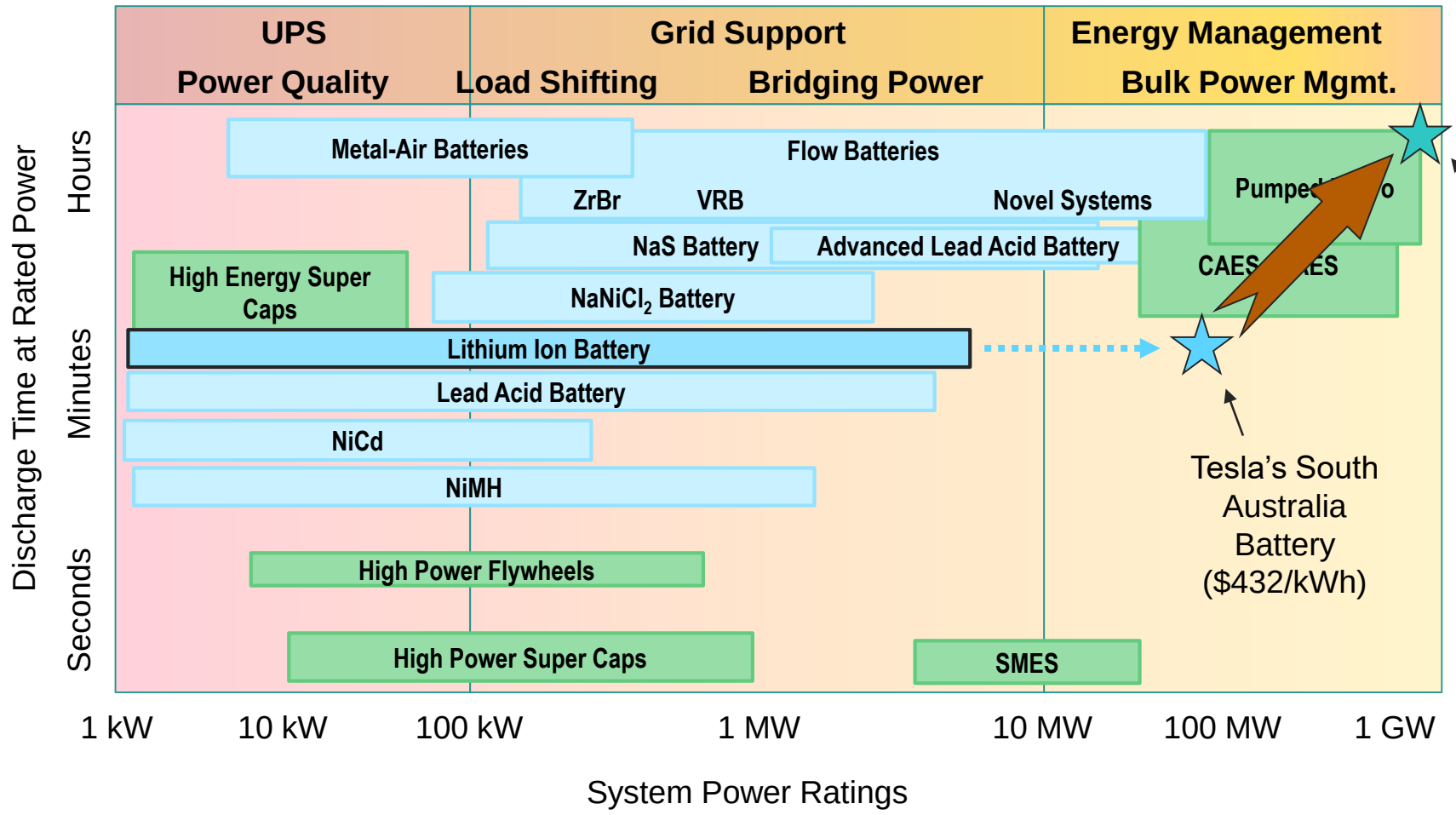


Bad Creek Pumped Hydroelectric Storage

Tesla's South Australia Battery ($432/kWh)

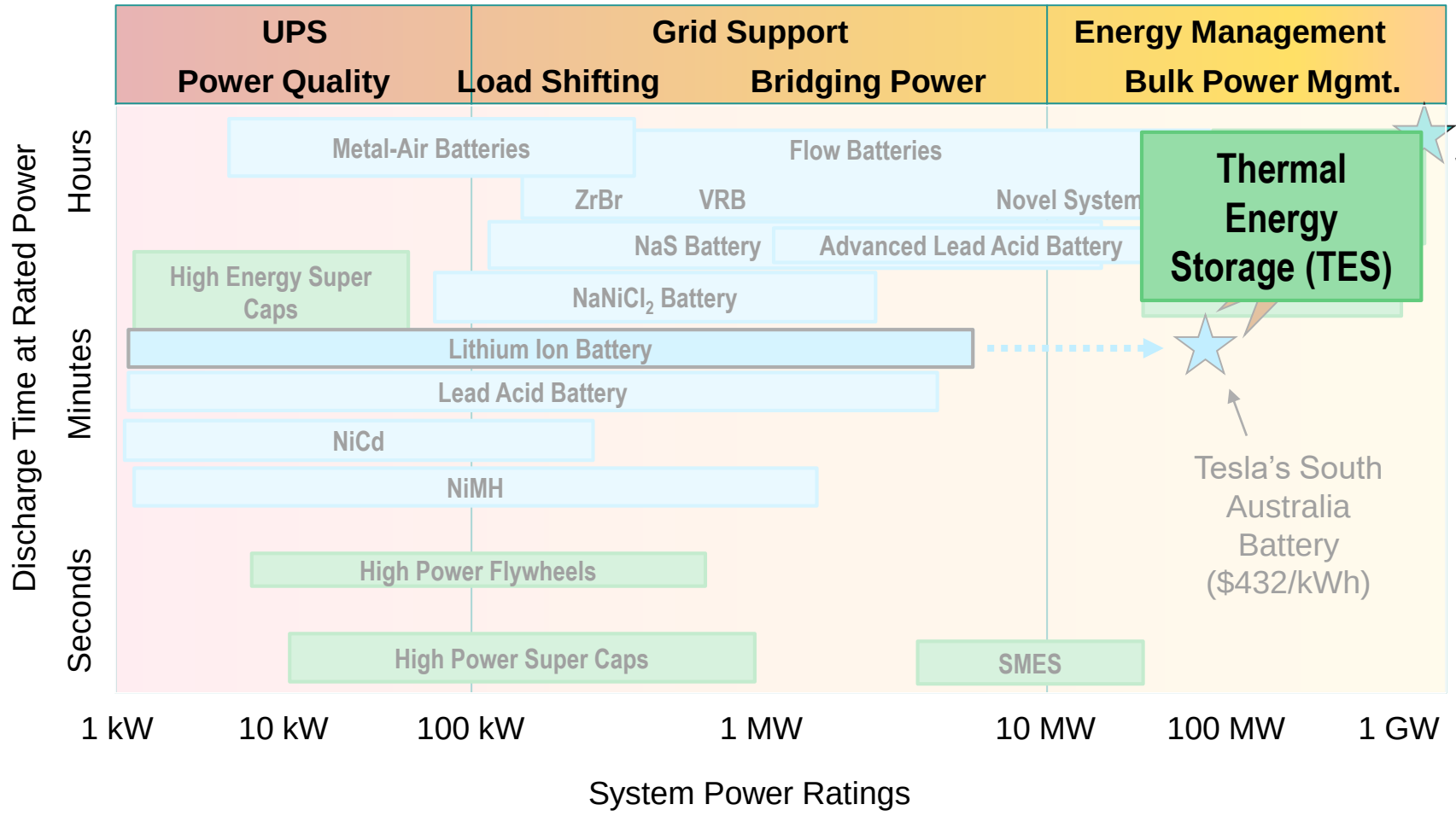
320x larger

Can a different type of bulk energy storage be cheaper than a battery?

Energy Storage Options – Power vs. Discharge Duration

Battery

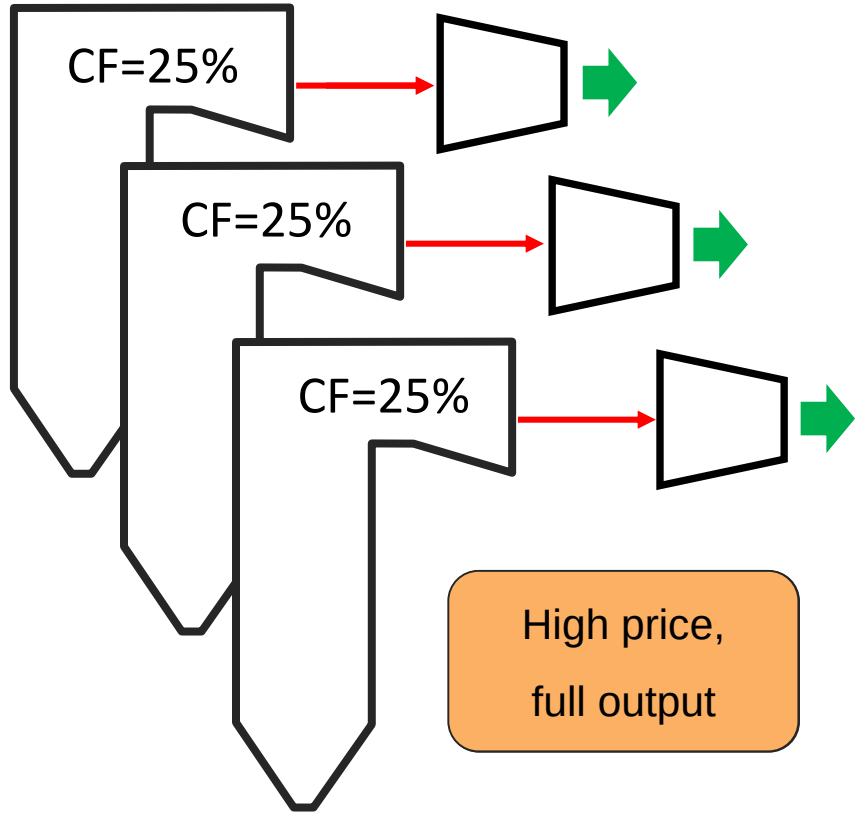
Non-Battery



Can a different type of bulk energy storage be cheaper than a battery?

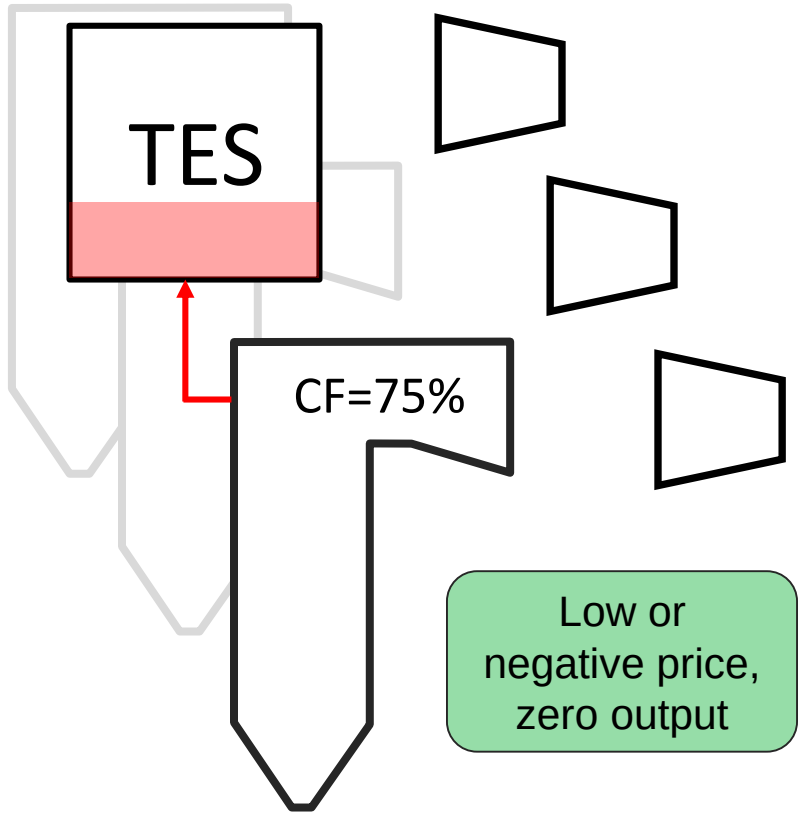
How Can TES Be Deployed?

- Consider a power facility with three units (of varying vintage) operating at low capacity factor and two of which are scheduled to be retired
- Renewable intermittency results in:
  - Boilers incur frequent starts and stops
  - Rapid ramping requirements
  - Overall low capacity factors
  - Higher O&M costs
  - Increased emissions per MWh exported



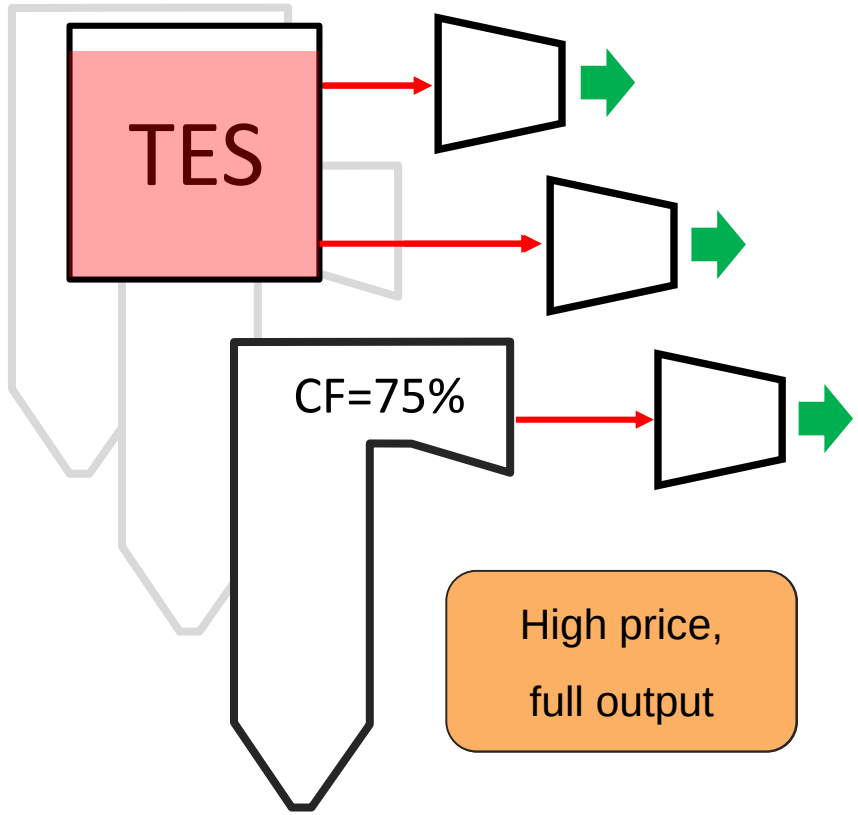
How Can TES Be Deployed?

- By providing steam to TES during periods of low grid prices, the unit remains operational, avoiding shutdown and restart

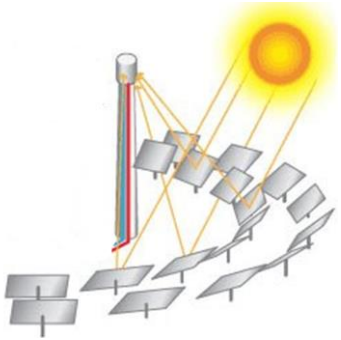


How Can TES Be Deployed?

- By providing steam to TES during periods of low grid prices, the unit remains operational, avoiding shutdown and restart
- When energy prices increase, steam from the boiler can be diverted to the unit steam turbine AND the TES units can provide steam to the turbine-generators of the units with retired boilers
- All three units generate power when needed



Further Application of TES



Concentrated solar

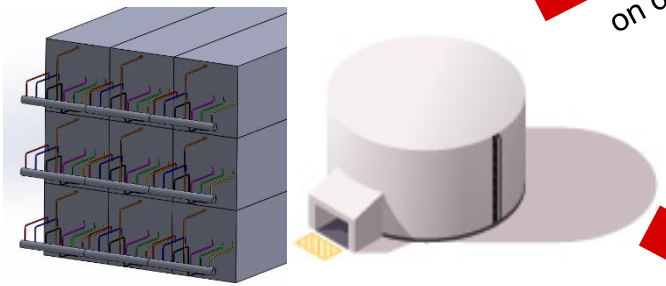
Nuclear unit

Solar PV, wind

Steam constant

Electricity heat intermittent

Heat intermittent



Thermal Energy Storage

Steam on demand

Steam/ sCO_2 cycle

Electricity

Grid services

Coal unit with CCS

CO_2

Steam constant

Flue Gas constant

Steam

Steam constant

Industrial heating load

24/7 demand

constant

CO_2

EOR or Storage

Gas unit with CCS

TES Materials

- Low-cost materials critical for long duration
- Three categories:

Sensible Heat	Latent Heat	Heat of Reaction
Ceramics, concrete, glycol, molten nitrate and fluoride salts, oil, rocks, sand, and water	Aluminum and magnesium alloys, elemental silicon, hydrocarbon waxes, steam accumulators, sulfur, and water/ice	Carbonate CaO, MgO, and CO_2, hydration/dehydration, metal oxides/hydroxide, and thermochemical endothermic and exothermic reactions

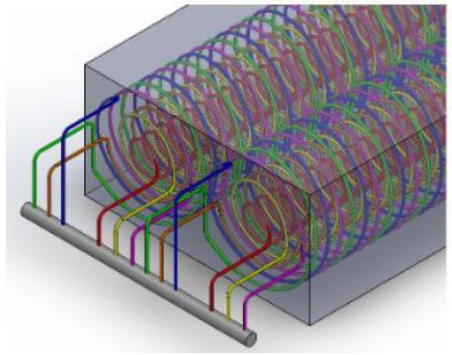
- Applications:
  - Adiabatic compressed air, liquid air (compression heat, cold)
  - Direct thermal (store heat from power plant, dispatch when needed)
  - Pumped heat energy storage (AC-AC storage, better round trip efficiency)
  - Resistive heating (low-cost AC-AC storage, limited round-trip efficiency)

Concrete TES

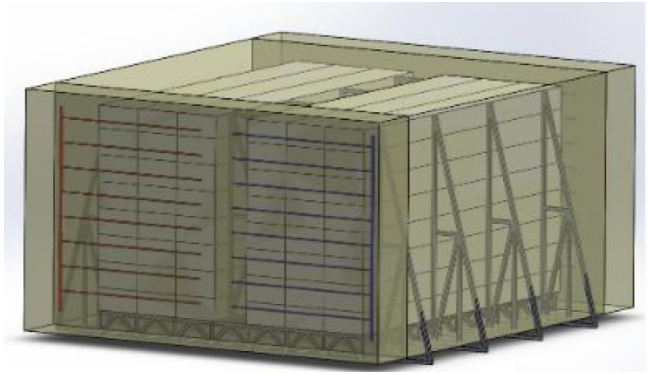
- Solid ‘thermocline’ structure used to store thermal energy
- Low-cost material **$68/tonne**
- Modular system (41 ft [12.5 m])
- Road/rail transportable

3-block, flue gas-heated testing modules

- Steam tubes embedded into concrete monoliths as coils – conductive heat transfer only
- No moving parts
- Pilot planned under FOA-1989



Tube internal arrangement



10 MWh-e scale pilot plant

Images courtesy of Bright Energy Storage Technologies

Initial Conclusions from EPRI's Analysis

- TES effective round-trip efficiency can be high as the thermal energy was never converted to power before discharge
- Capital cost is on the order of **$100/kWh,** i.e., 3 to 4 times less than Li-ion batteries today
- TES systems do not degrade with cycling – longer plant life
- TES can enable use of fossil plants with CO_2 capture installed at 100% production with 24/7 operation regardless of grid price

Additional research needed to validate technology and costs

Together...Shaping the Future of Electricity