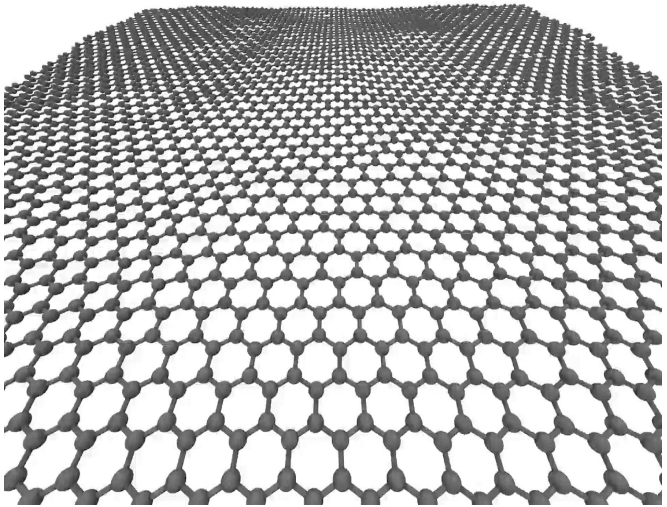
Thermal Energy Storage: The Basics

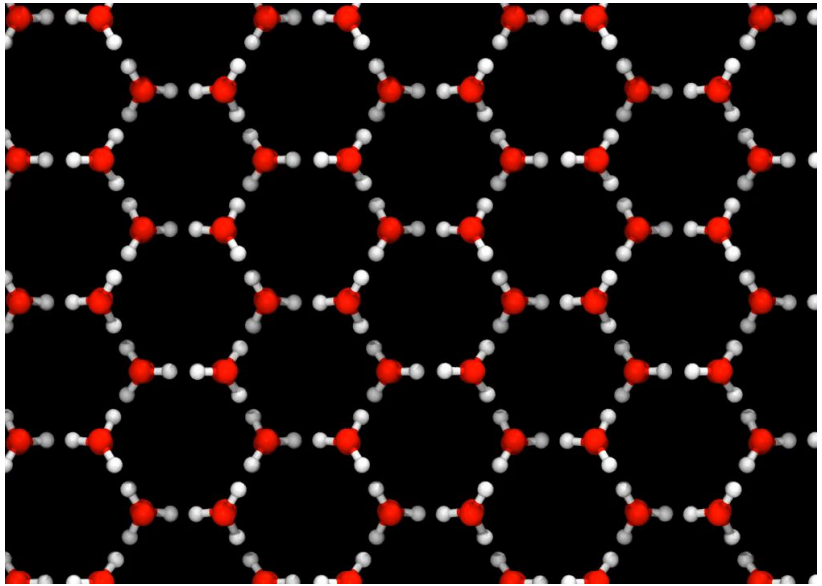
Kinetic Energy: $E_K \propto \frac{1}{2}mv^2 \propto T$

Sensible



Potential Energy: $E_P \propto \frac{q_1 q_2}{r_{12}}$

Latent



Advantages & Disadvantages

Advantages

- It can be very cheap $1-10/kWh-e (we think)
- 10-100x cheaper than Li-ion $1T vs $10T
- Similar energy density to Li-ion
- Infinite cycle life (in principle)
- Abundant materials
- May not require new manufacturing
- Physical economies of scale

$3.6/kWh Carbon as an example

$\$10^{-6}/J = [\$0.5/kg] \div [2000\ J/kg/K \cdot (500\ K) \cdot 0.5]$

Disadvantages

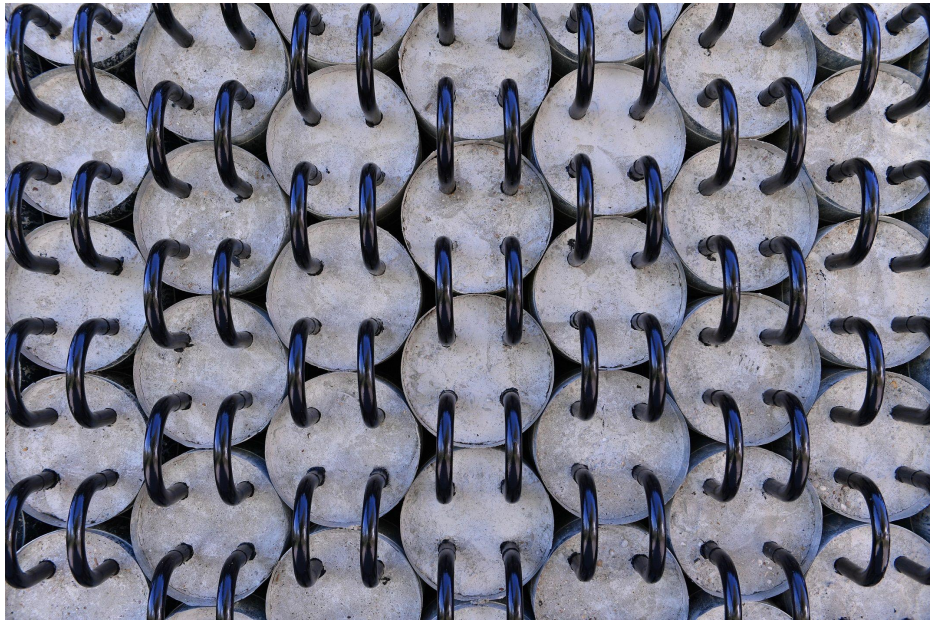
- Efficiency < 70%
- System/infrastructure cost
- Integration/transport challenges
- Not easily scaled down

Cost per unit energy | Cost of the medium | Energy Stored | Roundtrip Efficiency

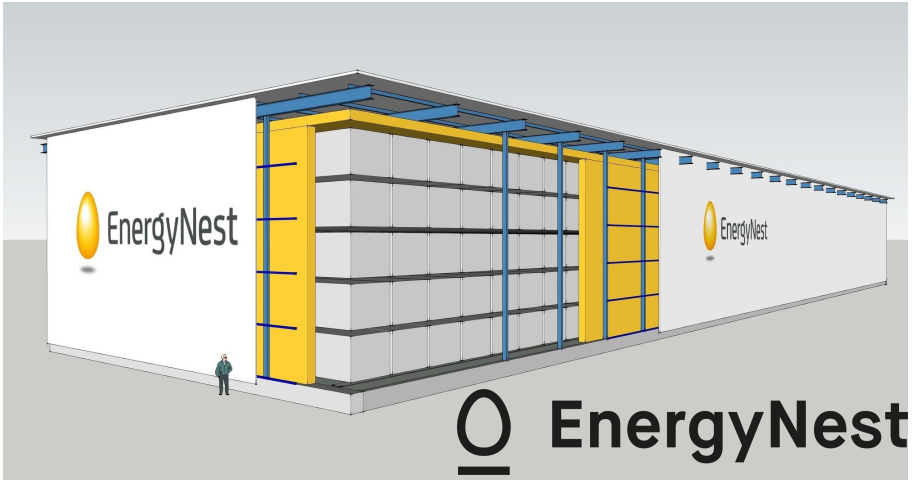
$CPE_{min} = [\$/kg] \div [C_p \cdot (T_{High} - T_{Low}) \cdot RTE]$

Medium Temperature – Cement

- 400°C in air
- Steam cycle? < 35%



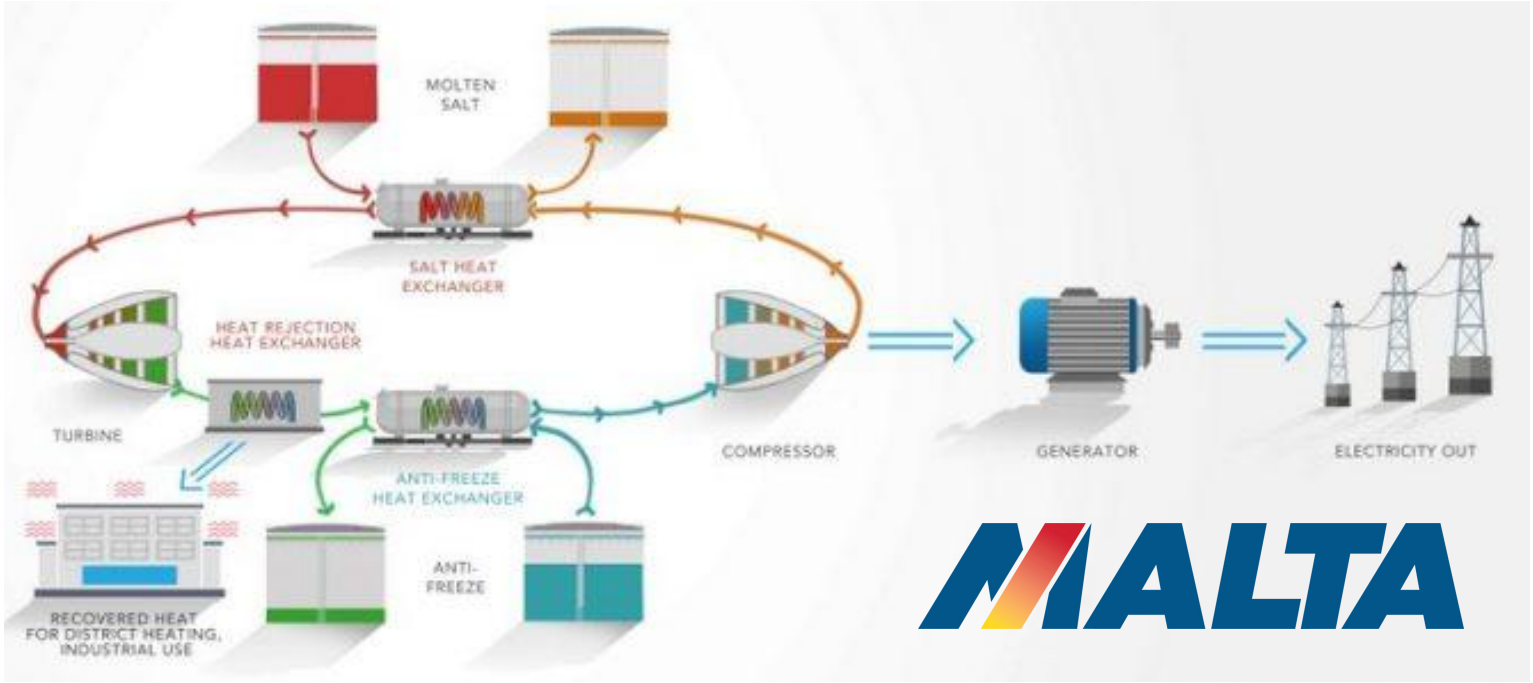
- Cost? > $7/kWh-e
- Pilot with heat discharge



- Conversion to electricity?
- Components proven in CSP
- Efficiency vs. T

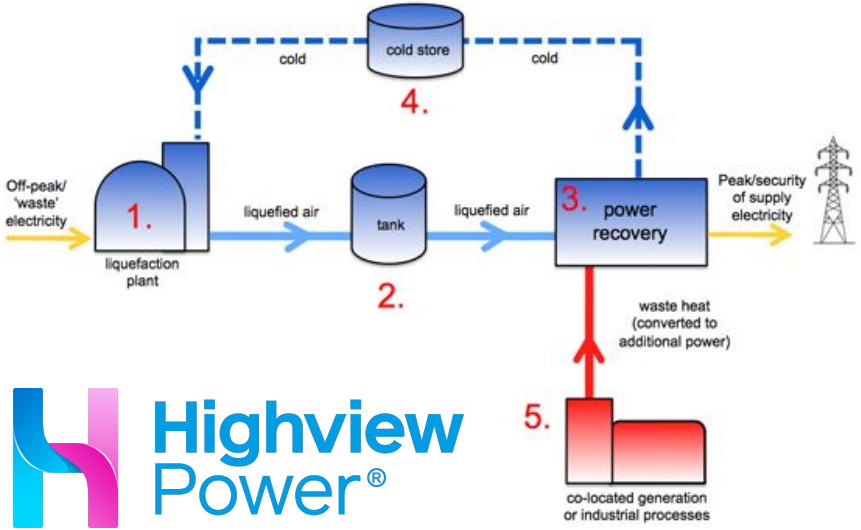
Pumped Heat Storage – Salt

- Boost efficiency with heat pump (60%)
- All components are proven
- Cost? > $30/kWh-e
- Building a commercial demo



Cryogenic Storage – Liquid Air

- Use process heat, or the atmosphere
- All components are proven
- Cost ~ $150/kWh-e
- Building a commercial demo



Highview Power®

High Temperature – Carbon/Silicon

Silicon at 1414°C

- Silicon latent heat
- Heat engine?? 60% max
- > $4.5/kWh-e
- System cost
- Cyclic freezing?

Graphite at 1900-2400°C

Thermal Battery

- Graphite sensible
- Thermophotovoltaics
- Target 50%
- Liquid metal
- $10-20/kWh-e
- Components demo'd

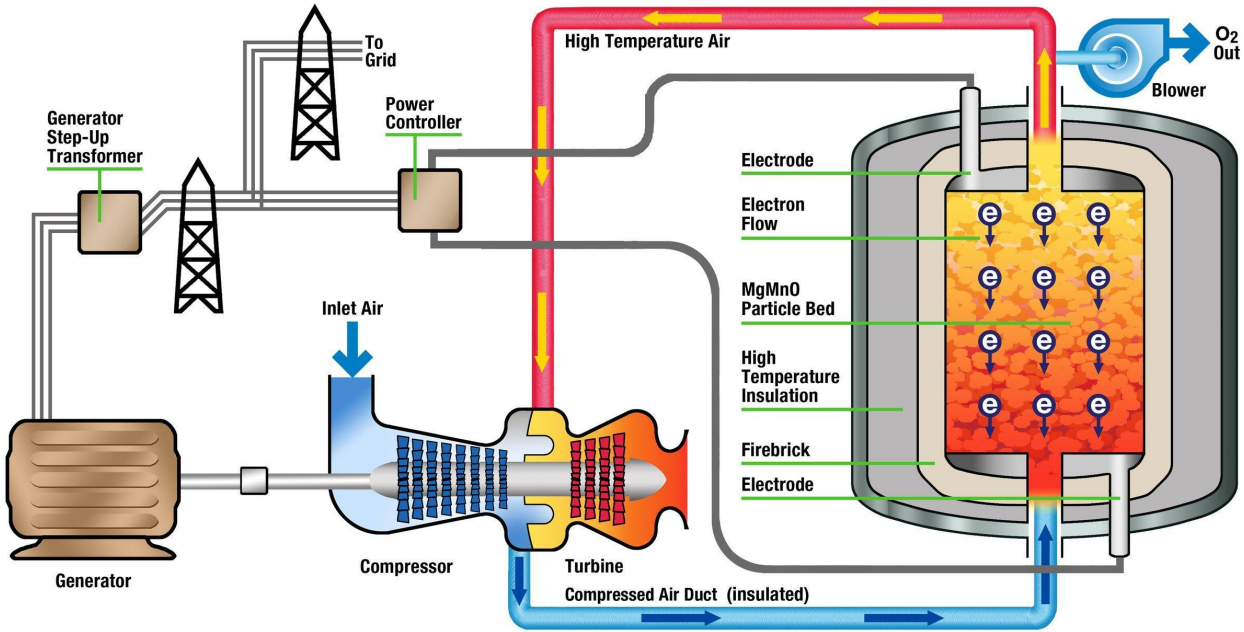
Graphite at ? >1200°C

ANTORA

- Graphite sensible
- Thermophotovoltaics
- Target > 40%
- $10-20/kWh-e
- No liquid metal

High Temperature – Thermochemical

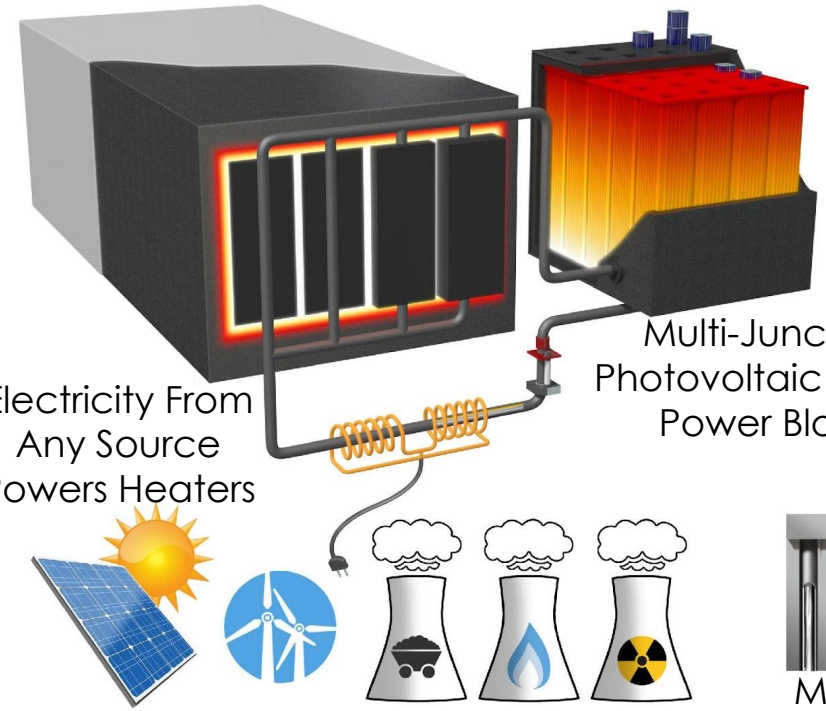
- Metal + Oxygen Bonds
- 60% max
- 1500°C
- Demonstrated +1000 hrs
- Scaling up
- Cost?



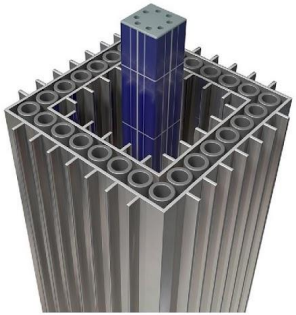
BACKUP SLIDES

High Temperature – Carbon/Silicon

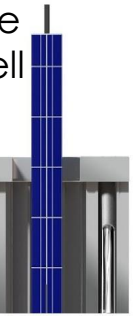
Electricity □ Heat □ Electricity



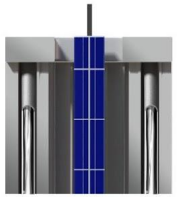
Electricity From Any Source Powers Heaters



Multi-Junction Photovoltaic (MPV) Power Block

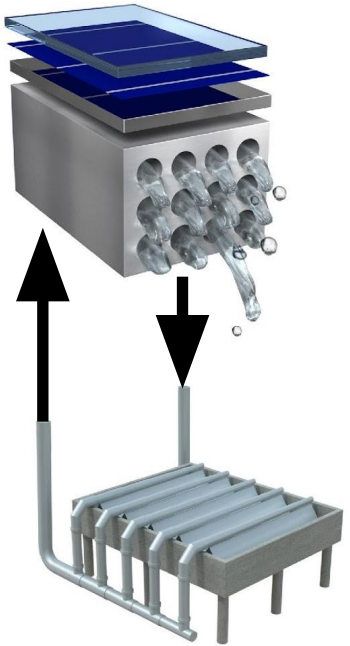


MPV Module Unit Cell



MPV Can Be Retracted

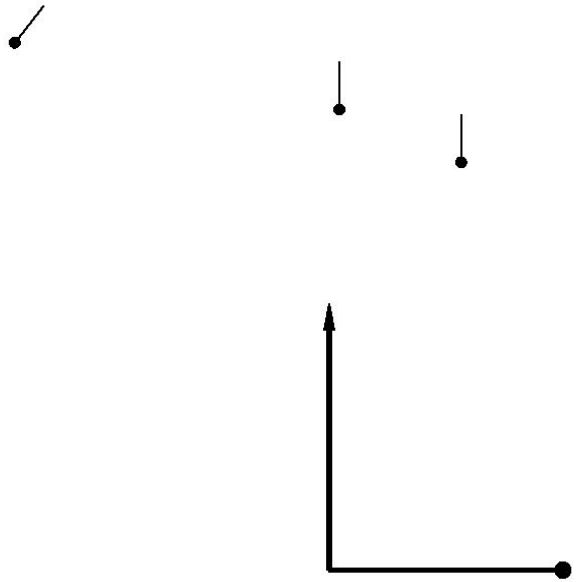
Water Cooled MPV with Integrated Mirror



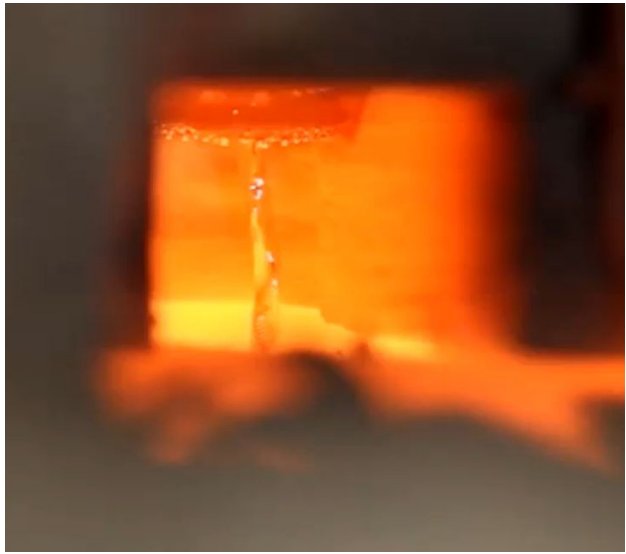
Dry Cooling Unit

C. Amy et al., Energy Environ. Sci., 12, 334-343 (2019)

Pumping



Pumping at 1400°C

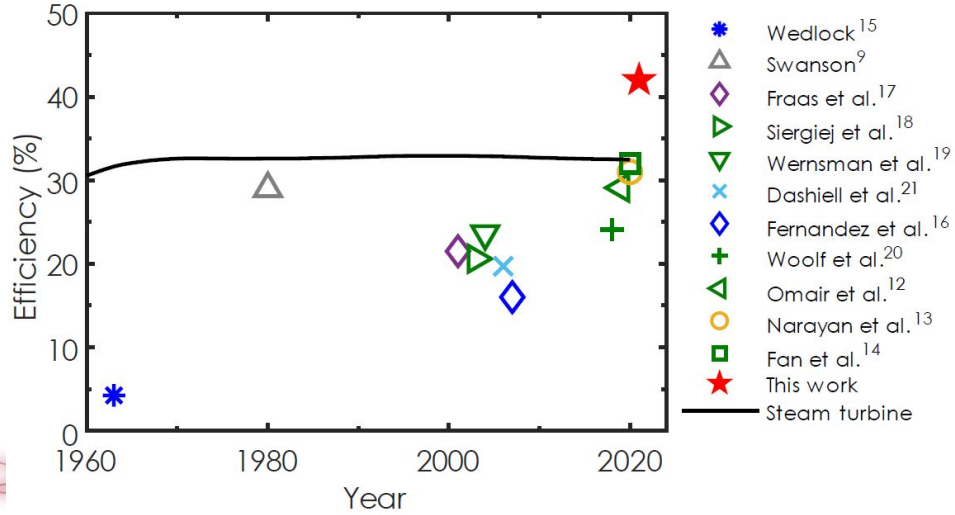


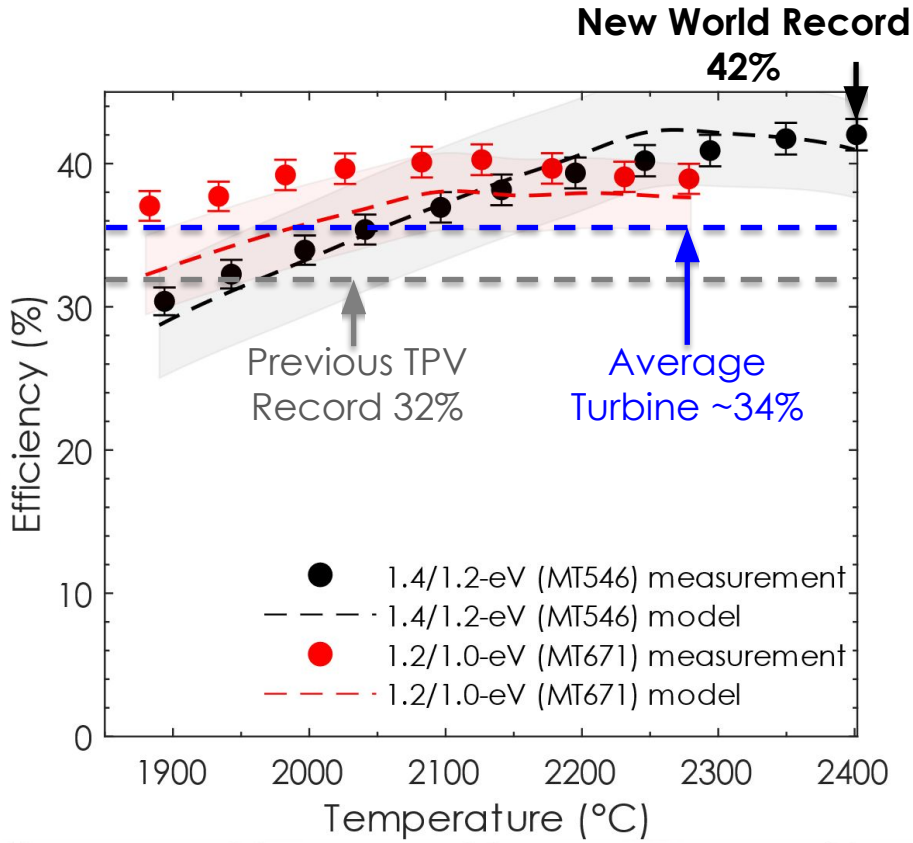
C. Amy et al., **Nature** 550, 199–203 (2017)

C. Amy et al., Energy, 233, 15, 121105 (2021)

New TPV World Record

- Thermophotovoltaic (TPV) efficiency
- TPV record was 29% for 40 years
- Record broken last year at 30%
- Our new record = 42%
- 40% = high enough to commercialize
- Plan to push to 50%





What will the full system look like?

Full scale system mockup: 1 GWh = 100 MW x 10 hrs of storage