4TU.Energy

Heat-Temperature Heat

Prof. Dr. Kamel Hooman, HTT Chair, TUDelft

TU Delft Delft University of Technology

TU/e Eindhoven University of Technology

University of Twente.

Wageningen University & Research

- To cultivate a collaborative community,
- To strengthen the binding between researchers,
- a platform for researchers:
  - to forge connections,
  - expand their professional network,
  - and seek inspiration from their peers.

Gratitude

- Drs. C. Zhao, M. Opolot, A. Medon, M. Calati and Mr. R. Flewel-Smith

- ARENA & ASTRI through CSIRO, UniSA, UQ, & UniPD

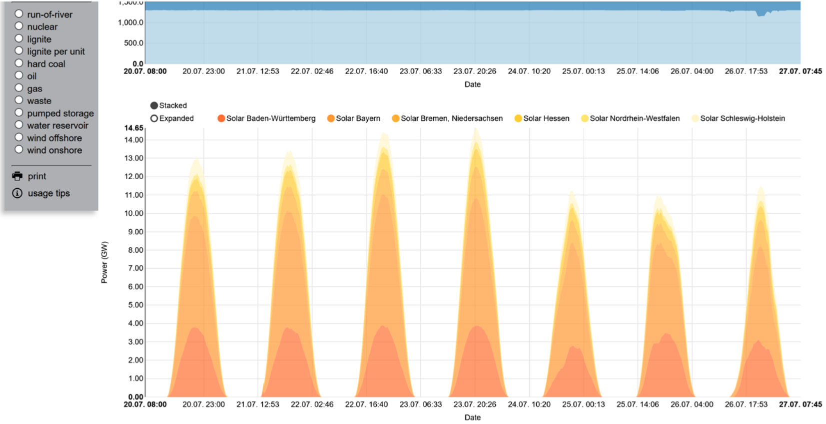

Brisbane 2032
Olympic and Paralympic


395·ESD
QUEENSLAND - SUNSHINE STATE

High grade heat

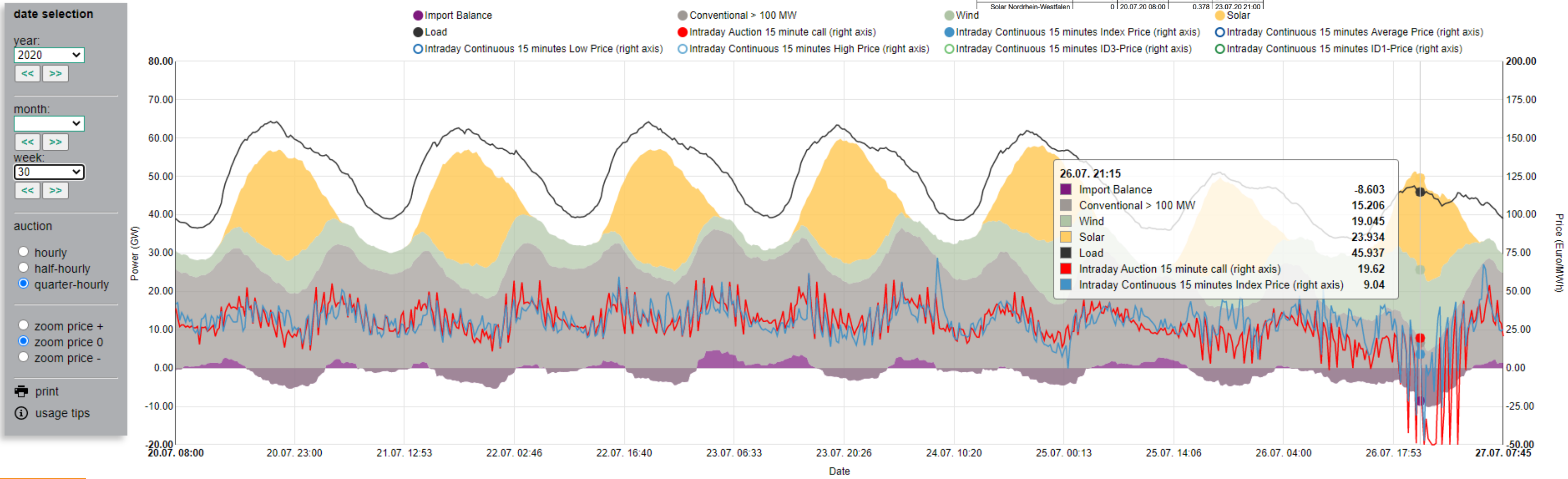
- Power to heat
- Waste heat recovery
- Solar energy

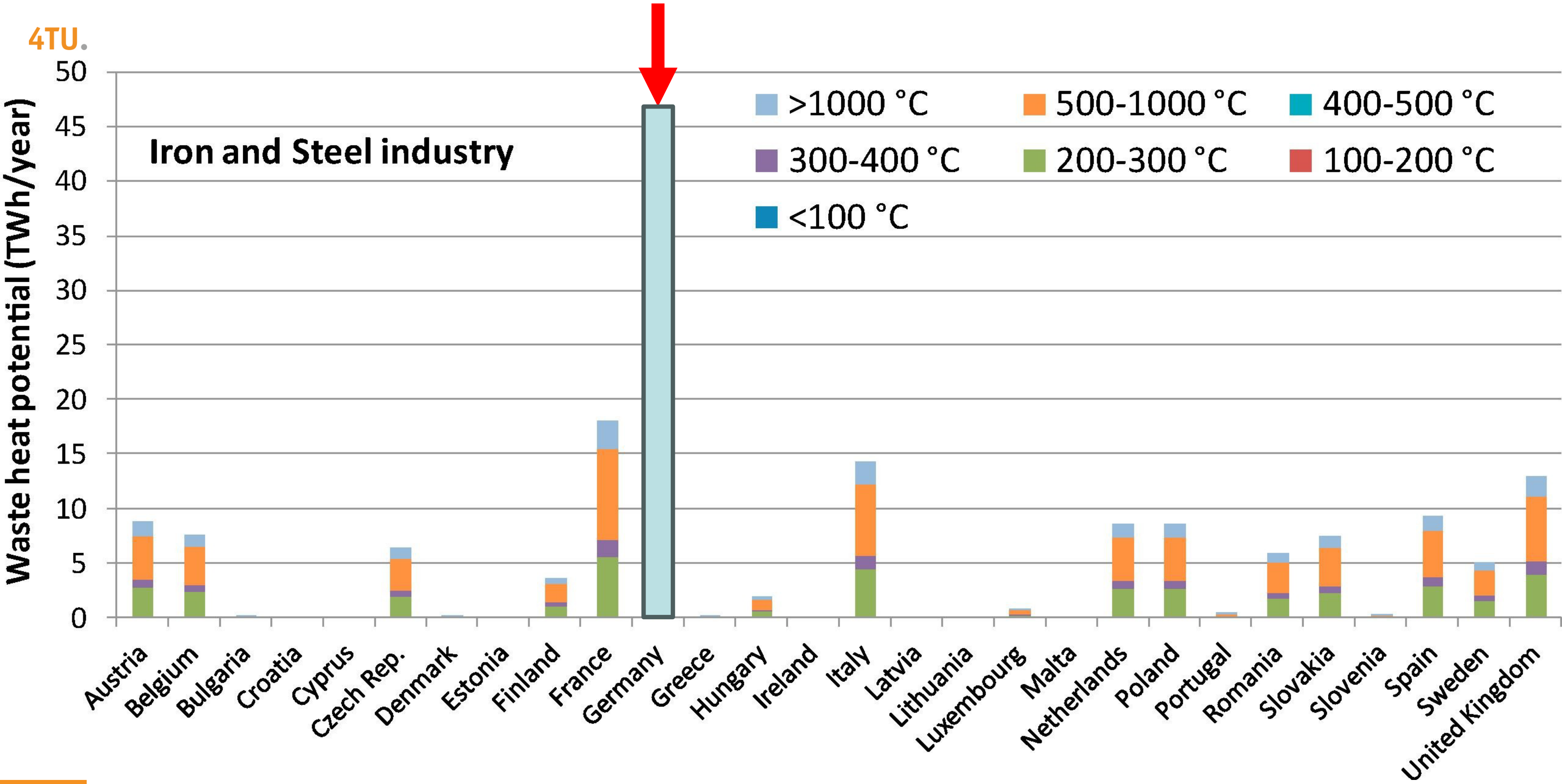
Power to heat



Electricity production and spot prices in Germany in week 30 2020 (Fraunhofer)

Source	Minimum Power (GW)	Date	Maximum Power (GW)	Date
Solar Baden-Württemberg	0	20.07.20 08:00	3.896	22.07.20 20:30
Solar Bayern	0	20.07.20 08:00	7.172	22.07.20 21:00
Solar Bremen, Niedersachsen	0	20.07.20 08:00	1.716	23.07.20 21:15
Solar Hessen	0	20.07.20 08:00	0.955	23.07.20 21:00
Solar Nordrhein-Westfalen	0	20.07.20 08:00	0.378	23.07.20 21:00





Papapetrou et al. (2018)

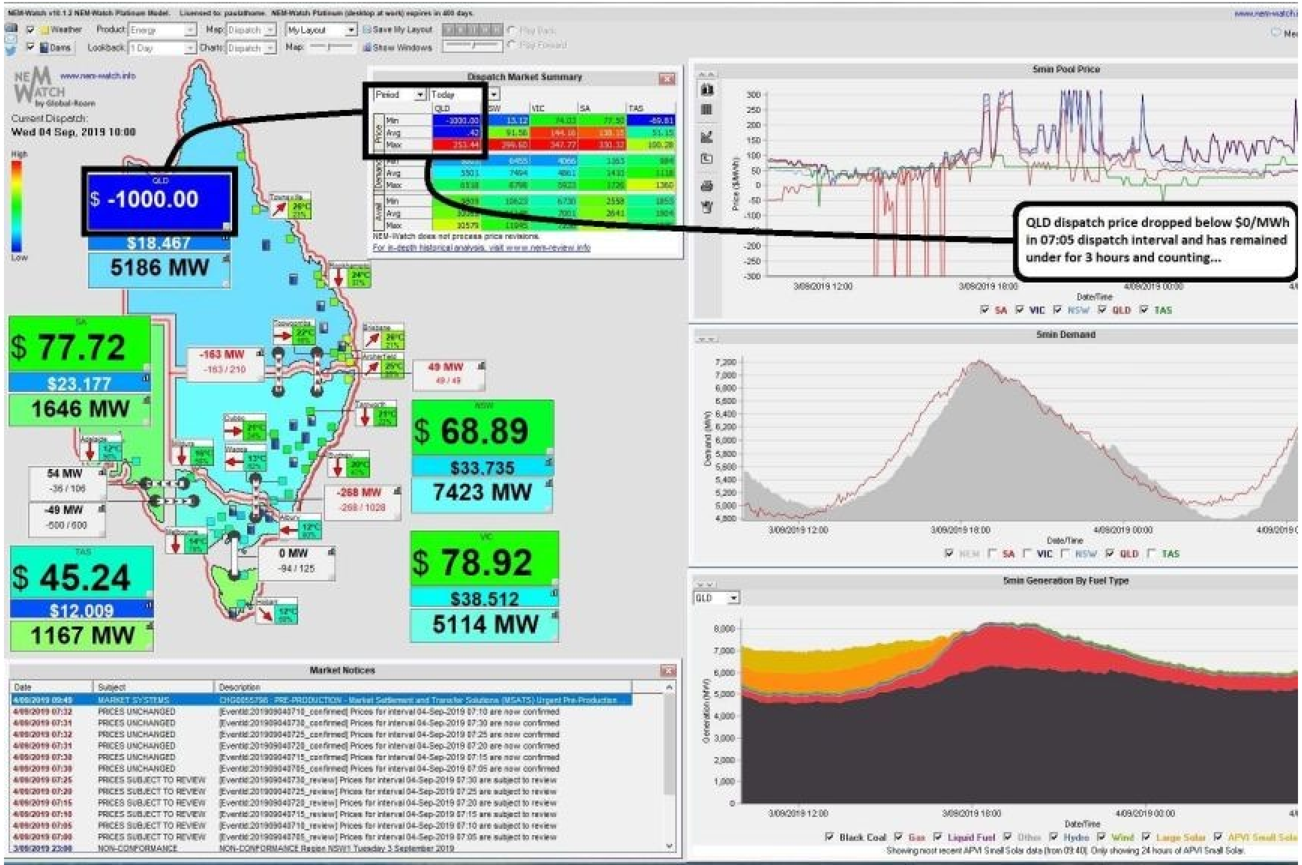
Heat market

Energy in Australia

- Export: coal, iron ore, gas…
- Renewables: hydro, solar, wind.

Negative price

4/9/19

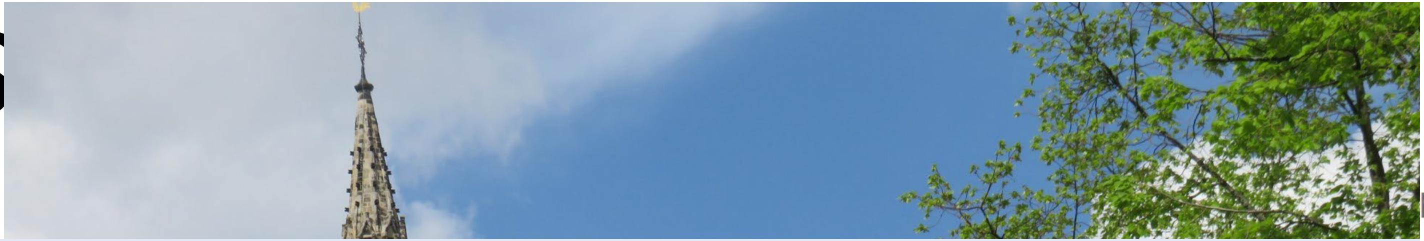


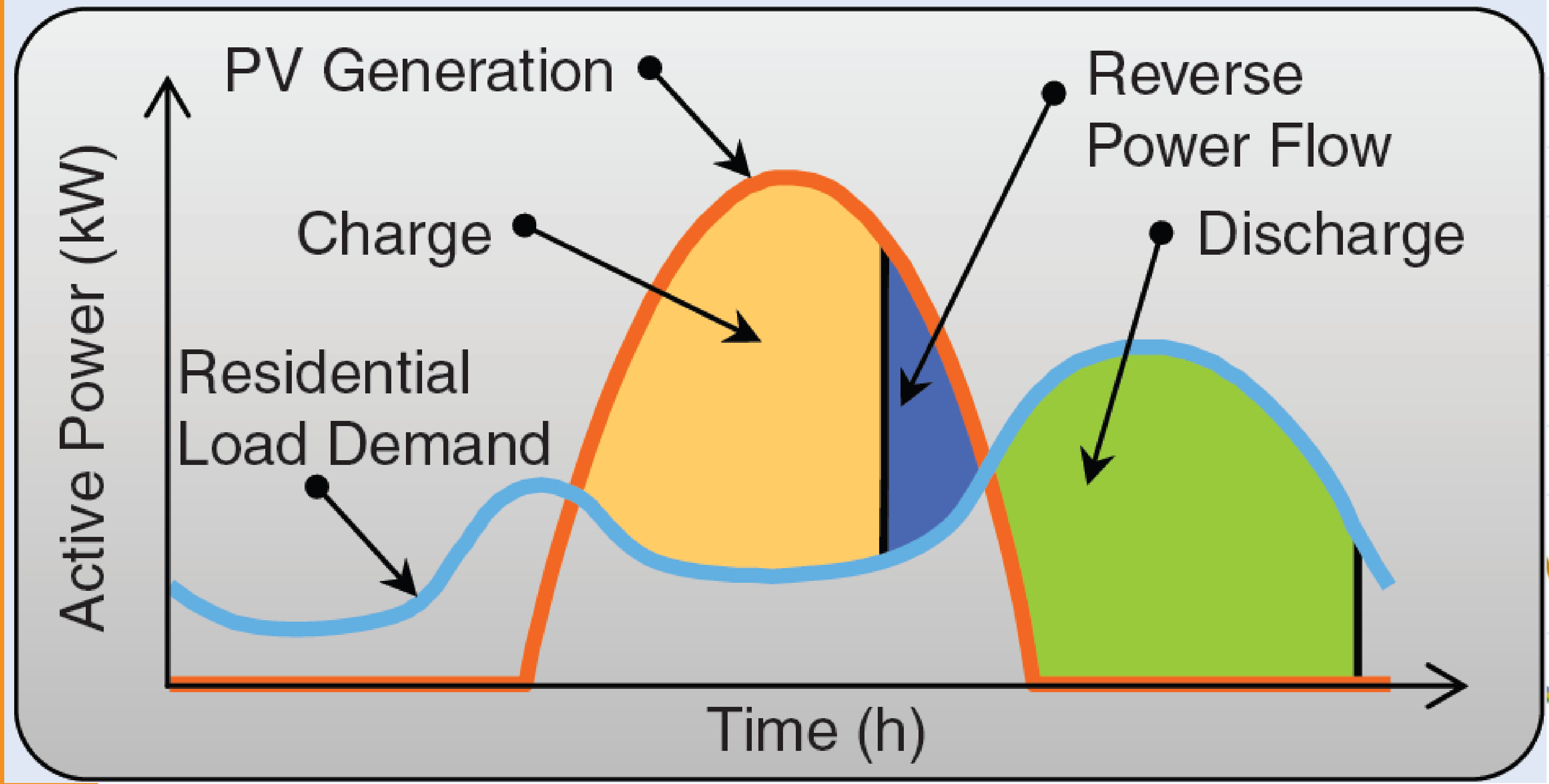
Let’s peel the onion

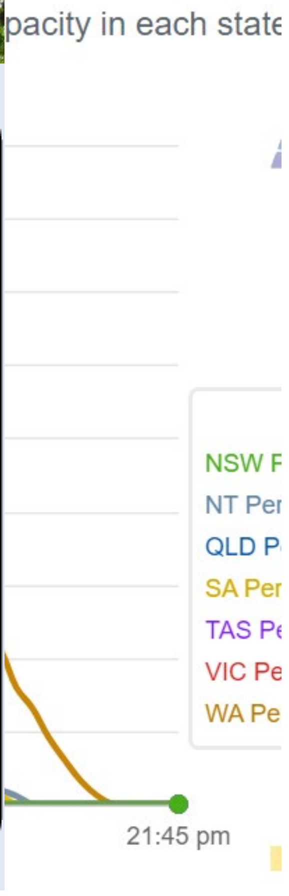
- Technical,
- Contractual.

4TU.

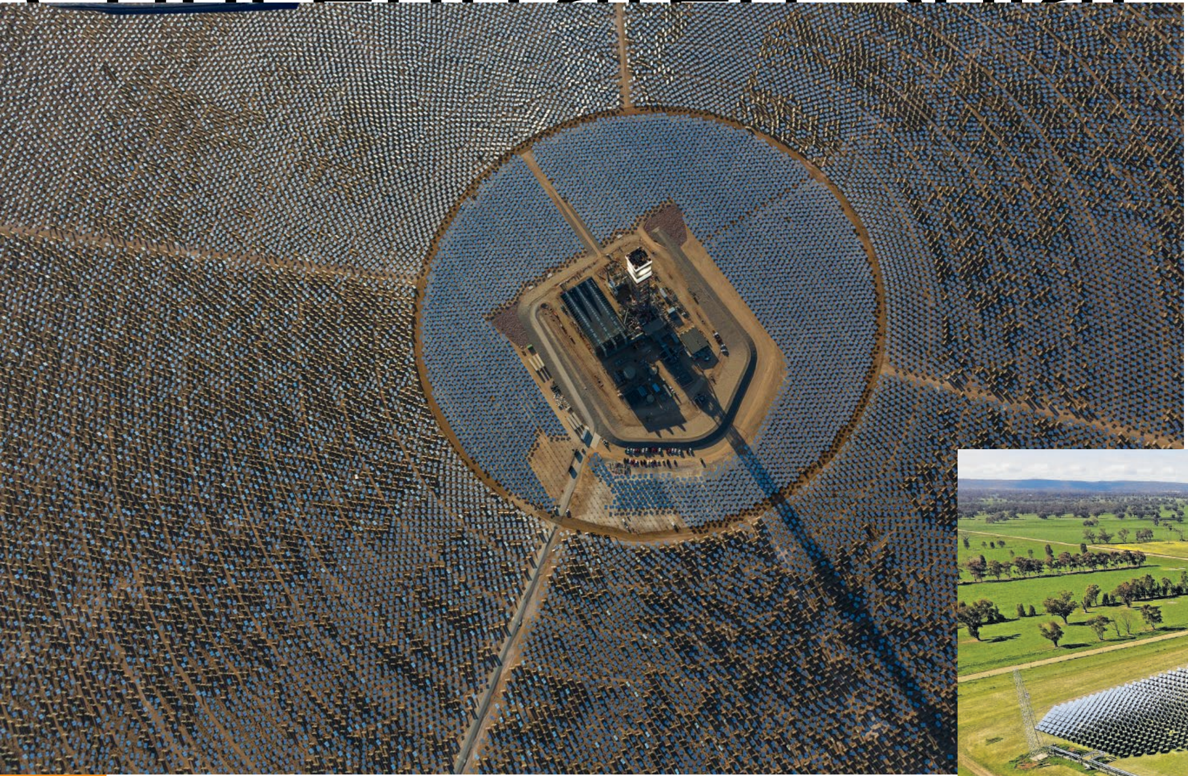
S
:

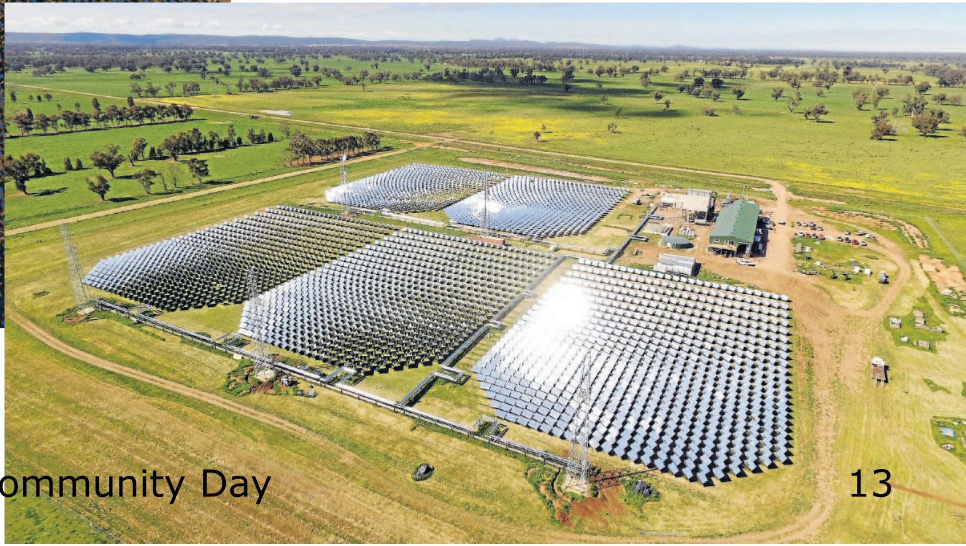


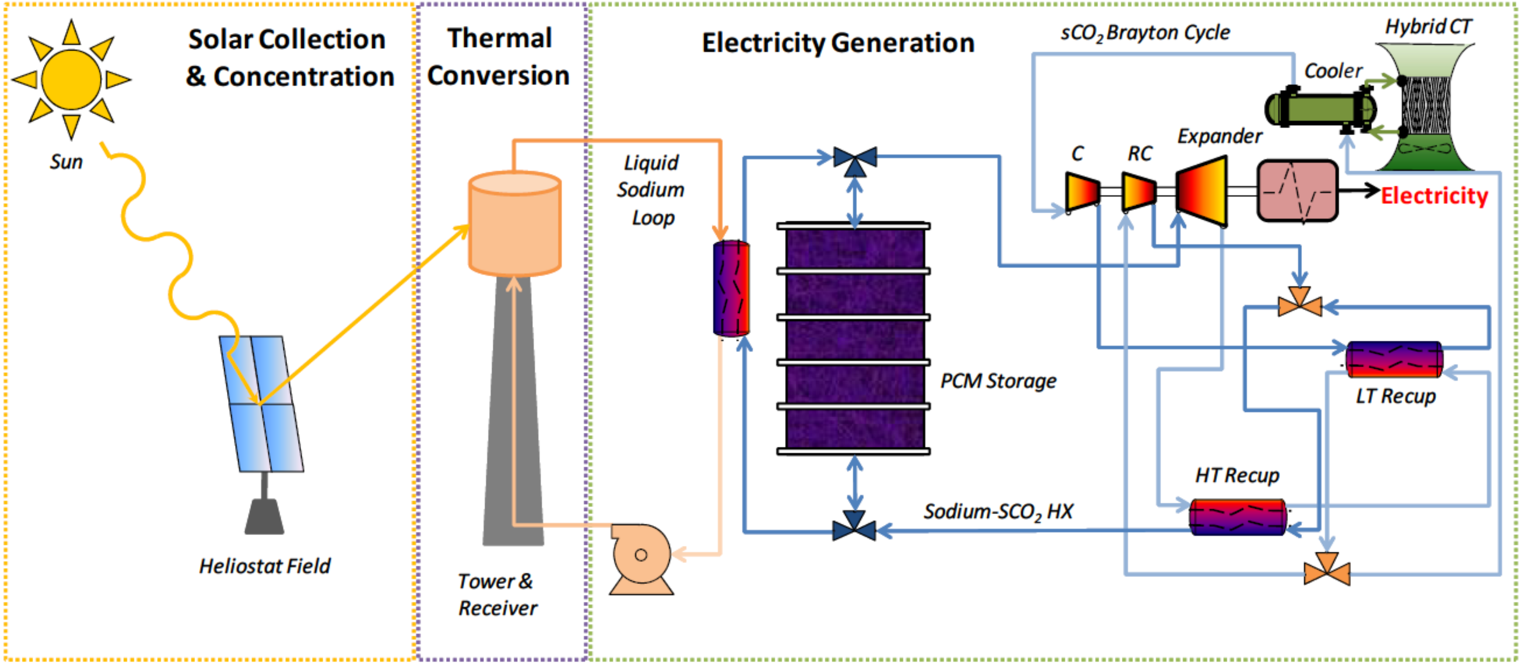

PV Generation
Reverse
Power Flow
Charge
Discharge
Residential
Load Demand
Active Power (kW)
Time (h)


pacity in each state
NSW P
NT Per
QLD P
SA Per
TAS Pe
VIC Pe
WA Pe
21:45 pm

Concentrated Solar Power






Solar Collection & Concentration
Thermal Conversion
Electricity Generation
Sun
Heliostat Field
Tower & Receiver
Liquid Sodium Loop
PCM Storage
Sodium-SCO2 HX
sCO2 Brayton Cycle
Hybrid CT
Cooler
Expander
C
RC
Electricity
LT Recup
HT Recup

CSP: ASTRI

Storage at high temperature

- How high?
  - Thermodynamics
  - Economics: Cost
  - Technoeconomic

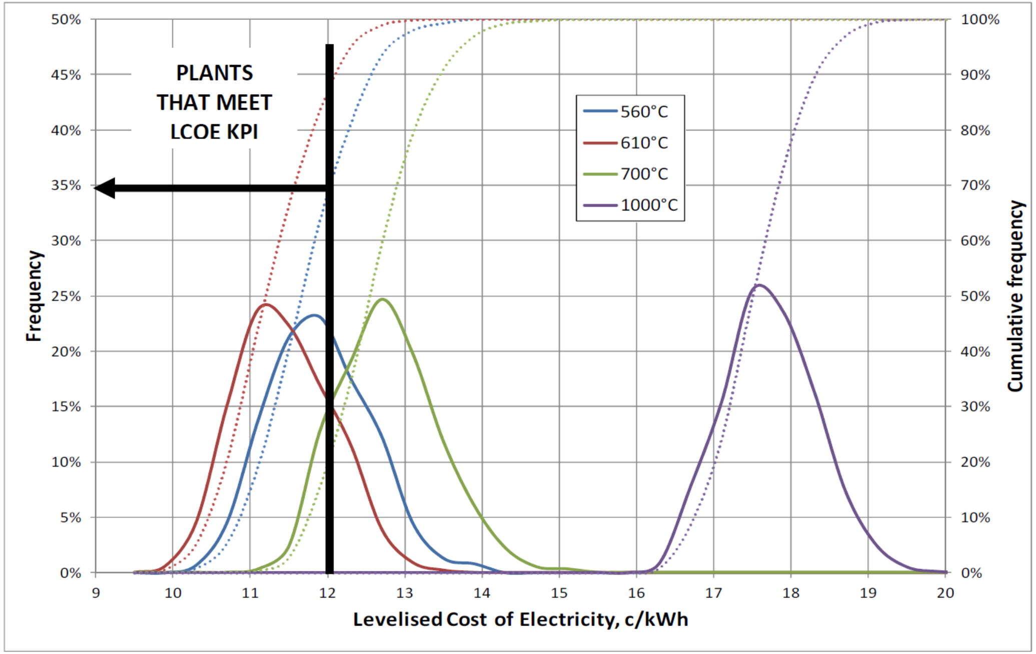


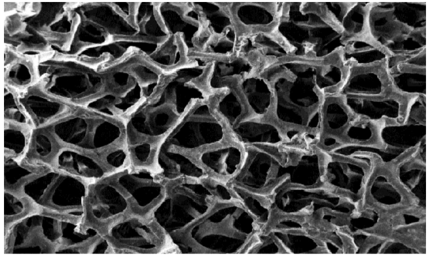
FIGURE 5. Frequency distribution for LCOE of CST systems showing percentage of systems achieving 12c/kWh

Salts

- Low conductivity, corrosion.

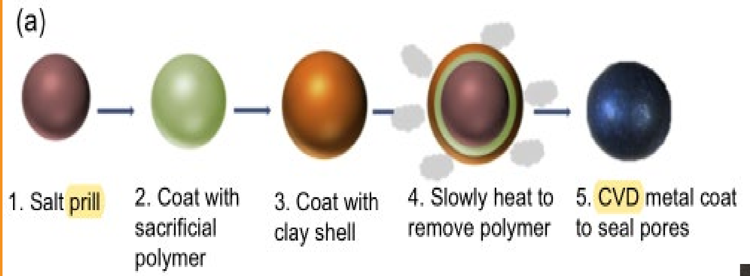
UniSA	Material	T_m (°C)	L (J/g)	C_p, s/l (J/g·K)	k, s/l (W/m·K)
PCM570	Na_2CO_3-KCl-NaCl	569	249.6	1.34 / 1.41	0.6/0.5
PCM635	NaCl-Na_2CO_3	635	311	1.25 / 1.55	0.6/0.5
PCM710	Na_2CO_3-K_2CO_3	705.8	144.9	1.54 / 1.5	0.6/0.5

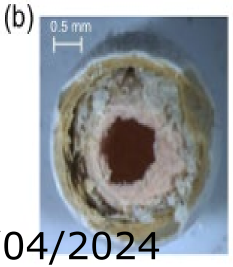
How to increas

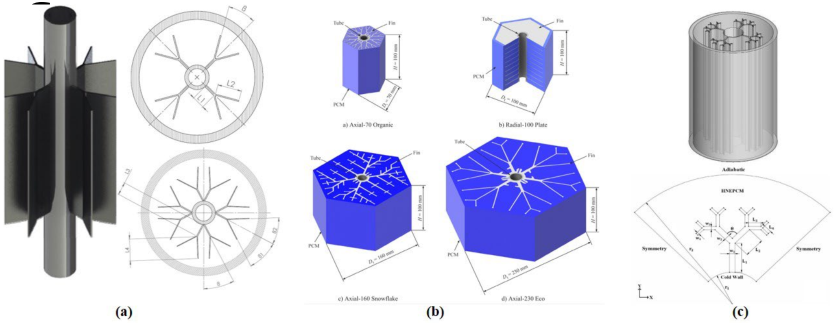


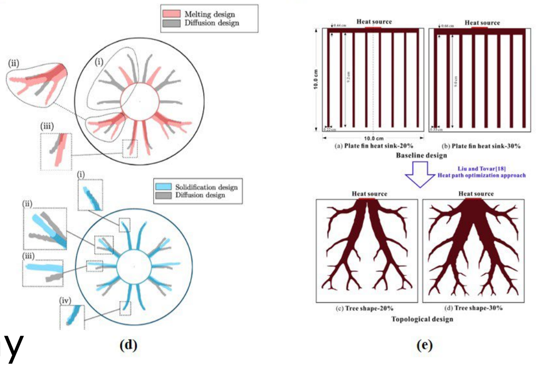
- Nanoparticles, fins,

d PCMs

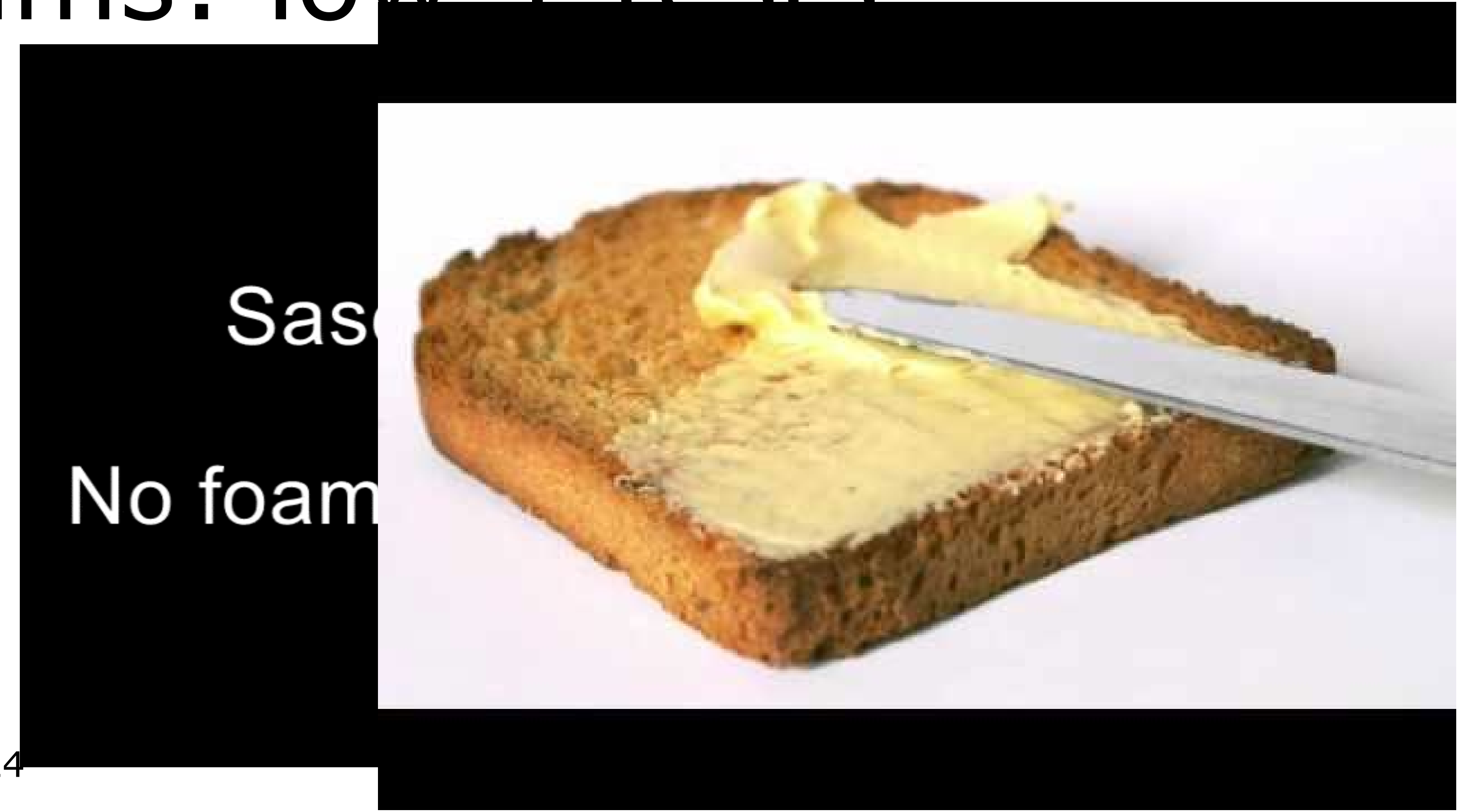




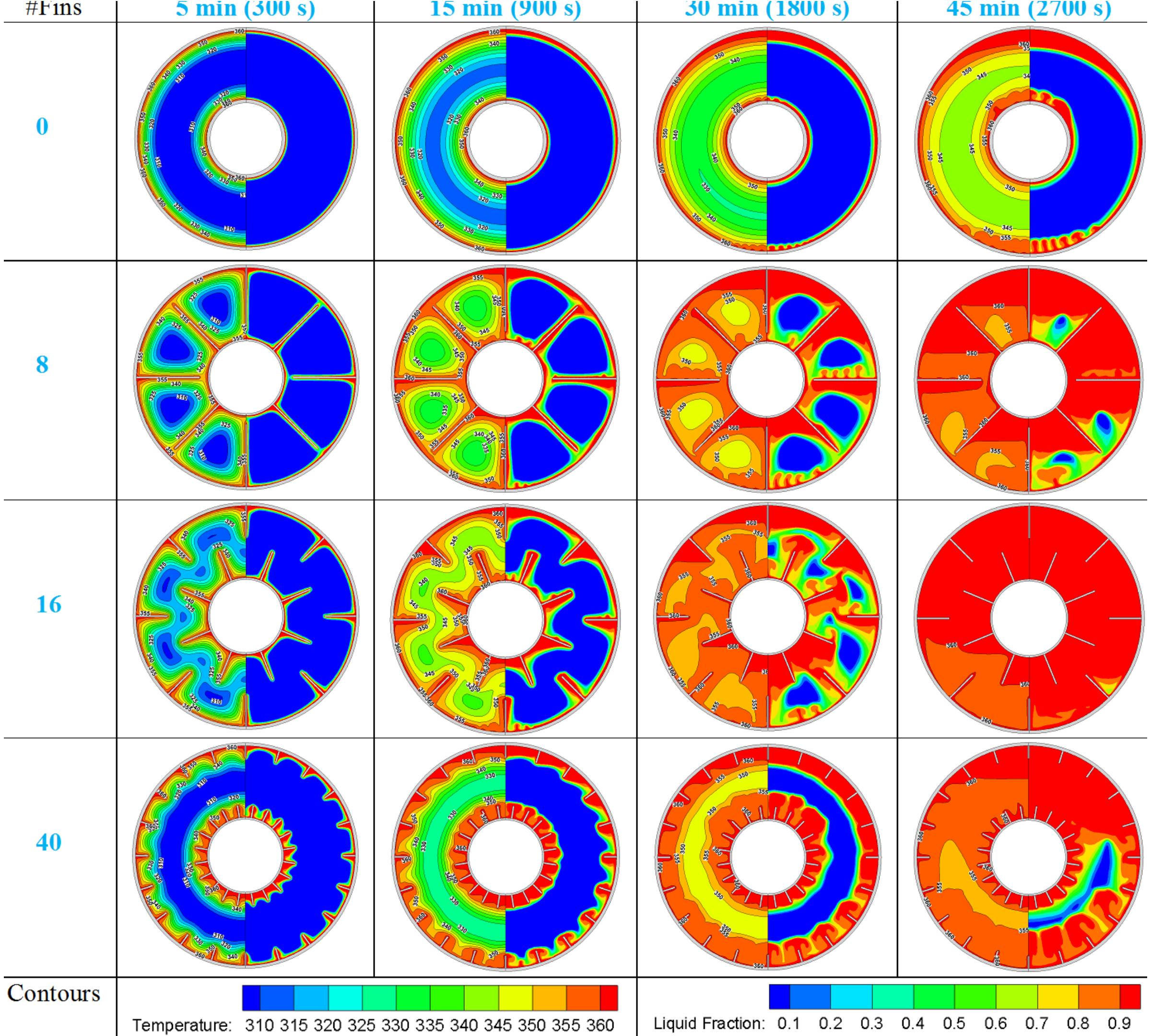




Foams: low-T tests



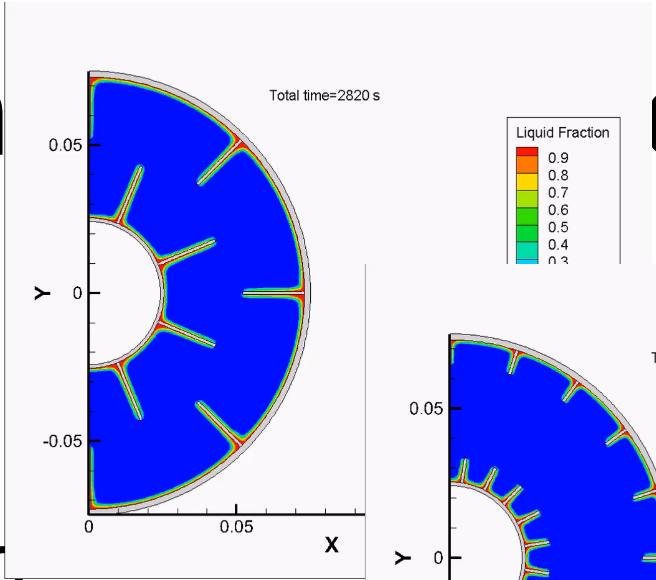
Fins

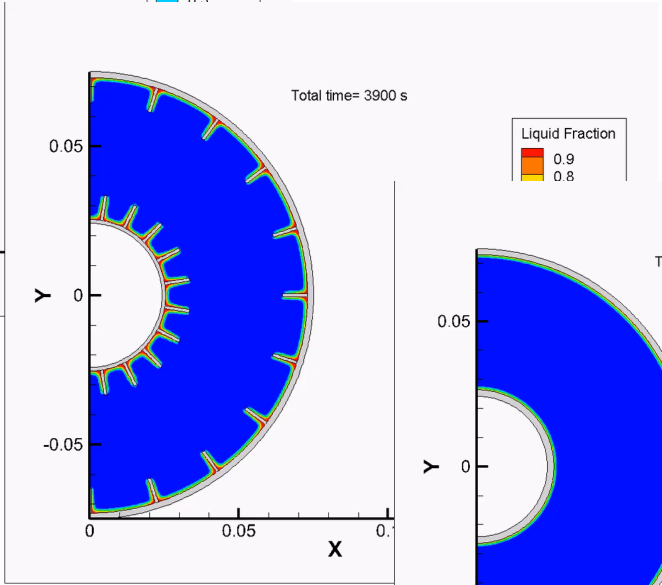


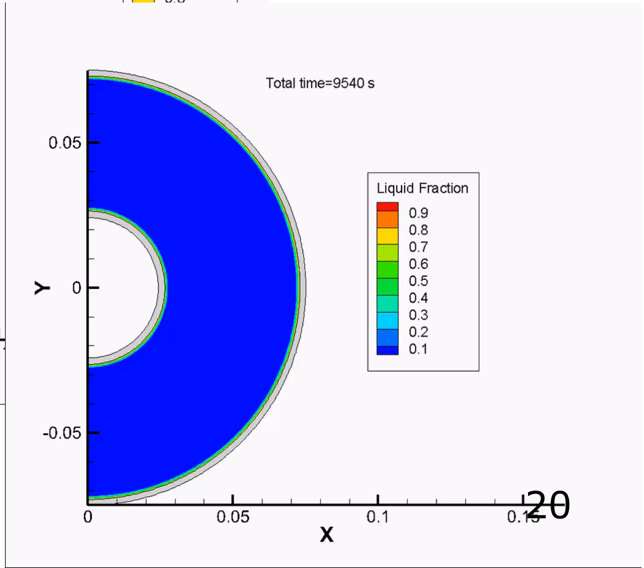
#Fins
5 min (300 s)
15 min (900 s)
30 min (1800 s)
45 min (2700 s)
0
8
16
40
Contours
Temperature: 310 315 320 325 330 335 340 345 350 355 360
Liquid Fraction: 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

Therm… design

- Stefan
- Inexpe
- Coating
- Optimization





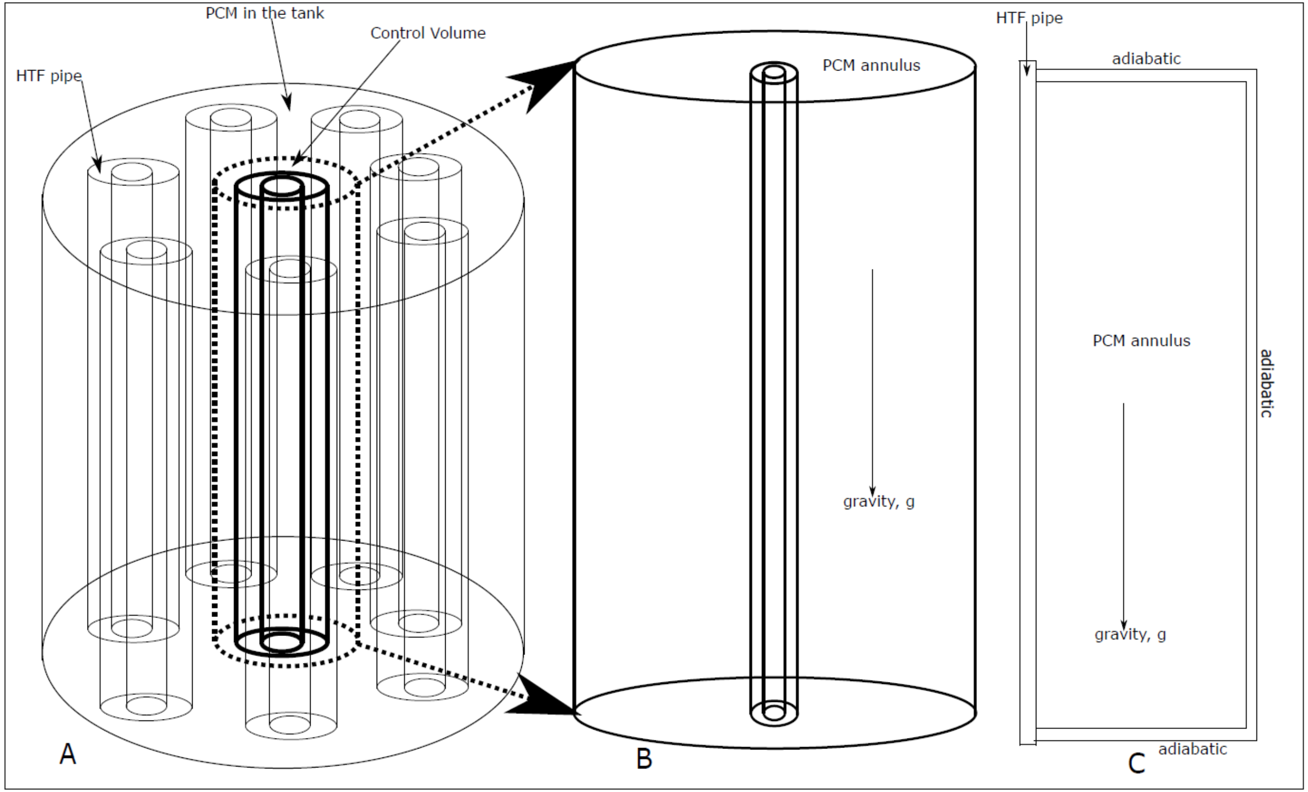


Criteria

- Anticipated performance,
- Meticulous,
- Cost,
- Pragmatic.

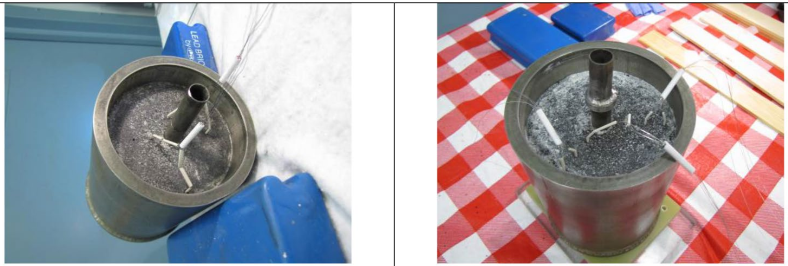
Heat exchanger design

- HTF: tub
- PCM: sh
- Corrosio



ANL tests

ANL-ESD 17/10

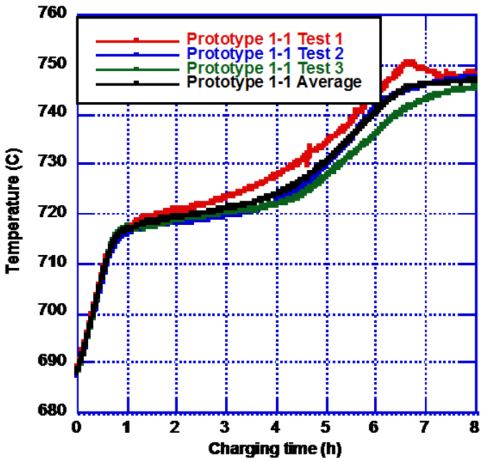


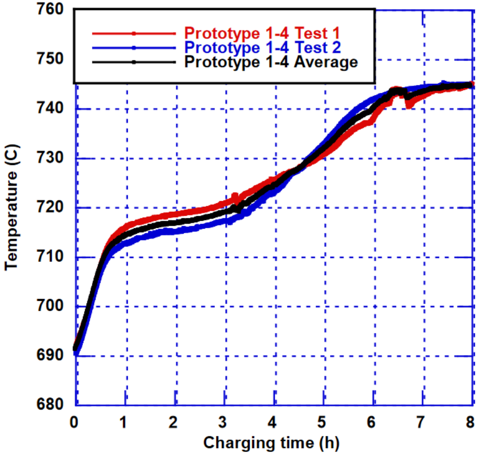
(a) (b)

Figure 10-37. Prototypes after installation of thermocouples: (a) 1-2 and (b) 1-3.

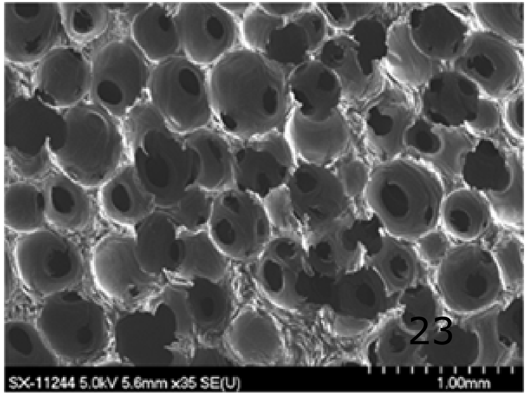
(a) (b)

Top plates for prototypes after feedthroughs installed: (a) 1-2 and (b) 1-3.



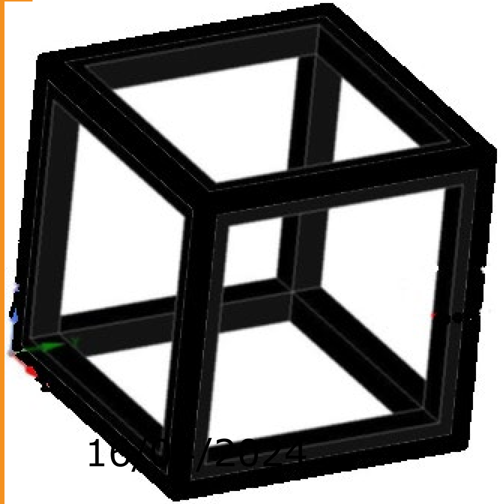


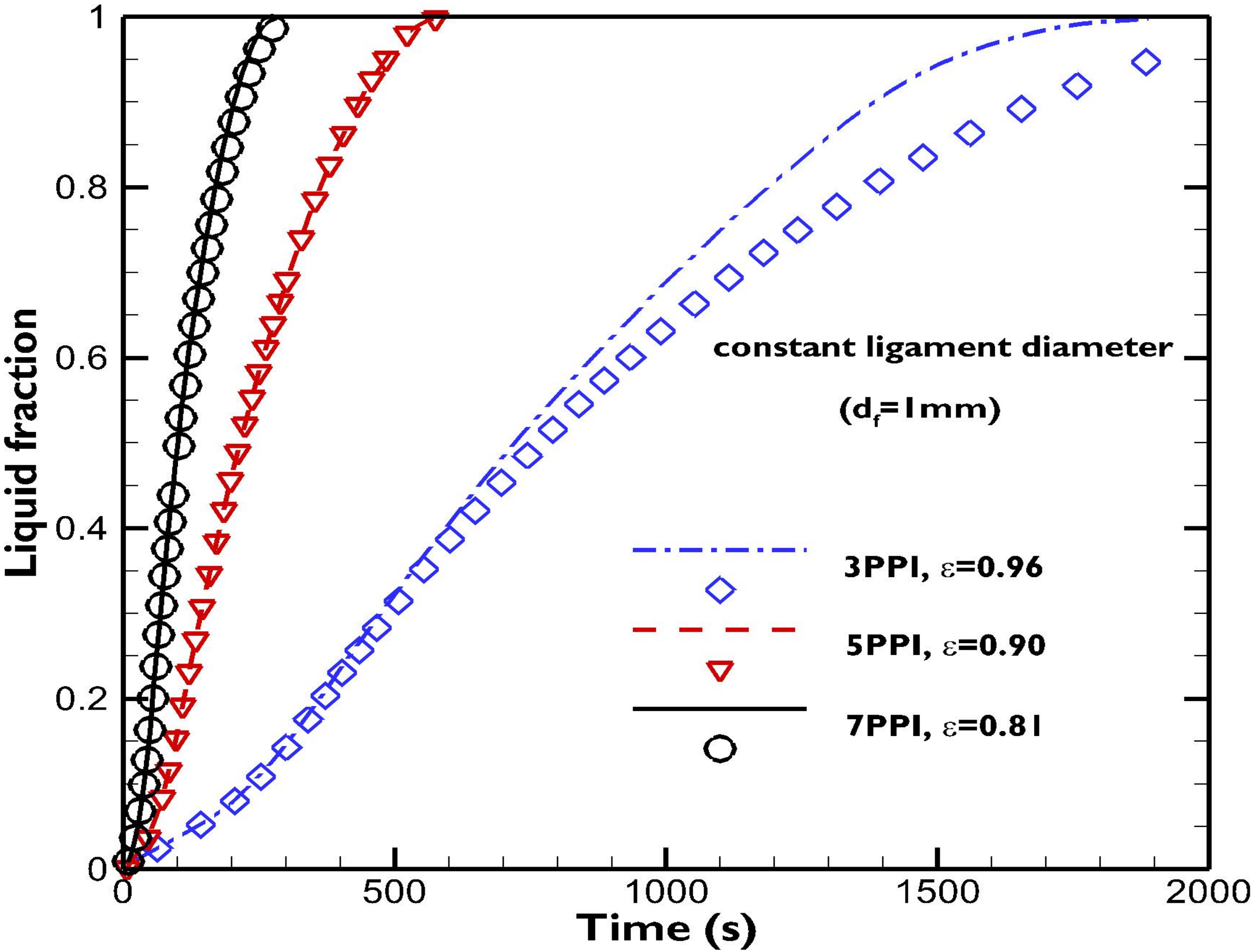
Day



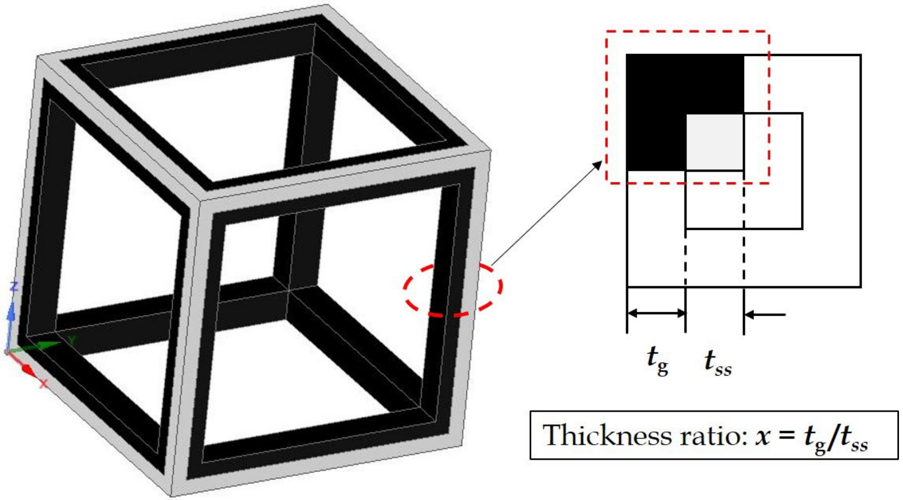
Cost

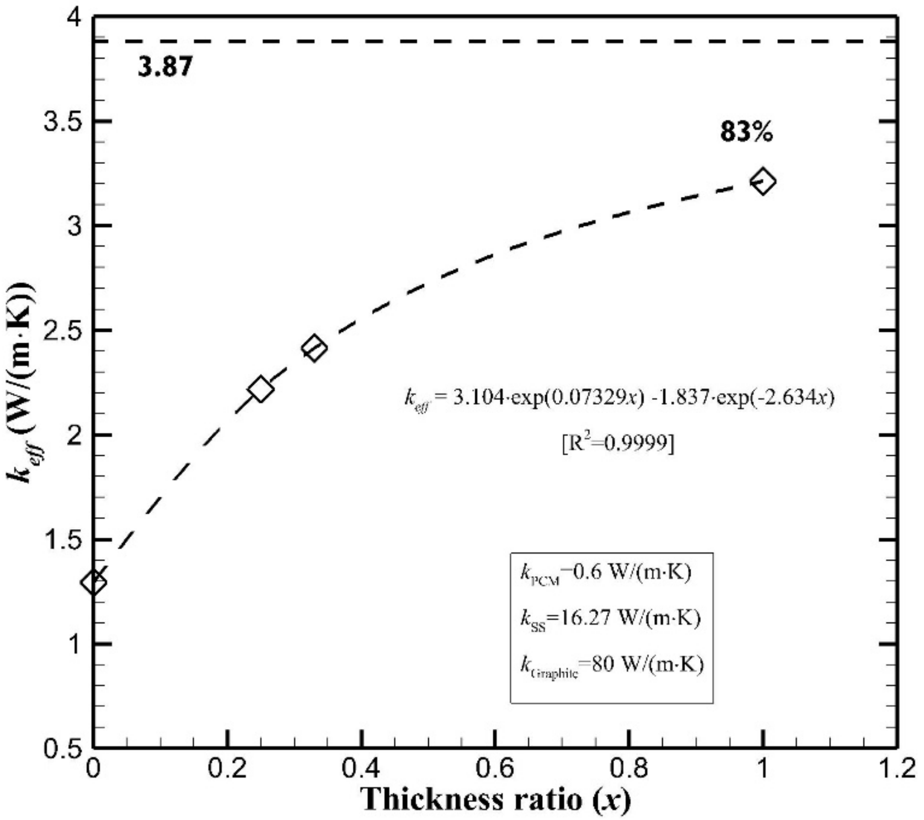
Foam vs
periodic structures



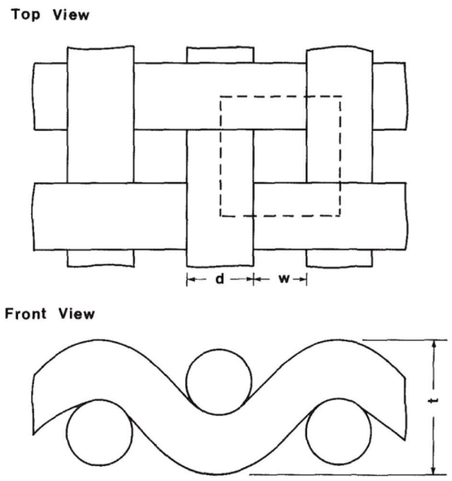


Further cost reduction: coating





Mesh

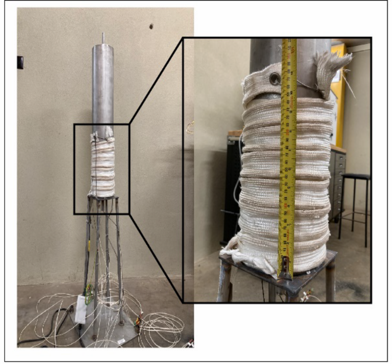


(a) Wire screen standard layout [38]. For this study, d = 1.6mm, w = 5.2mm while t = 3.2mm and the open area is 67%

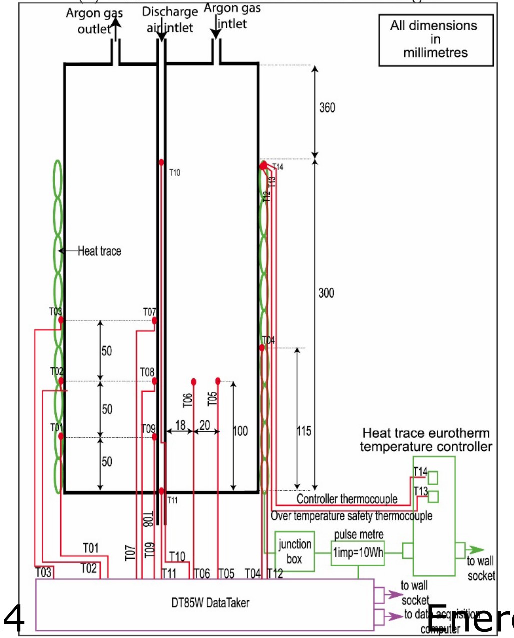
(b) Top view of experimental Periodic structure

(c) Side view of experimental Periodic structure

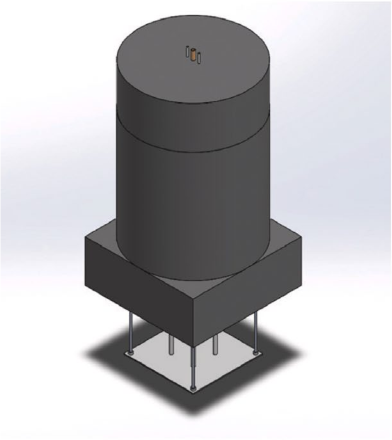
Set·



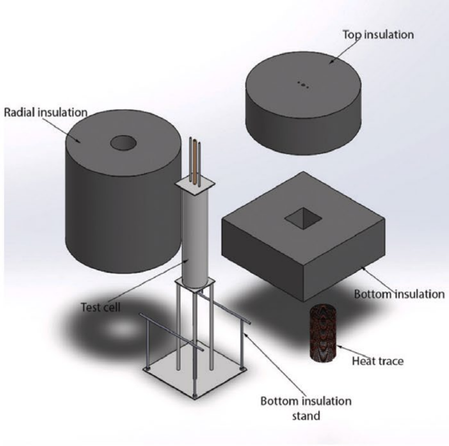
(a) 1.05kWh heat trace location and length



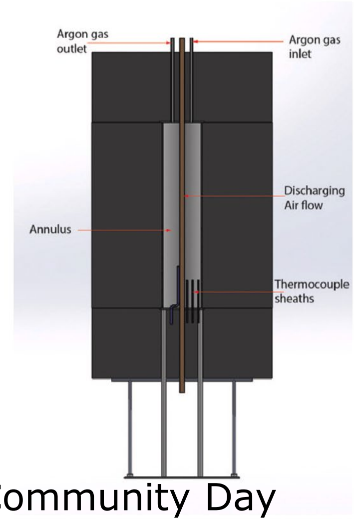
(b) Thermocouple and connection schematic



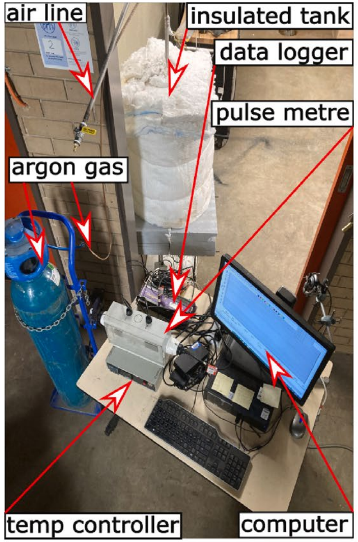
(a) Isometric view



(b) Exploded view

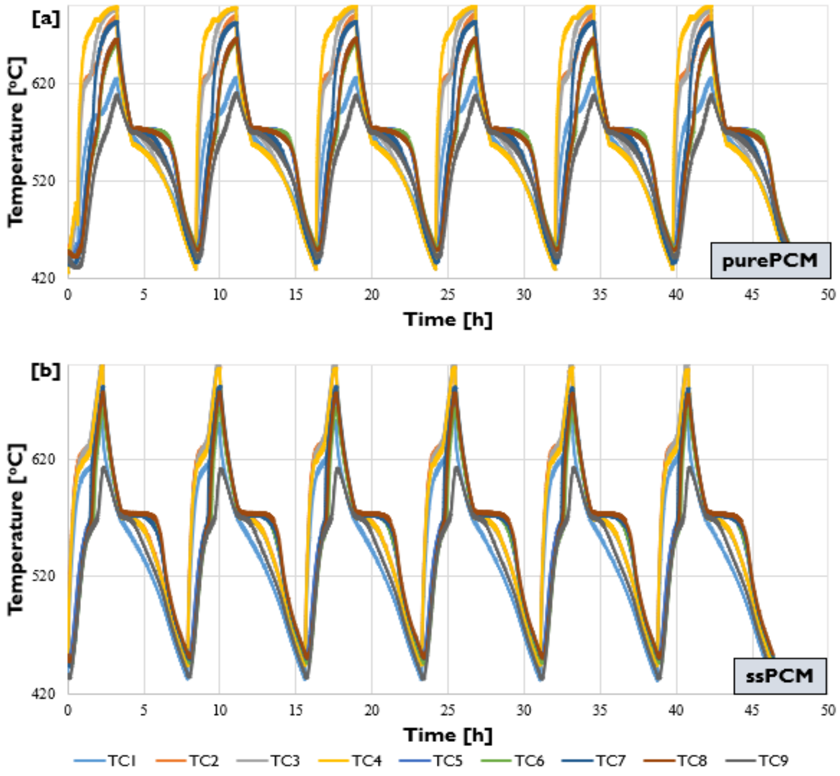


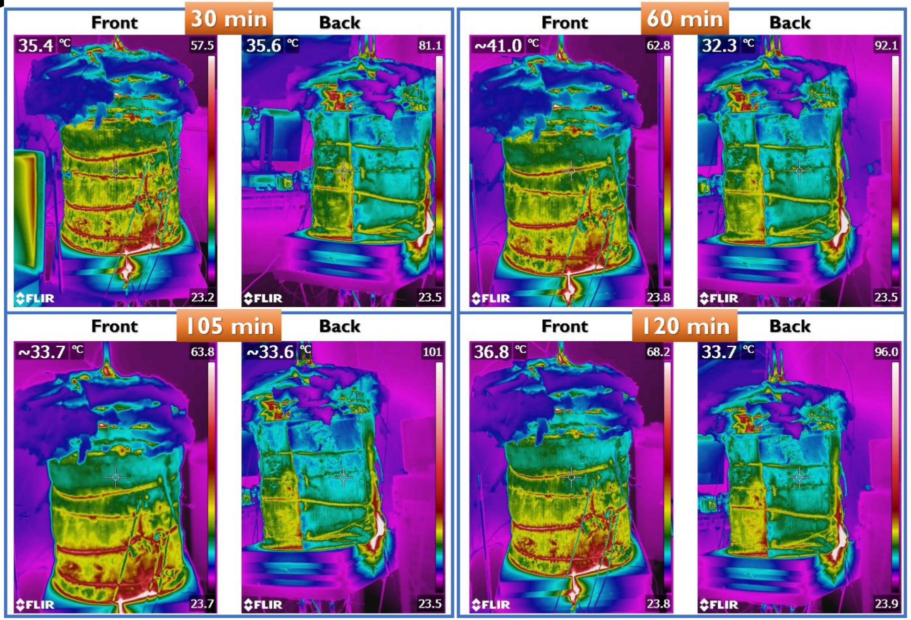
(c) Front cross section view



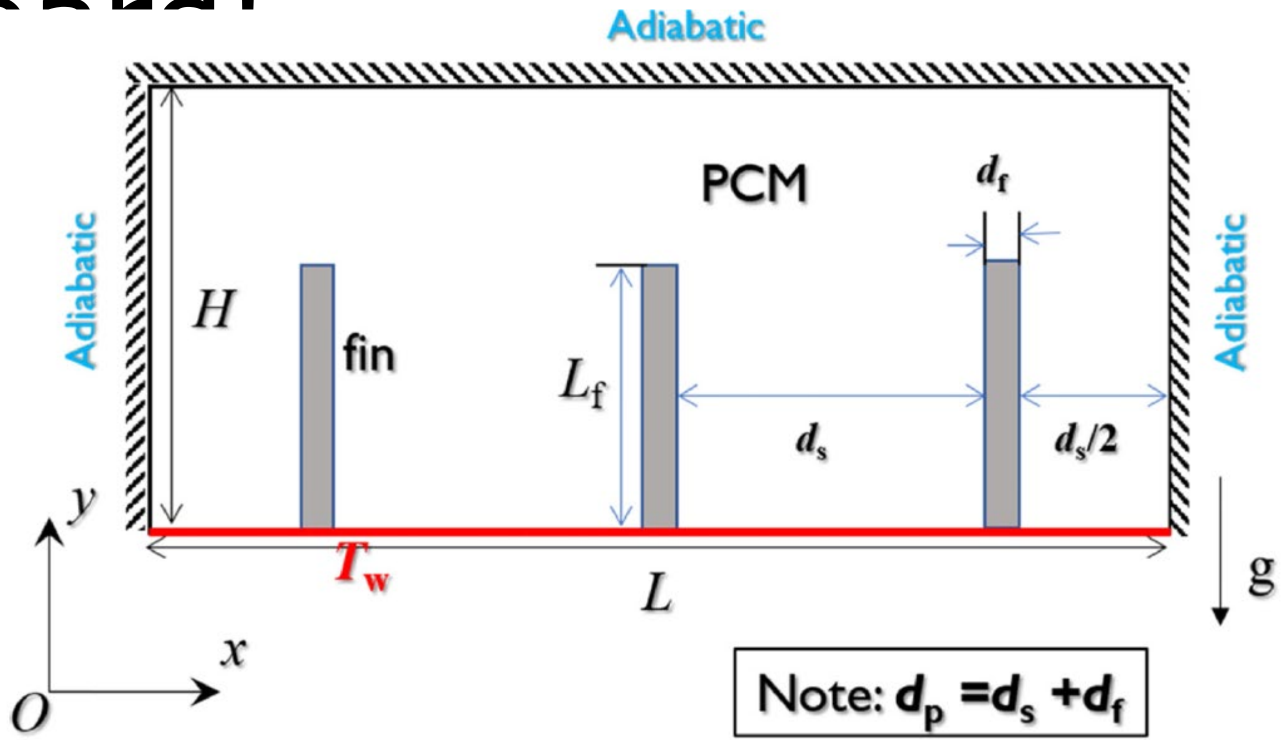
(d) Lab set up

PCM tests: Na_2CO_3-KCl-NaCl





Design: Back to drawing board!



Numerical results

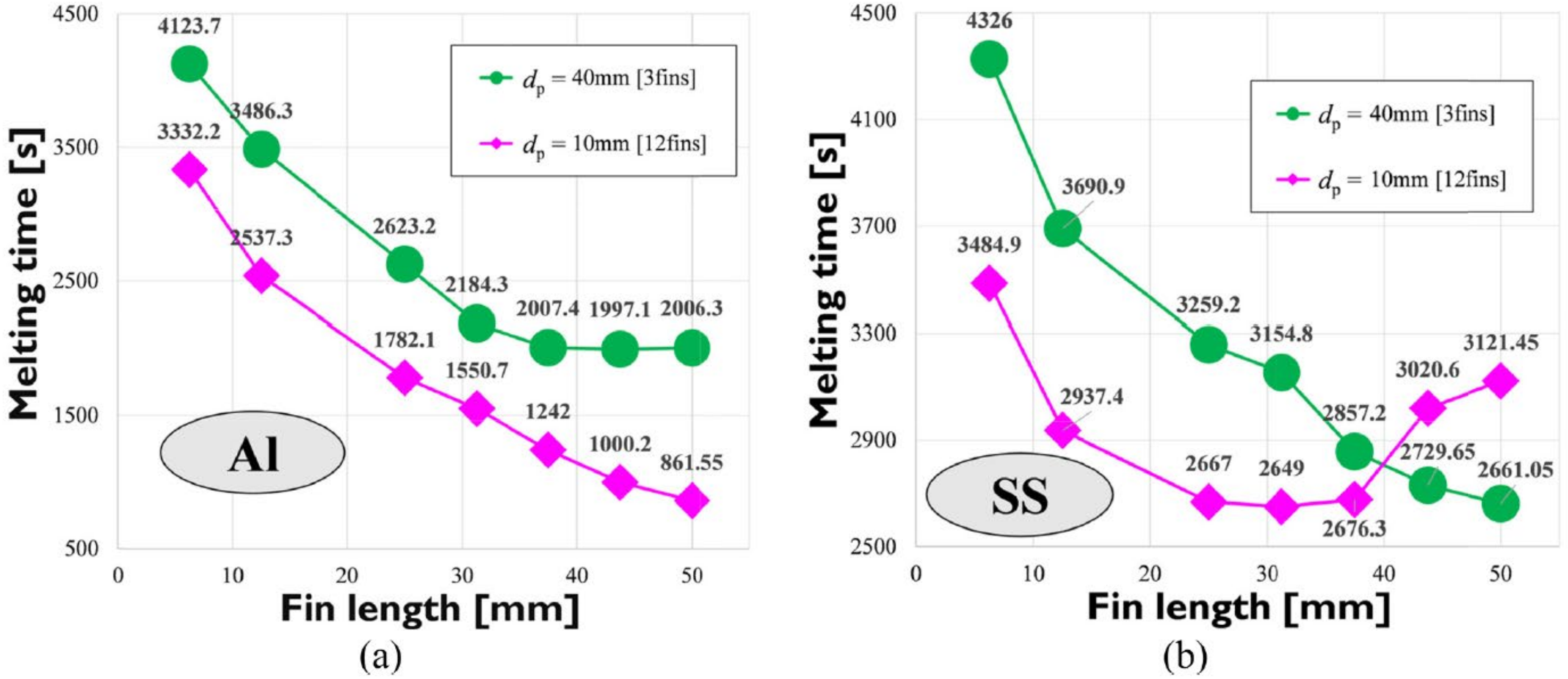
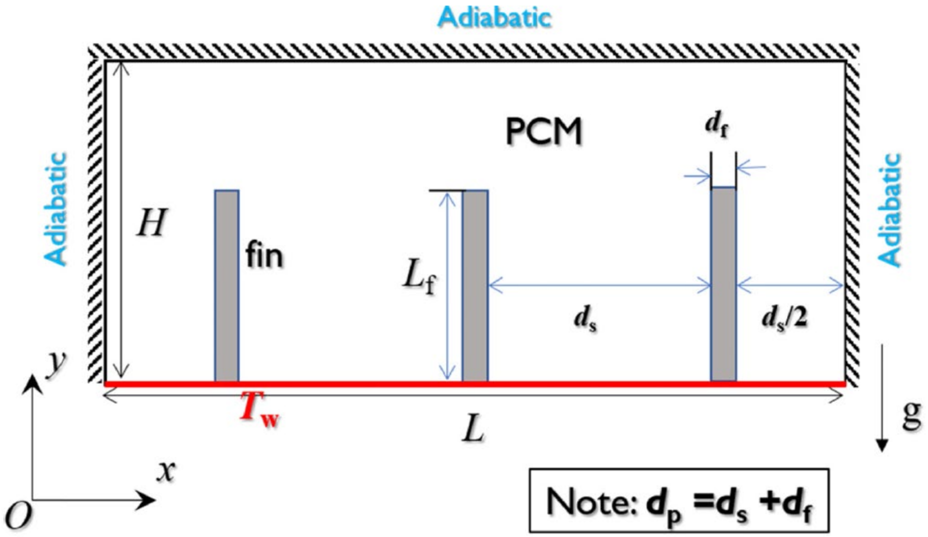


Fig. 8. Melting time versus fin length for aluminium (a) and stainless-steel (b).

Fin number



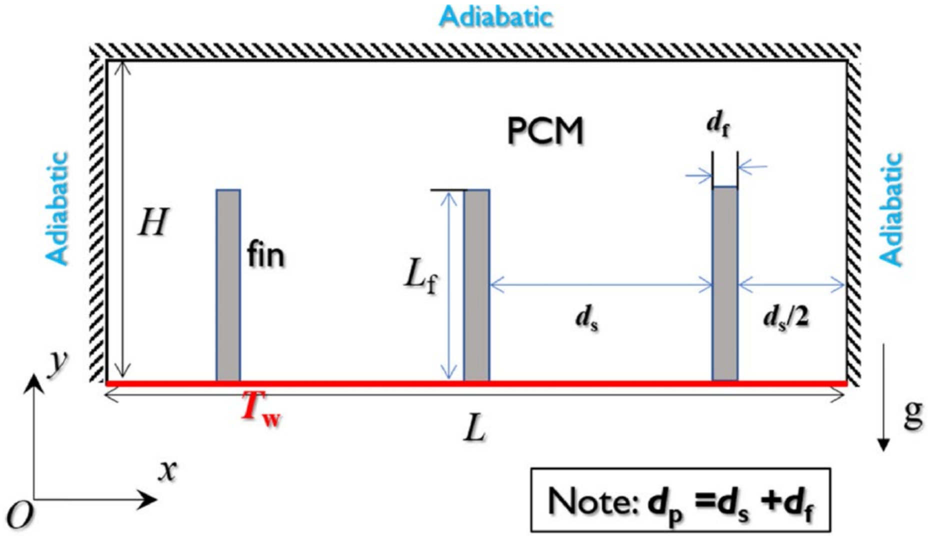
- Free convection along
- $\delta_v \sim \mathrm{Pr}^{0.5} \delta_t$
- $\delta_t \sim L_f Ra_L^{-0.25}$

- Interferences of adjacent boundary layers:
- $d_{s,max} \sim 2\delta_v$

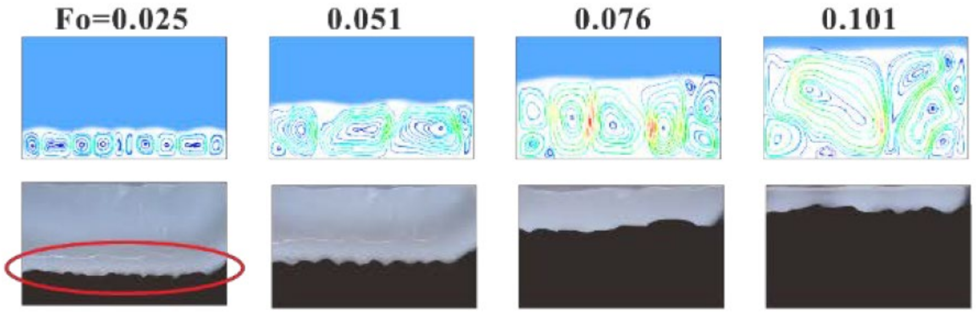
- $d_{s,max} \sim 2Pr^{0.5} L_f Ra_L^{-0.25}$

Fin length

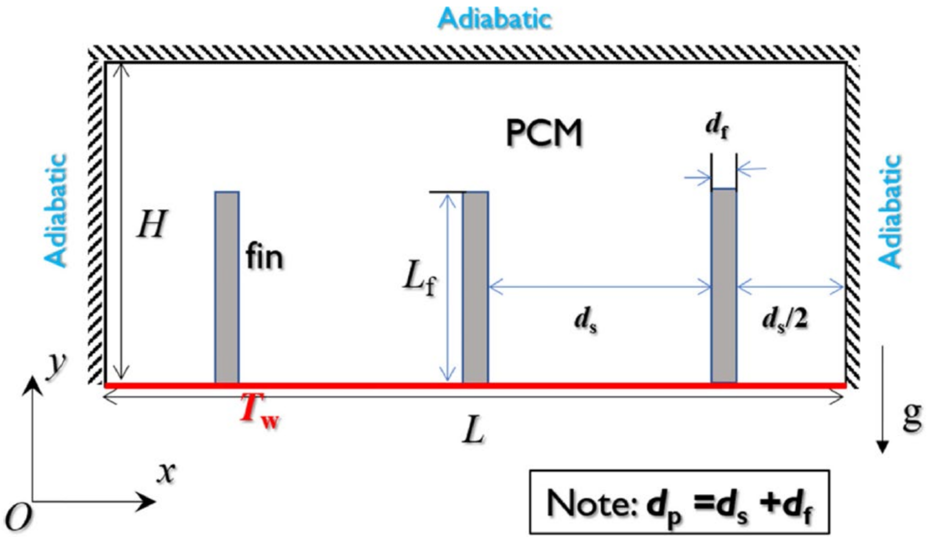
- Infinite ml for a fin (ml <2)
- $m^2 = \frac{hp}{k_s A}$
- $mL_f \quad = \left(\frac{hp}{k_s A}\right)^{0.5} \mathrm{L_f} < 2$
- $h = \frac{2k_f}{d_s}$
- $L_f^2 \sim d_f d_s \frac{k_s}{k_f}$



Shell size



- Short fin in a large shell:
- Mushrooms with the same penetration rate in both direction
- $H - L_f \quad \sim 0.5\, d_s$



Results

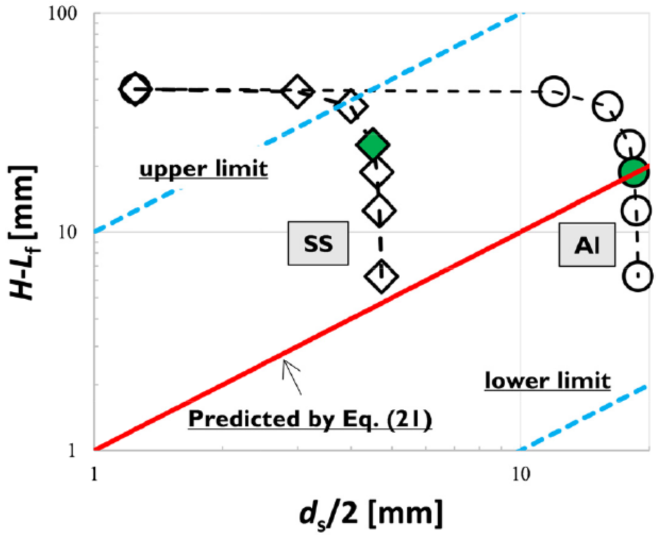


Fig. 11. Comparison of Eq. (21) with numerical results.

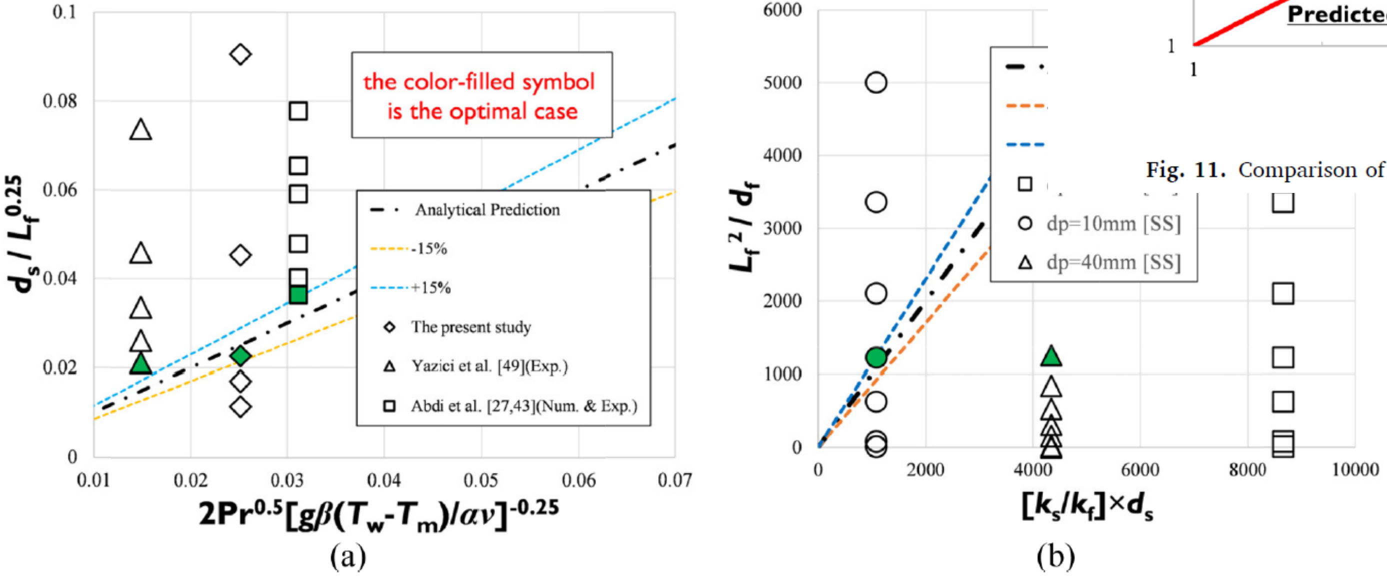


Fig. 10. Comparisons of Eqs. (13) and (19) with simulated/experimental results [27,43,49].

Conclusion

- Transient convection-conduction balance,
- Practicality: contact resistance, corrosion, fast charge/discharge,
- Cost reduction,
- Imagination; pen-&-paper game,
- Simple yet pragmatic (engineering) solutions.

THANK YOU VERY MUCH!