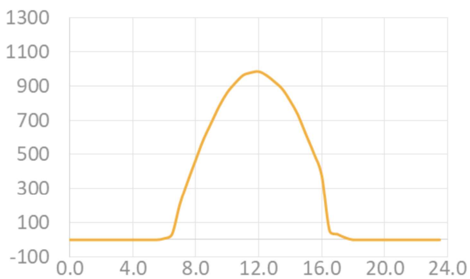
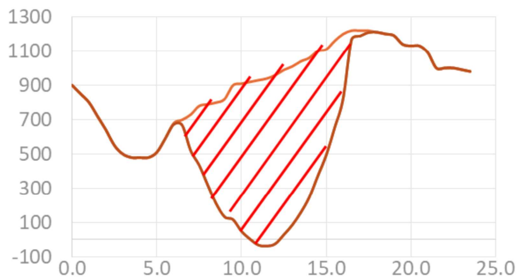
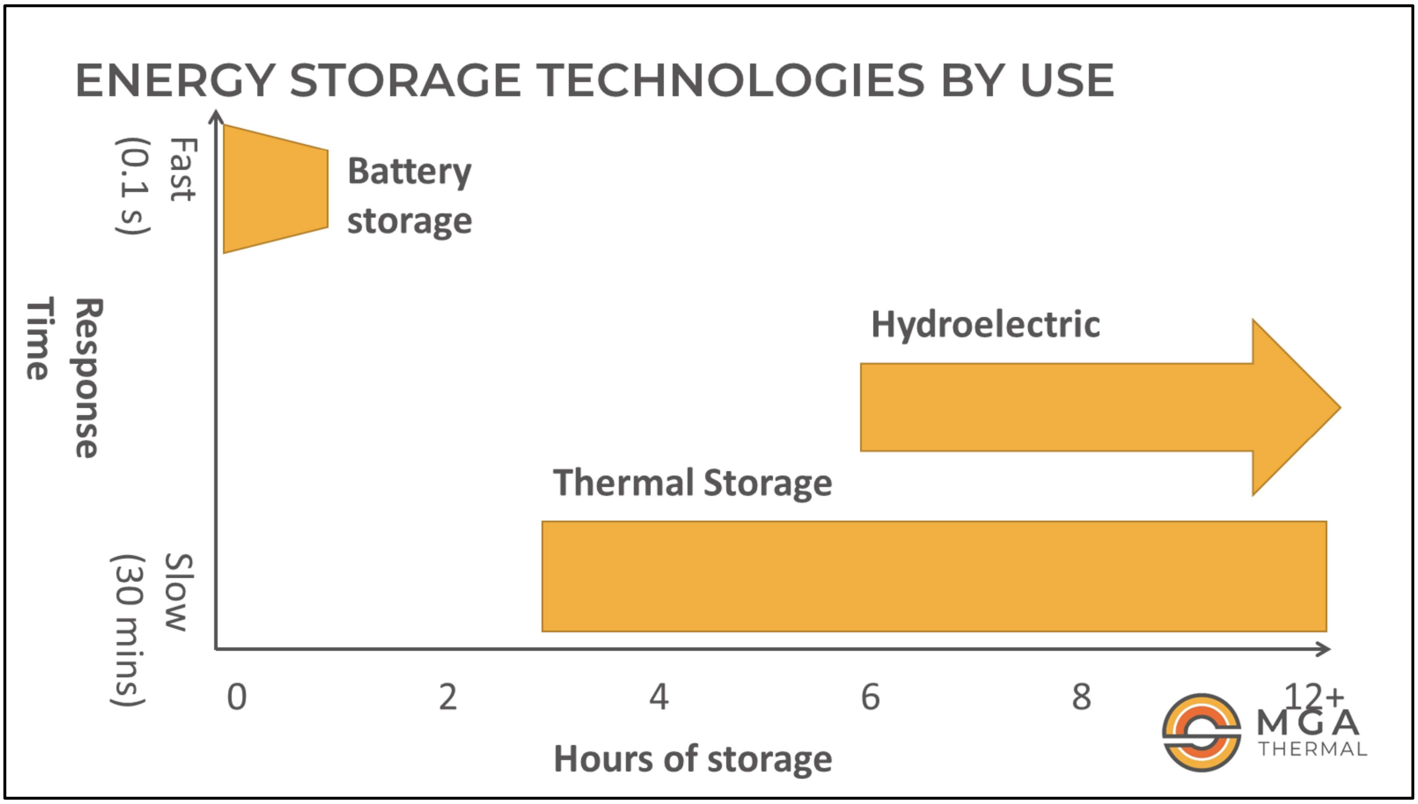

MGA
THERMAL

THE PROBLEM – A LOOMING ENERGY CRISIS





- Renewable energy is now far cheaper than fossil fuel generated energy (capital cost, operating cost, decommissioning cost)
- Solar energy production LH graph, wind is up and down all day
- Energy demand in orange RH graph
- Fossil fuel plants, trying to produce the brown curve, sometimes negative….
- Everybody has an energy storage problem
- We are working with a European JV to put these two together and create the ideal transitional system


ENERGY STORAGE TECHNOLOGIES BY USE
Response Time
Fast (0.1 s)
Slow (30 mins)
Battery storage
Hydroelectric
Thermal Storage
0
2
4
6
8
12+
Hours of storage
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WHY THERMAL ENERGY STORAGE?

- Widespread form of energy
- Low cost materials to store
- Not location sensitive
- **Physical inertia for grid frequency control (spinning reserve)**

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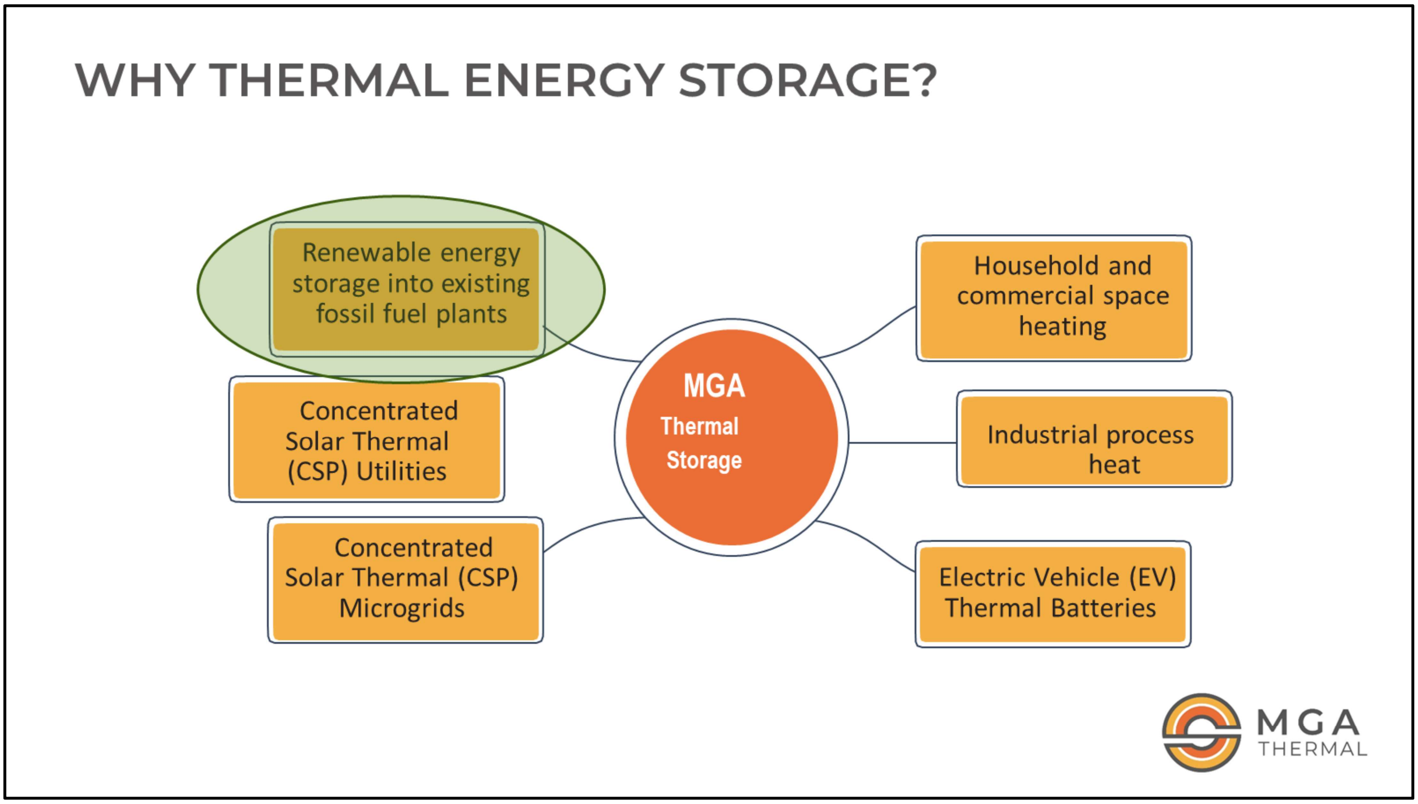
- All energy used by humans starts as, passes through or ends up as heat
- 52% of global energy use is as heat

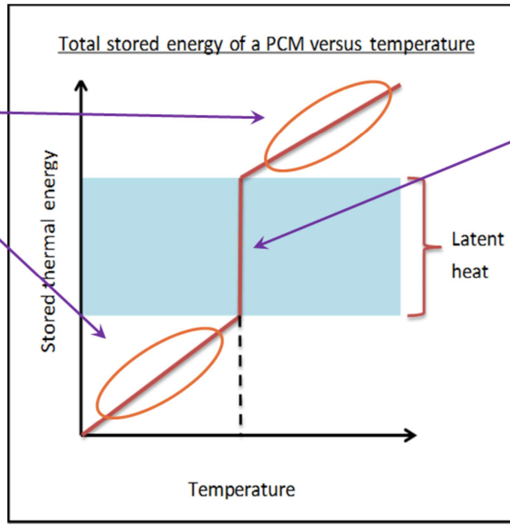


- The focus on heat means we have many market segments to work in
- Our first traction is in the fossil fuel power plant retro-fit market

THE TWO APPROACHES TO TES

Sensible Heat storage

Low cost materials
- Gravel
- Molten Salt
- Concrete



Latent Heat storage (PCMs)

- Eutectic salts
- Wax
- Ice
- Metals and alloys

High energy density

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- Heat can be stored as temperature rise (sensible heat) in a solid, sensible heat in a liquid, or as latent heat due to a phase change
- Current thermal storage options include low cost materials such as concrete, rocks, ceramics etc. but the state of the art are the molten salt based methods – 2 tank molten nitrate salts being the industry standard

Market Leader – Molten Salt Storage

Infrastructure intensive – high capital cost

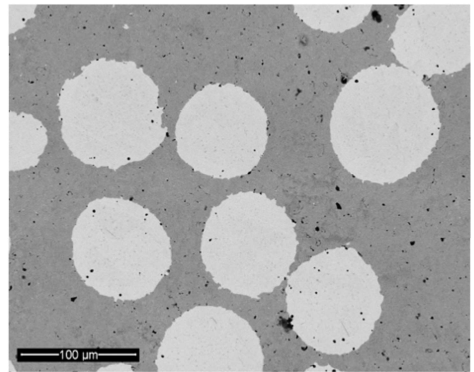
Inefficient due to parasitic losses

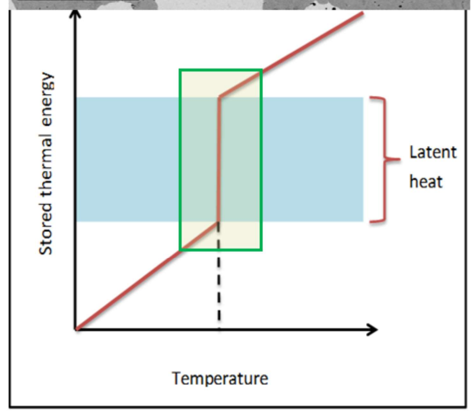
Considerable operating and maintenance costs

BUT, they were first to market so they have an advantage in the CSP market

MGA TES Materials

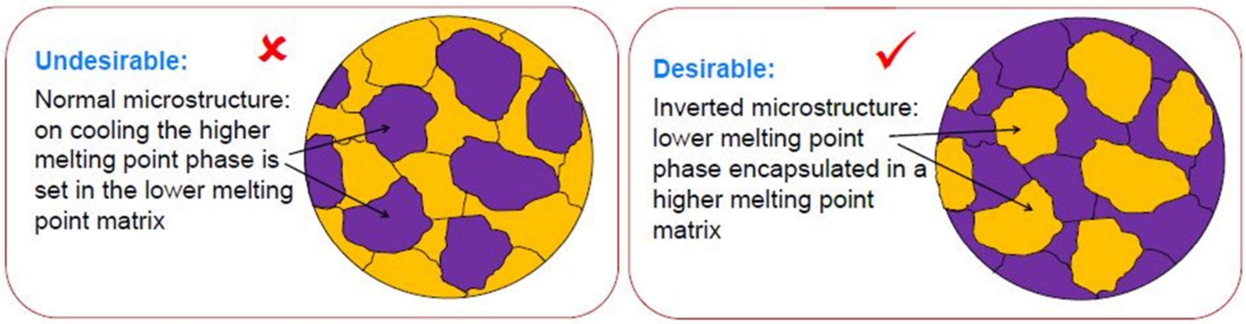
An engineered microstructure with metal PCM particles in a ↑ T_m metallic matrix:





- Miscibility gap alloys or MGA use an engineered microstructure to trap ~50 vol% of metal Phase Change Material particles within a metallic or semi-metal matrix with which they are immiscible
- In the above image, the spherical PCM particles appear brighter than the matrix.
- During heating, energy is stored as sensible heat, the latent heat, then more sensible heat
- We can target a particular operational temperature using different particle materials
- Energy density is typically in the range 0.34 – 2.25 MJ/L

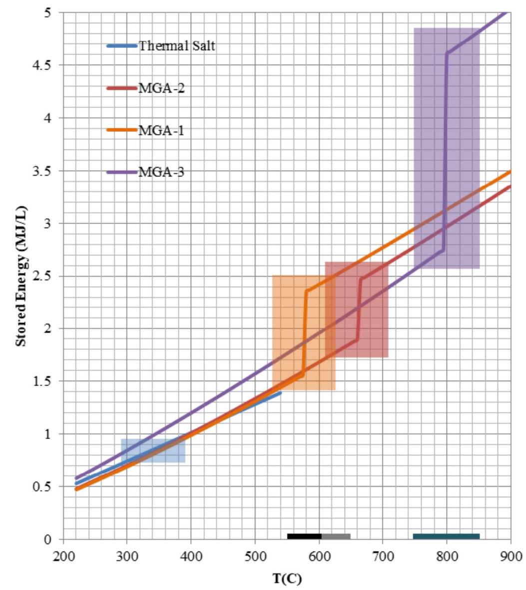
Our IP – The Inverse Microstructure



- Our IP concerns the deliberate manipulation of microstructure to make a material perfectly suited for thermal energy storage

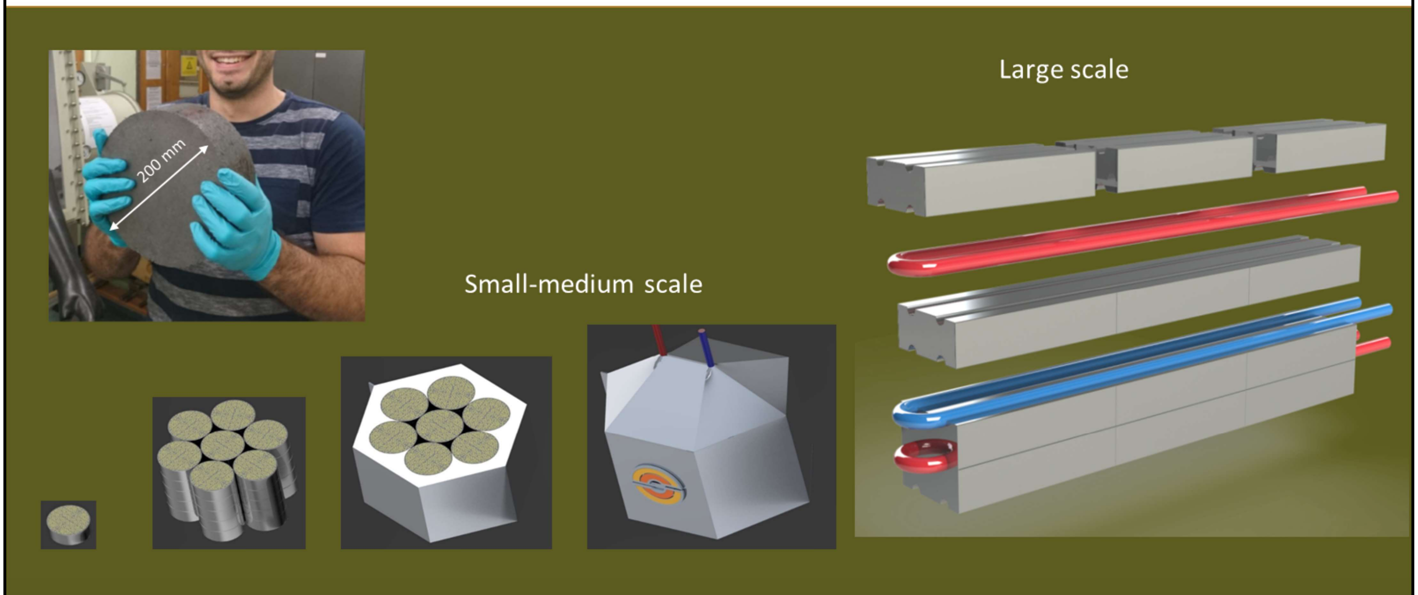
MGA Properties

- Macroscopically solid (no freeze risk or parasitic energy cost)
- 1/10 cost of electrical batteries (as little as $22/kWh)
- Higher temperatures
- High thermal conductivity (50-200W/mK)
- Combined latent and sensible heat – higher energy density
- Narrow band of temperature if desired
- Long life
- Common and safe starting materials
- 100% recyclable at end of life
- Low operating risk
- Multiple applications

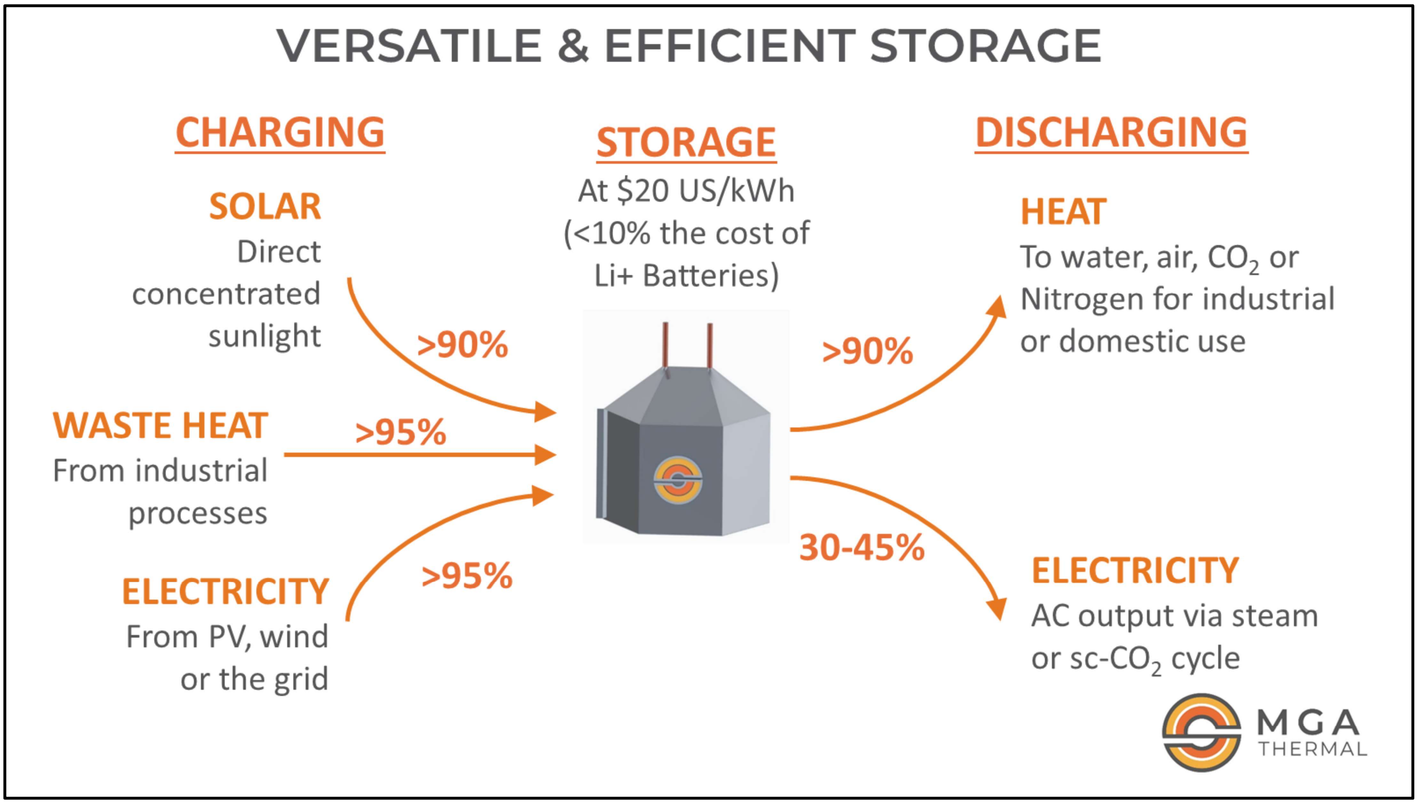


- Rectangles here show stored energy (vertical) in a temperature band +/- 50 C around the phase change
- Note that the molten salt rectangle is for the most commonly used version of this technology
- Bands on the horizontal axis show the inlet temperatures of various thermodynamic power cycles (sub-critical and supercritical steam Rankine cycles, Brayton cycles and Stirling cycles)

How Can We Manufacture and Deploy?

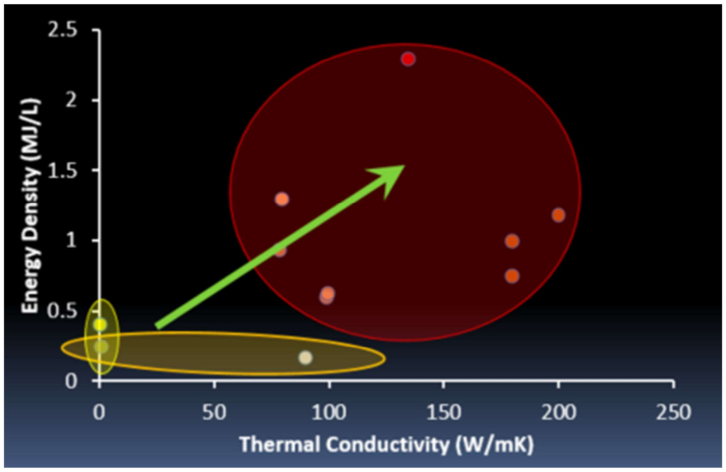


- We have a new solid material class which is manufactured into ‘blocks’ by a modified powder metallurgy process
- Blocks are stacked into ‘modules’, insulated and integrated with energy source and sink
- Stores and delivers energy as heat to run a power plant
- 1/10 of the cost of batteries
- Scalable
- Modular
- Reliable
- Safe



- Heating can be by a heat transfer fluid, electrical resistance or direct solar irradiation
- Energy extraction is via direct conduction and/or a heat transfer fluid (Water/Steam, CO_2 etc.)

Comparison to Sensible Heat Storage Materials



Molten Salts

- 12-24% parasitic losses
- Freeze risk
- Very complex plant design
- Corrosive/erosive
- Accelerant
- Temperature limited

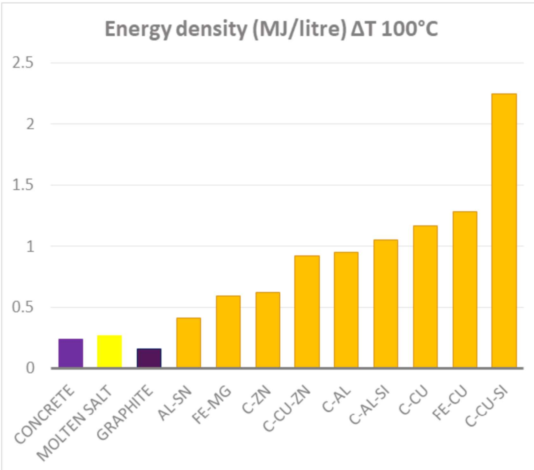
Concrete, rocks, sand

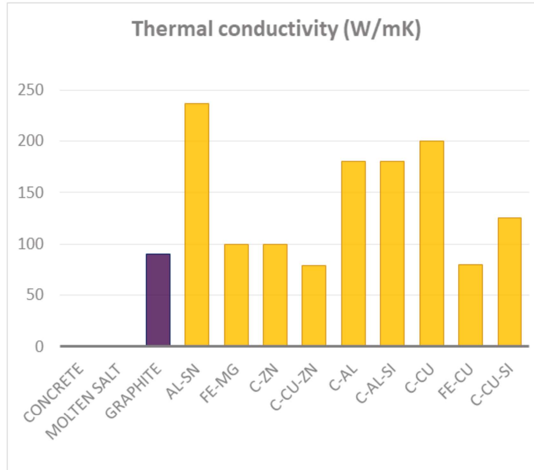
- Very poor heat transfer (overcapacity, infrastructure)
- Temperature limitations
- Heat quality degrades with ↓T

Graphite

- Relatively low energy density
- Heat quality degrades with ↓T

- The ideal thermal storage material is up and to the right on this diagram because it enables great simplification in the overall plant design and hence cost
- Molten salts and concrete (lower left) are quite poor (note depends on the temperature range used)
- Graphite has good conductivity but low energy density at steam turbine temperature
- MGA (red ellipse) have a good combination





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- Some more detailed comparison of MGA properties with sensible heat storage media

Phase Change Systems (non-MGA)

Non-metals

- Very low thermal conductivity (heat transfer enhancement required, limitations on scale)
- Shrinkage displacement disrupts thermal contact (reduced conduction)
- Shrinkage/expansion displacement imposes large stresses and causes failures
- Safety (rupture of tanks)
- Temperature limitations (except halide salts)

Metals (additional factors only)

- Containment
- Safety
- Low state of development (despite some claims)

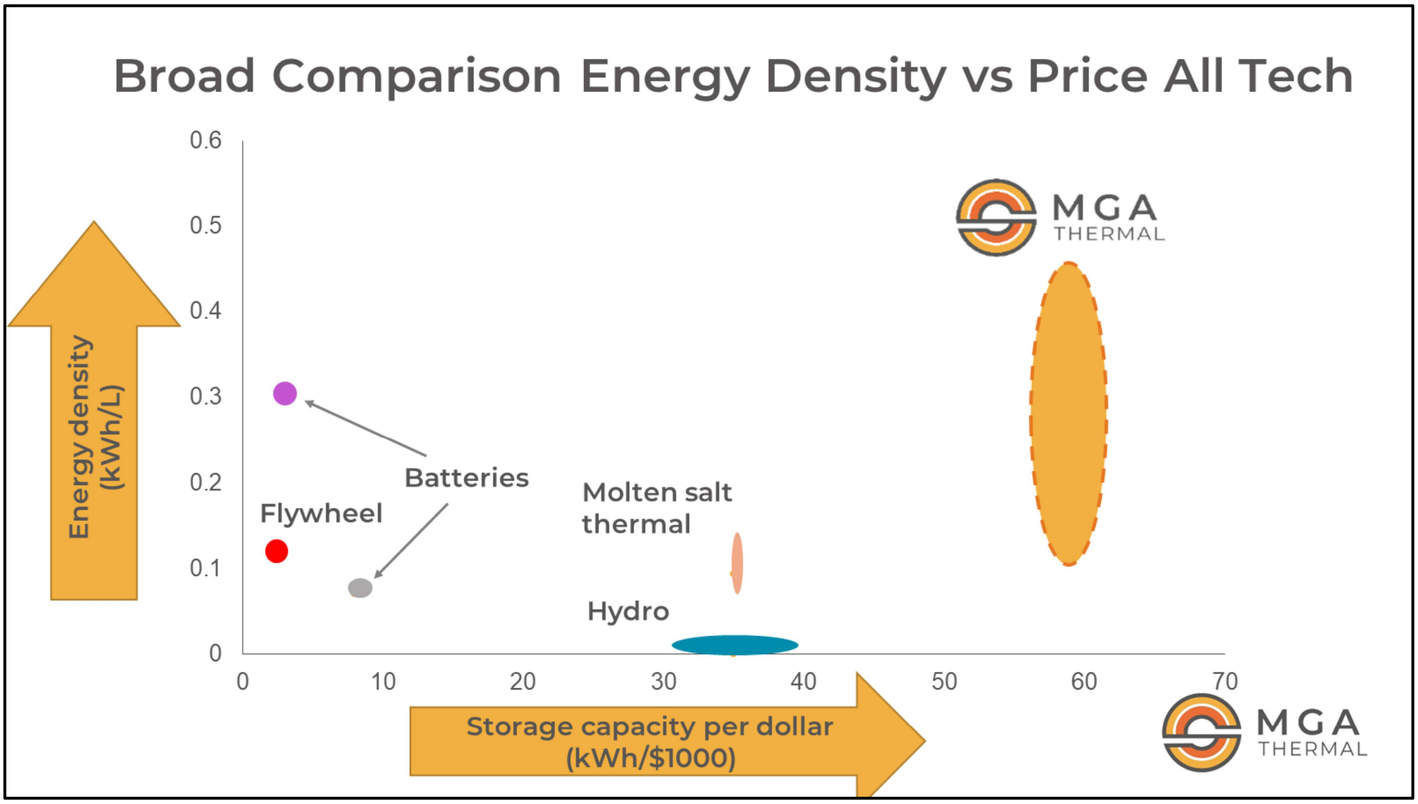
Broad Comparison to Non-thermal Energy Storage

Pumped hydro

- Extremely low energy density (1m^3 at 100m = 0.27 kWh)
- Elevated water storage in a flat dry continent - difficult
- Expensive, especially in remote areas
- Conservation and land management issues

Electric Batteries

- Energy density is similar
- Battery cost is 10x as much as MGA in $/kWh
- Installation cost can be 150% of battery cost for large storage (SA, $908 $/kWh)
- Rapid cycle life is compromised (300 – 800 cycles, 2 – 4 years)



- Broad comparison to alternative energy storage methods
- In addition to these metrics, our tech is suitable for longer term storage on a massive scale
- No legacy issues (salts, batteries)
- Long lifetime expected

THE MARKET

- World thermal energy storage market
  - > US$ 9 billion in 2017 https://www.smartenergy.org.au/news/thermal-energy-storage-market-growth
  - Forecast US$55 billion by 2024 (see for e.g. https://www.smartenergy.org.au/news/thermal-energy-storage-market-growth)

- Specific Opportunity
  - Germany (20% of market, $9GW_e$, $27GW_{th}$, x10h, $9.45B turnover)
  - Europe https://climateanalytics.org/media/coalphaseouteu-market.gif
  - Worldwide, $2{,}000GW_e$ (60,000 GWh of thermal storage)

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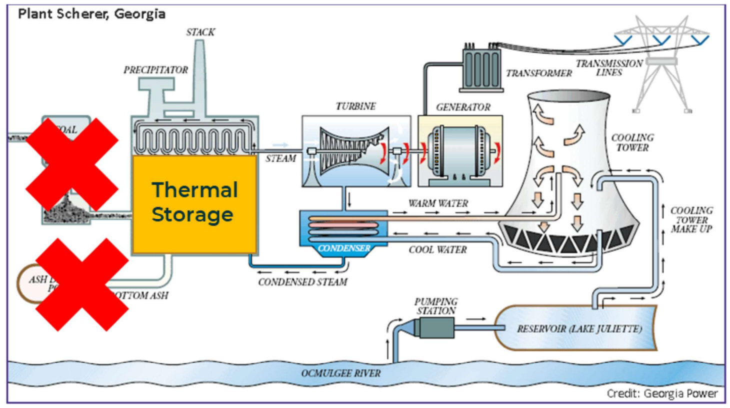
- The overall thermal storage market is immense

KEY APPLICATION

Value Proposition

- Massive scale Energy Storage as HEAT
- Long duration storage
- 1/10 the cost of electrical batteries and longer life
- Low commercial and environmental risk
- Re-purposing of existing infrastructure and stranded assets
- Save de-commissioning costs
- Reduction in ash handling costs
- Reduction in coal purchase & handling costs
- Continued operation and employment



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- Fossil fuelled power plants will have to close
- In Germany, this is already mandated for coal (7GW by 2022, additional 23GW by 2032, balance by 2038), in Canada 90% will close by 2030
- There is a huge investment in infrastructure and there are huge decommissioning costs associated with this
- What if we took all the coal fuelled power plants and replaced the coal fired boiler with a boiler heated by stored renewable energy?
- Billions of $ in non-polluting infrastructure is re-purposed and remains in use
- Massive financial and environmental savings on CO2 emissions but also NO_x, SO_x, and coal ash