Clean, dispatchable power generation with hydrogen combustion coupled with TPV

Shomik Verma, Mehdi Pishahang, Kyle Buznitsky,
Alina LaPotin, Santosh Shanbogue, Asegun Henry

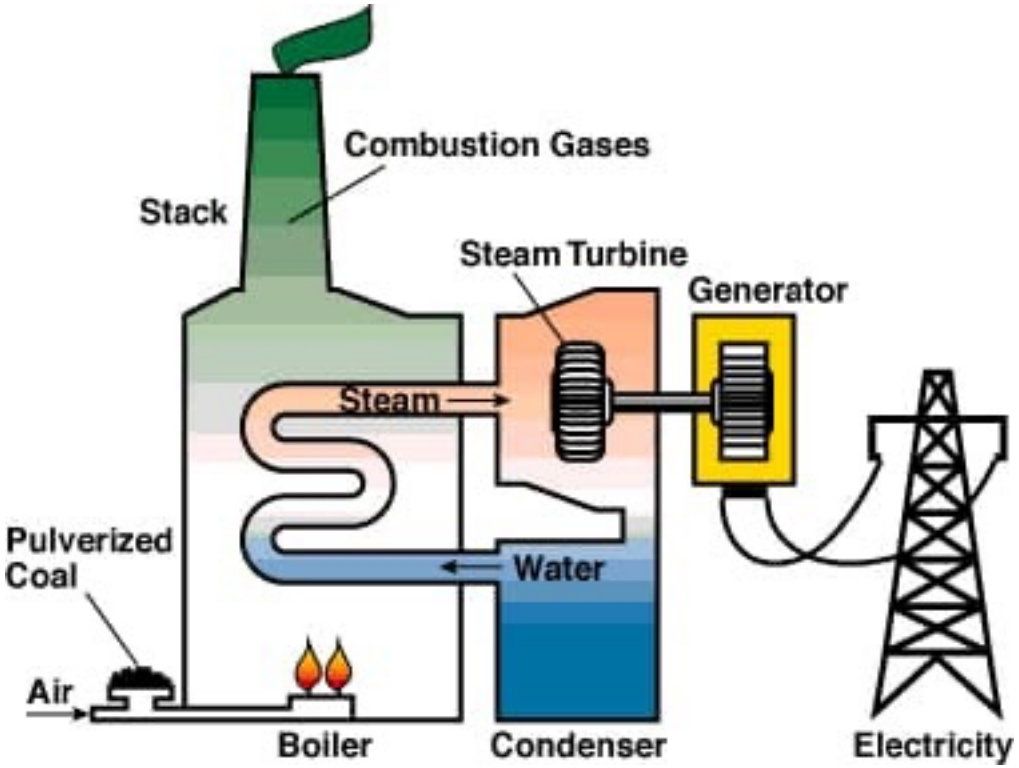
Massachusetts Institute of Technology

TPV-14 Conference

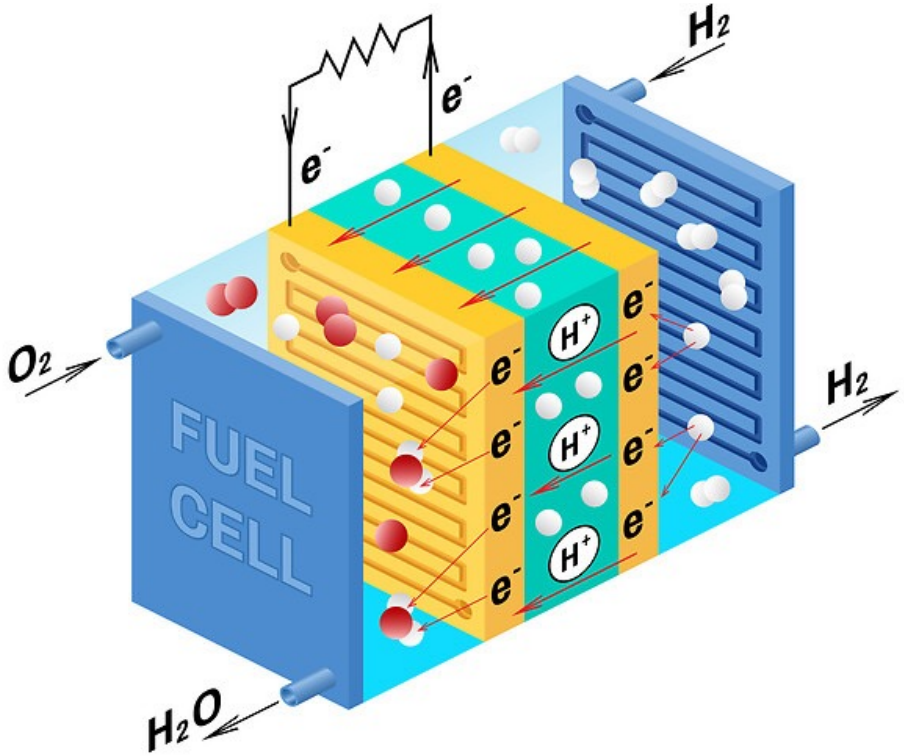
31 May 2023

Massachusetts Institute of Technology

Existing power generation is inelegant



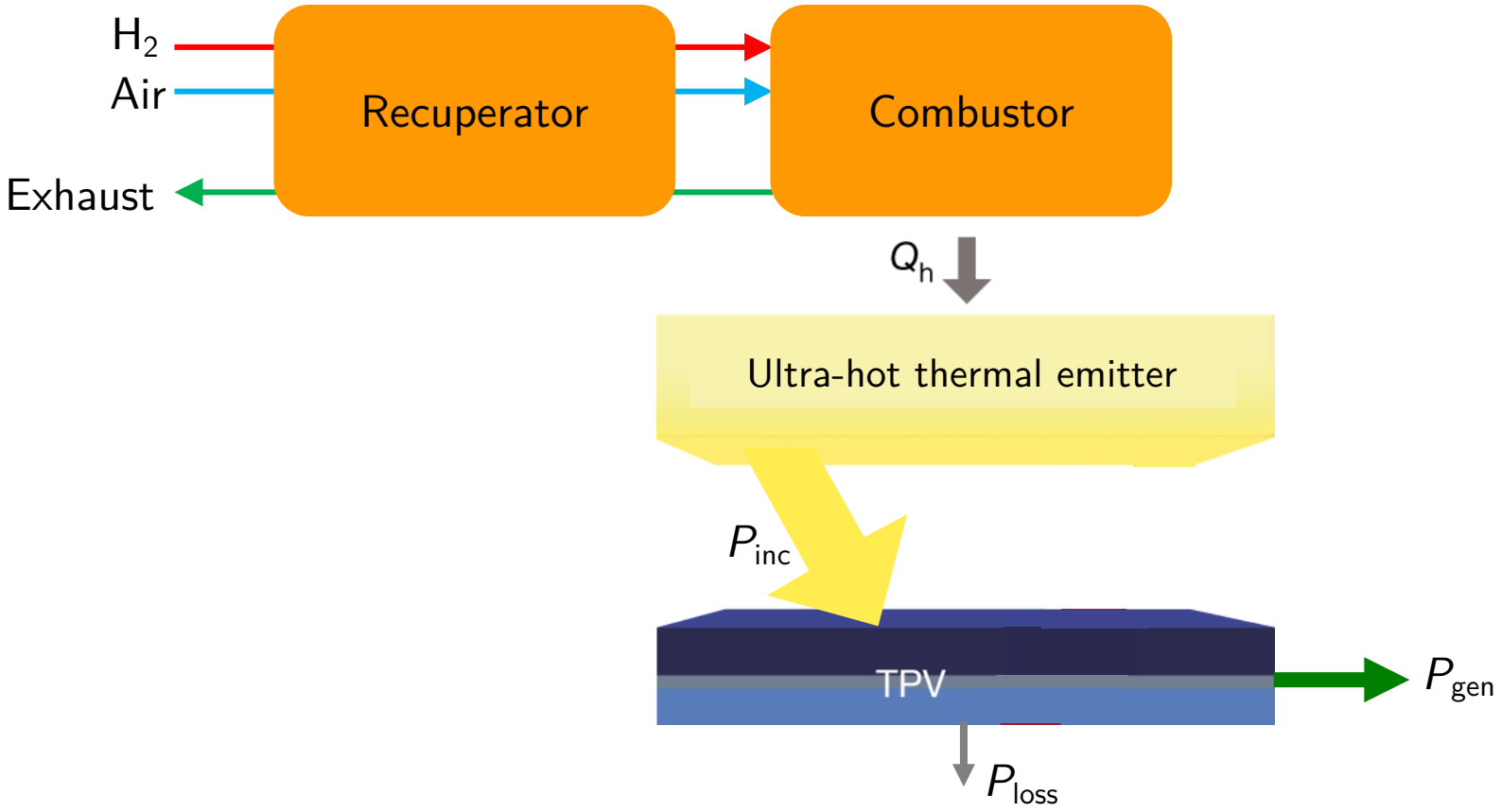
High-temperature, heavy rotating machinery

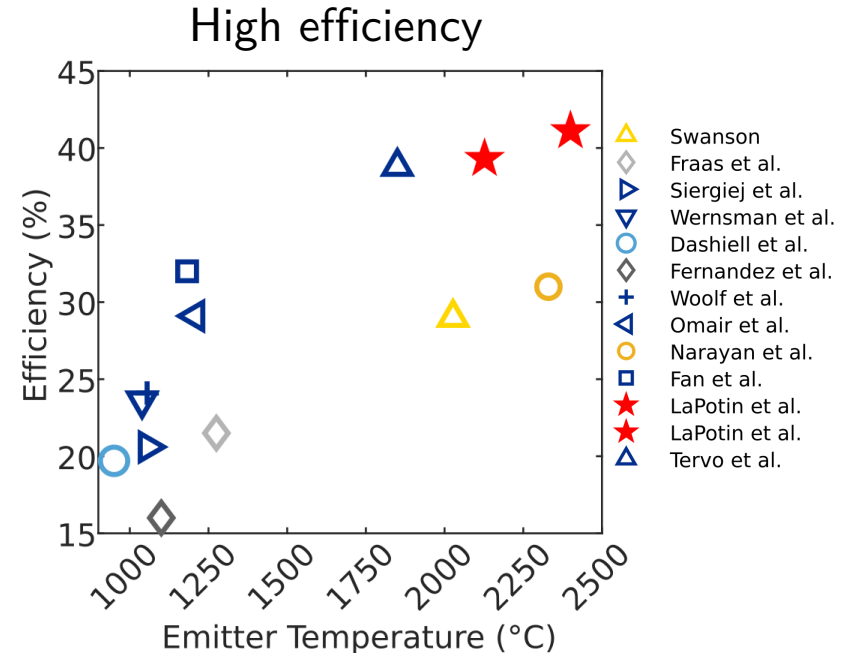


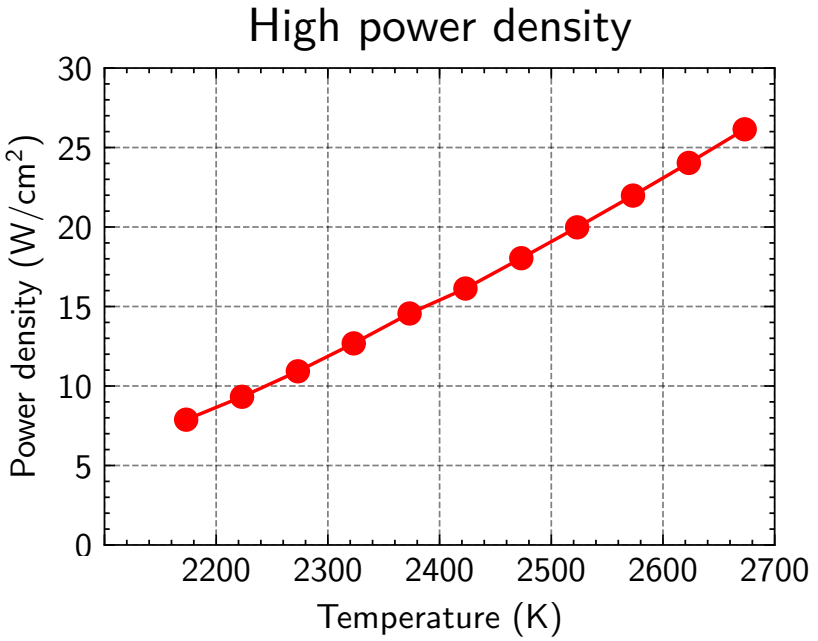
Expensive catalytic process, low power density

Steam turbine | Fuel cell

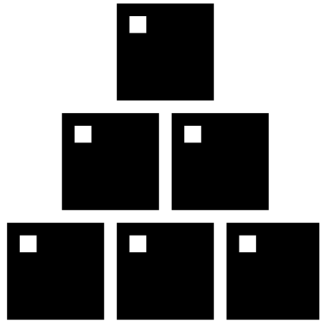
Combustion-powered TPV is a promising alternative



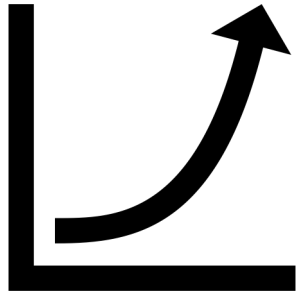




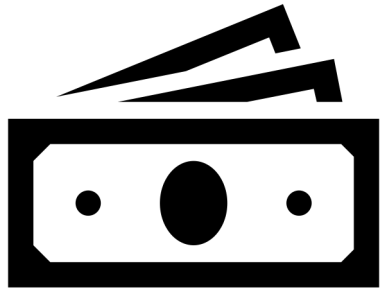
Challenges with combustion TPV



What materials can we use?



Can we design a scalable system?



How can we make it cost-competitive?

What materials can we use?

Constraints and objectives

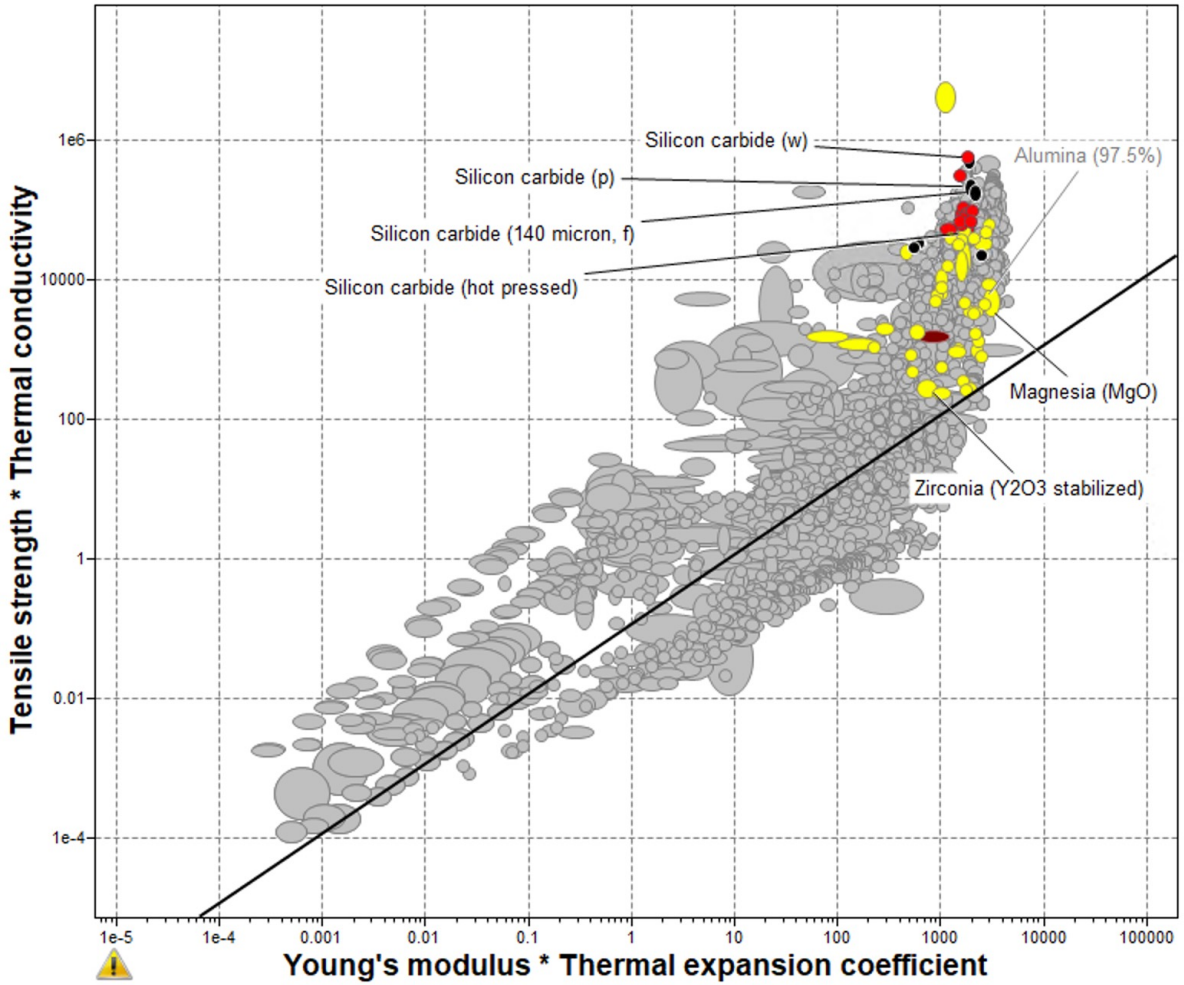
- Low thermal stresses
- High yield strength
- High thermal conductivity

Materials index: $\frac{\sigma_y k}{E\alpha}$

Filters

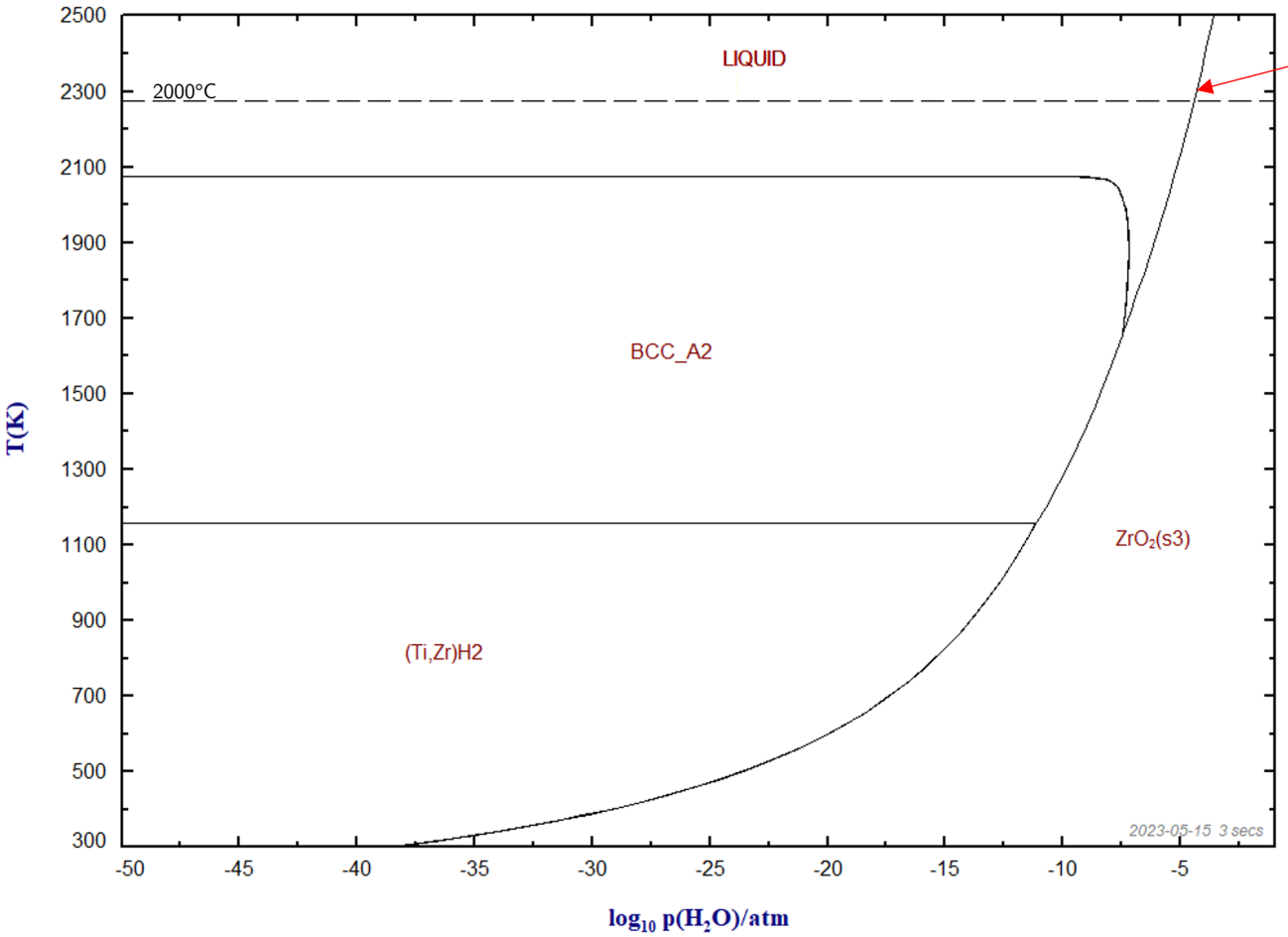
- Oxidation resistant
- High melting point / service temp

Oxides may reduce in a high-temp H_2 environment!
Add H_2O to change equilibrium state



Preventing ZrO_2 reduction in H_2 environment

ZrO_2 phase diagram with 1atm H_2 and varying H_2O pressure

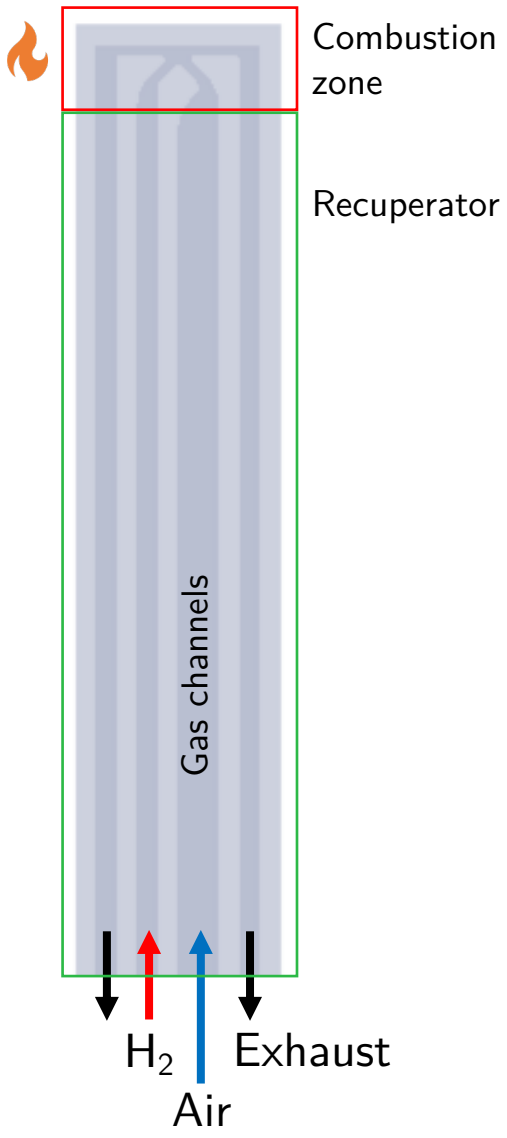


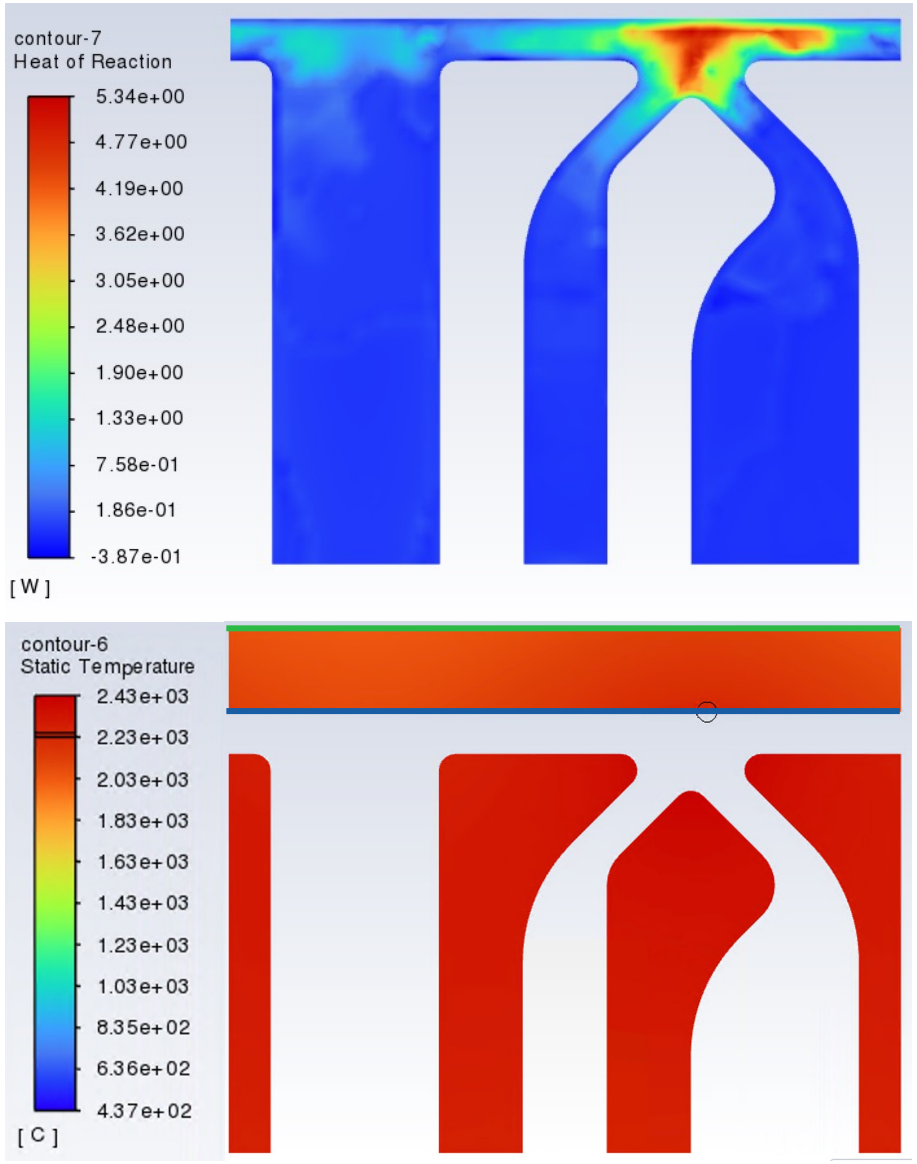
H2/H2O ratio of at most 10^4 required
At least 100 ppm H2O prevents reduction @ 2000C

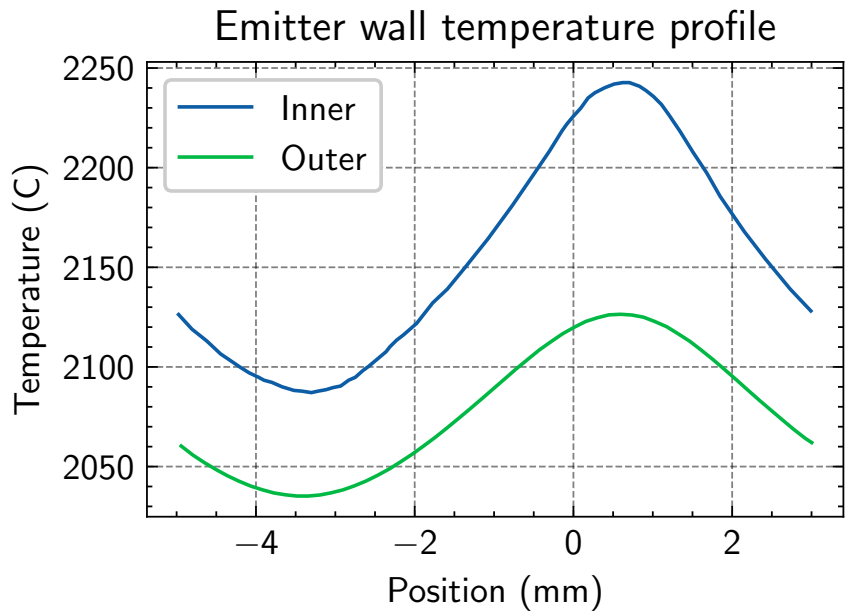
Environment	Adiabatic flame temperature (C)
1atm H_2	2108.87
1atm H_2 + 100ppm H_2O	2108.81

Challenge #1: Materials selection ✓

Scalable combustor design with near-isothermal emitter



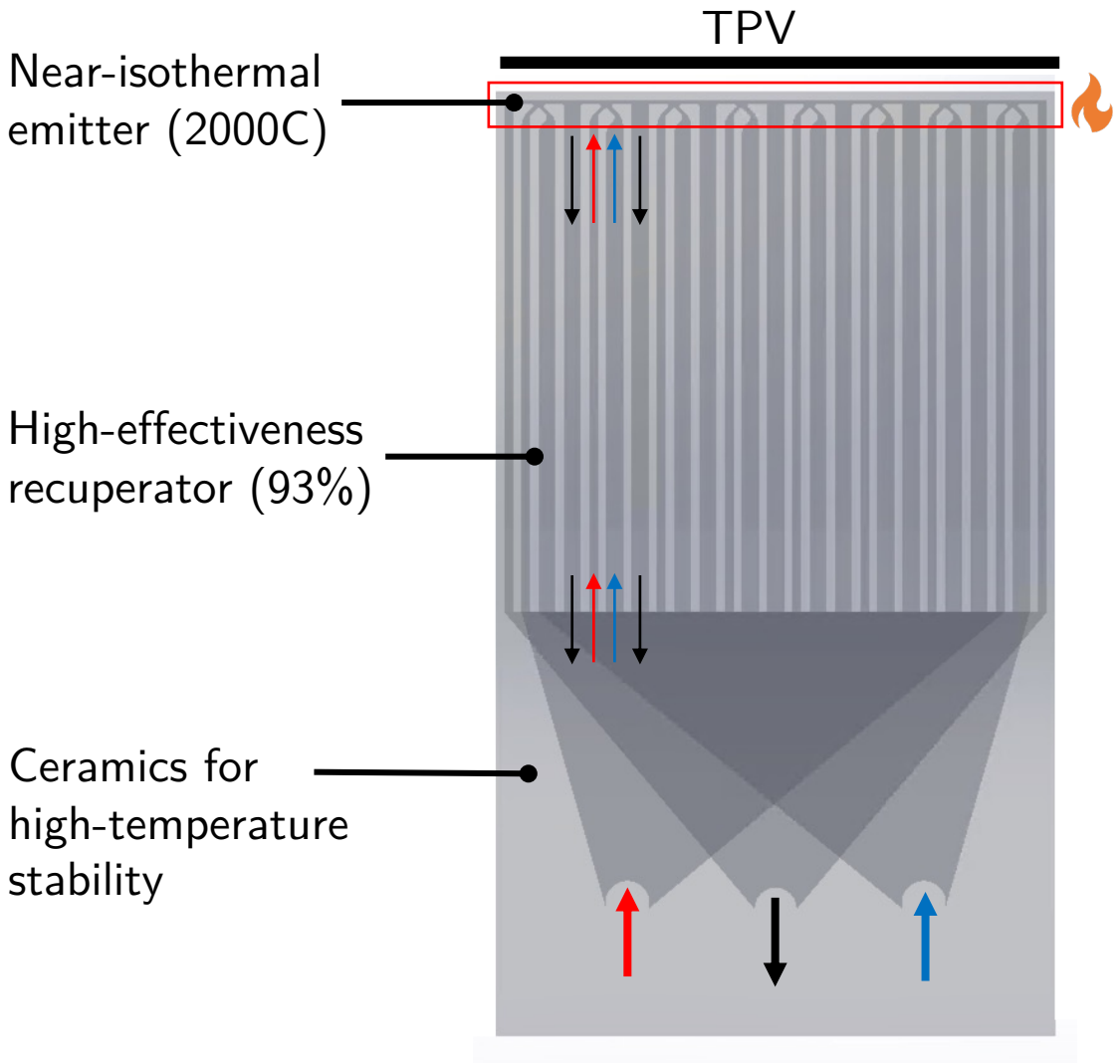


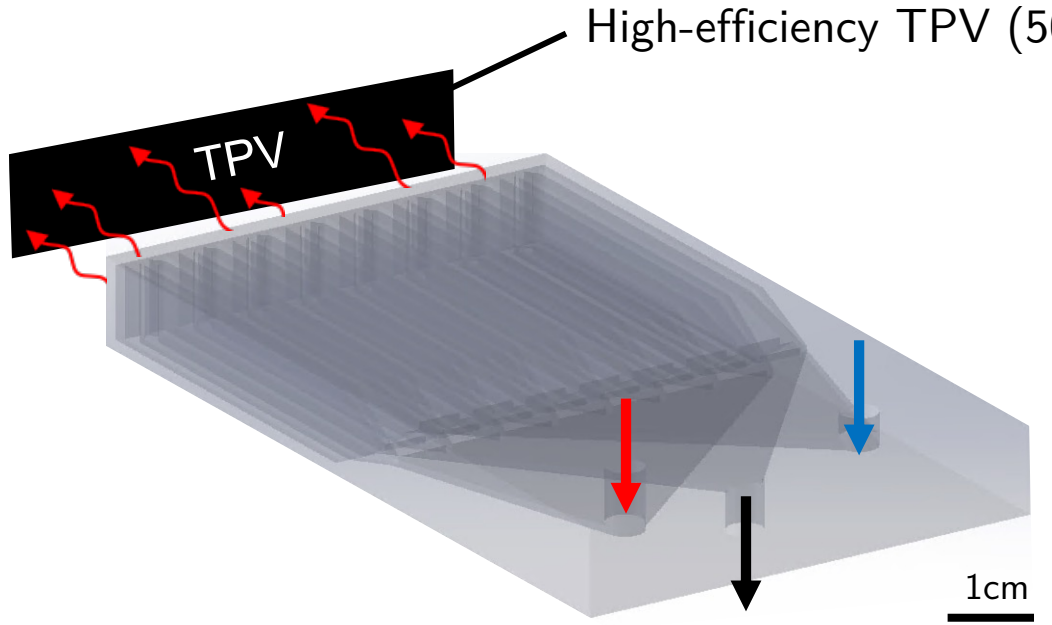


Recuperator design

	Efficiency (%)	
	LHV	HHV
10 cm	93	80
50 cm	99	93

Combustor integration with TPV





H_2

Air

Exhaust

Fuel-to-electricity efficiency: ~47%

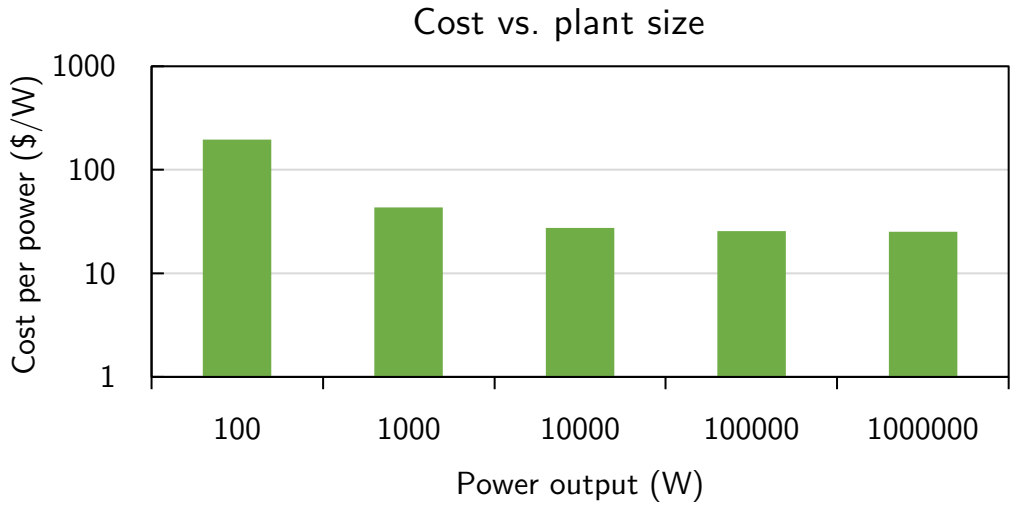
Modular design enables stacking to reach large length scales

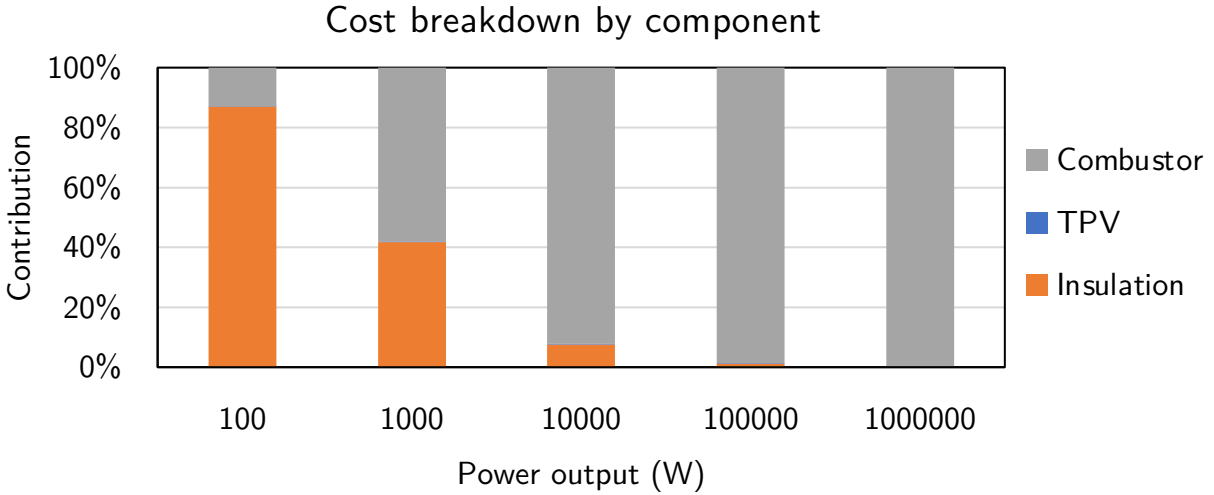
Challenge #2: Scalable combustor design ✓

Can we make it cost-competitive?

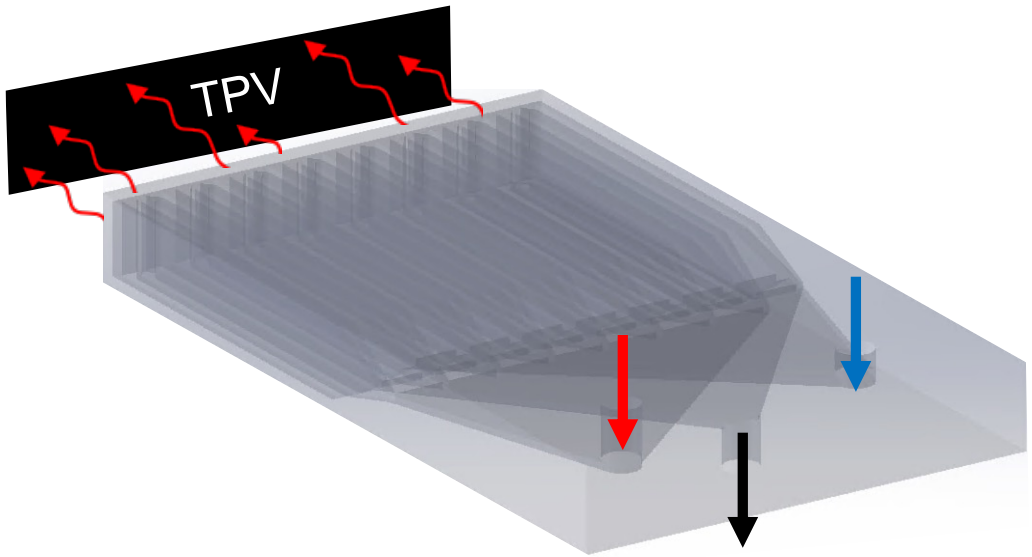
- 3D-printed combustor (quote): $\$42/cm^3$
- TPV cells: $\$1/cm^2$
- TPV power output: $5W/cm^2$
- Insulation cost: $\$2000/m^3$

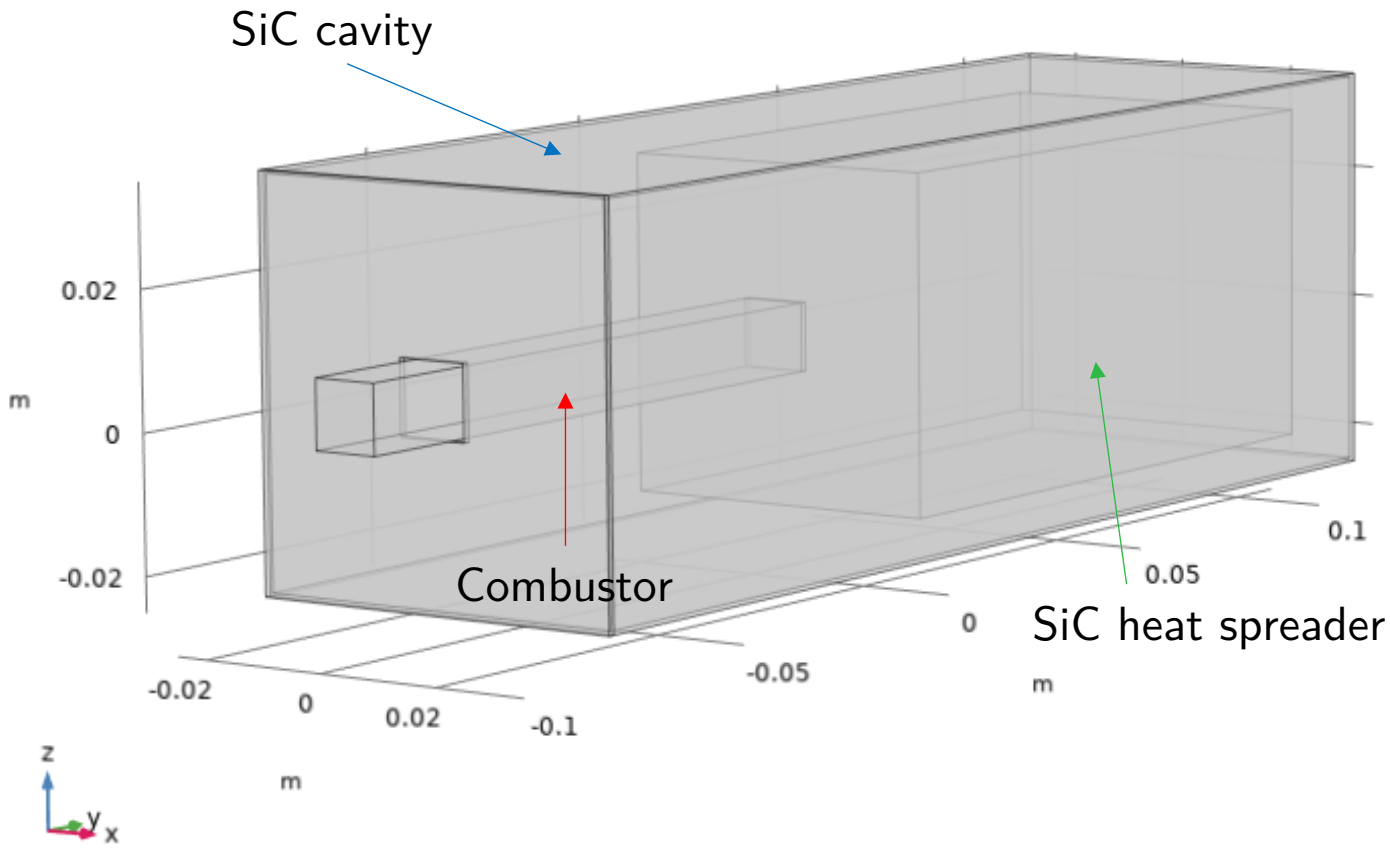
Solutions:
- Extract more power per combustor volume
- Decrease cost of manufacturing



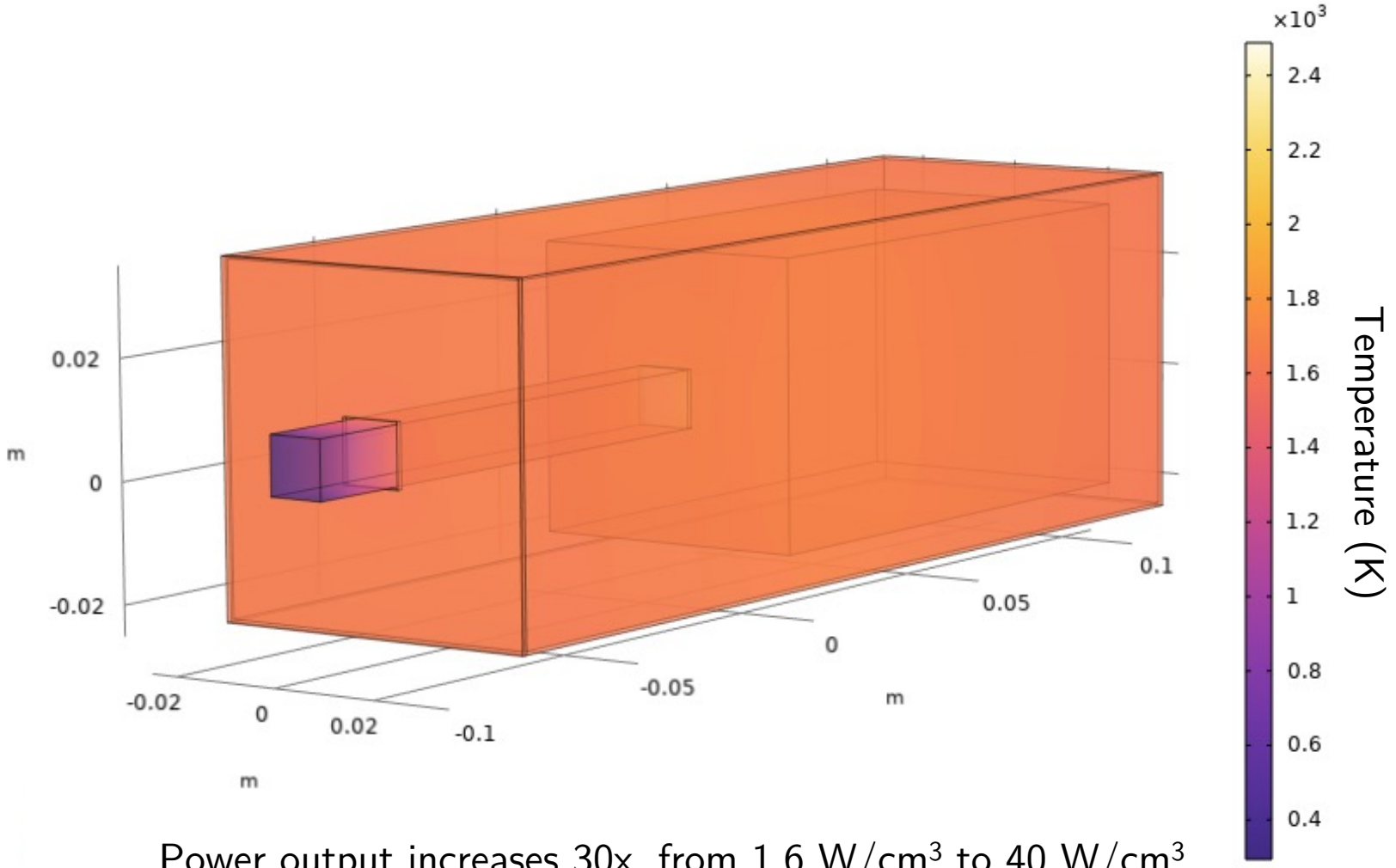


Increase emitter surface area



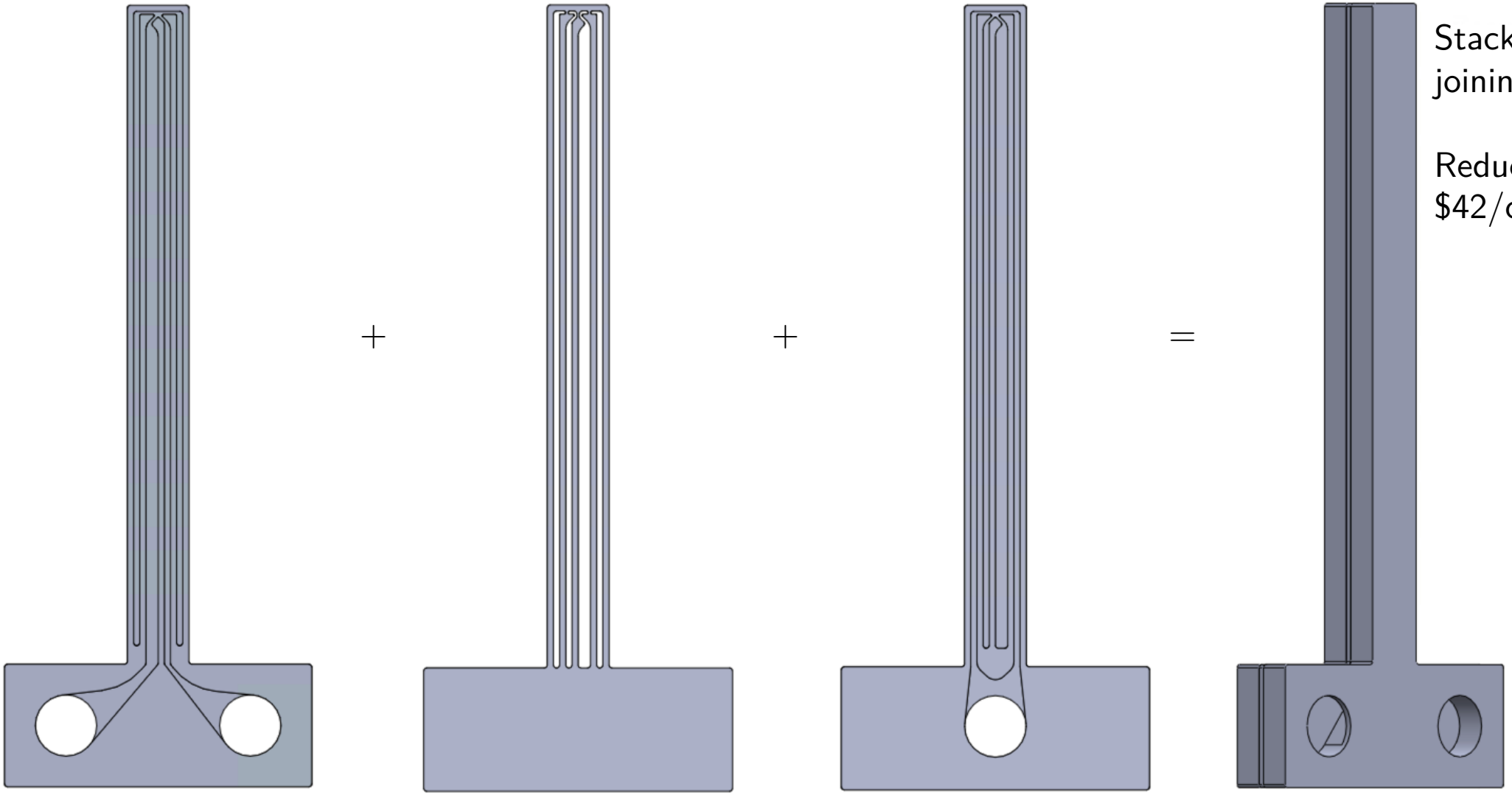


Increase emitter surface area



Power output increases 30x, from 1.6 W/cm^3 to 40 W/cm^3
(of combustor volume)

Design for manufacturability

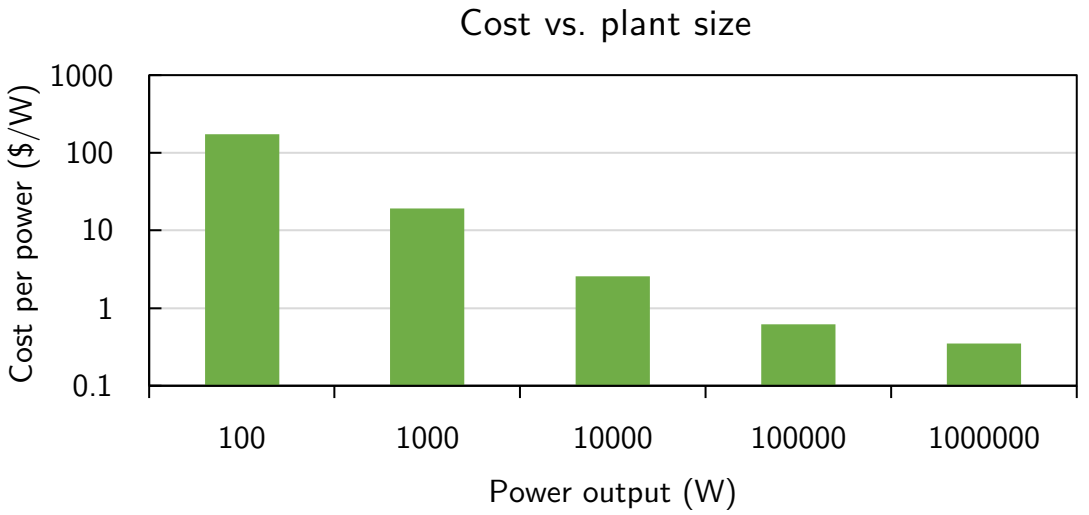


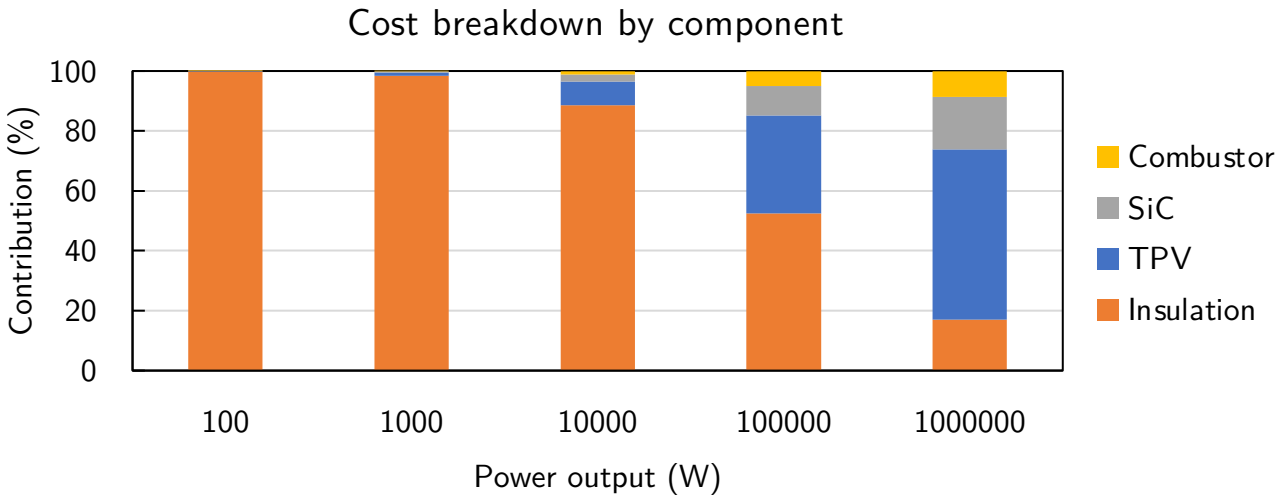
Stacked geometry allows joining of machined parts

Reduces cost 30x, from $\$42/cm^3$ to $\$1.5/cm^3$

Techno-economic analysis of new design

- Machined combustor: $\$1.5/cm^3$
- SiC cost: $\$0.06/cm^3$
- TPV cells: $\$0.2/cm^2$
- TPV power output: $2W/cm^2$
- Insulation cost: $\$2000/m^3$

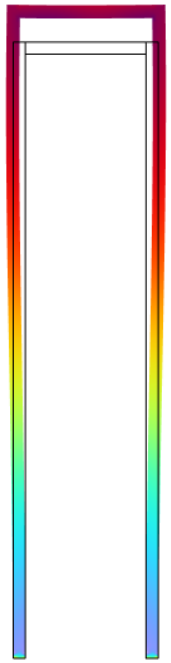


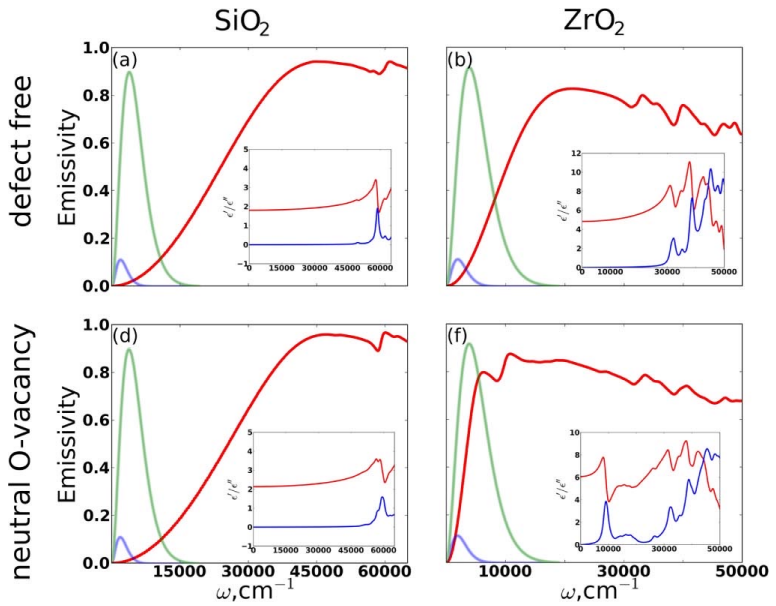


Challenge #3: Cost-competitive with turbines ✓

Next steps

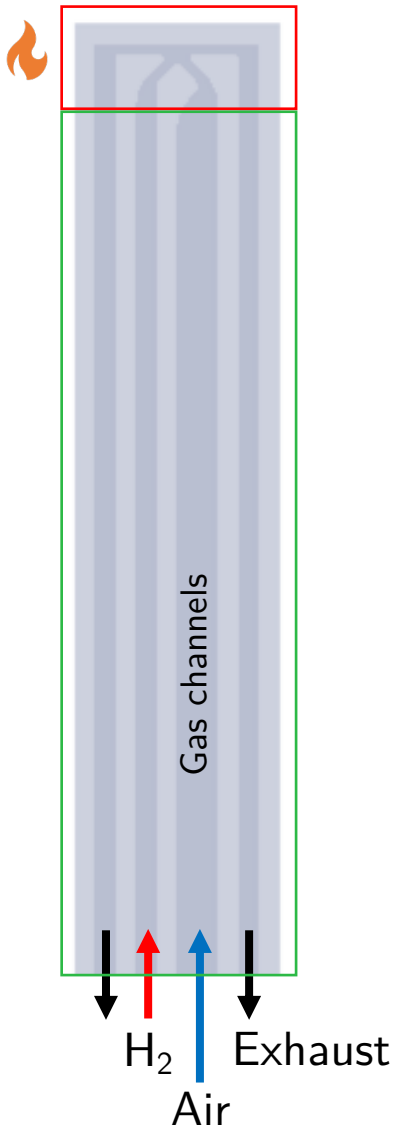
- Thermal stresses
- Surface engineering to improve emission
- Device fabrication



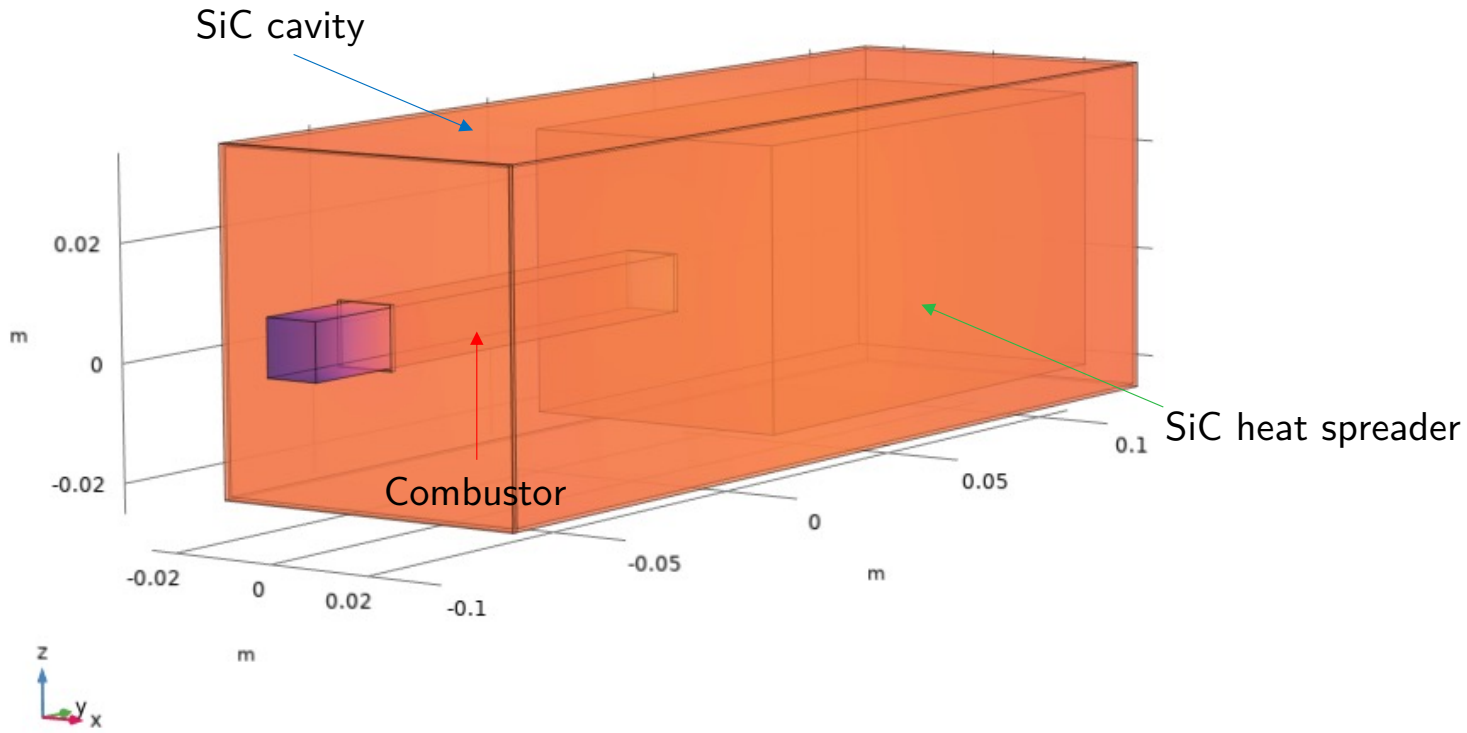


Summary

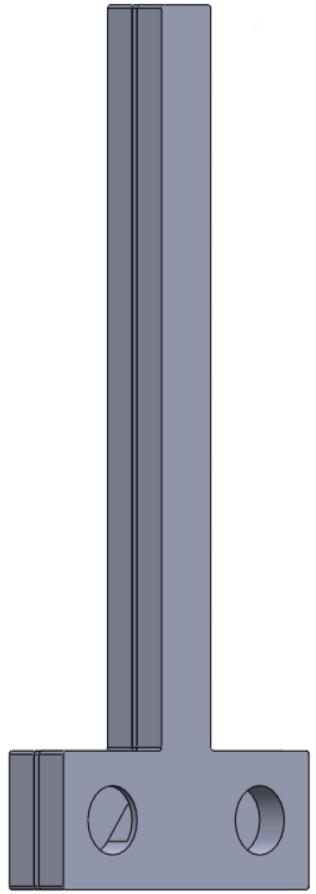
Combustor design with high-temp materials



Integration with TPV for scalable power generation



Manufacturability to reduce cost

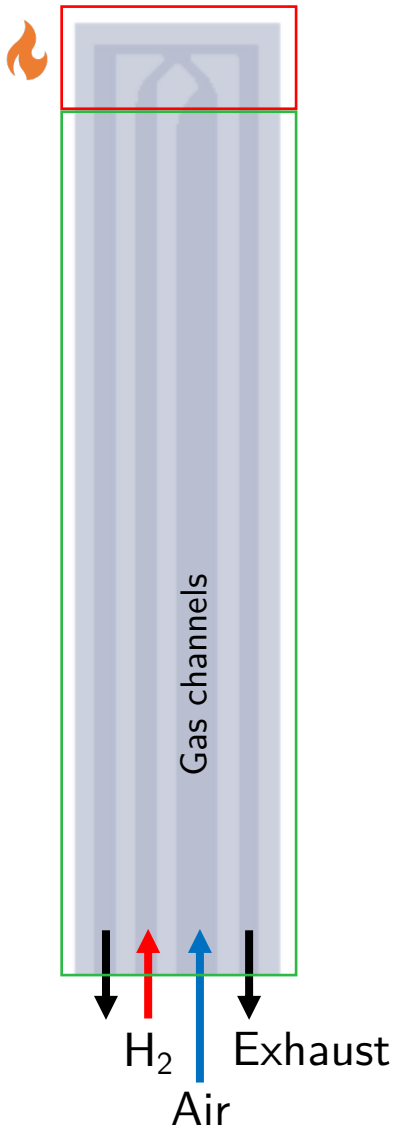


Cost-competitive, carbon-free, high-efficiency alternative to traditional power generation

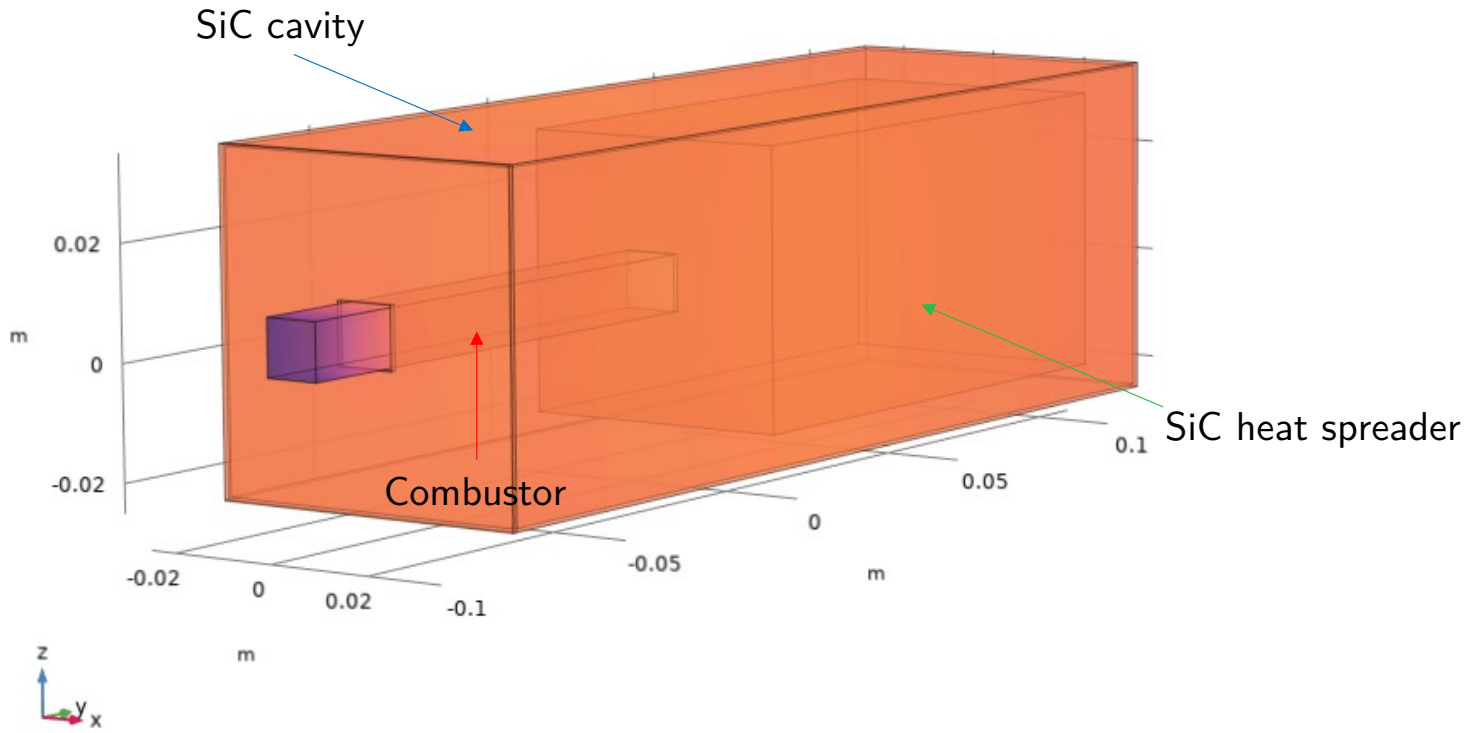
Thanks!

skverma@mit.edu

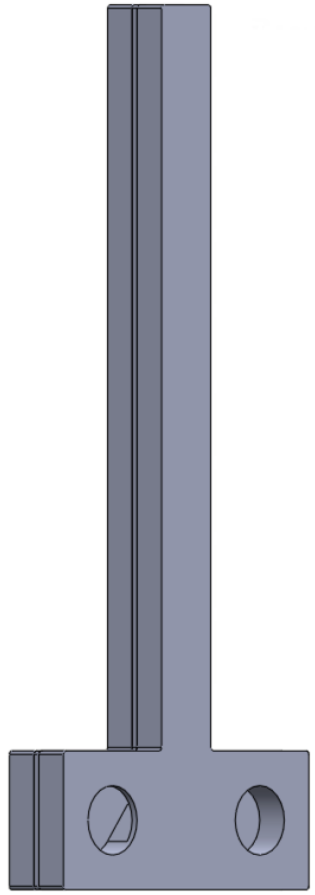
Combustor design with high-temp materials



Integration with TPV for scalable power generation



Manufacturability to reduce cost



Cost-competitive, carbon-free, high-efficiency alternative to traditional power generation

Massachusetts Institute of Technology