HIGH DENSITY THERMAL STORAGE WORKSHOP

BREAKOUT REPORT

ALTERNATIVE APPLICATIONS FOR THERMAL STORAGE

Alternative Applications for Thermal Storage

The goal of this breakout session is to identify and characterize additional areas of impact on the US Energy landscape and beyond

1. Identify and characterize additional areas of impact on the US
   - Non-obvious direct applications for thermal storage?
   - Can thermal storage be used to overcome a critical barrier to deployment or impact of other energy technologies?

Data from NREL

Other areas to consider

Automotive

- Storing waste and redeploying
- 10+ Billion gallons oil used for steady state A/C
- Up to 10% of fuel used for cold start (in summer, no less)
  - Storage needs only 1-2 days to accommodate 80% of cold start
- EV has even more important need: cabin heating/cooling
  - Range anxiety
  - Cold start issues for LIB
  - Also look at EV as thermal source
  - Same for fuel cell vehicles
- Thermal storage should be comparable in energy density and possibly better in power density…but must be cheaper.

Possible Targets

- 1MJ/L target, ½ MJ/kg
- 5 kW/L
- Cold start 1kWh, 30kW
- Heating cabin is up to 5kW / 5kWh
- 10k cycles
- Must be low cost
  - EV ceiling cost $500/kWh
- these are current roadmap goals add 2x to be aggressive
- Note: Will compete and/or co-exist with conversion technologies (e.g. thermoelectrics)

Other areas to consider

Defense

- High energy weapons thermal absorption
  - MW scale for up to a minute
  - Waxes used today for solid state lasers
  - may be one-time
- Ships – stabilize thermal power or use for internal loads
  - Use thermal energy to run the engine steady state
- Major fuel consumption is for heating/cooling
  - Insulation technology
    - Lightweight
    - Masking thermal signatures for equip/ships
- Small scale A/C and heating (such as personal A/C body armor)
- Cooling jets
- Active heat sink for carrier deck
  - Maybe no opportunity b/c it needs to accommodate many take-offs (approaches steady state

Other areas to consider

Industrial and other

- Refrigerated Warehouses
- Refrigerated Transport
  - Elimination of reefer/shipping containers
  - Pharmaceutical distribution
  - Long time constant and need high reliability
- Food/bio industry processes
  - Rapid heating/cooling cycles with energy wasted on both ends
  - Pasteurization / flash freezing
  - Temperature regulation of bio-reactors
    - Algae used with flu gas for carbon recycling
- Desalination
  - Reverse osmosis may be compatible to thermal storage
  - ~7MJ/m3 (scale of 15 kWhr/1000 gallons with regeneration)
- Other low-temp (LNG or other cryo apps)

Other areas to consider

Industrial and other

- Grid stabilization
  - For ramping/firming of renewables
  - Using water heaters / cold warehouse / ice → allows for distributed agile load
  - TWh scale agile, deployable loads can be imagined
- Modular / small scale heaters or coolers
  - Building, car, personal, etc.
- Hydrogen production
  - Convert heat to drive electrolysis at small scale or portable
- Solar cooking
- LNG production, transport, and release
- Municipal scale heating/cooling
- Space applications for sun-exposure cycles

Programmatic thoughts

Top area of focus

- Vehicles – cost start and climate control

Other areas of focus

- Refrigerated transport/storage
- Defense
- Grid stabilization
  - Offers distributed agile load
  - Can leverage existing thermal reservoirs or new ones
- Oil and gas may be worth a closer look

Programmatic thoughts

Other programmatic thoughts

- Modular/portable cold/heat storage for vehicles and otherwise is an important cross-cutting primary area of focus
  - Note that to beat ice with something that's not water will be very accounting for cost and performance
  - Vehicle targets may be a good proxy for this whole suite of apps
- Alternative applications could be addressed in the FOA by tying these to primary applications that have similar targets
- Applications could be characterized by size or constraints (space/weight)
- Scale of the waste heat/cold source could be a good proxy for where the biggest impact area might be
- System and heat exchange design must be part of the innovation (with application in mind)

Other Breakout Slides

Breakout Slides

Data from NREL

Alternative Applications for Thermal Storage

Agenda for the breakout session

1. Introduction (15 minutes)
2. Alternate application brainstorm (20 minutes)
3. Compile ideas and select top areas of impact (20 minutes)
4. Characterize top areas and recommend programmatic elements (30 minutes)
5. Sum up and generate report-out (15 minutes)

Examples:
Vehicle A/C

The opportunity:

- 7-10+ billion gallons of gasoline used every year for vehicle A/C
  - Roughly 10% of US imported crude oil

- A/C load can increase vehicle fuel consumption by as much as
  - 35% for typical ICE vehicle
  - 100+% for strong HEV

- A/C can reduce EV range by as much as 35%

Data from NREL

Examples:
Vehicle A/C

The challenge:

- Peak A/C load ~ 3 kW_e / 9 kW_t
- Regular A/C load ~ 1 kW_e / 3 kW_t

- 40% of all vehicle trips are under 10 minutes
- 85% of all vehicle trips are under 30 minutes

- So to displace A/C for 85% of trips would require between 5.4 -16 MJ of thermal storage → **16 - 48 kg of ice**

	10 Min Trips	30 Min Trips
High A/C	1.5 kWh_t (5.4 MJ)	4.5 kWh_t (16 MJ)
Reg A/C	0.5 kWh_t (1.8 MJ)	1.5 kWh_t (5.4 MJ)

Primary Obstacles:

- Energy density
- Controllability
- Rate
- Cost

Data from NREL

Examples:
Other Vehicle Applications?

Additional impacts in vehicles

- Thermal protection/management for vehicles
  - Cold start mitigation for ICE or EV
  - Zebra battery is suitable for EV but operates at 250 ºC
- Cabin heating in electric vehicles is not free!
  - Avoid heating load on battery, which also kills range
- Other ideas?

Image from Tesla Motors, US Army

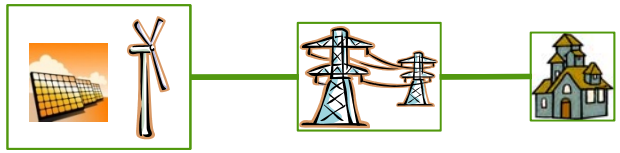
Examples:
Agile loads for grid support

Could thermal storage be used as a massive controllable and distributed load for grid stabilization?

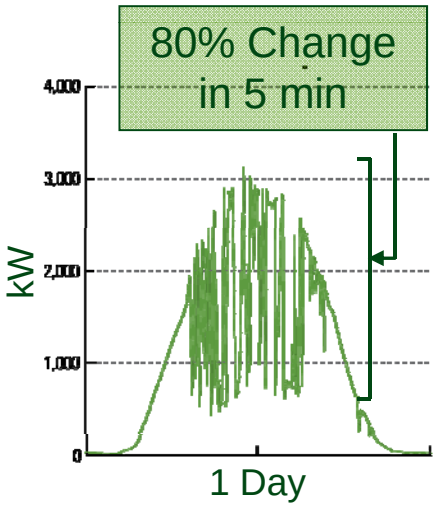
Example: Refrigerator/Freezers

- US has
  - ~100 Million Primary Refrigerators
  - ~30 Million Secondary Refrigerators
- If 5% of each refrigerator/freezer's volume was dedicated to H2O phase change..
  - **Total up to ~150 GWh of controllable load**

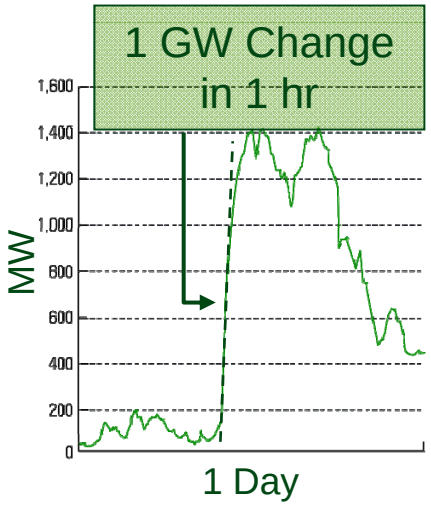
Renewables Today



Solar PV in AZ (TEP)



Wind in OR (BPA)



Problem:
Minutes-to-Hours Changes in Power

Other areas to consider

1. Critical thermal management/protection needs
2. Carbon capture applications
3. Oil and gas exploration/production/transport (e.g. LNG?)
4. Electricity generation / power plants
5. Additional and high-value non energy-specific applications

Examples:
Temperature Regulated Shipping

Heated or Refrigerated Transport

- Cold Chain Transport
  - 2010 estimated ~ 1.75M TEUs of refrigerated containers @ 39 cu-m /TEU
  - ~3.6 kW per TEU
- Current Solutions:
  - Dry ice
  - Gel packs
  - Eutectic plates
  - Liq N2
  - Reefers or Refrigerated Trucks
- EPA estimates over 20% of all transportation HFC emissions are from refrigerated transport (14 Tg CO2 eq HFC**)**