

Thermophotovoltaic systems can provide cost-effective, dispatchable clean power

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Department of Mechanical Engineering, Massachusetts Institute of Technology

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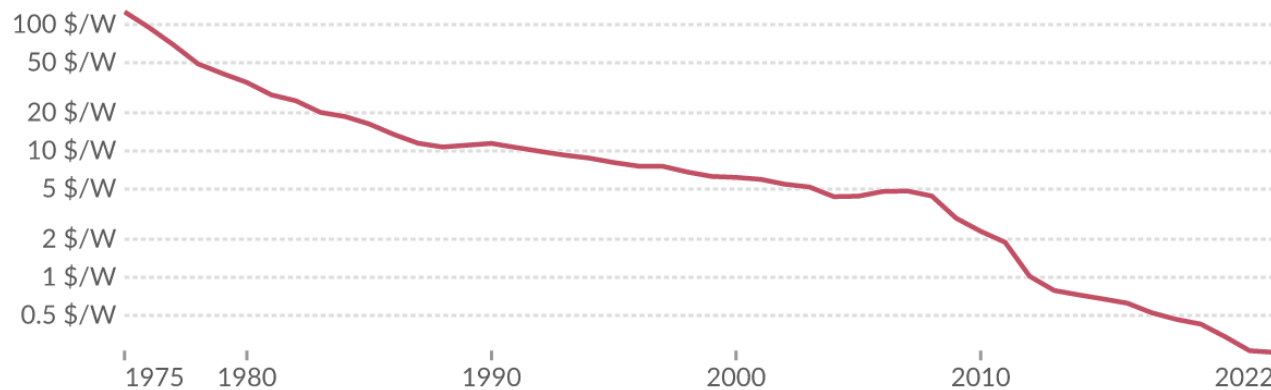
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What is TPV and how does it work?

Solar PV is the cheapest energy source

Solar (photovoltaic) panel prices

This data is expressed in US dollars per Watt, adjusted for inflation.



Data source: International Renewable Energy Agency (2023); Nemet (2009); Farmer and Lafond (2016)

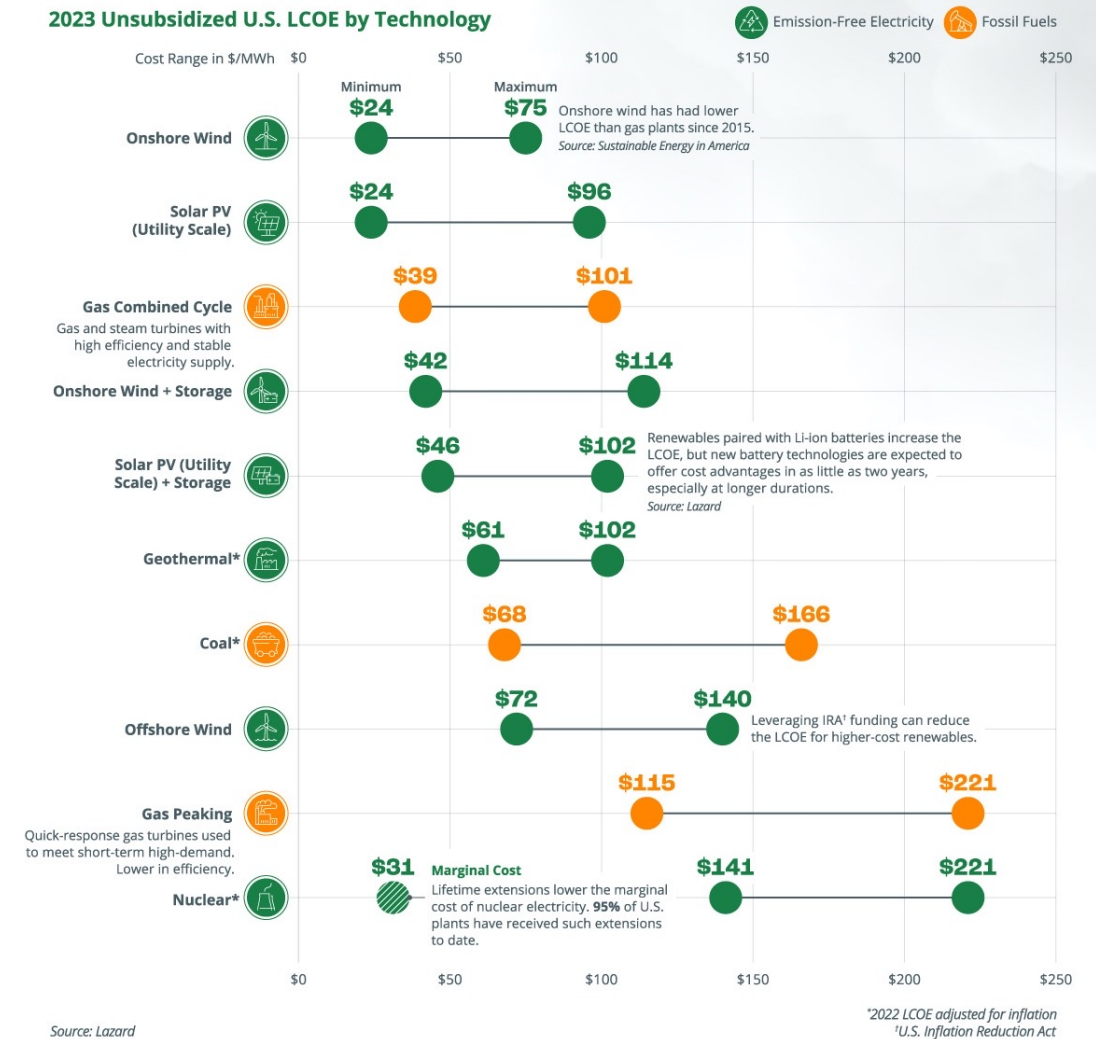
Note: Data is expressed in constant 2022 US\$ per Watt.

OurWorldInData.org/energy | CC BY

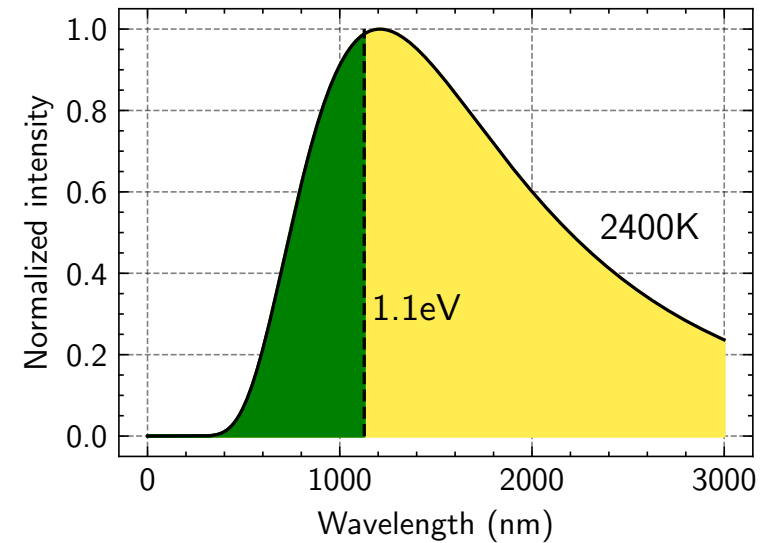
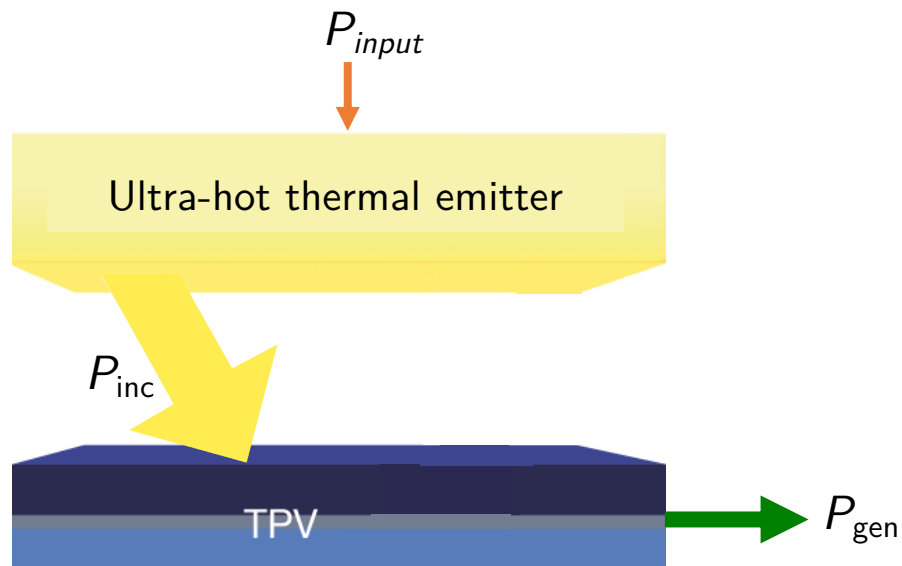
The problem with solar is intermittency

What if we could make solar dispatchable?

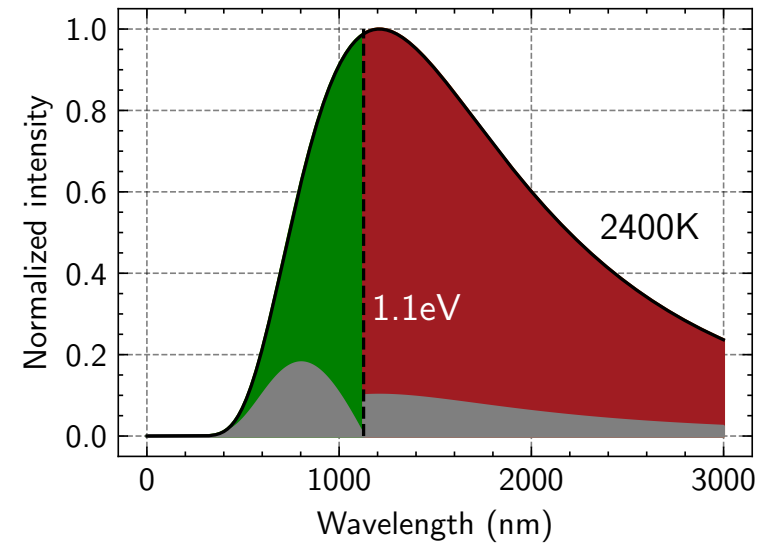
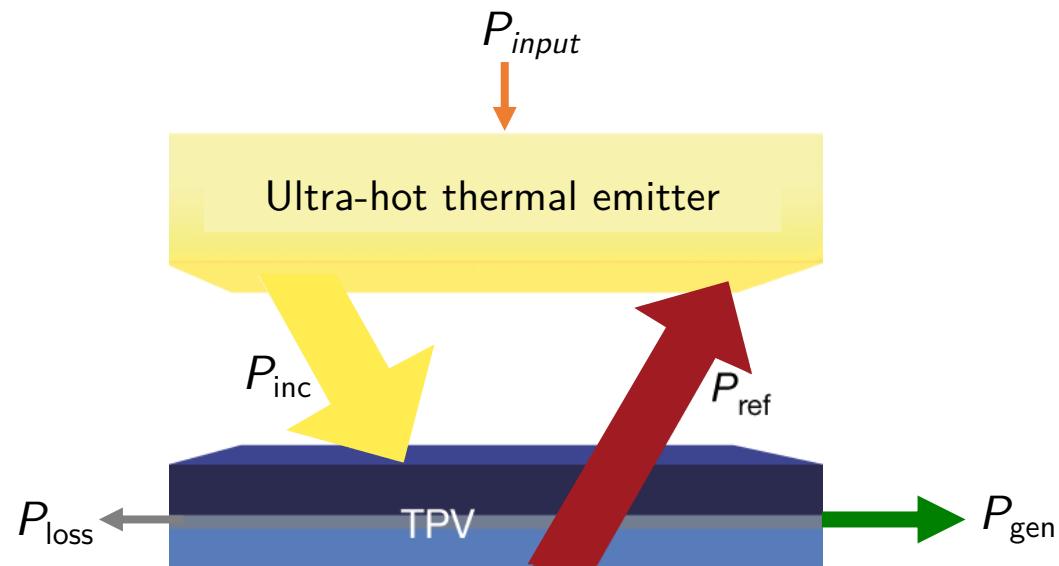
2023 Unsubsidized U.S. LCOE by Technology



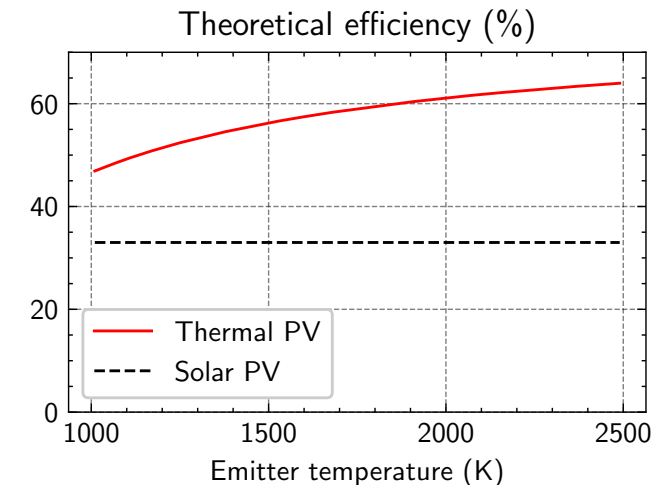
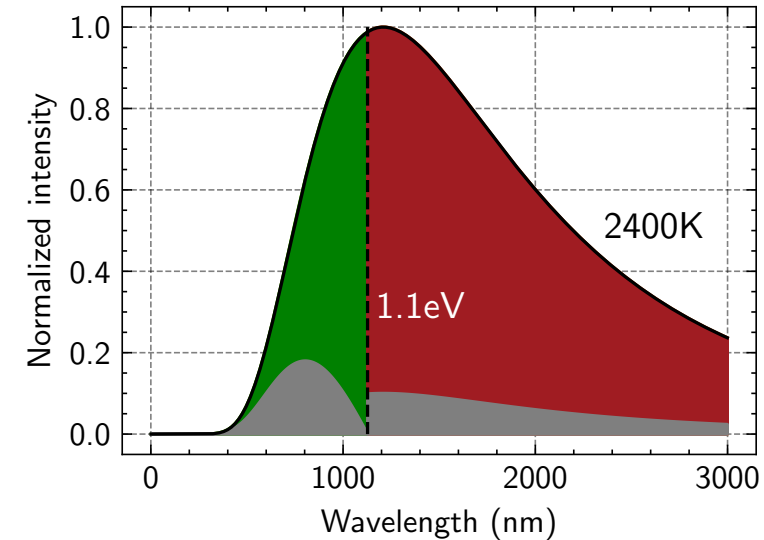
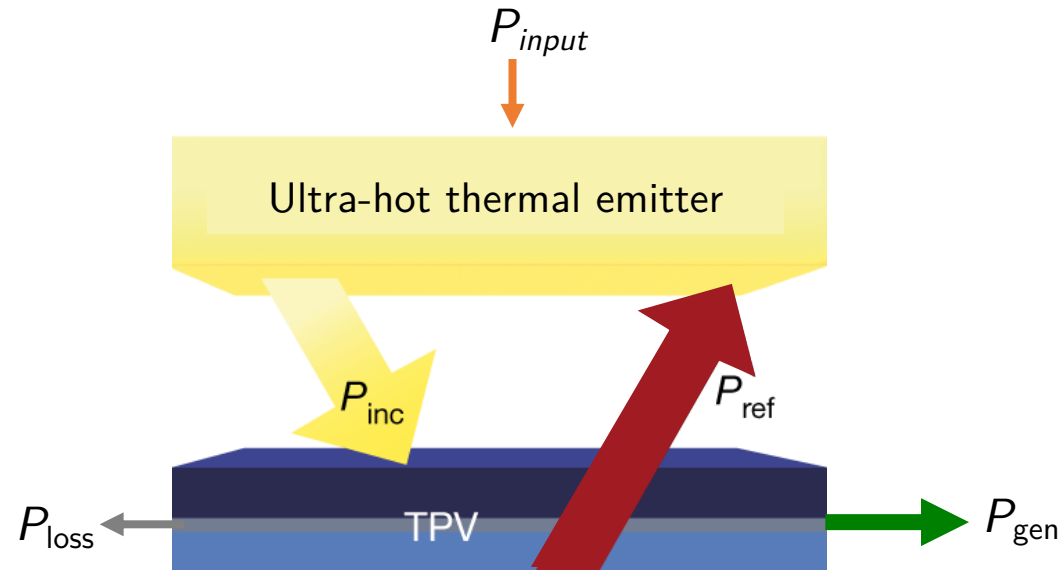
Thermophotovoltaics (TPV) makes PV dispatchable



Thermophotovoltaics (TPV) makes PV dispatchable



TPVs can be much more efficient than solar PV



$$\text{Efficiency } \eta = \frac{P_{gen}}{P_{input}}$$

$$\text{For solar, } P_{input} = P_{inc} = 1000 \frac{W}{m^2} \Rightarrow \eta = \frac{P_{gen}}{1000 \frac{W}{m^2}}$$

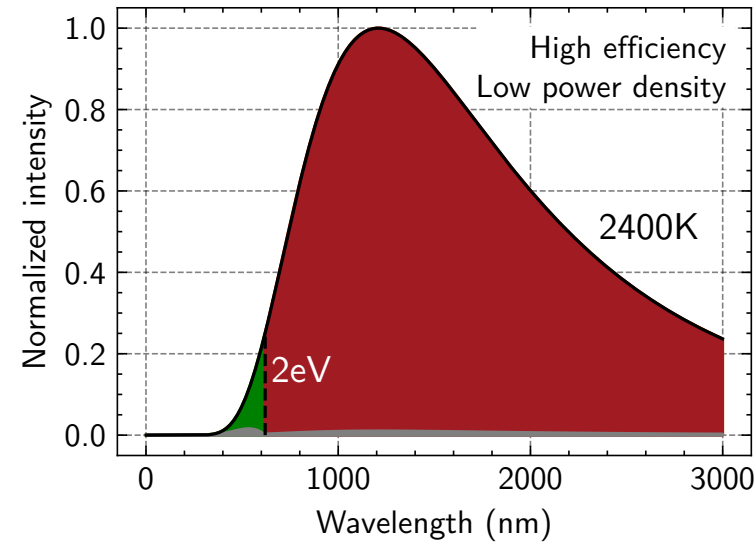
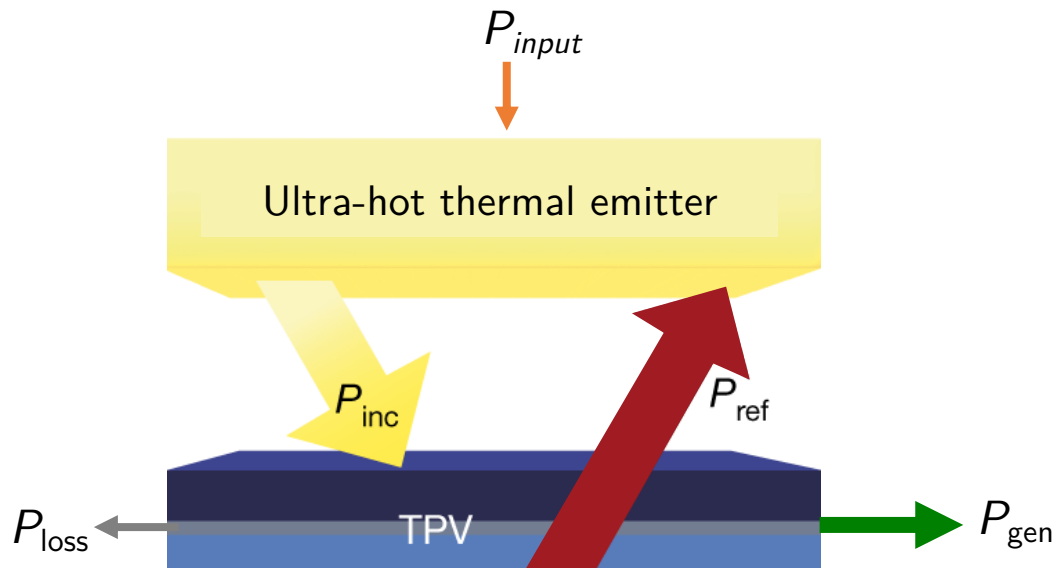
$$\text{For TPV, } P_{input} = P_{inc} - P_{ref} \Rightarrow \eta = \frac{P_{gen}}{P_{inc} - P_{ref}}$$

Efficiency is not the only metric for TPV performance

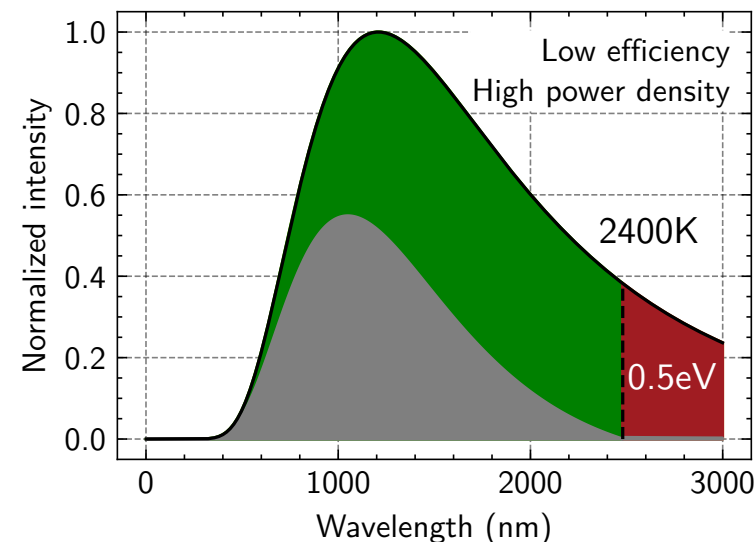
$$\text{Efficiency } \eta = \frac{P_{gen}}{P_{input}}$$

$$\text{For solar, } P_{gen} = \eta \cdot 1000 \frac{W}{m^2}$$

$$\text{For TPV, } P_{gen} = \eta \cdot (P_{inc} - P_{ref})$$



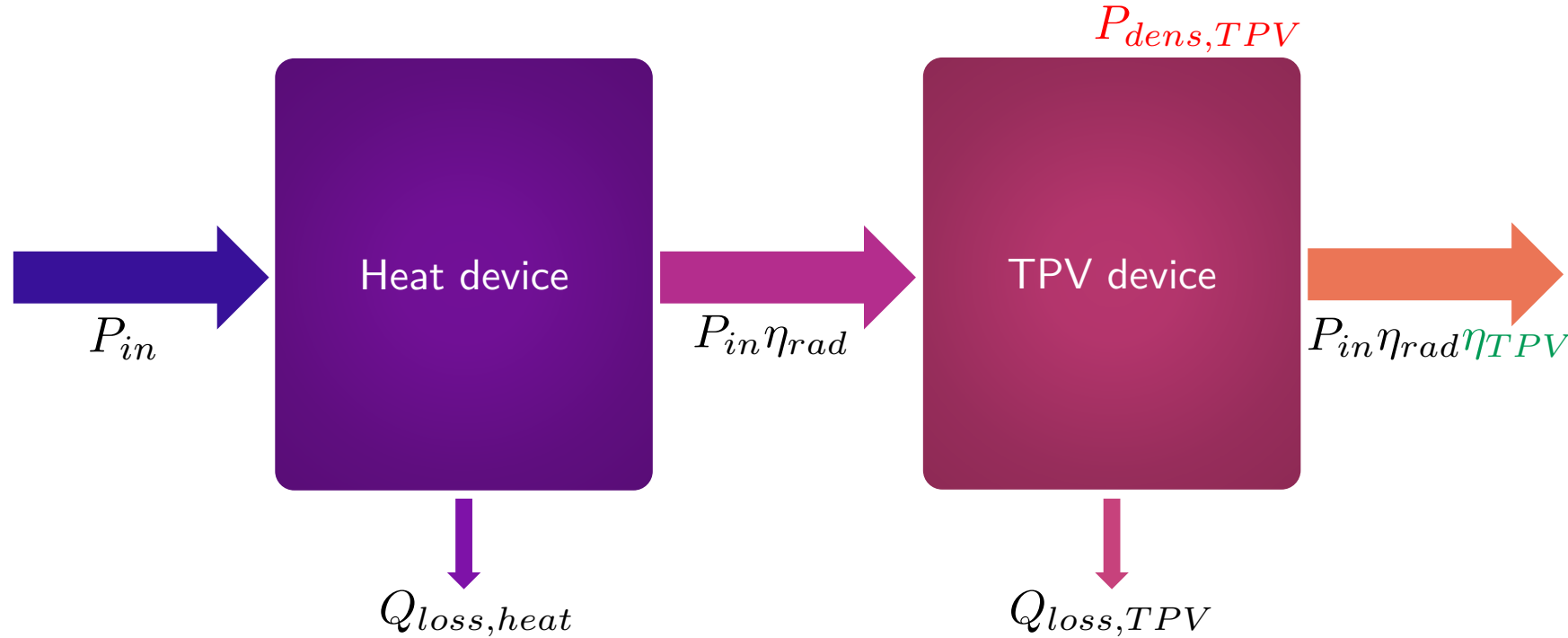
vs.



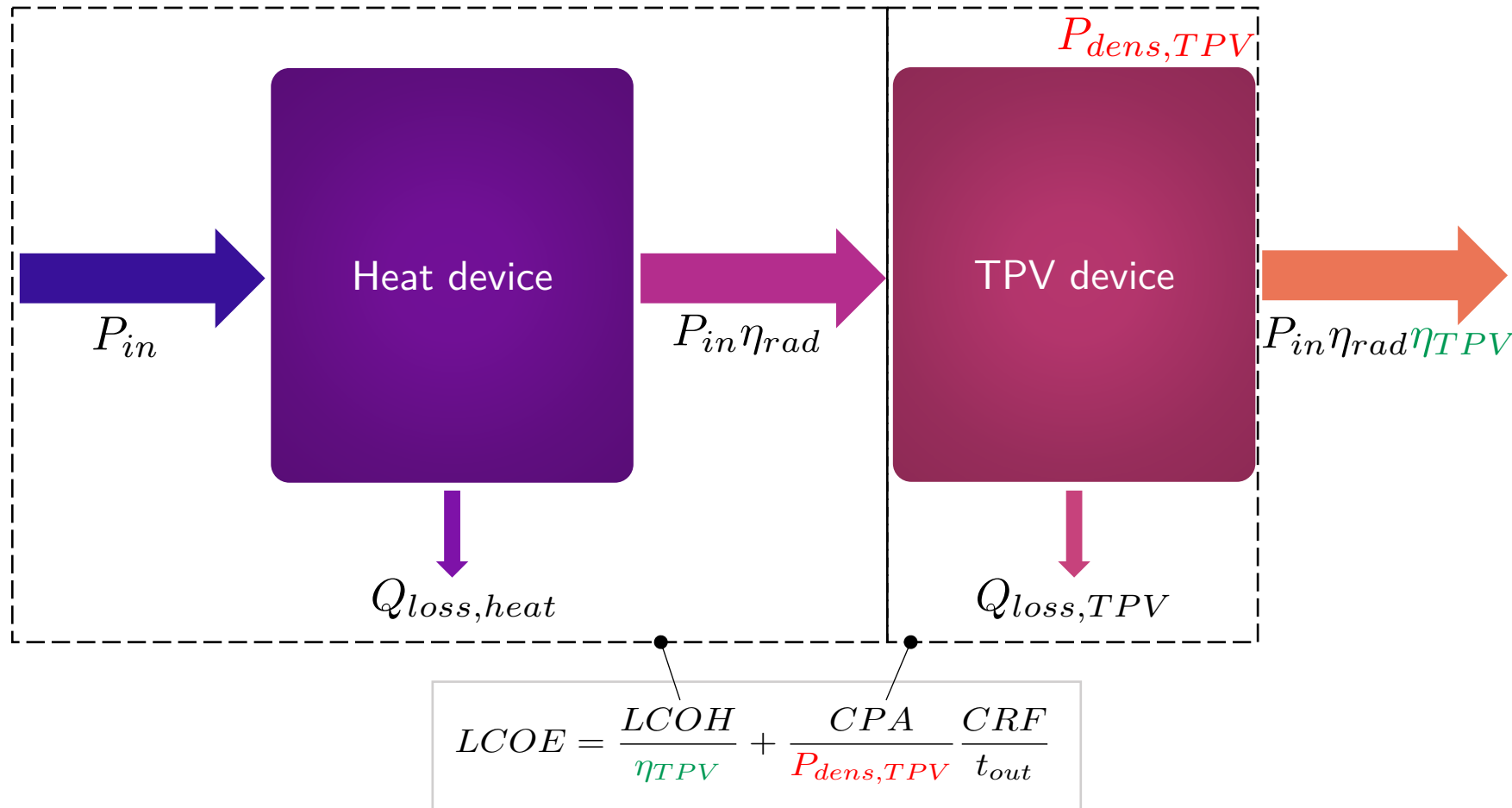
Both efficiency (%) and power density (W/cm^2) matter!

What is the cost of TPV systems?

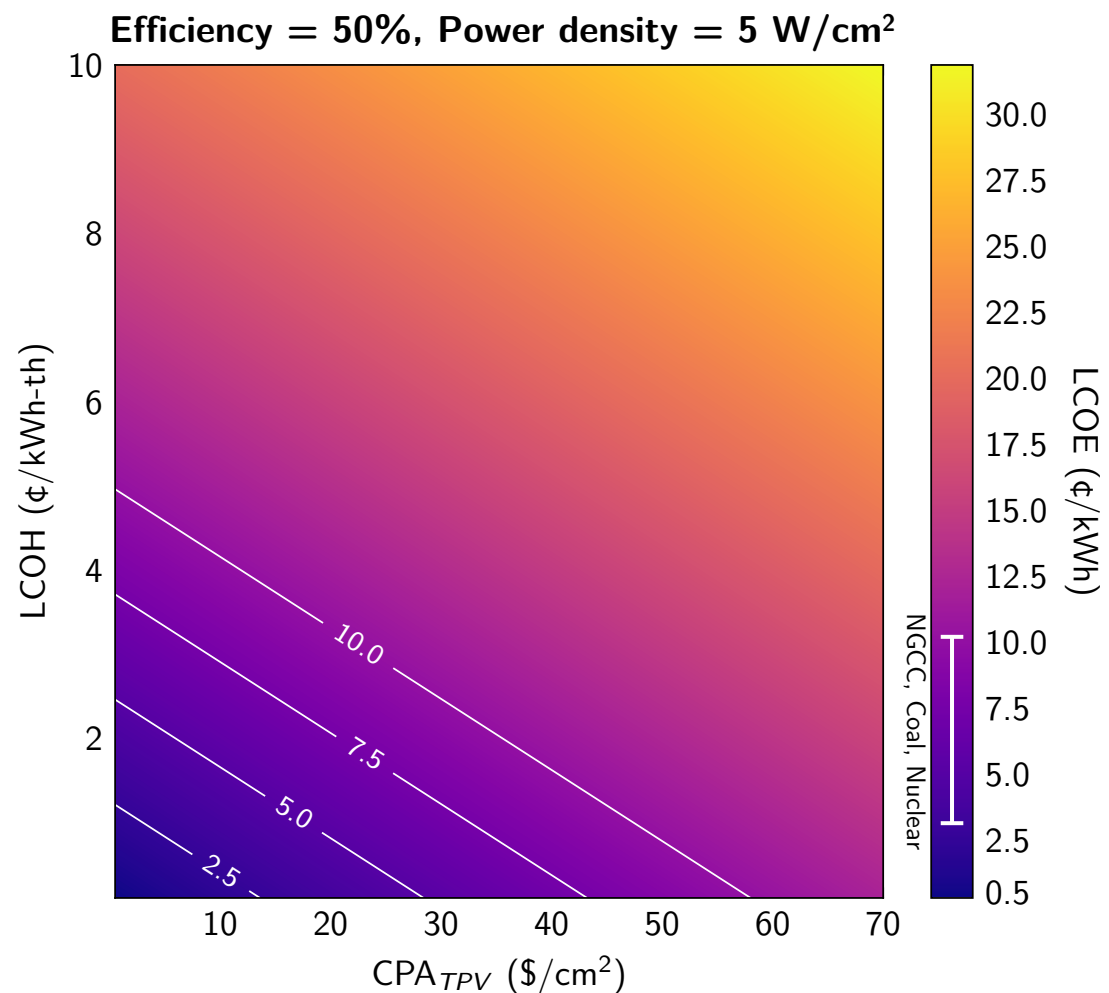
We can evaluate the cost of TPV with LCOE



We can evaluate the cost of TPV with LCOE

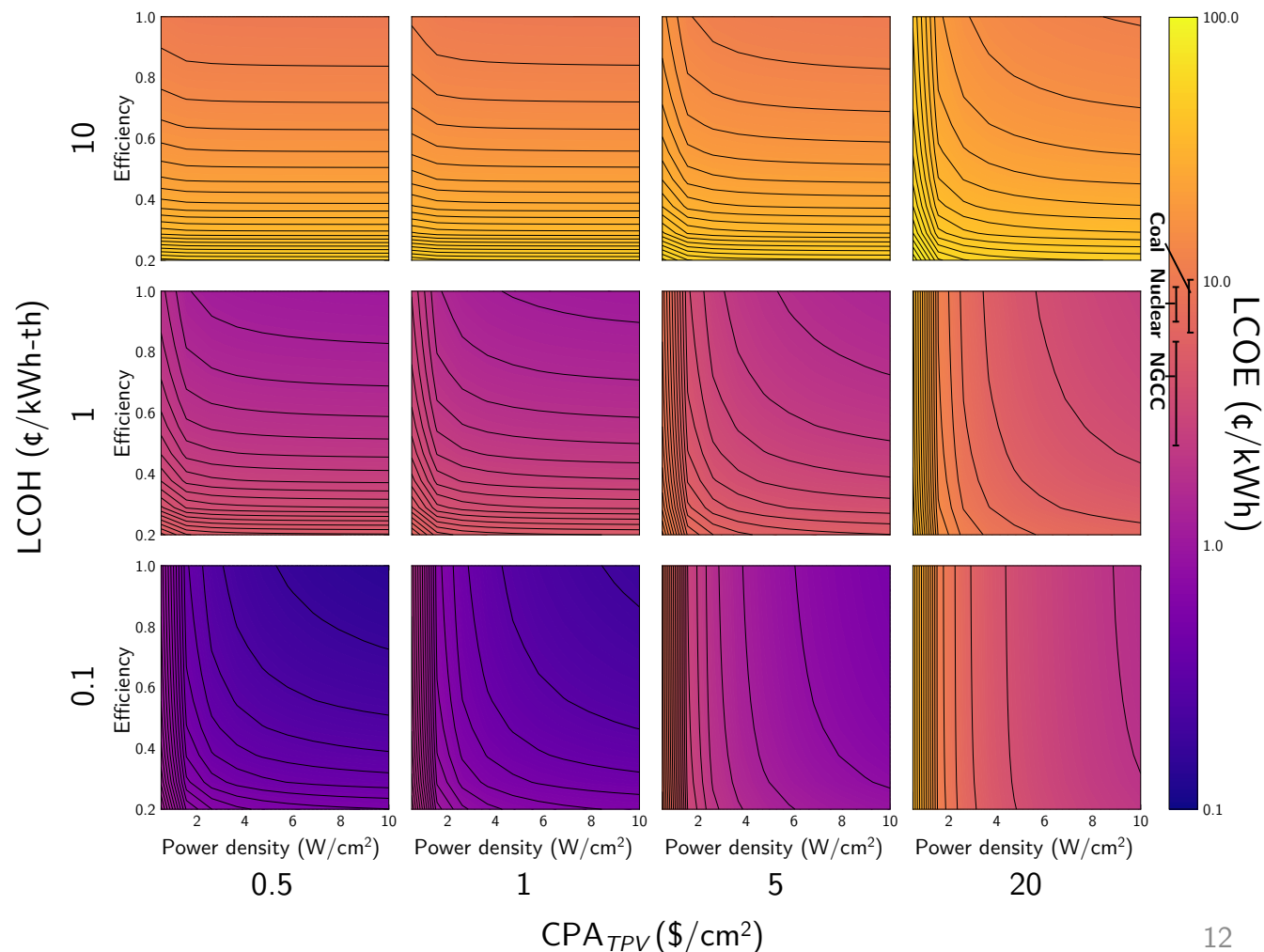
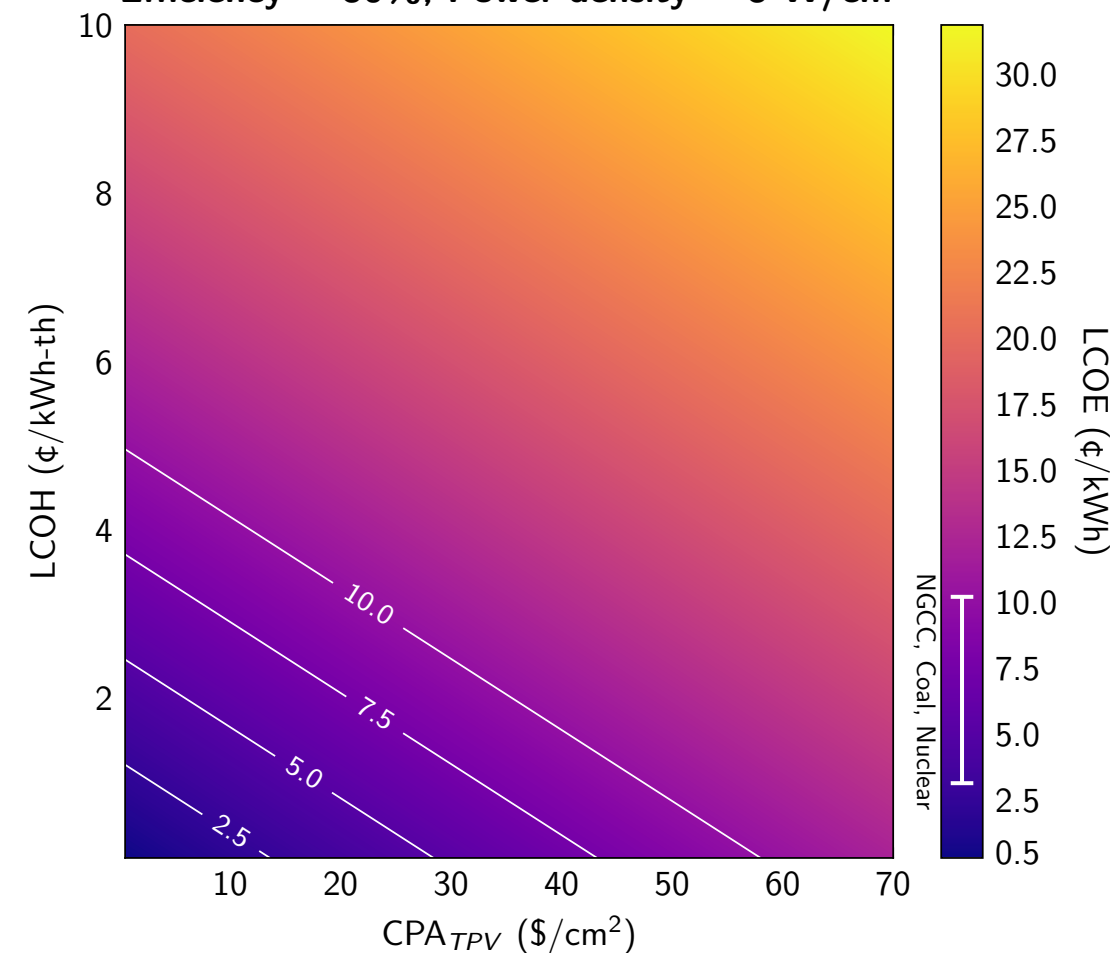


TPV can be cost-competitive with NG, coal, nuclear



TPV can be cost-competitive with NG, coal, nuclear

Efficiency = 50%, Power density = 5 W/cm²



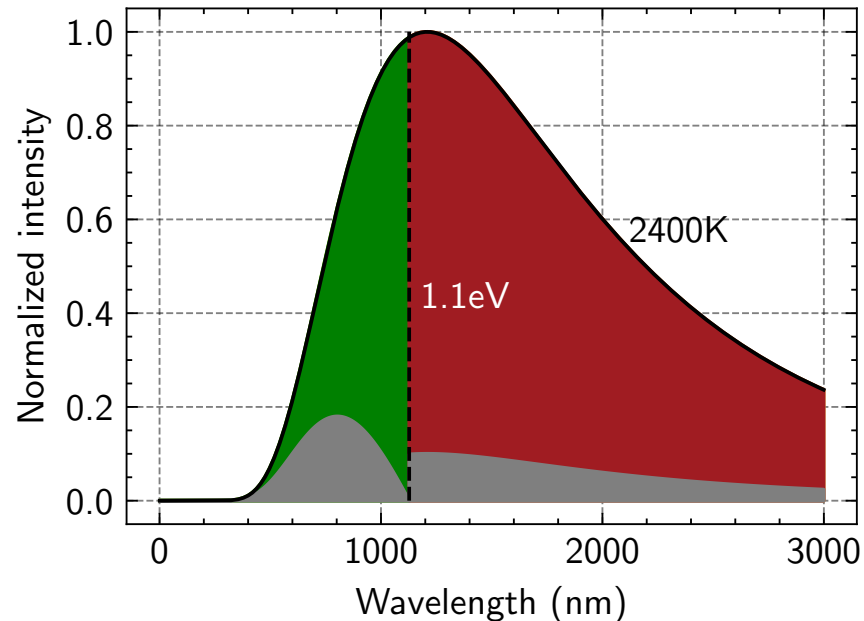
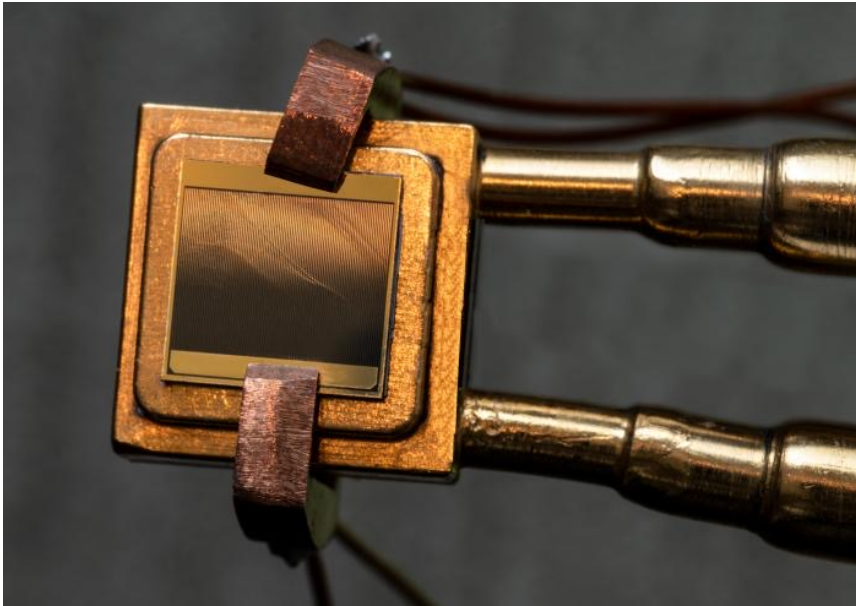
Ideal metrics: high efficiency and power density, low LCOH and CPA

**How can we design low-cost
TPV systems?**

TPV cell improvements for high efficiency

$$\eta = \frac{P_{gen}}{P_{abs}} = \frac{P_{gen}}{P_{gen} + P_{loss}}$$

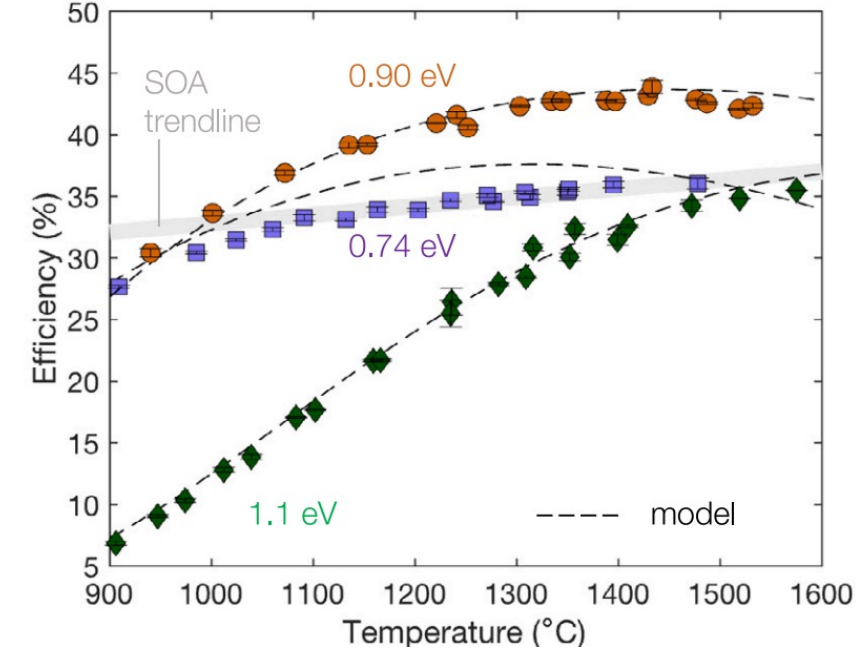
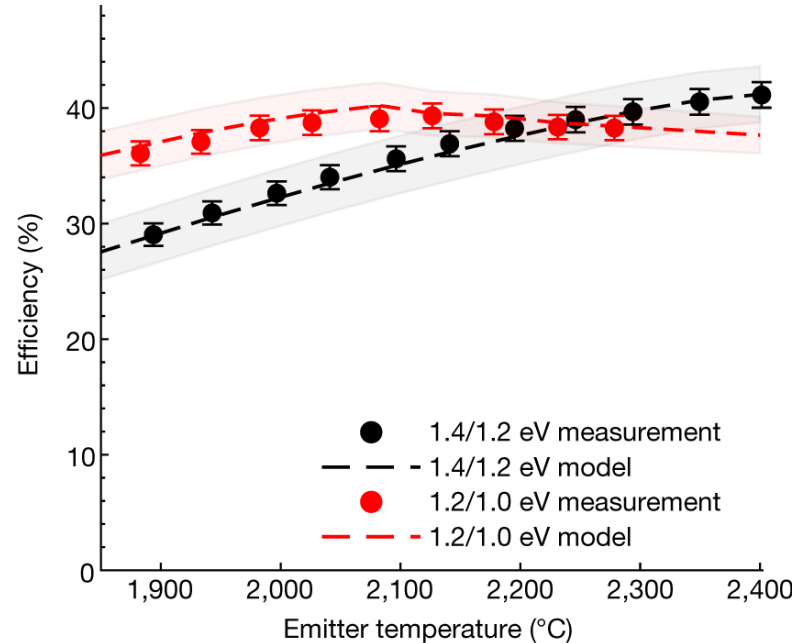
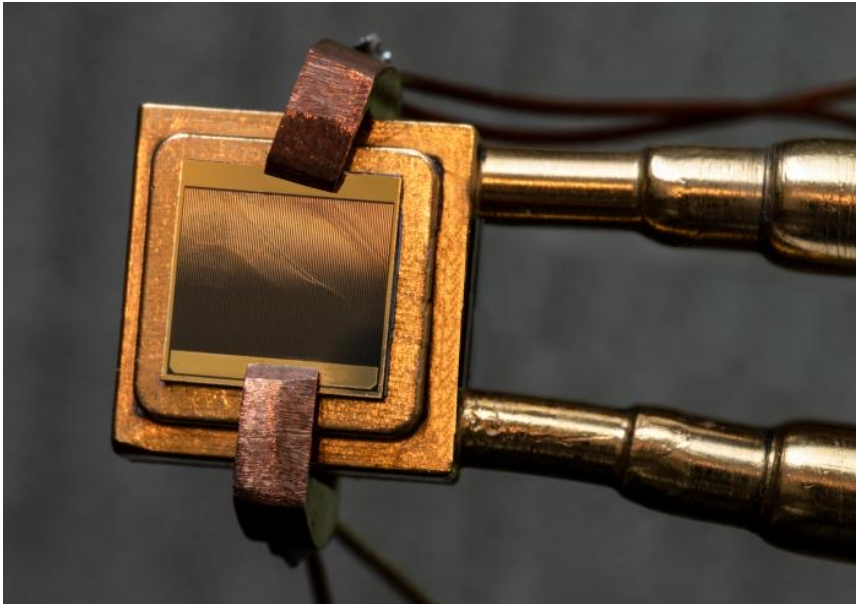
Minimize P_{loss} : low parasitic heating and high photon conversion efficiency



TPV cell improvements for high efficiency

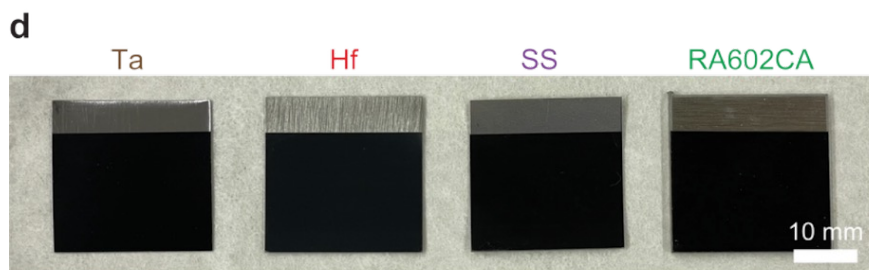
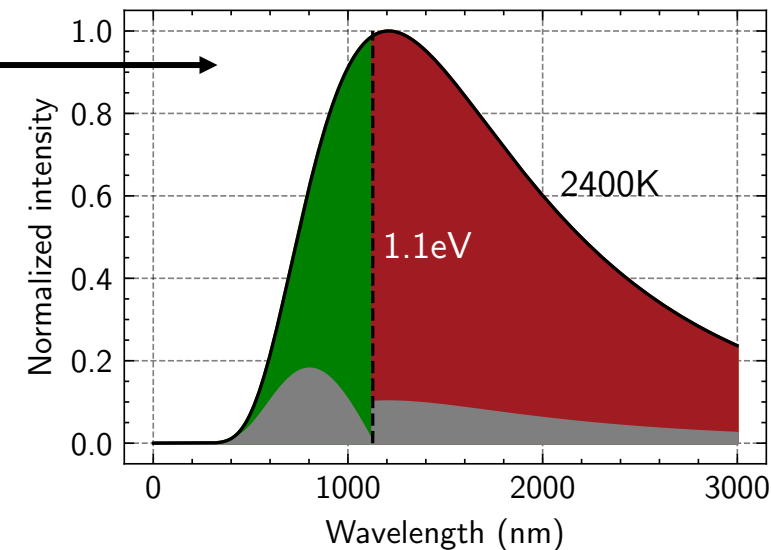
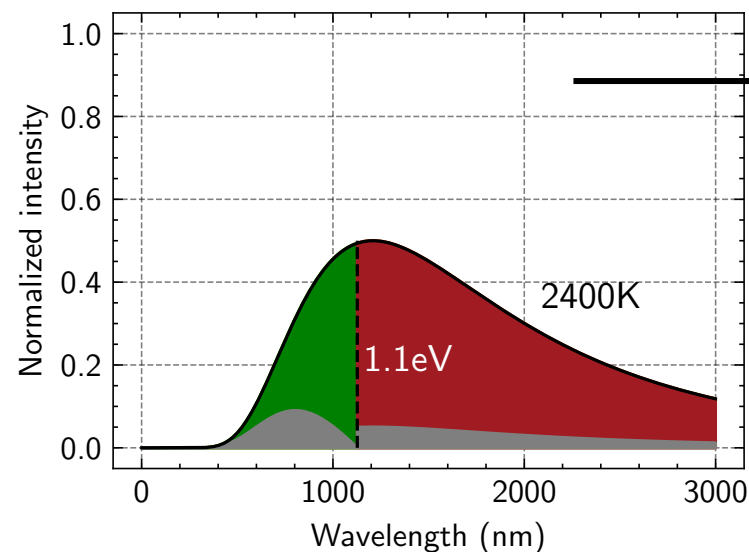
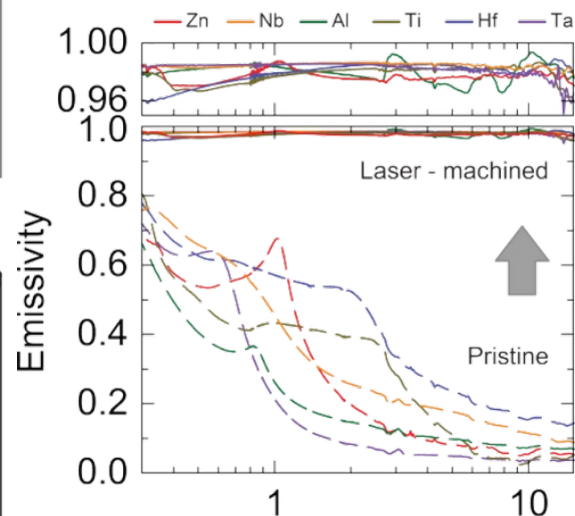
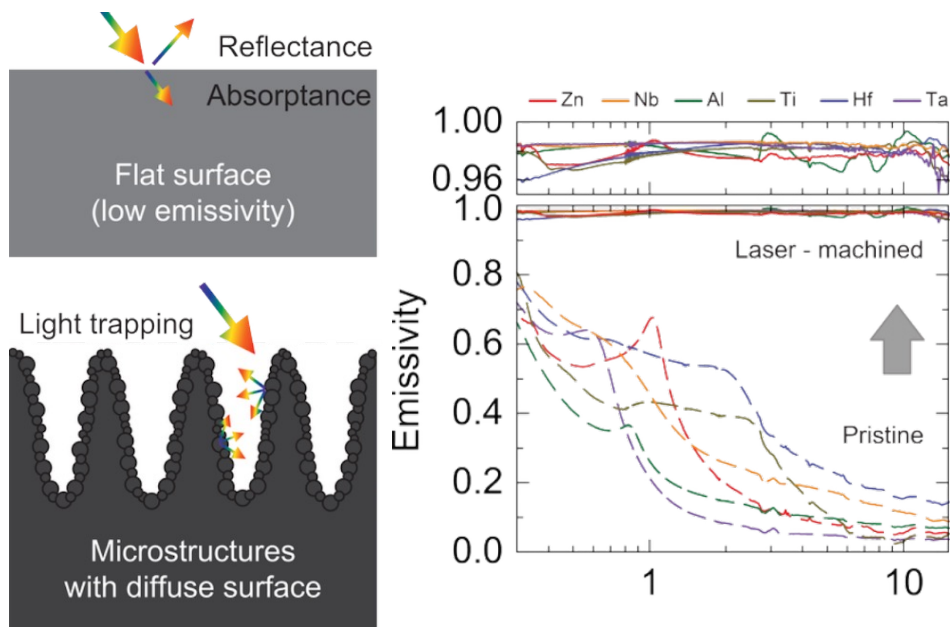
$$\eta = \frac{P_{gen}}{P_{abs}} = \frac{P_{gen}}{P_{gen} + P_{loss}}$$

Minimize P_{loss} : low parasitic heating and high photon conversion efficiency

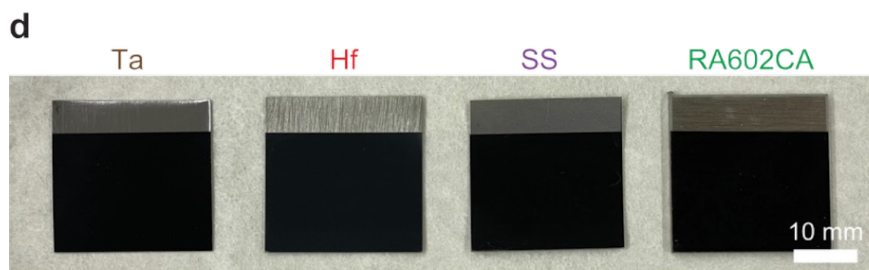
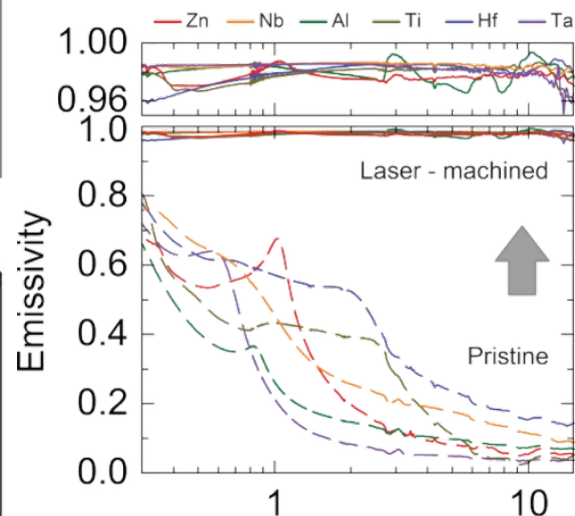
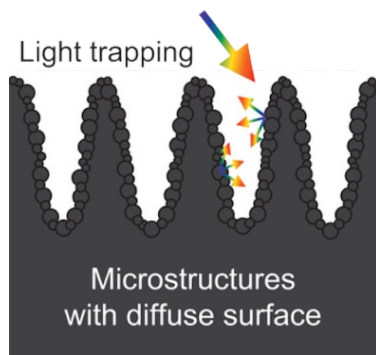
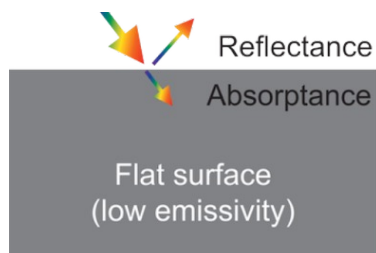


40-45% efficiency achieved with:
High reflectance back-surface (93%),
III-V high-bandgap cells (high IQE and low series resistance)

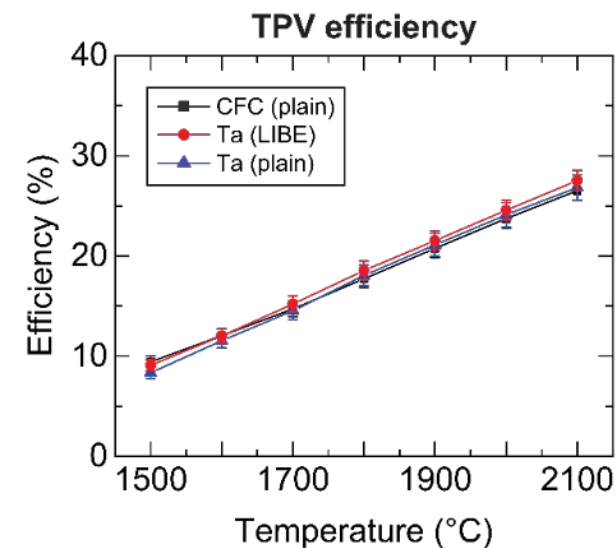
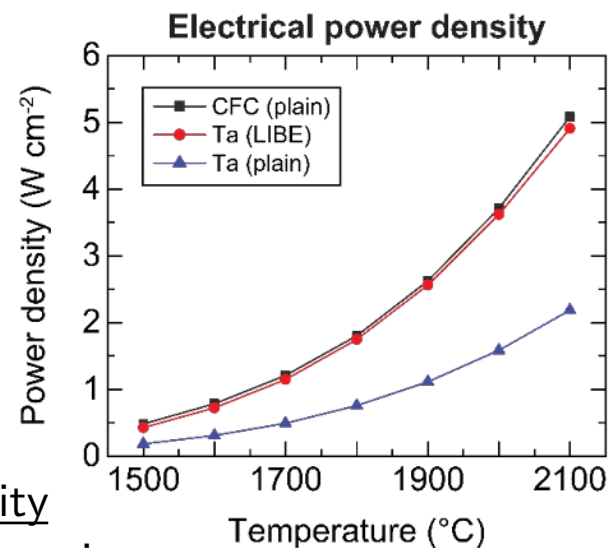
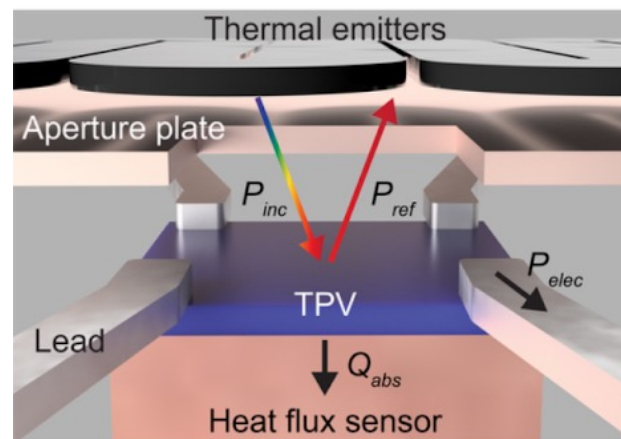
Emitter improvements for high power density



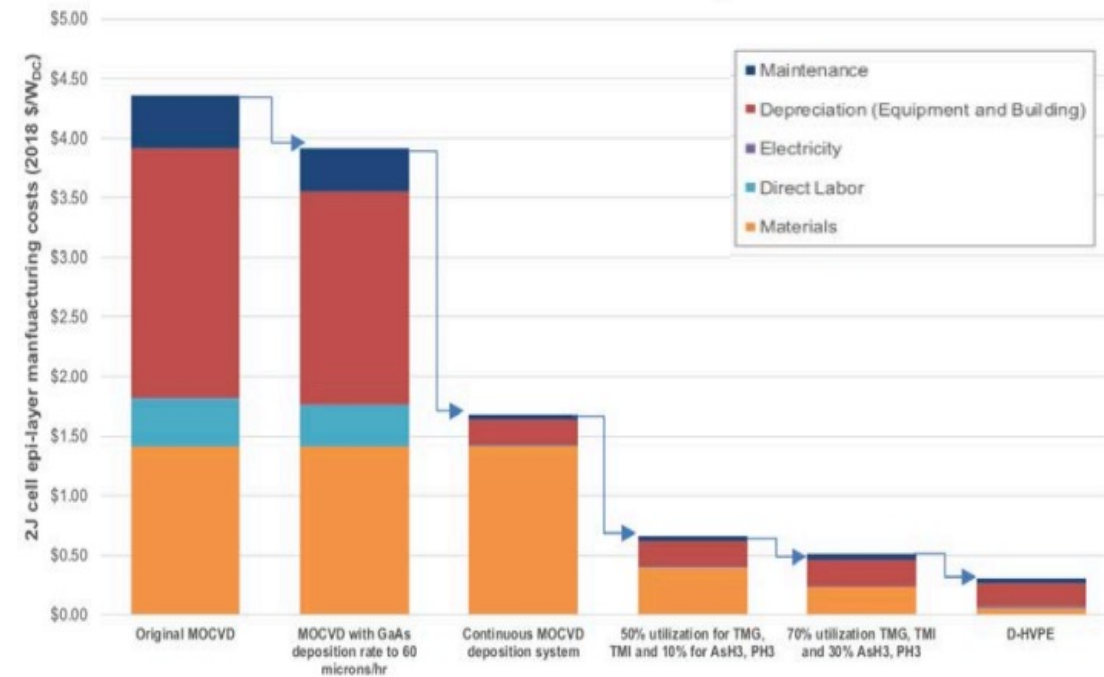
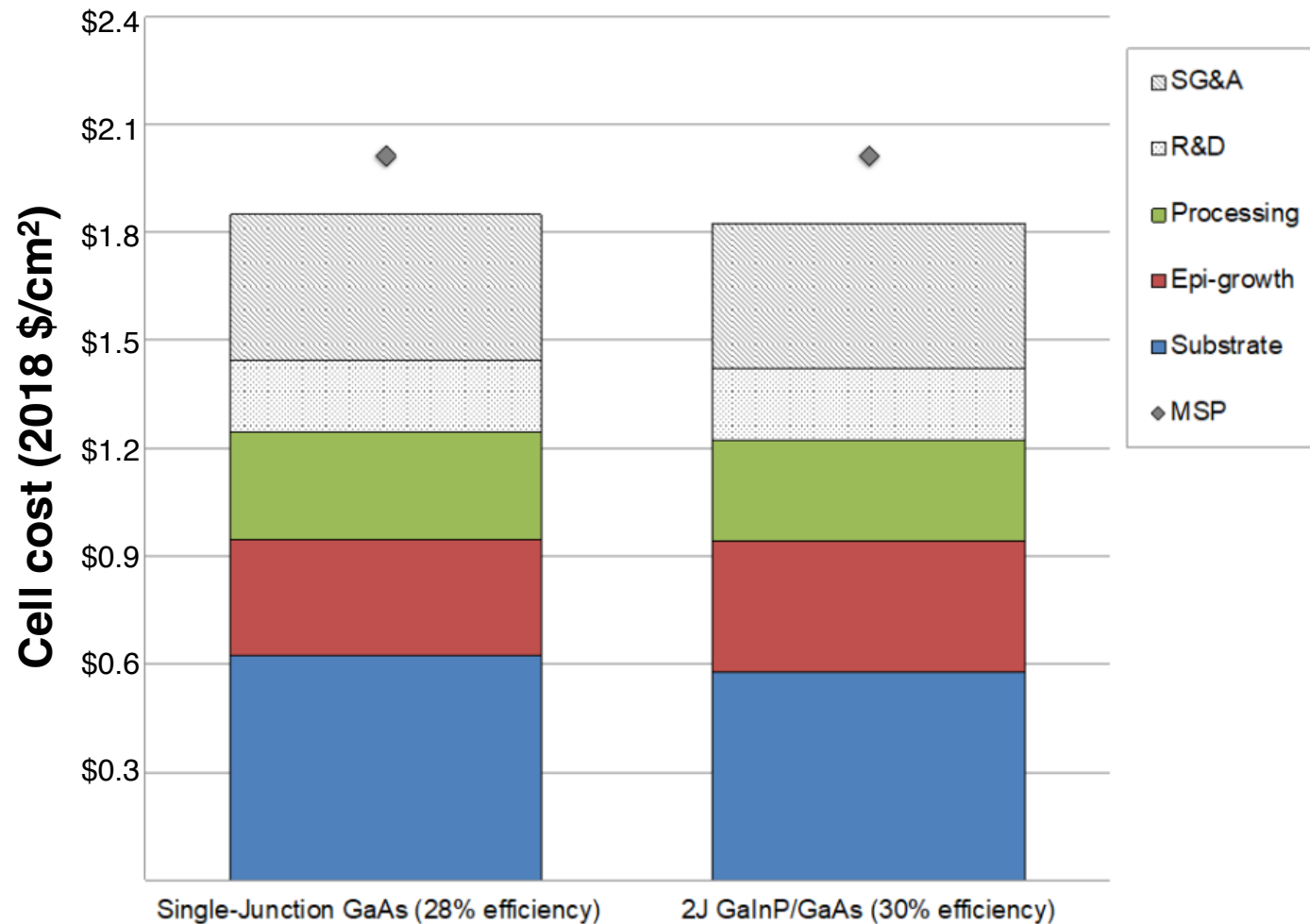
Emitter improvements for high power density



$>5\text{W}/\text{cm}^2$ power density
with laser surface engineering
and high-temp operation



Low TPV cell cost per area



Current cost: ~\$2/cm²
10x reduction possible in cell cost
with improved manufacturing

Low LCOH with cheap power and infrastructure

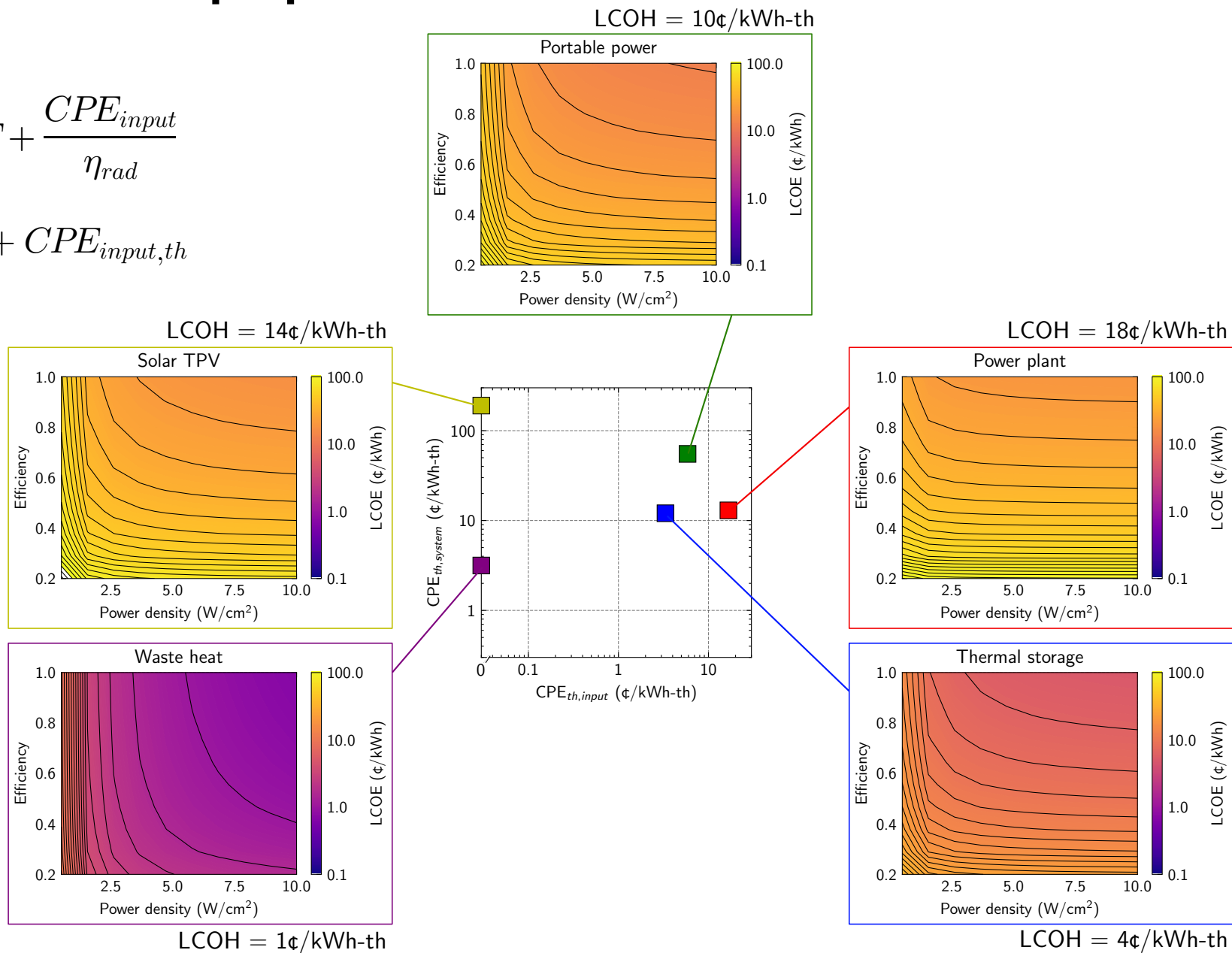
$$\begin{aligned} LCOH &= \frac{CAPEX_{infrast}}{P_{in}\eta_{rad}t_{out}} \cdot CRF + \frac{CPE_{input}}{\eta_{rad}} \\ &= CPE_{system,th} \cdot CRF + CPE_{input,th} \end{aligned}$$

Low LCOH with cheap power and infrastructure

$$LCOH = \frac{CAPEX_{infrast} \cdot CRF}{P_{in} \eta_{rad} t_{out}} + \frac{CPE_{input}}{\eta_{rad}}$$

$$= CPE_{system,th} \cdot CRF + CPE_{input,th}$$

Cheap infrastructure and input energy results in LCOH < 5¢/kWh-th



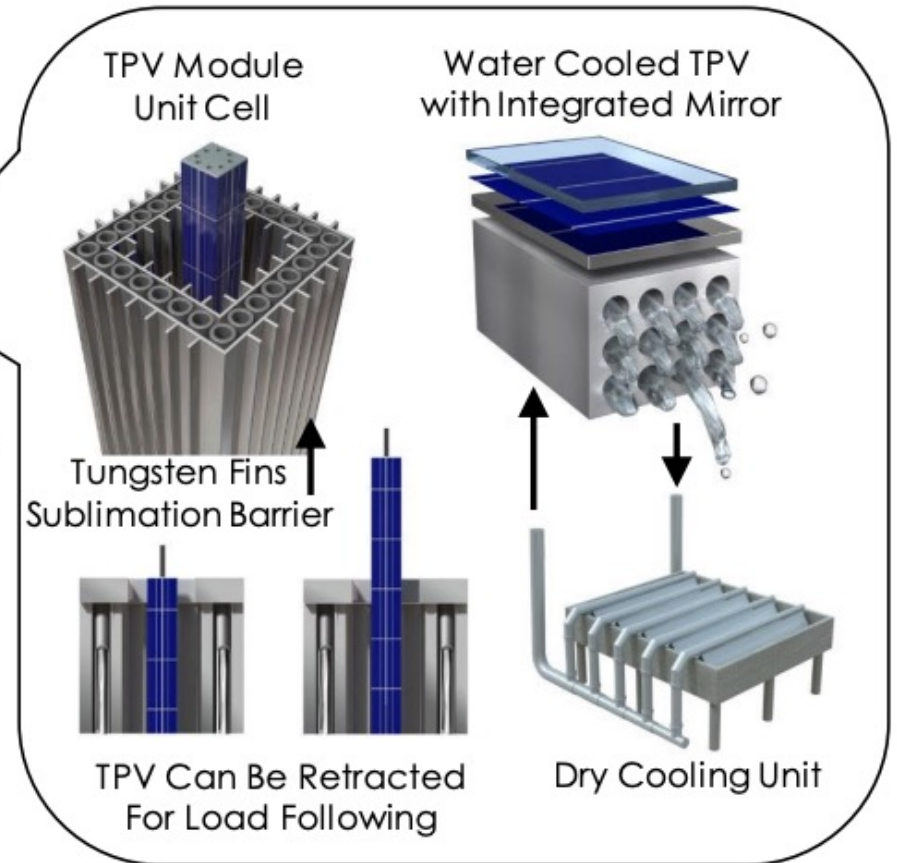
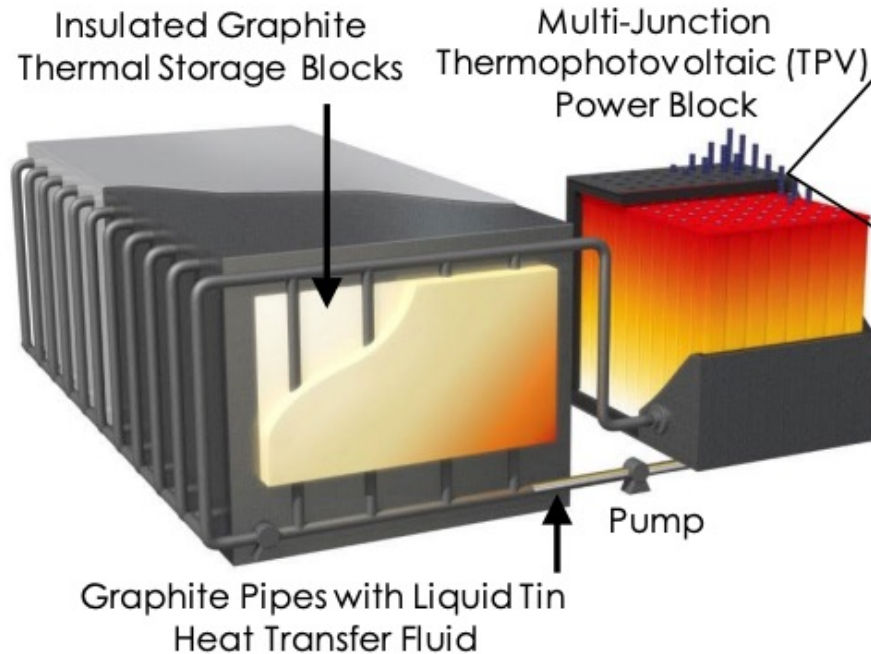
What are some examples of low-cost TPV systems?

Thermal energy storage

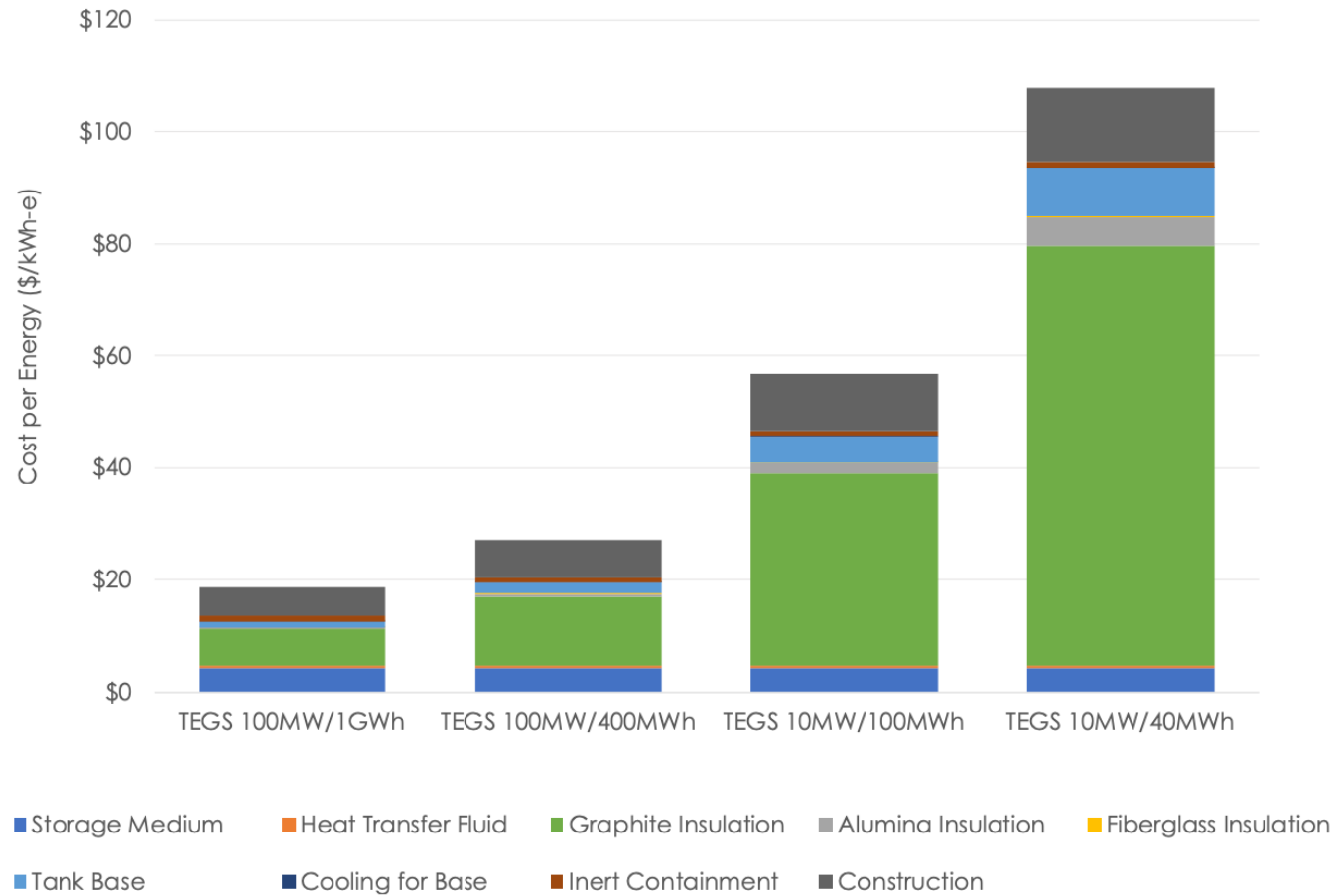
Proposed System Design:

Electricity → Heat → Electricity

Electricity From Any
Source
Powers Heaters



Thermal energy storage



Proposed System Design:

Electricity → Heat → Electricity

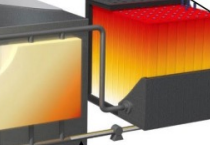
Electricity From Any Source Powers Heaters



Insulated Graphite Thermal Storage Blocks

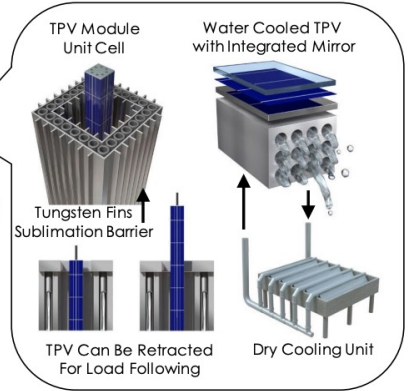


Multi-Junction Thermophotovoltaic (TPV) Power Block



Graphite Pipes with Liquid Tin Heat Transfer Fluid

Pump



Material	Density (kg/m ³)	Cost (\$/kg) ^{4,6}
Extruded Graphite	1700	0.5
Graphite Insulation	24	540
Aluminum Silicate Insulation	100	4.0
Fiberglass Insulation	12	7.1
Tungsten Foil	19000	350

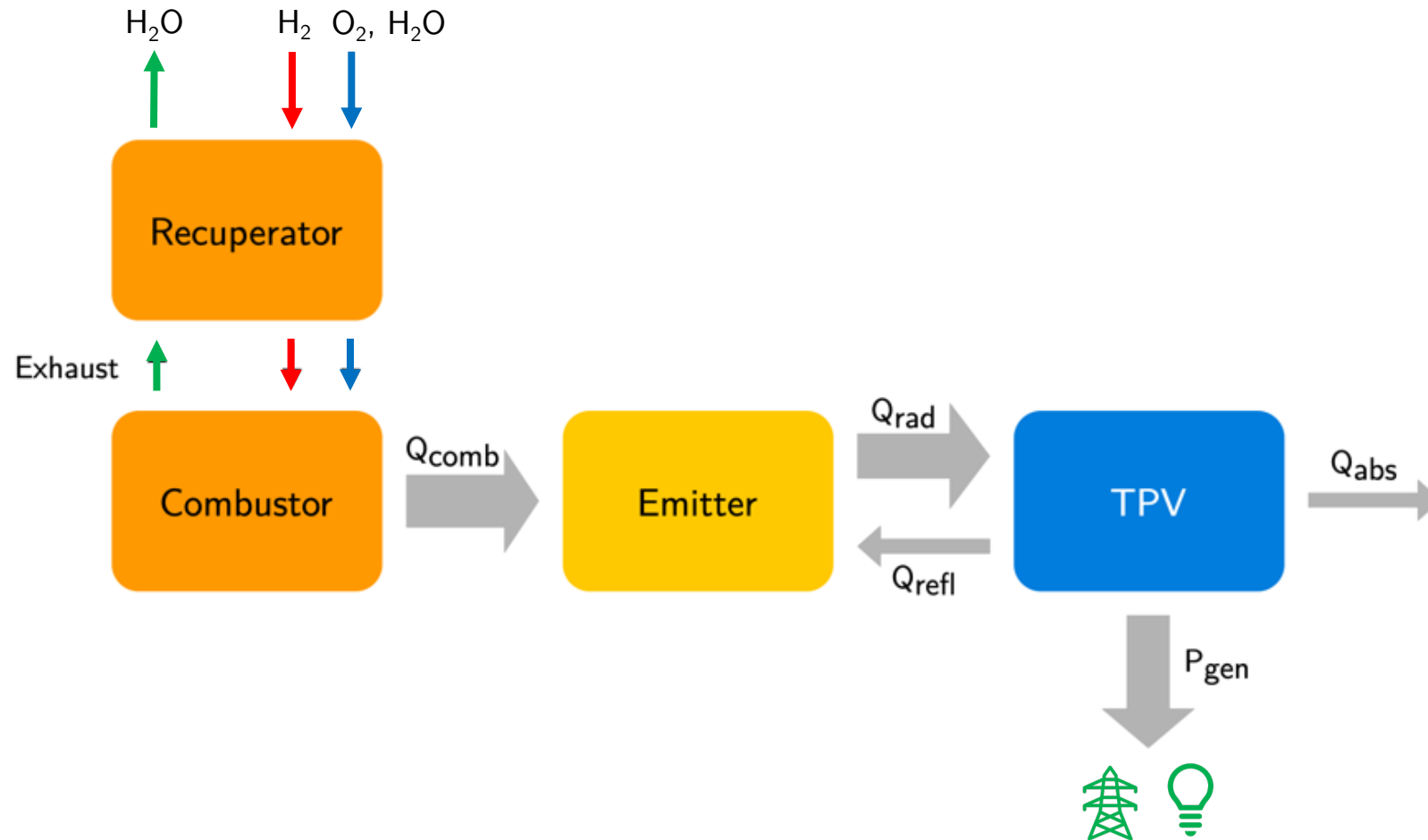
CPE_{input} : 3 ¢/kWh

CPE_{system} : 12 ¢/kWh $\Rightarrow$ LCOH: 4¢/kWh

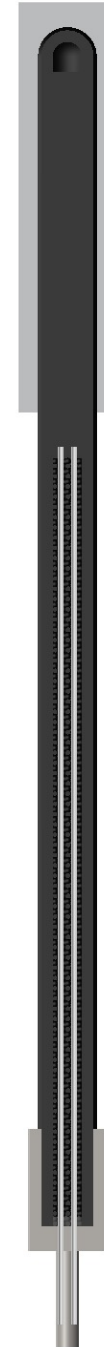
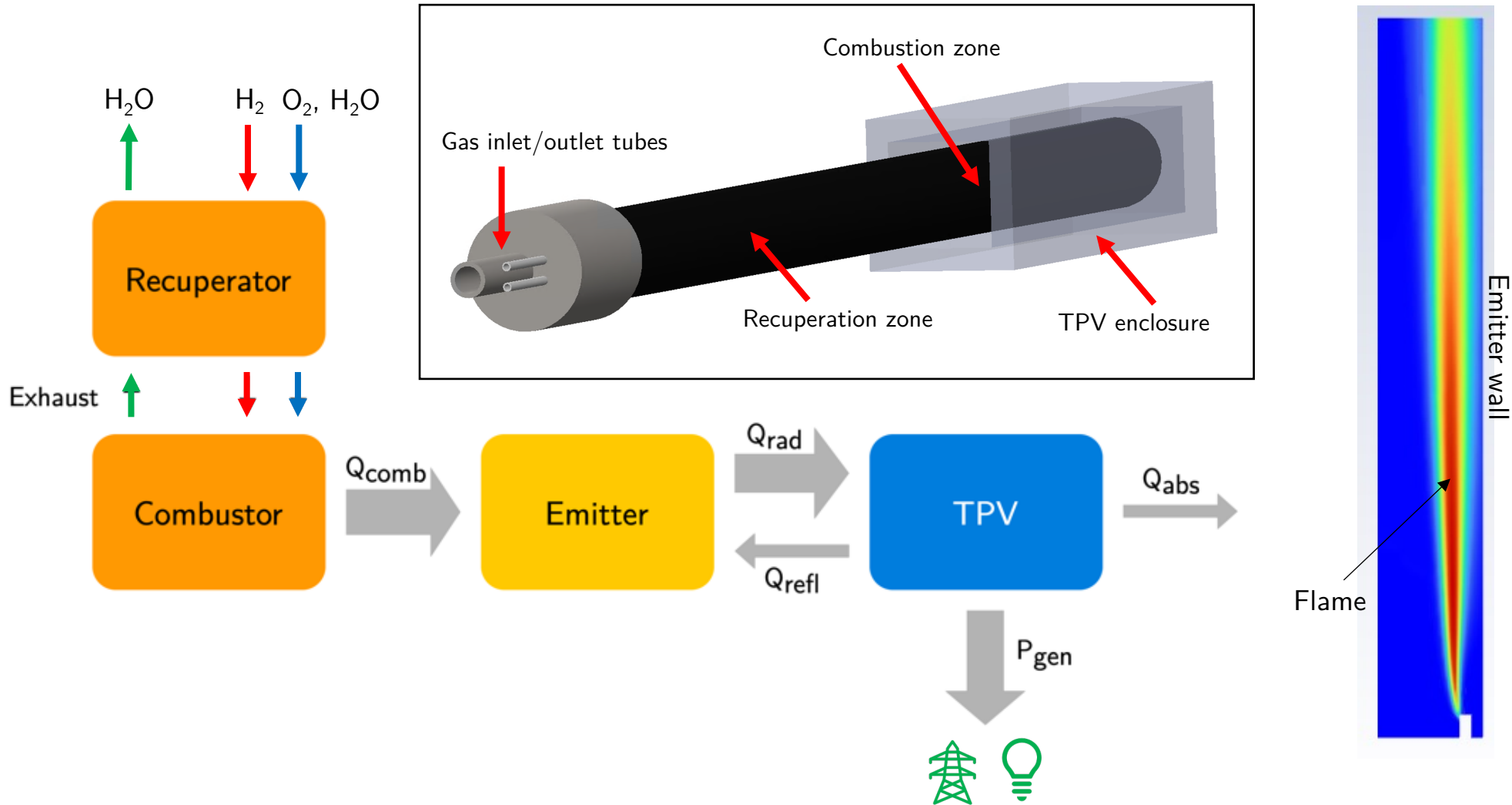
η_{rad} : 90%

LCOE: <8¢/kWh – available on demand!

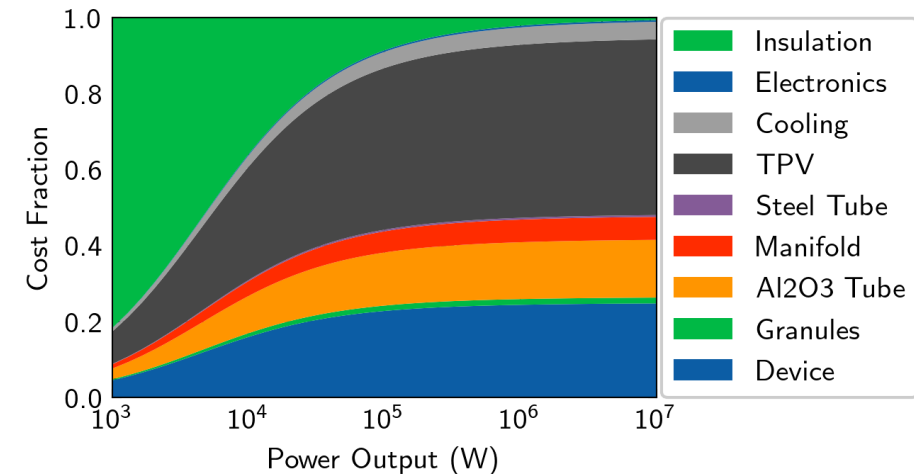
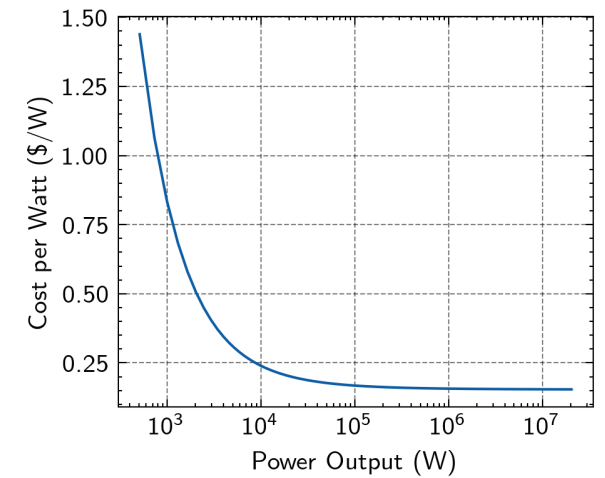
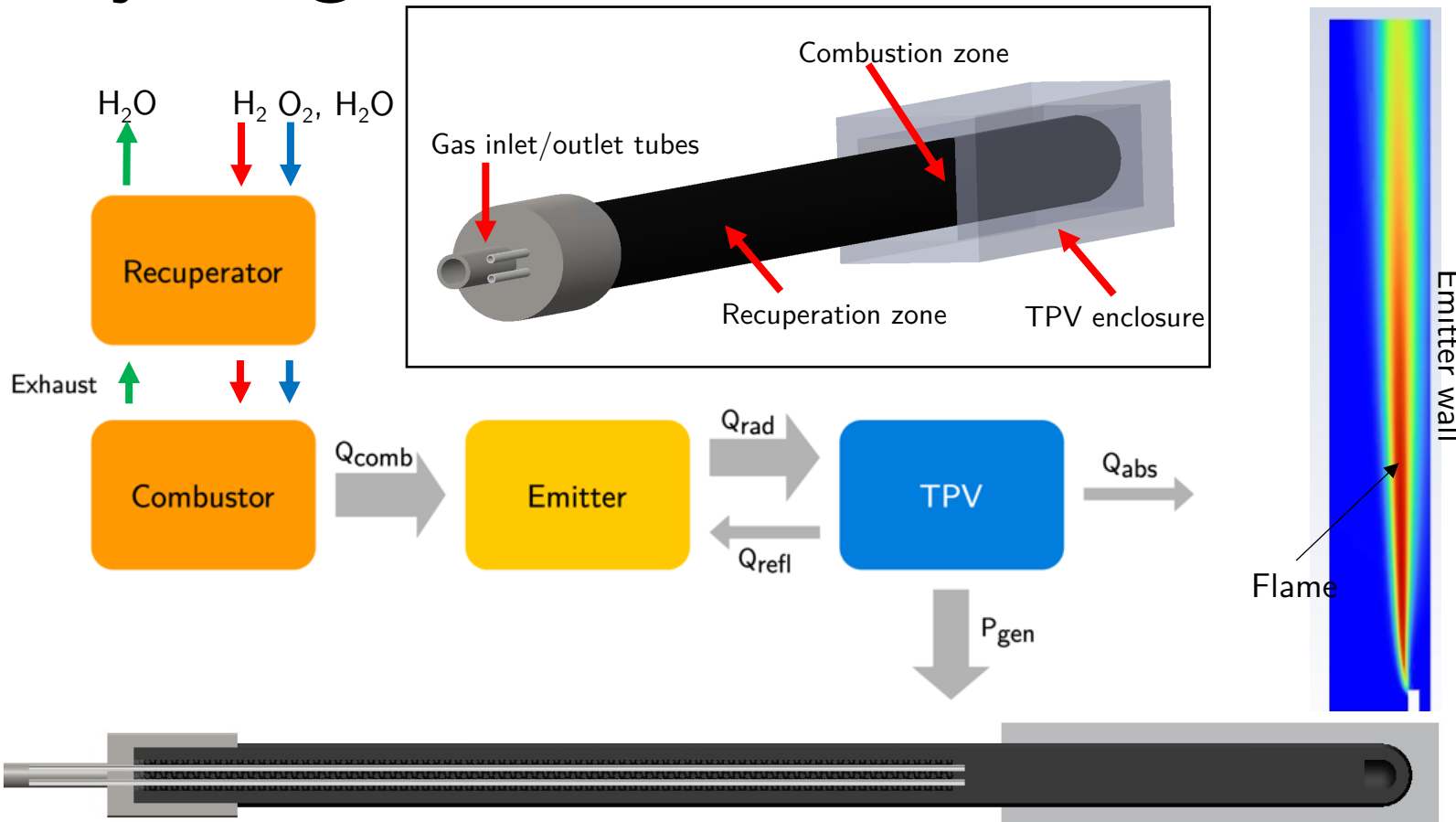
Hydrogen combustion → electricity



Hydrogen combustion → electricity

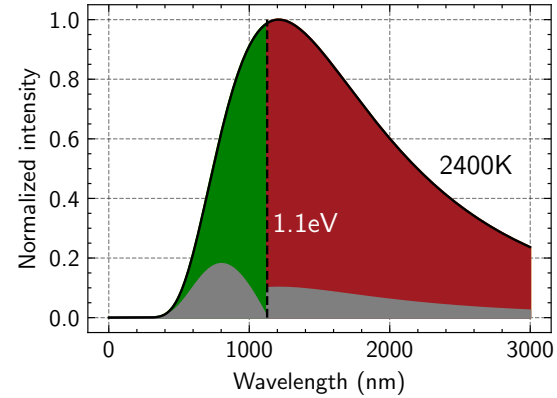
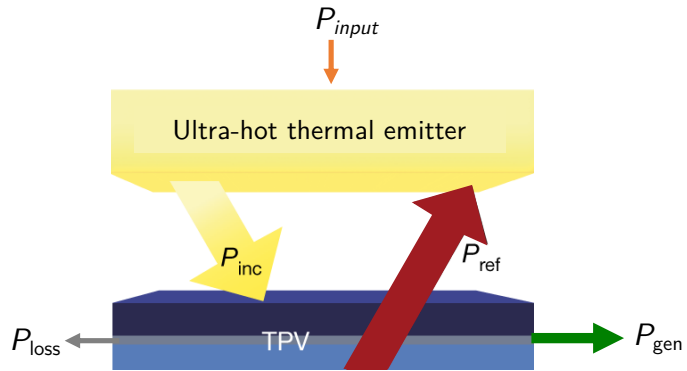


Hydrogen combustion → electricity

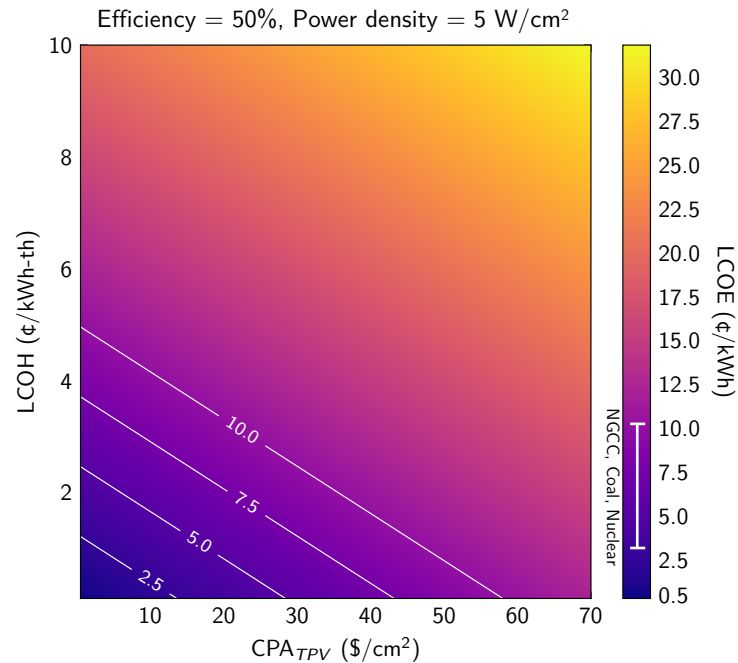
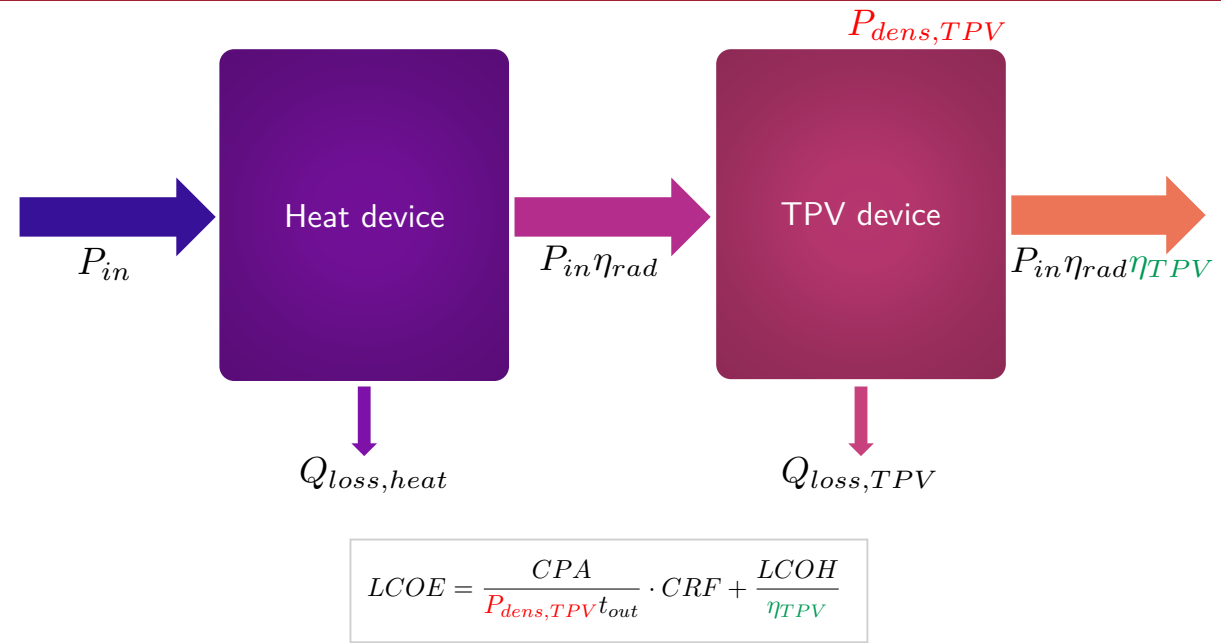
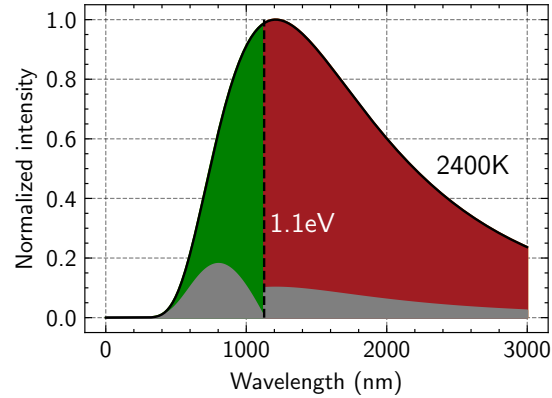
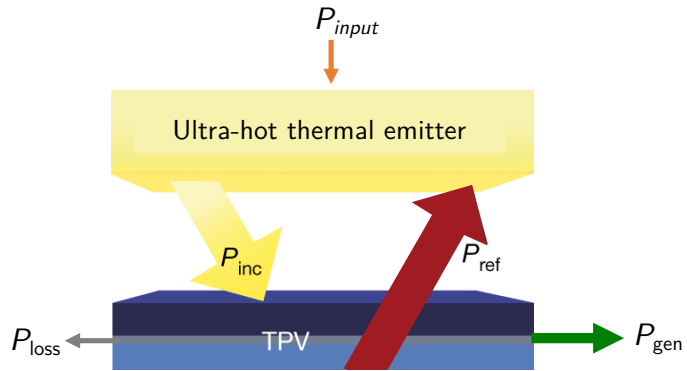


CPE_{input} : 3 ¢/kWh (\$1/kgH₂)
 CPE_{system} : 6 ¢/kWh
 $LCOH$: 3.5 ¢/kWh
 $LCOE$: <8¢/kWh – on demand!

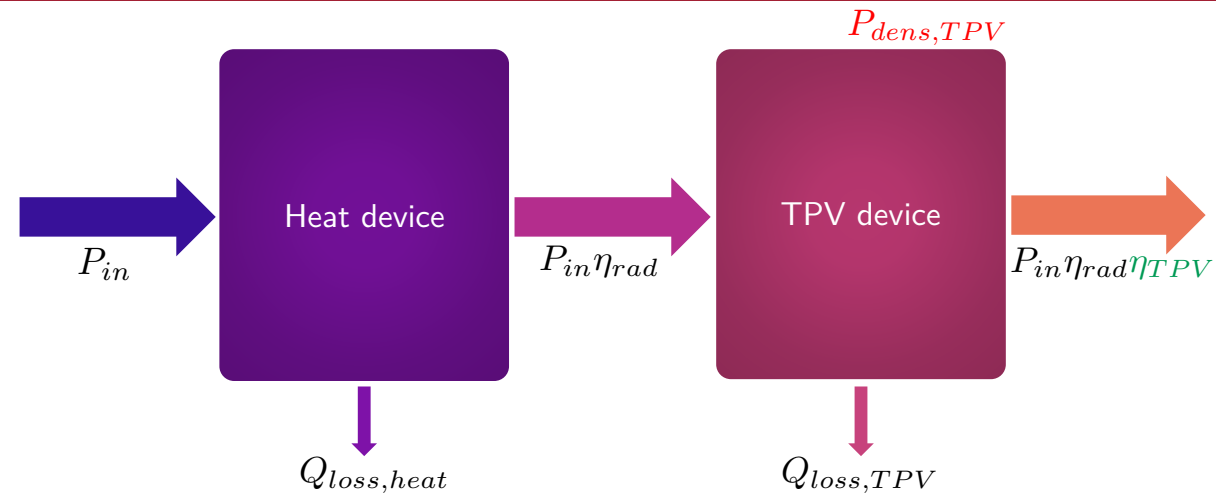
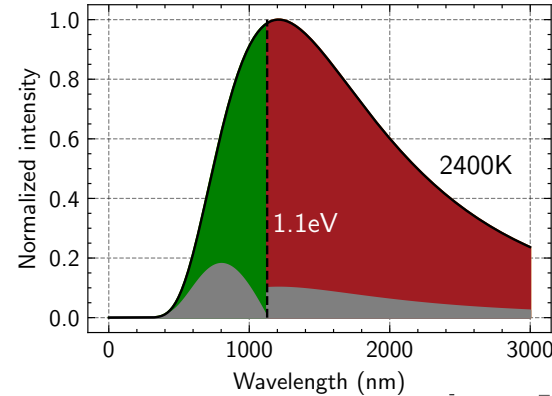
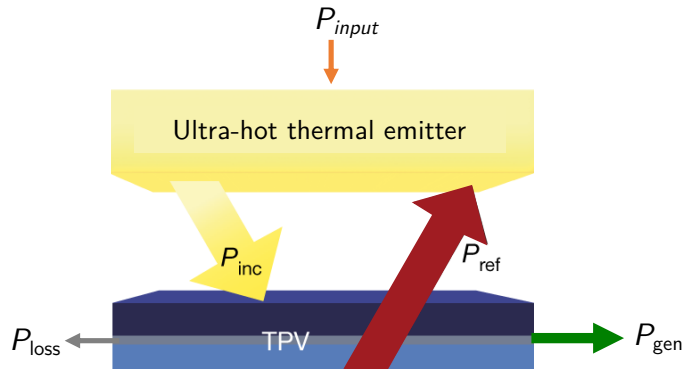
Summary of today's talk



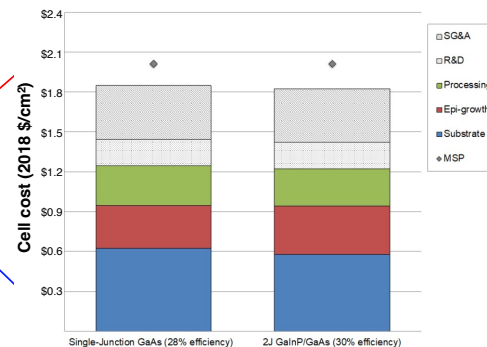
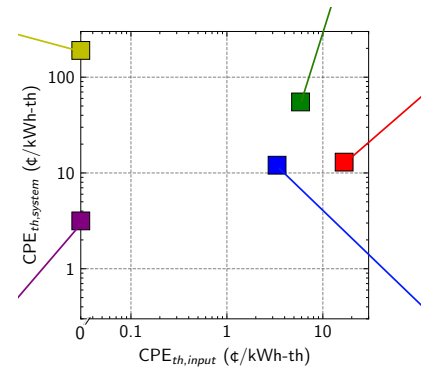
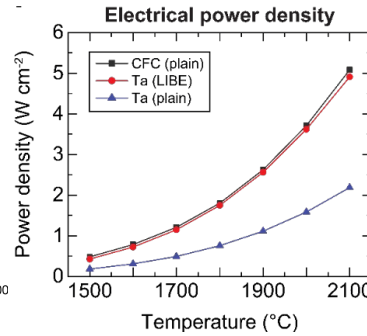
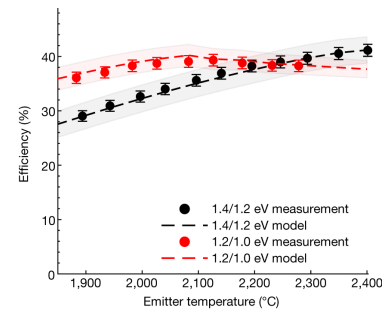
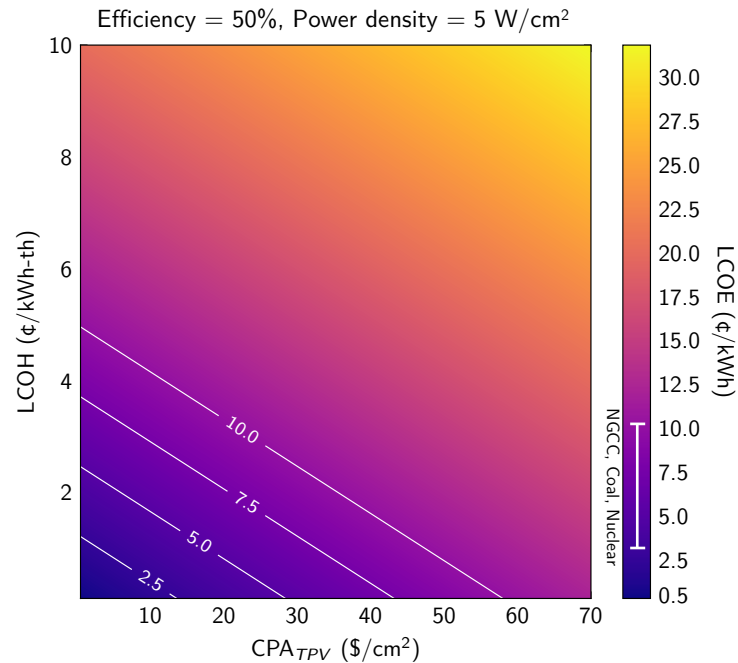
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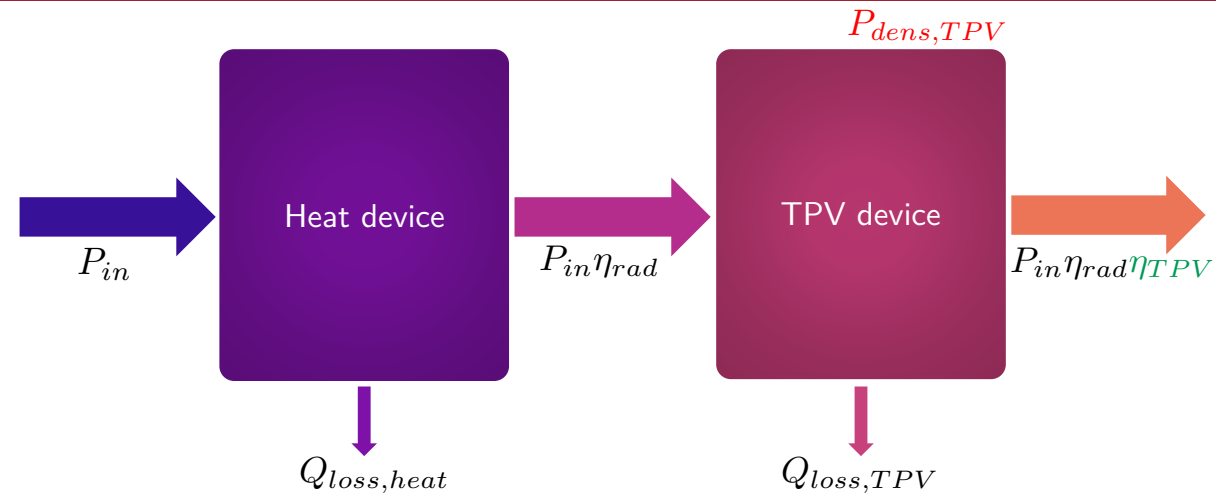
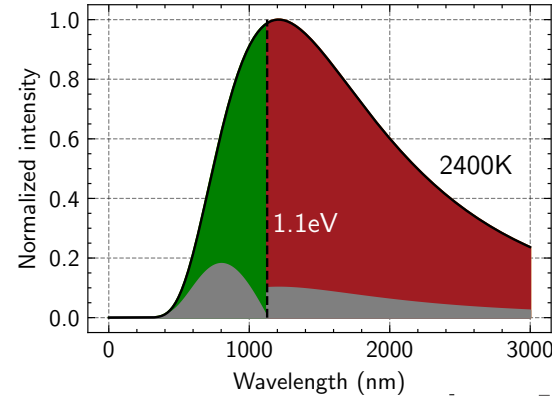
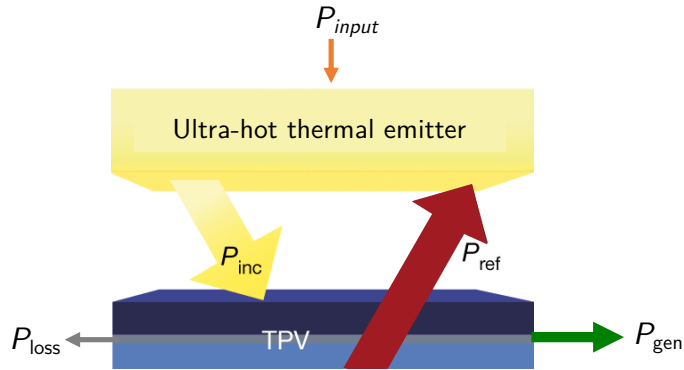
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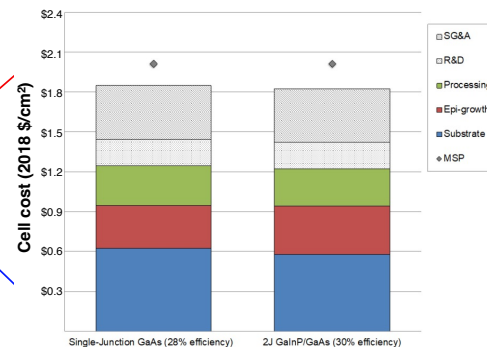
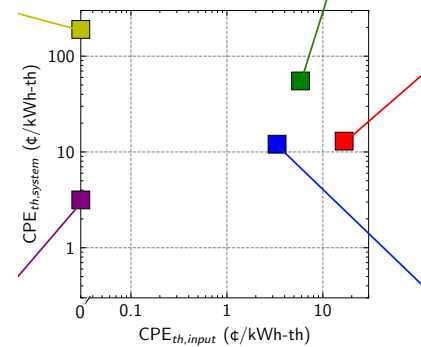
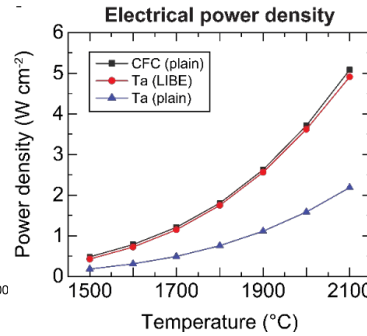
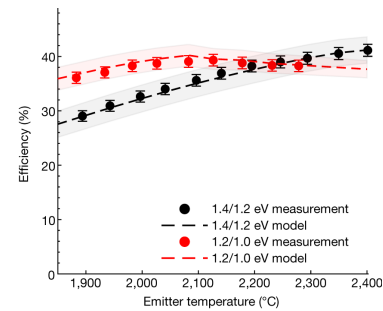
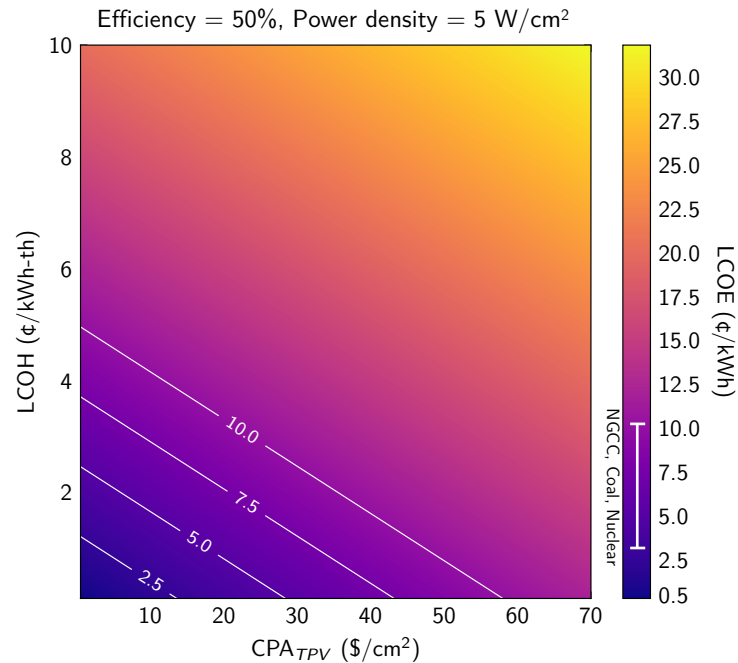
$$LCOE = \frac{CPA}{P_{dens,TPV} t_{out}} \cdot CRF + \frac{LCOH}{\eta_{TPV}}$$



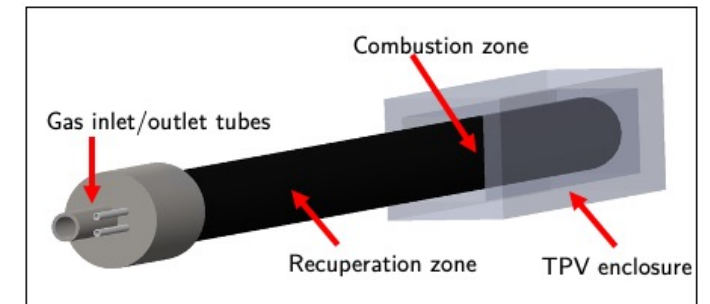
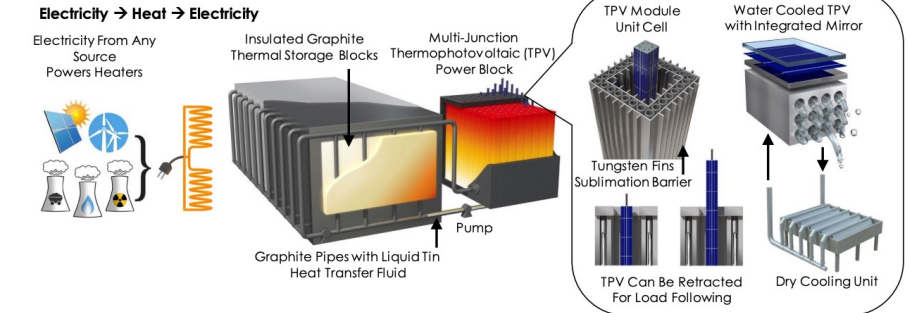
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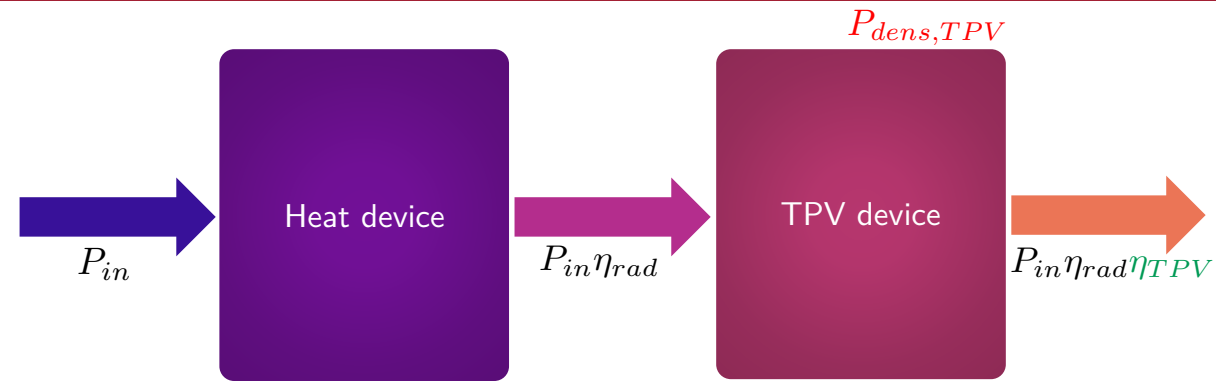
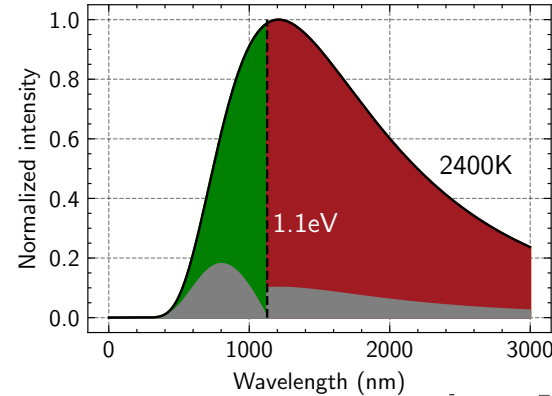
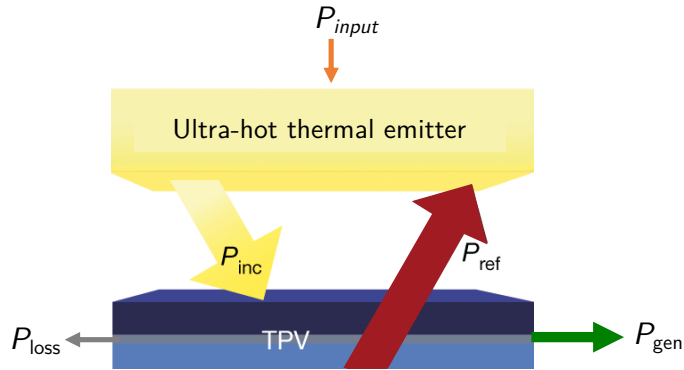
Proposed System Design:



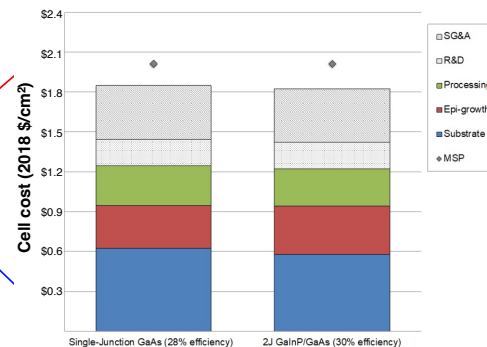
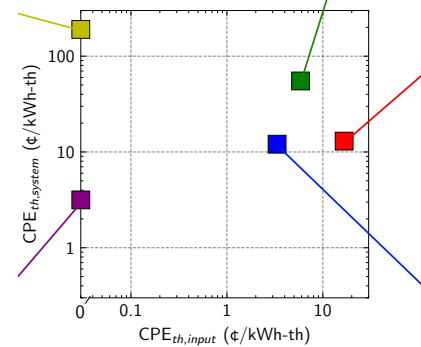
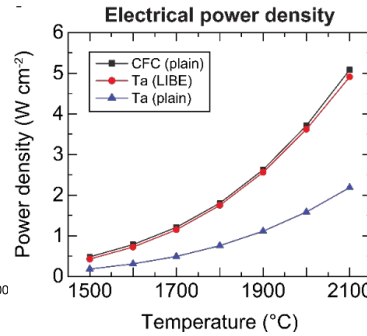
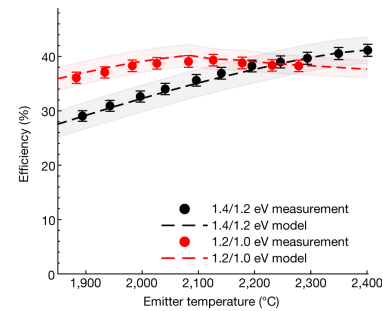
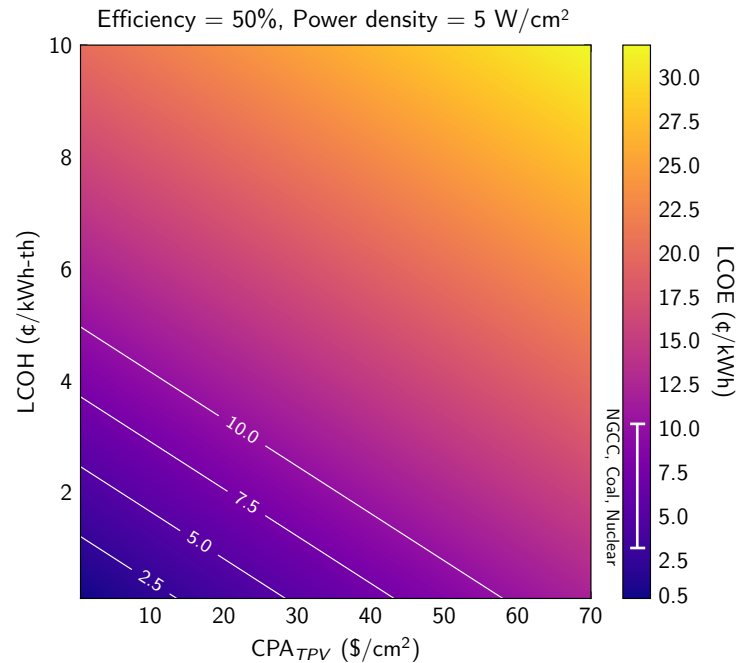
LCOE < 8¢/kWh, dispatchable

Thanks! Q&A

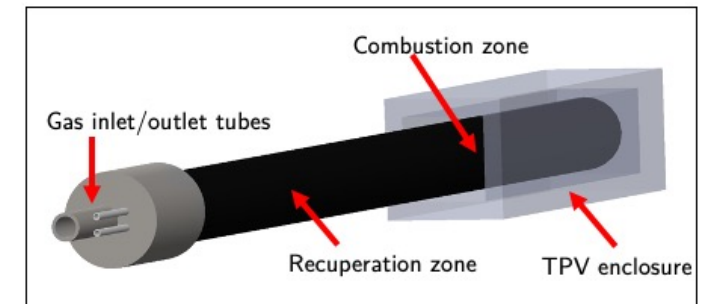
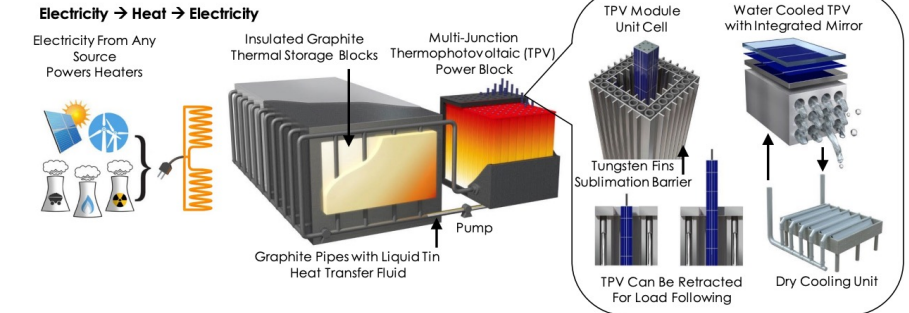
skverma@mit.edu



$$LCOE = \frac{CPA}{P_{dens,TPV} t_{out}} \cdot CRF + \frac{LCOH}{\eta_{TPV}}$$



Proposed System Design:



LCOE < 8¢/kWh, dispatchable