Thermophotovoltaics powered by combustion for long-duration chemical energy storage

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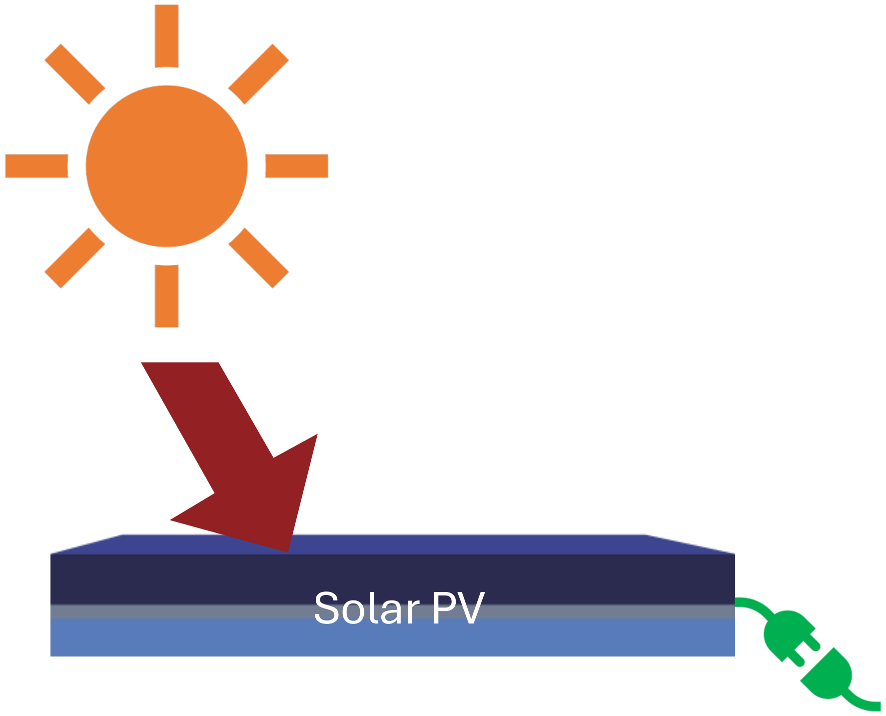
SHTC-ES Conference

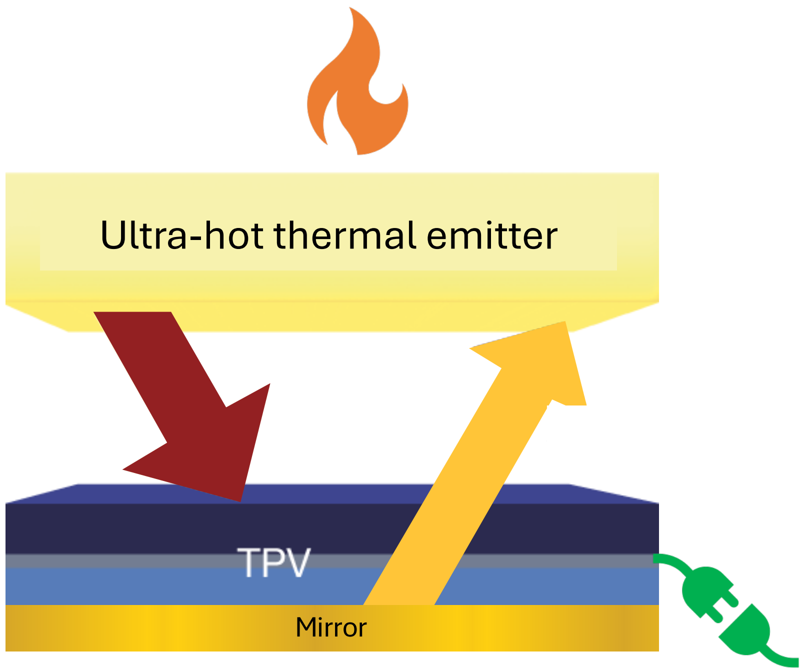
9 July 2025

Massachusetts Institute of Technology

What is thermophotovoltaics (TPV)?



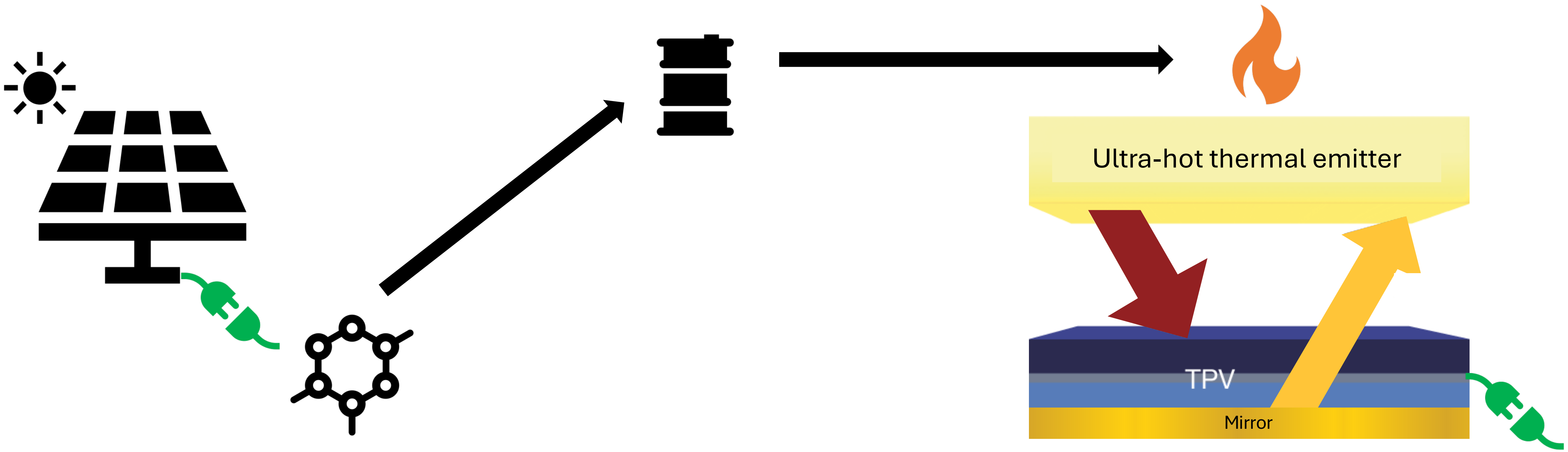
20% efficiency
200 W/m^2



40% efficiency
20,000 W/m^2

LaPotin et al. *Nature* 604 (2022)

What is thermophotovoltaics (TPV)?



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LaPotin et al. *Nature* 604 (2022)

1. What is long-duration chemical energy storage and how can it provide reliable electricity?

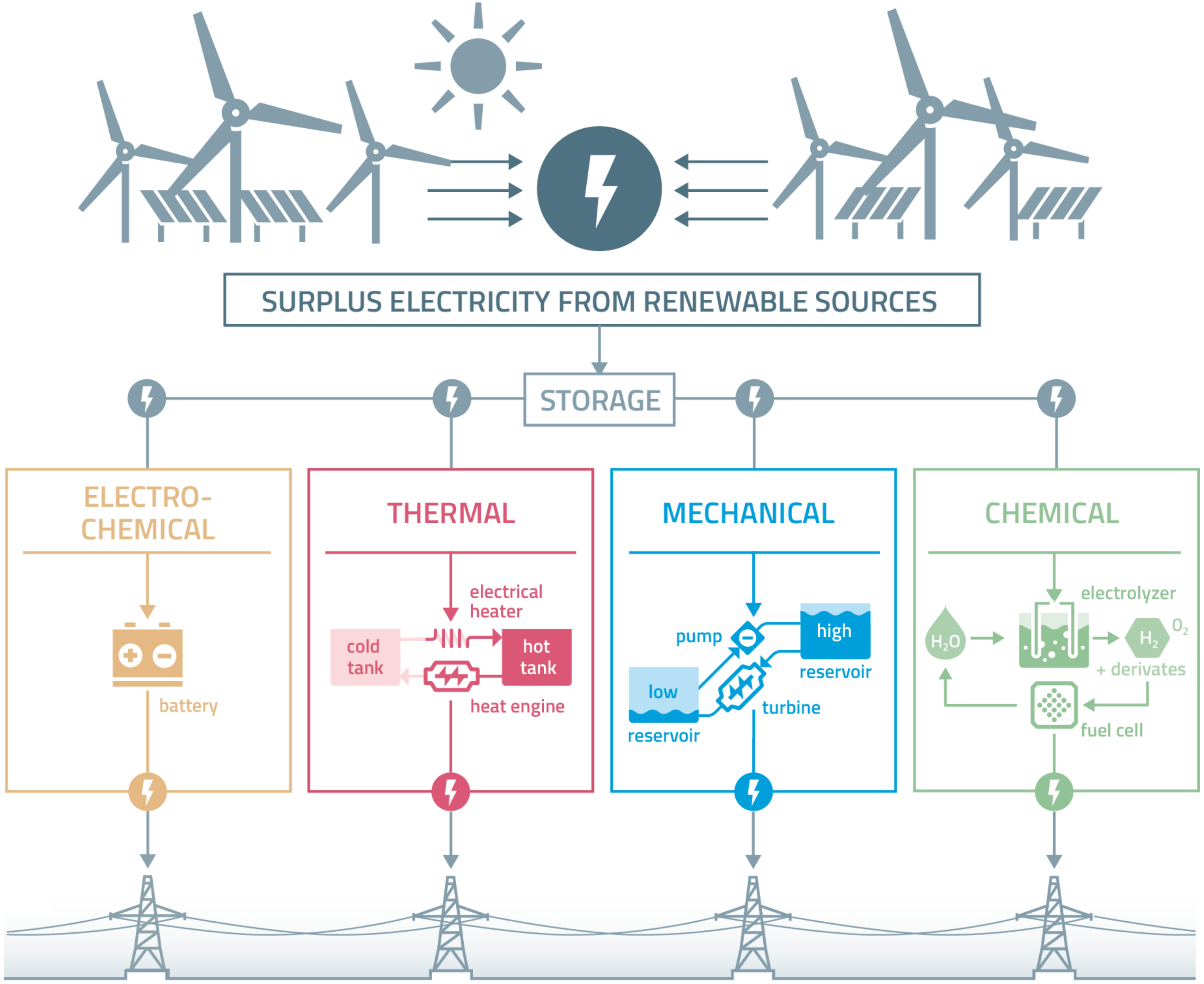
2. How can thermophotovoltaics be used to convert stored fuel to electricity?

3. What does a prototype combustion-TPV device design feature?

4. How does the prototype perform experimentally?

Chemical energy storage provides *ultra-long duration storage* for improved reliability

Because it fills in the gaps (low CF), capital cost must be very low

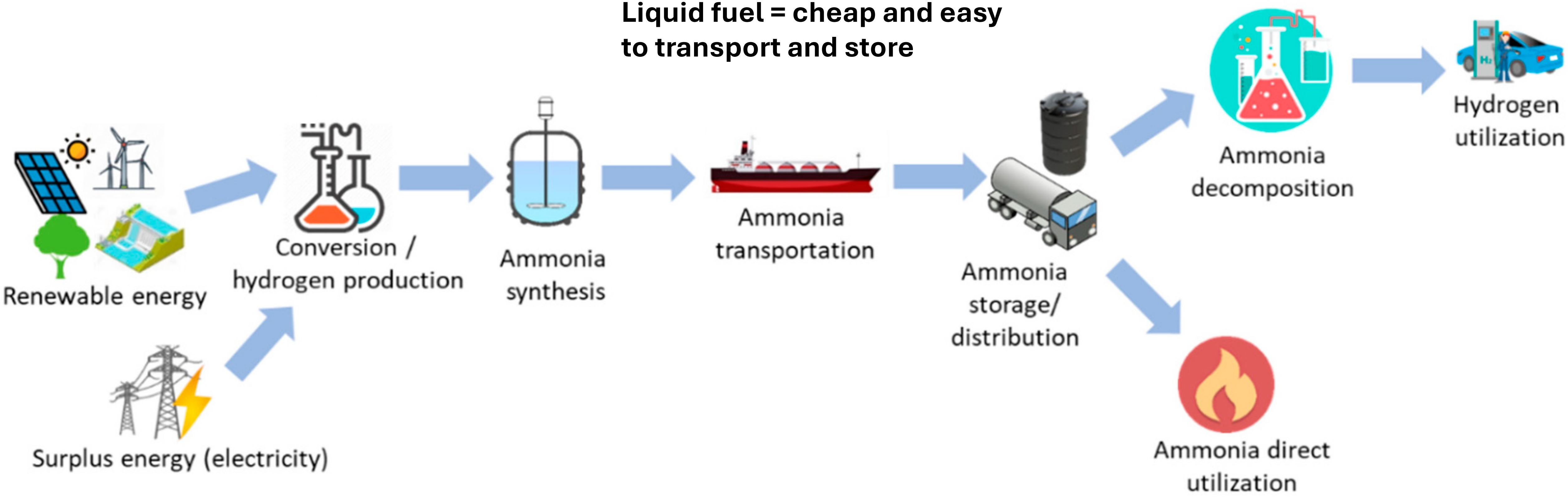


$$$ | Self-discharge | Geography | ??

Clean fuel, cheap storage

Ammonia: easy transportation and storage

Liquid fuel = cheap and easy to transport and store

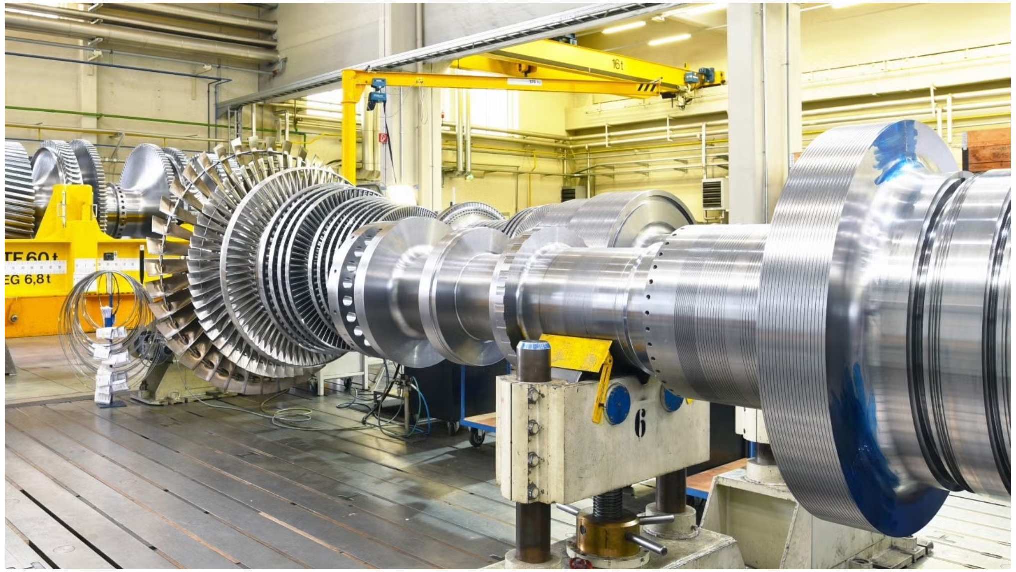


How to convert ammonia back to electricity?

Aziz et al. *Energies* (2020)

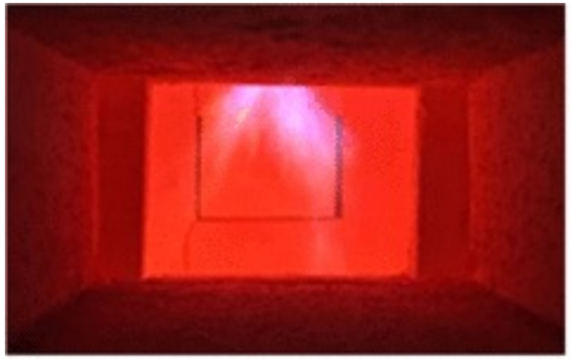
Ammonia combustion challenges: NOx emissions

Gas turbines

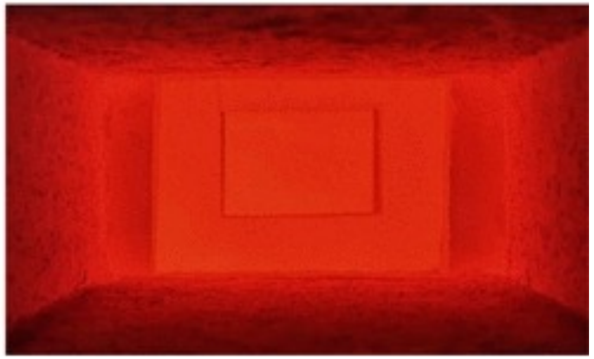


Flameless combustion not suited for gas turbines

- Issues:
  - NH_3 toxicity
  - Poor combustion characteristics
  - NOx & N_2O emissions ~1000ppm >> 15ppm
- Solution:
  - Rapid mixing, and low operating temperatures
- Flameless combustion achieves these characteristics:
  - **Preheated reactants + rapid mixing**
  - Distributed volumetric reaction zone (no flame front)



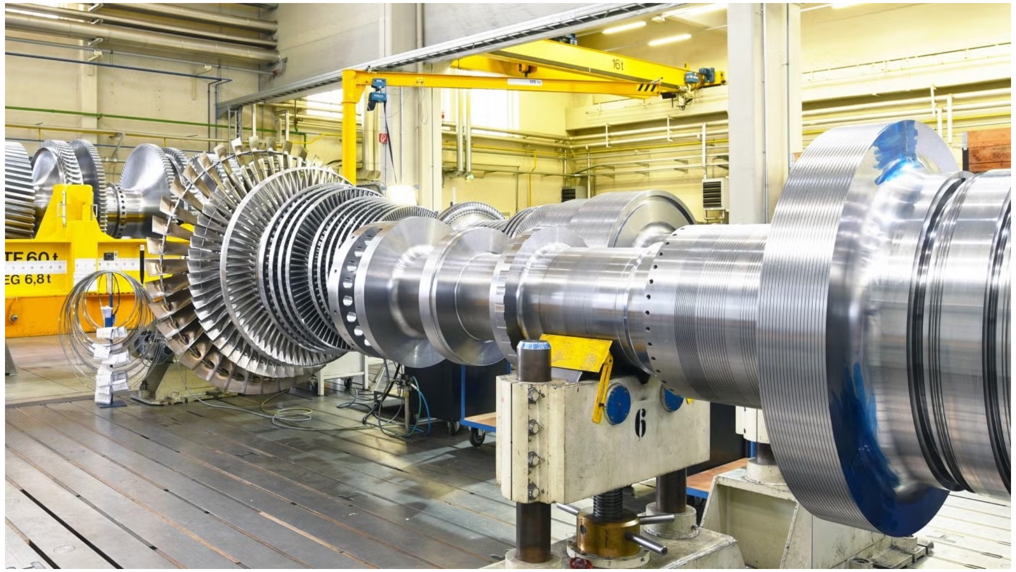
1000 ppm NOx



30 ppm NOx

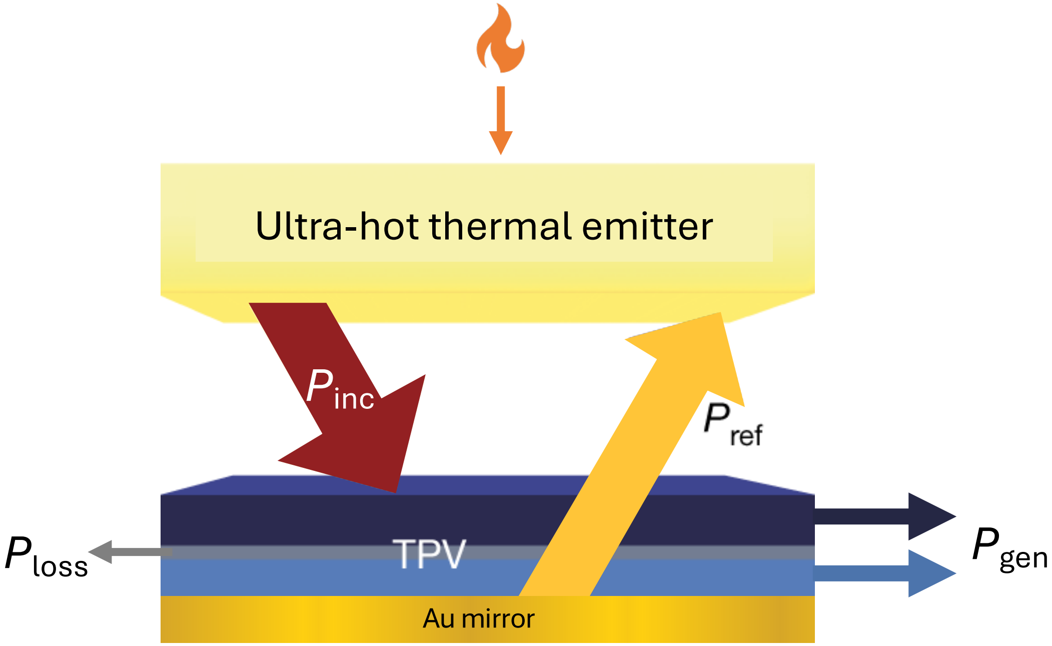
TPV can convert flameless combustion to electricity

Gas turbines



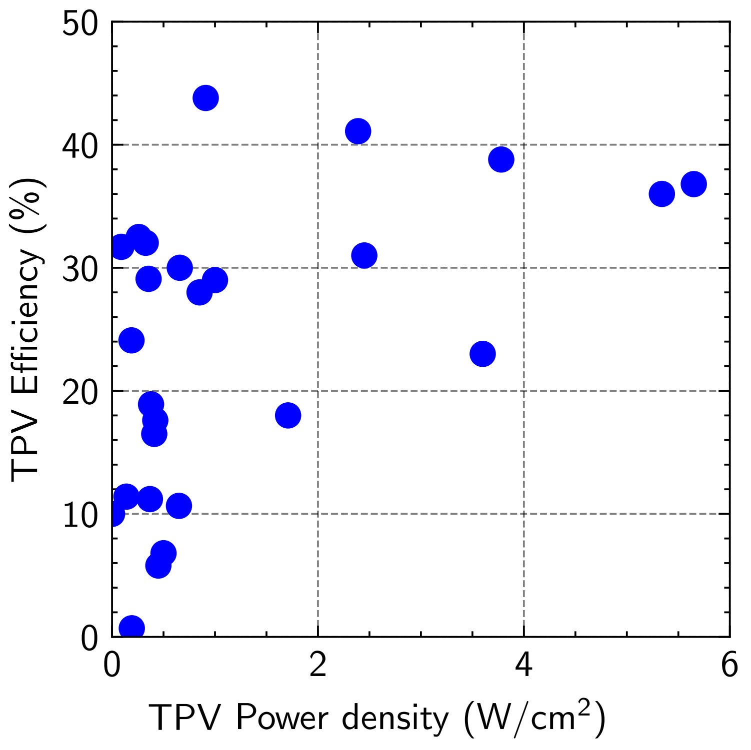
Issues:
- Unstable conditions (high RPM blades)
- Requires combustor redesign (preheating, recirculation, slow combustion)

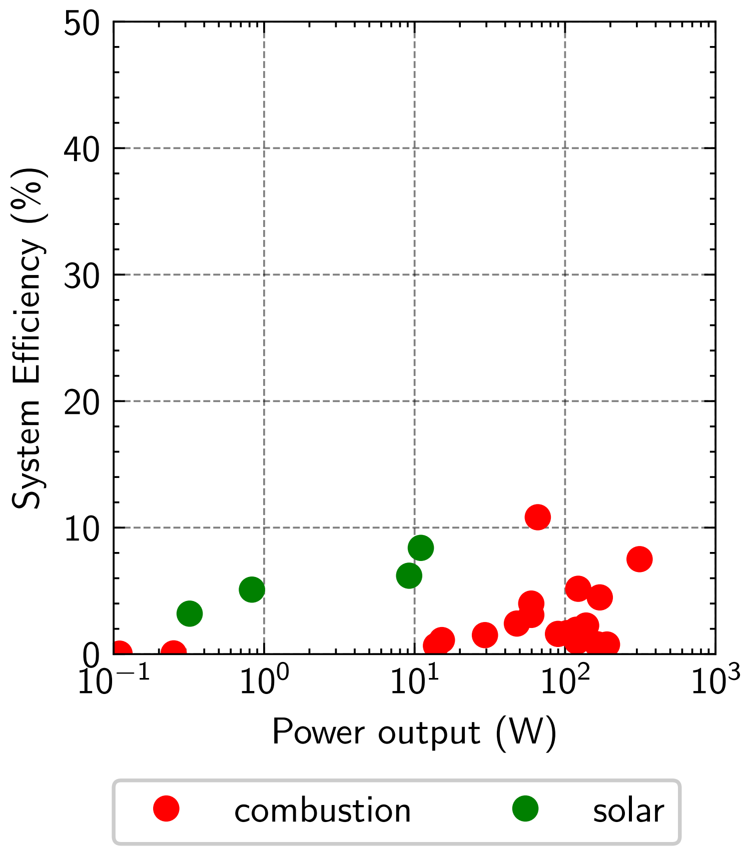
Thermophotovoltaics

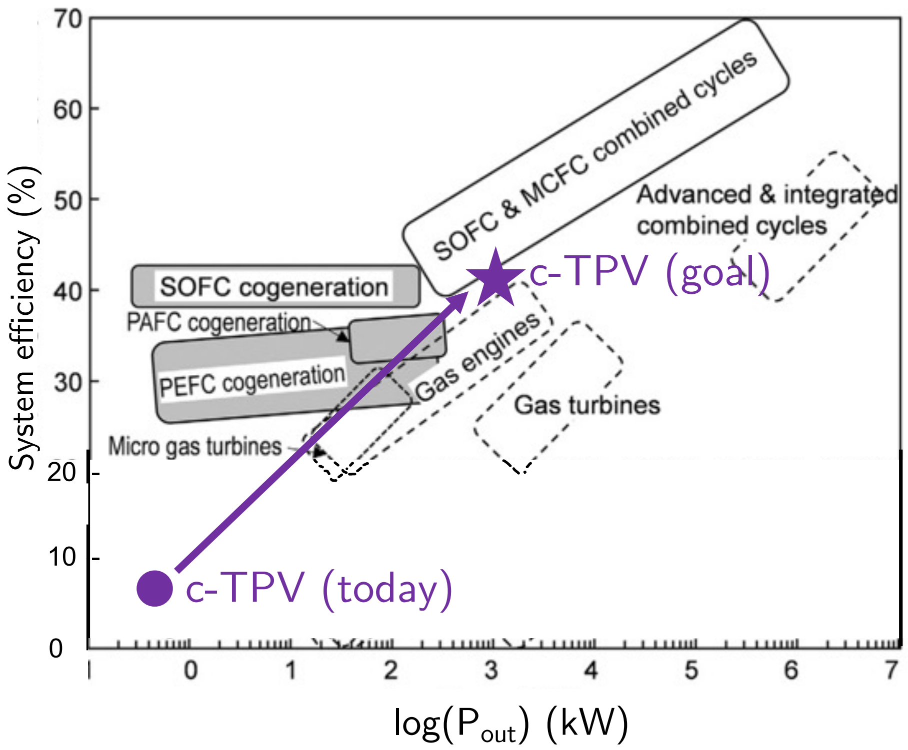


- Pros:
    - Flexible heat source
    - Solid state
- Challenges:
    - High emitter temperature (~1500C)
    - Historically low efficiency

Combustion-TPV system efficiency



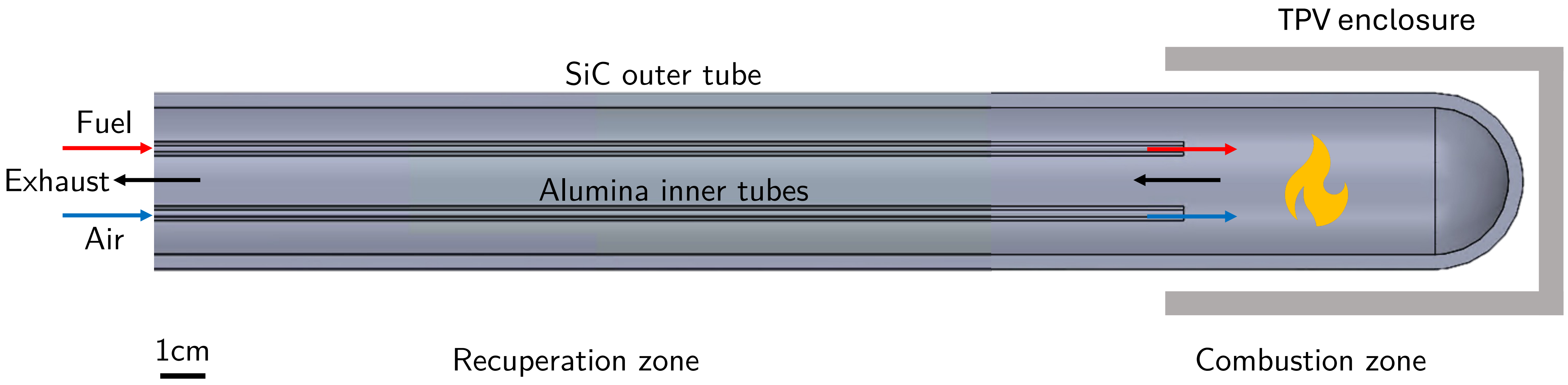




Goal: use flameless combustion to power TPV for clean, reliable electricity generation

Proposed prototype combustor design to achieve flameless conditions

- Preheated reactants
- Well-mixed combustion zone
- High emitter temperature



Commercially available materials – easy prototyping for proof of concept

Prototype design iterations

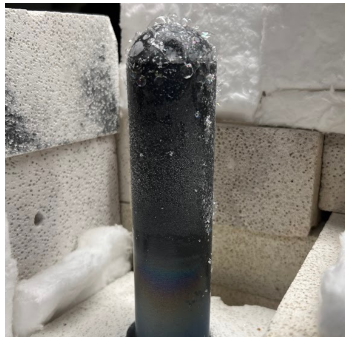
SiC grades

Nitride-bonded

Recrystallized

Reaction-bonded

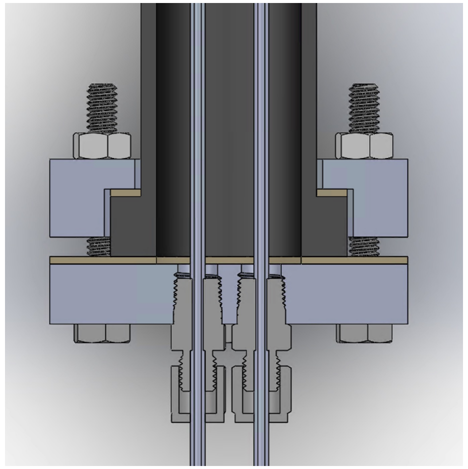
Sintered SiC



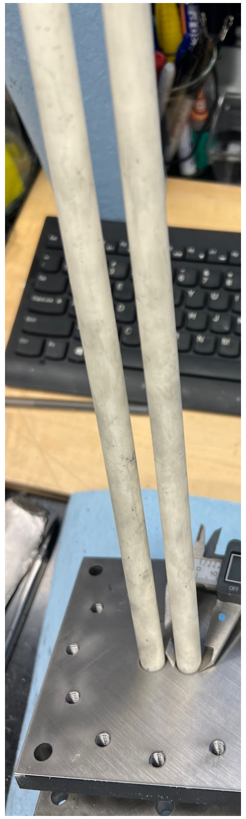
Metal-ceramic interface

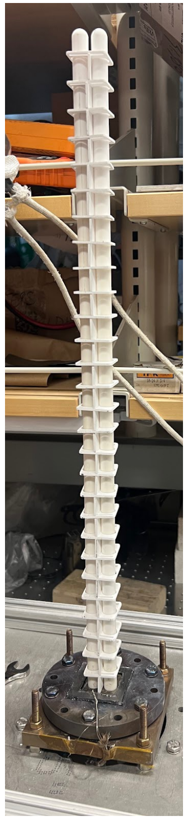
Compression fitting

Flange + clamping



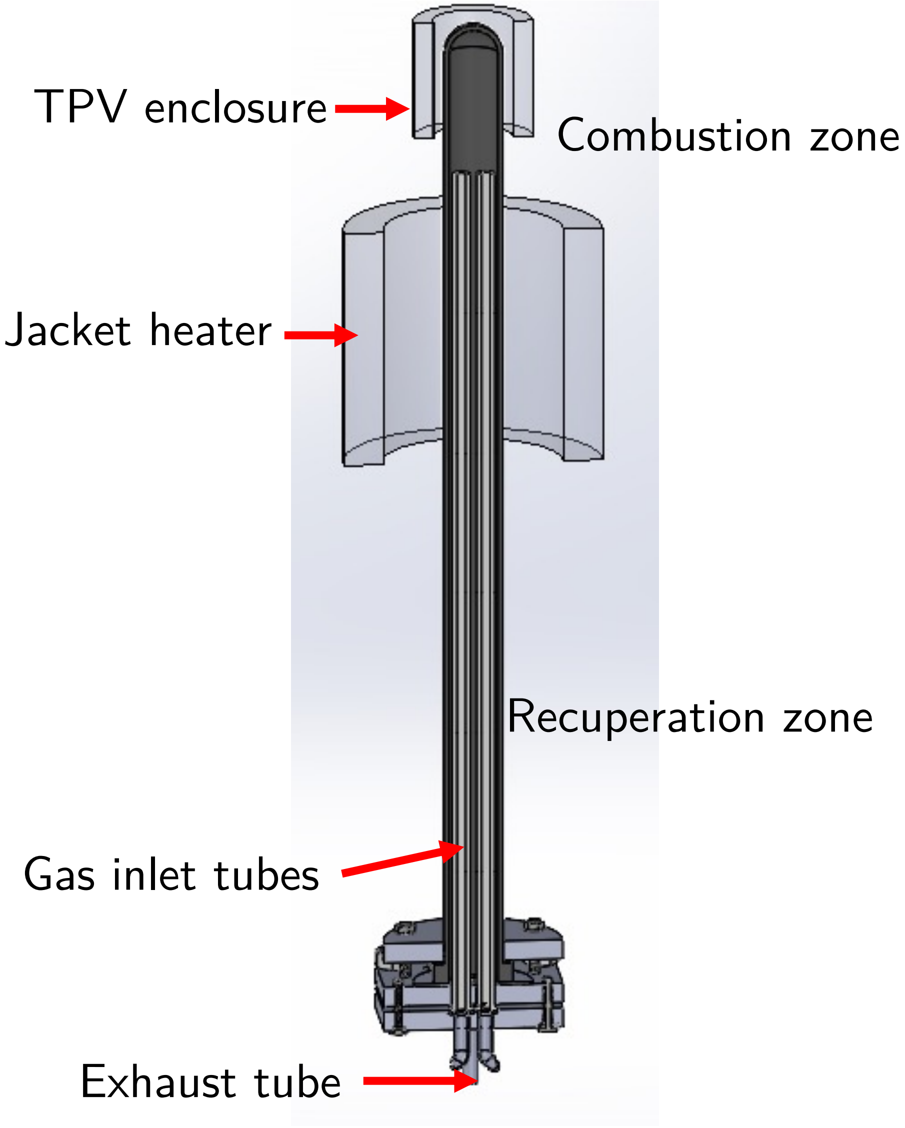
Inlet tube geometry

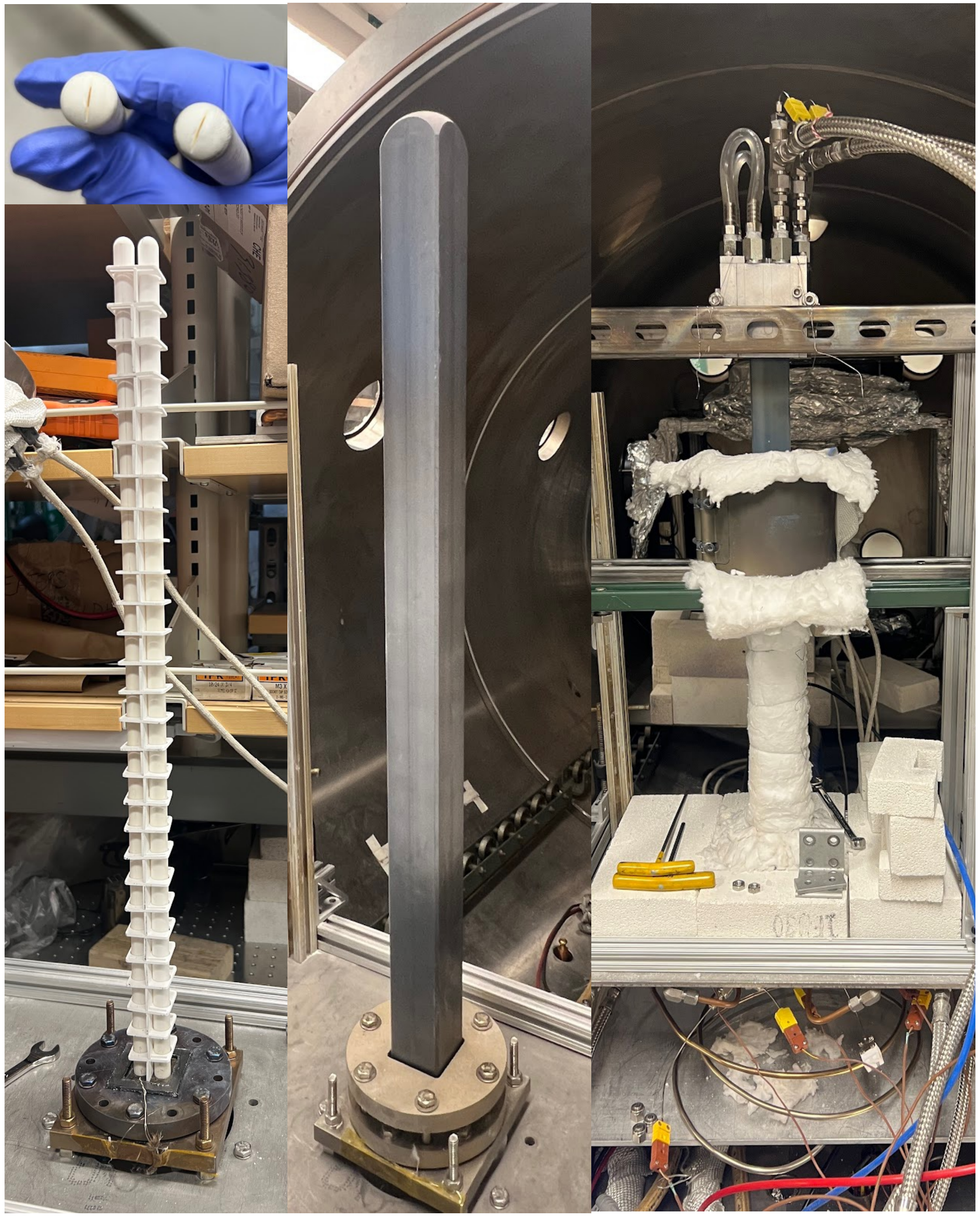




Large OD w/ nozzle end and baffles

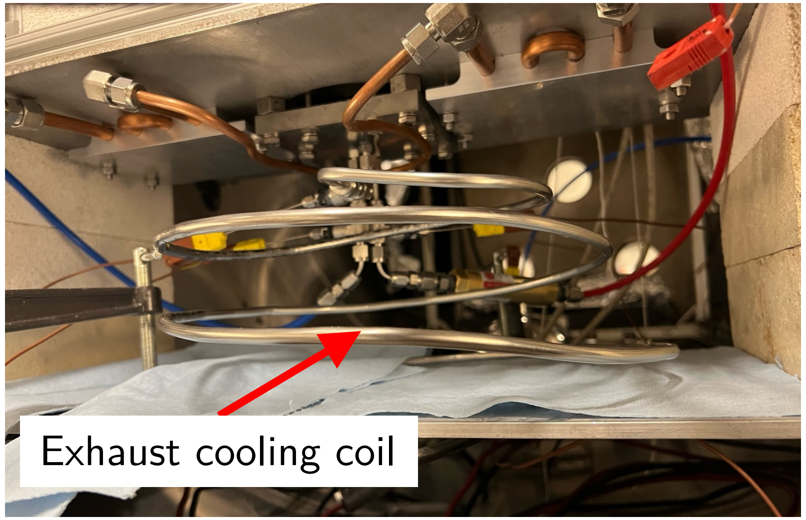
Final prototype design overview



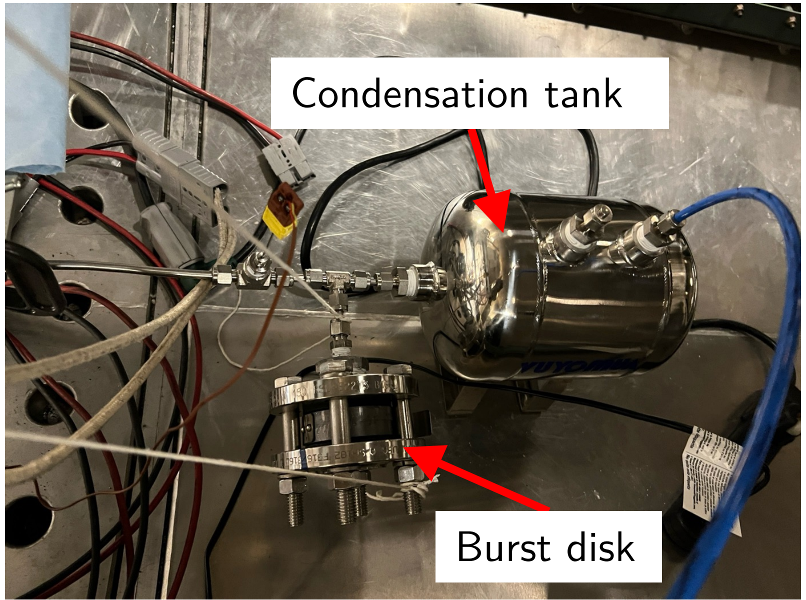


Experimental setup for safe, efficient conversion

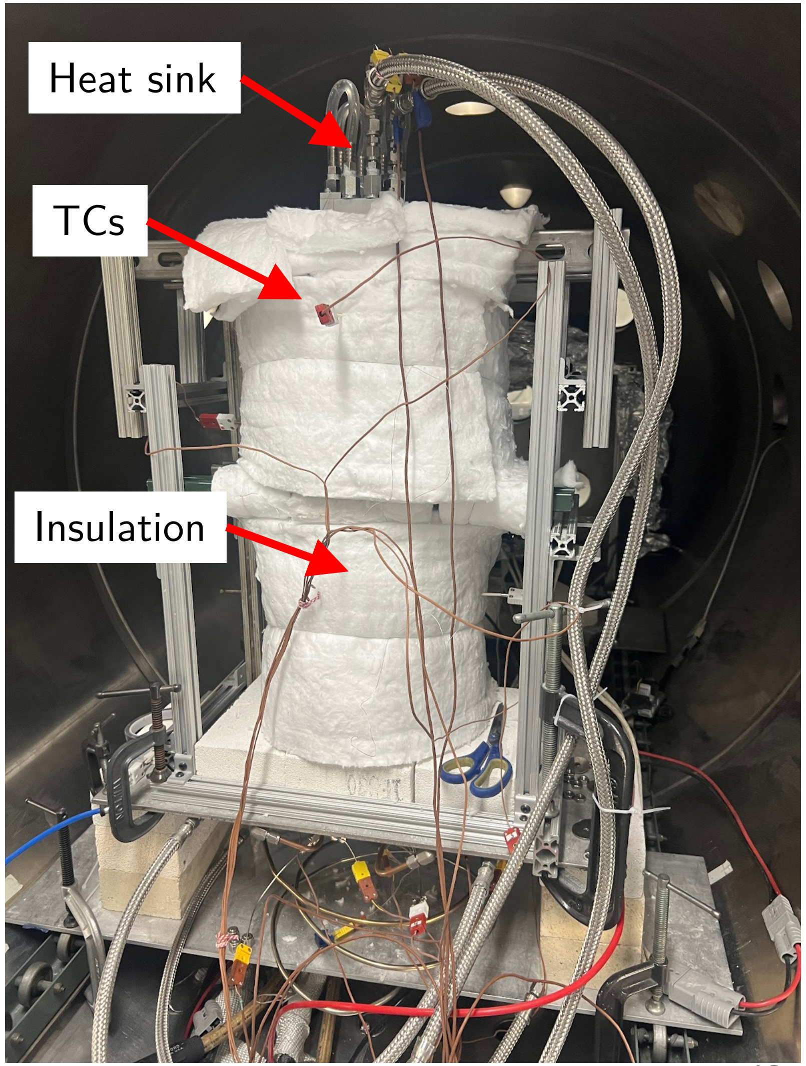
Underneath combustor



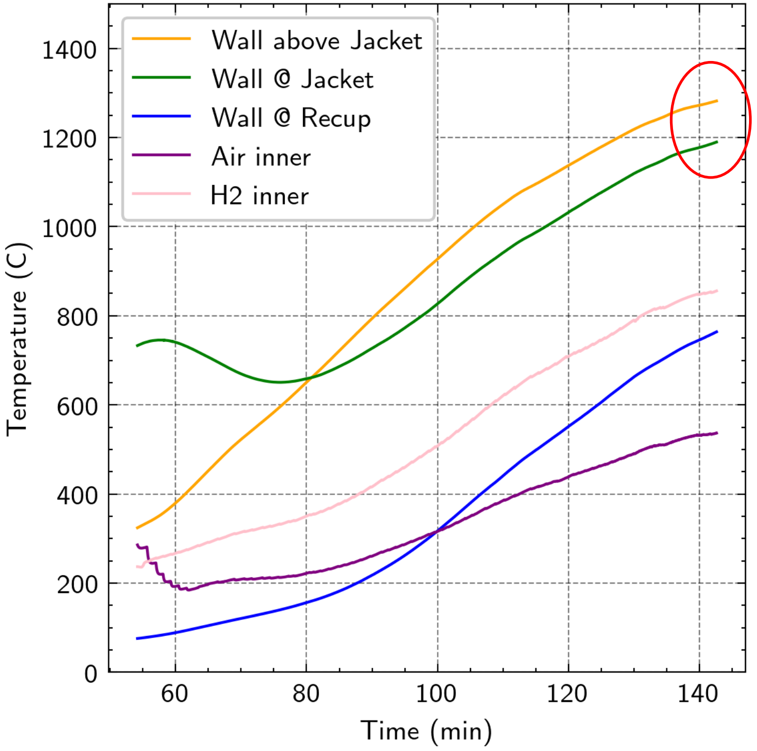
Behind combustor

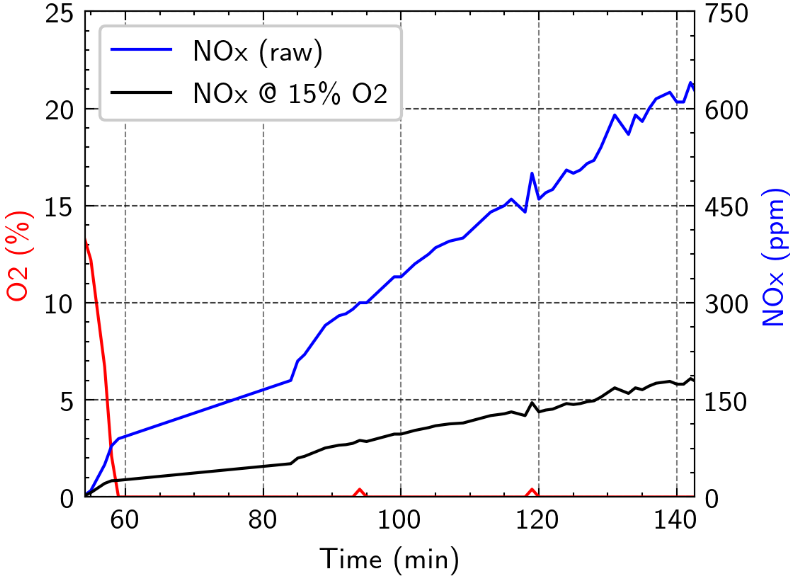


Assembled system



Preliminary results with hydrogen combustion





5kW chemical energy input

4kW thermal power output

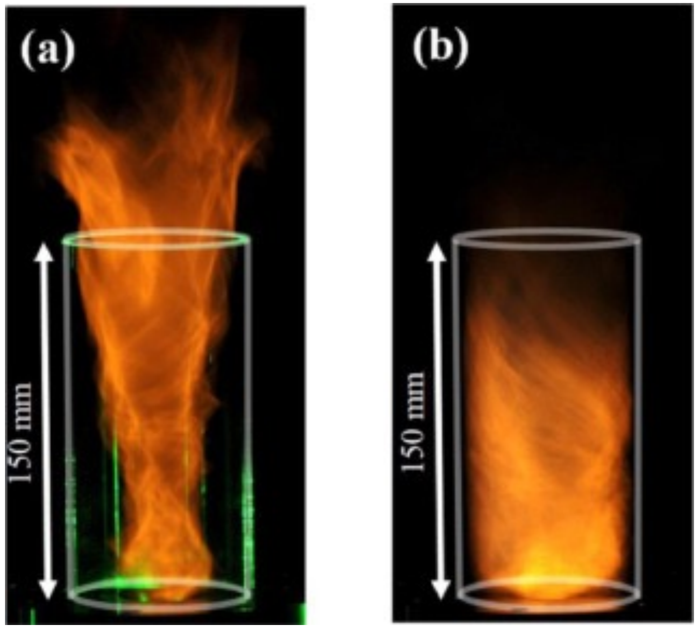
3.5kW absorbed by heat sink

65% thermal efficiency

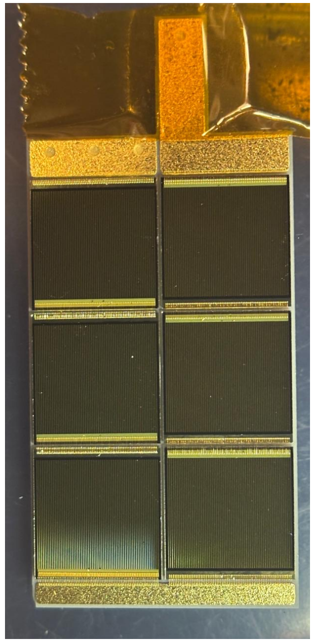
160ppm NOx @ 15% O2

Expected results with ammonia and TPV

- ~100 ppm with burner geometry improvements



- 30% system efficiency, 1kW W-e output (5 W/cm2)



Looking to the future:
Optimized custom design (3D printed microchannels)
Techno-economics (CAPEX/OPEX, grid integration)

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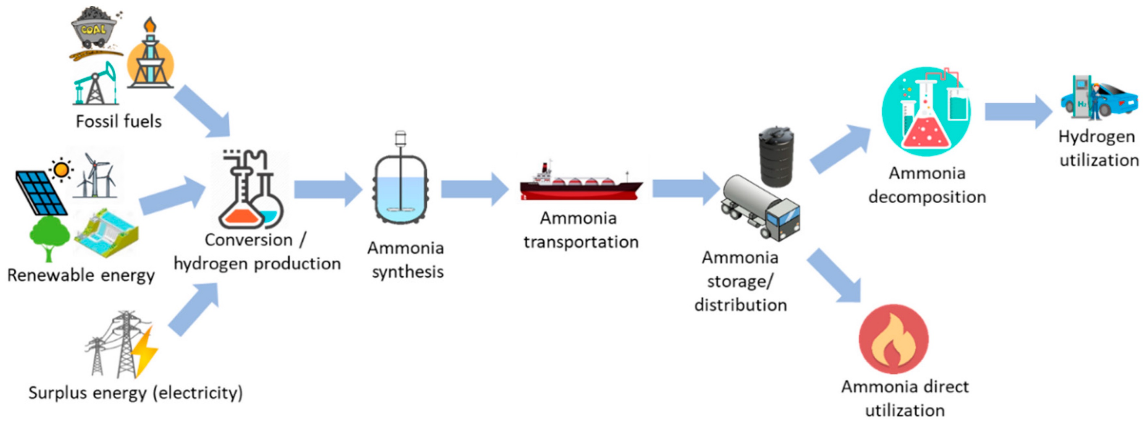

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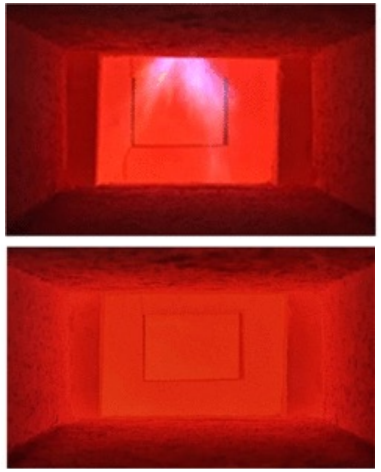

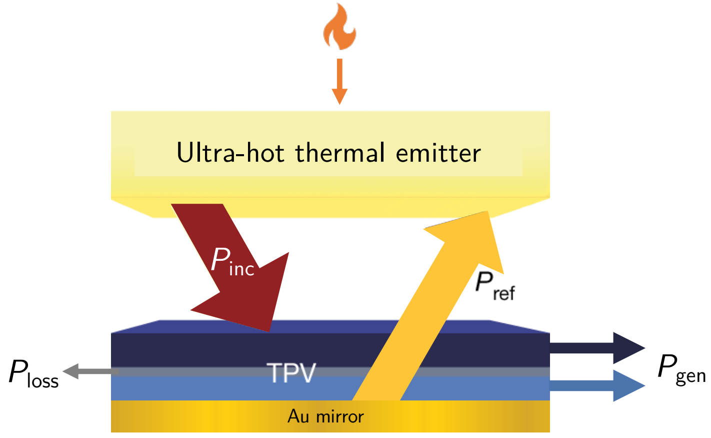

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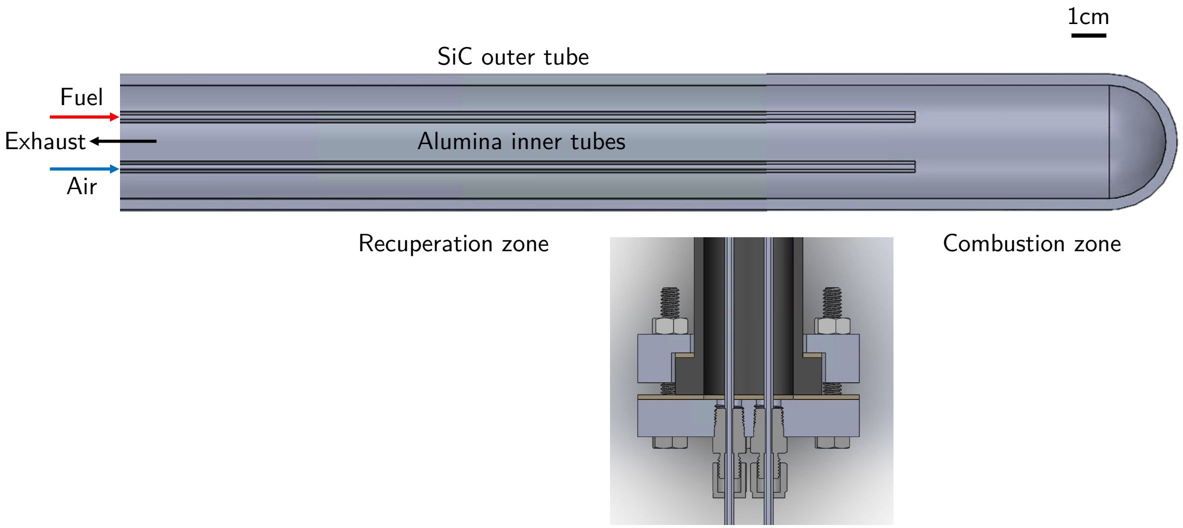

4. How does the prototype perform experimentally?

Current:
1300C wall temperature
3.5 kW heat output
160ppm NOx

Predicted:
30% system efficiency
1 kW electricity produced
100 ppm NOx

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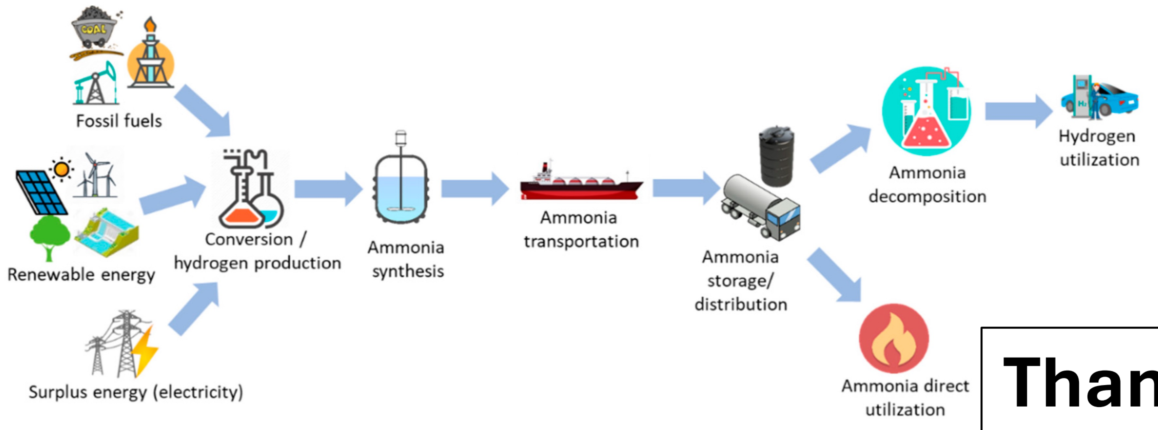

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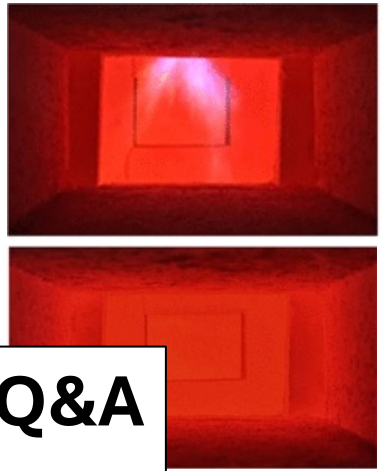

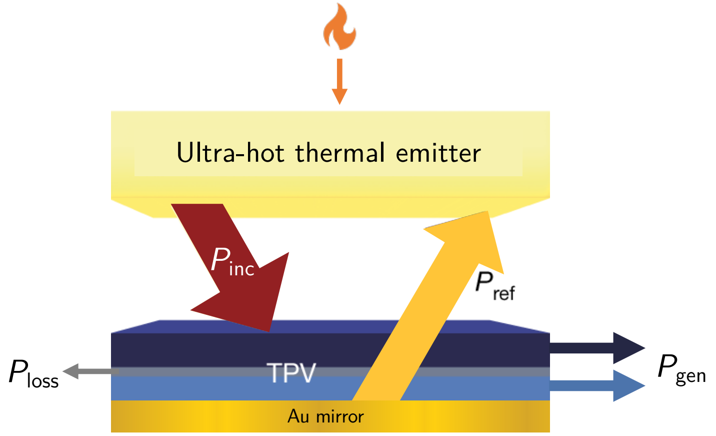

Thanks! Q&A

skverma@mit.edu

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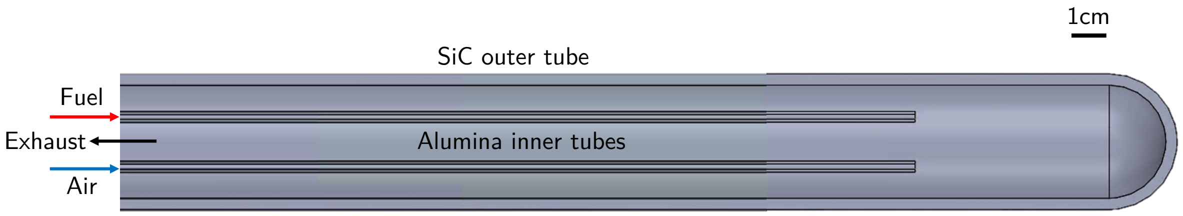

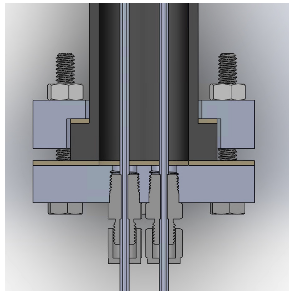

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