Power generation from low-NOx ammonia combustion enabled by thermophotovoltaics

Shomik Verma, Kyle Buznitsky, Santosh Shanbogue, Mehdi Pishahang, Tobi Majekodunmi, Ahmed Ghoniem, Asegun Henry

TPV-16 Conference

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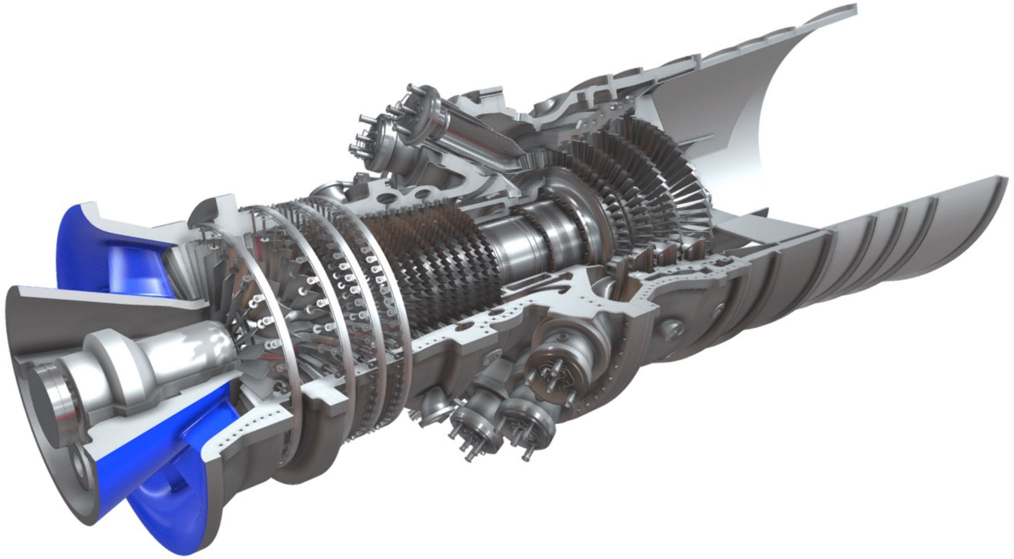
Massachusetts Institute of Technology

Stored ammonia can be a dispatchable power source

NH_3, no carbon content
Established supply chains (fertilizer)
Liquid-phase storage
Fuel of the future?



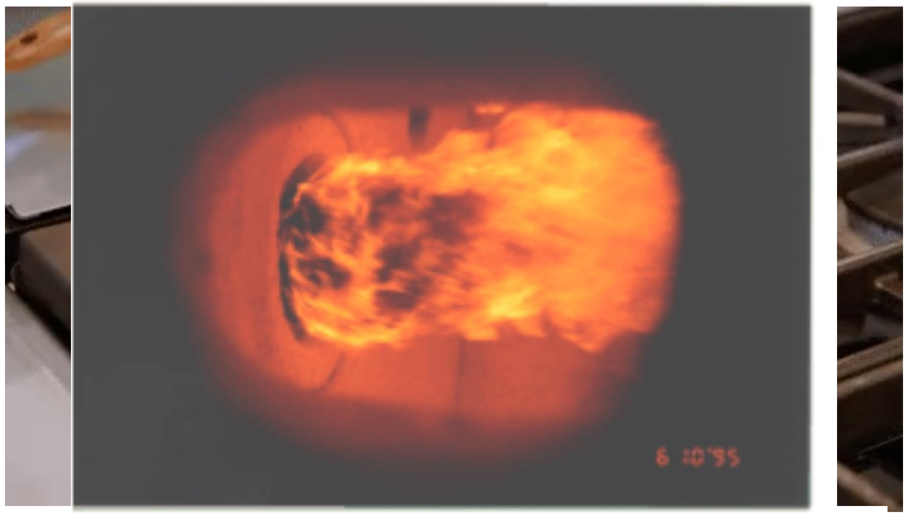
Ammonia combustion in turbines: high NO_x production
NO_x is a toxic and greenhouse gas, EPA limit 15ppm

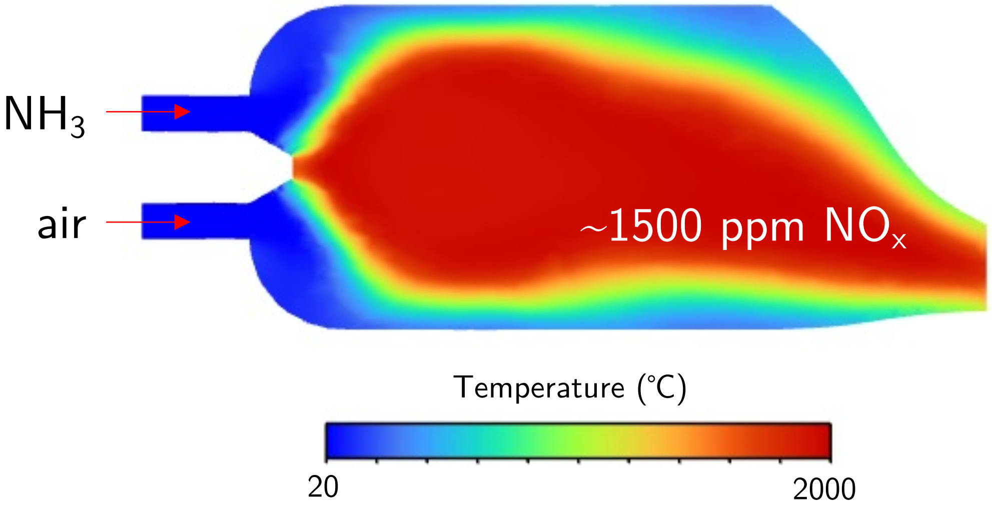
Reasons for high NOx production:
High-temperature flames (~2000°C)

Forum News Service, Savree Images

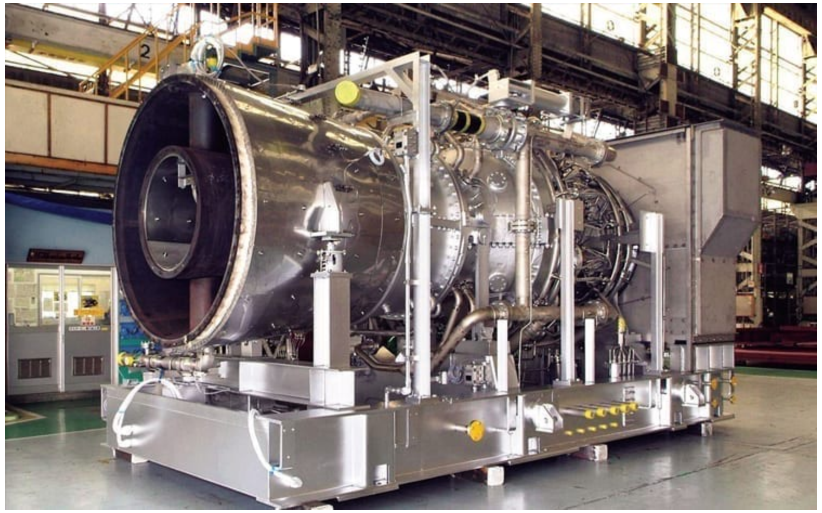
Turbines: high NO_x production in ammonia flame

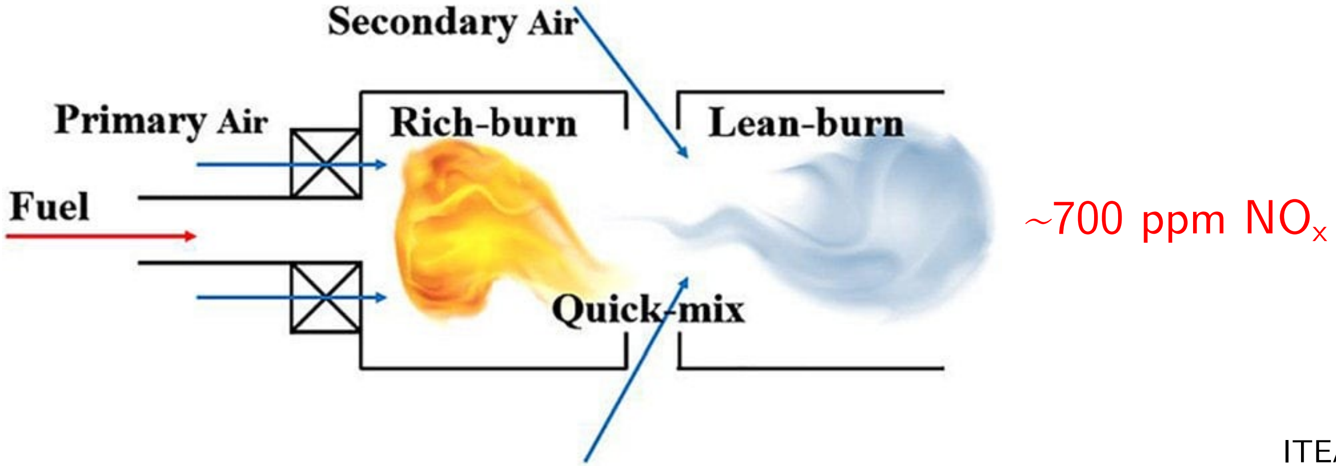
Conventional combustion





Ammonia turbines
(Rich-Quench-Lean staged combustion)

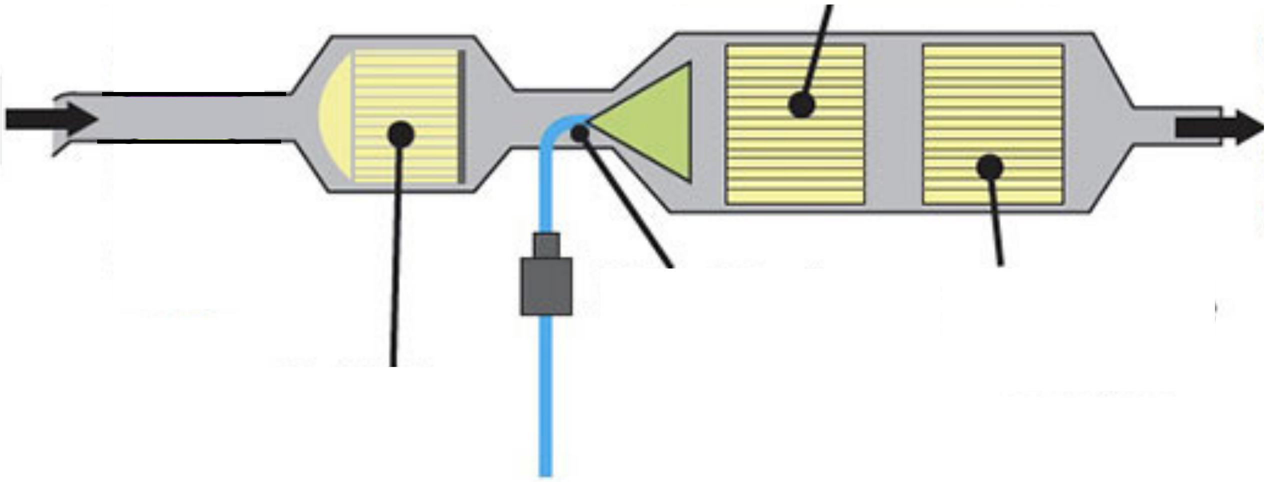




ITEA,
Clean. Eng. and Tech. 5 (2021) 100321

Turbines: NO_x control via expensive selective catalytic reduction (SCR)

Ammonia turbine exhaust (~700 ppm NO_x)



Clean exhaust (<20 ppm NO_x)

Requires expensive catalysts + urea injection (30% overhead)
Makes ammonia turbines uncompetitive with natural gas turbines

SCR

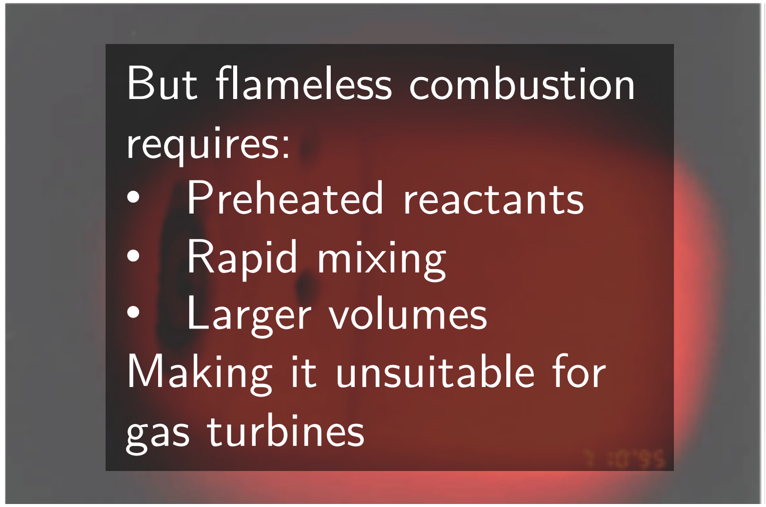
How can we move beyond flamed combustion?

How can we make NO_x control cheaper?

Flameless combustion

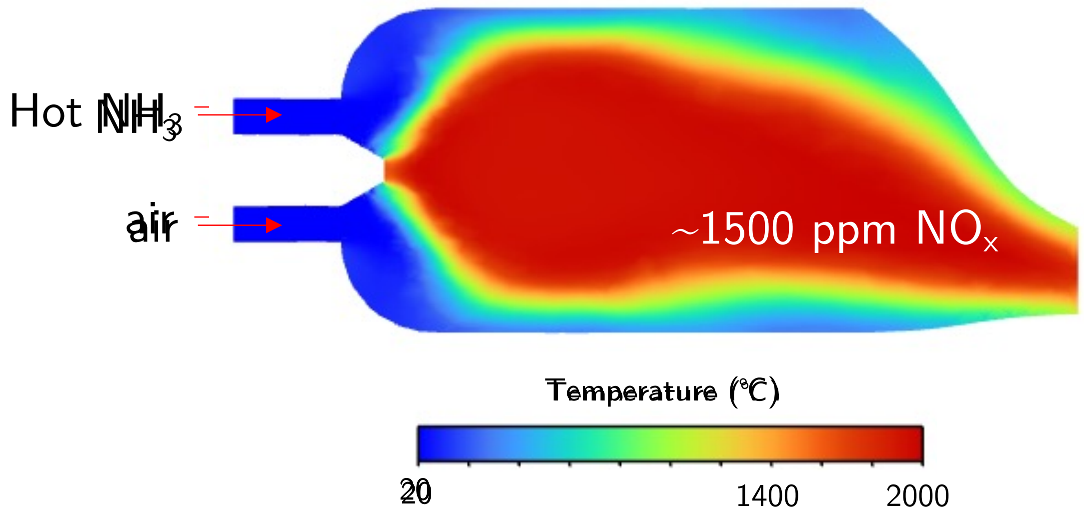
Ammonia SNCR

(selective non-catalytic reduction)



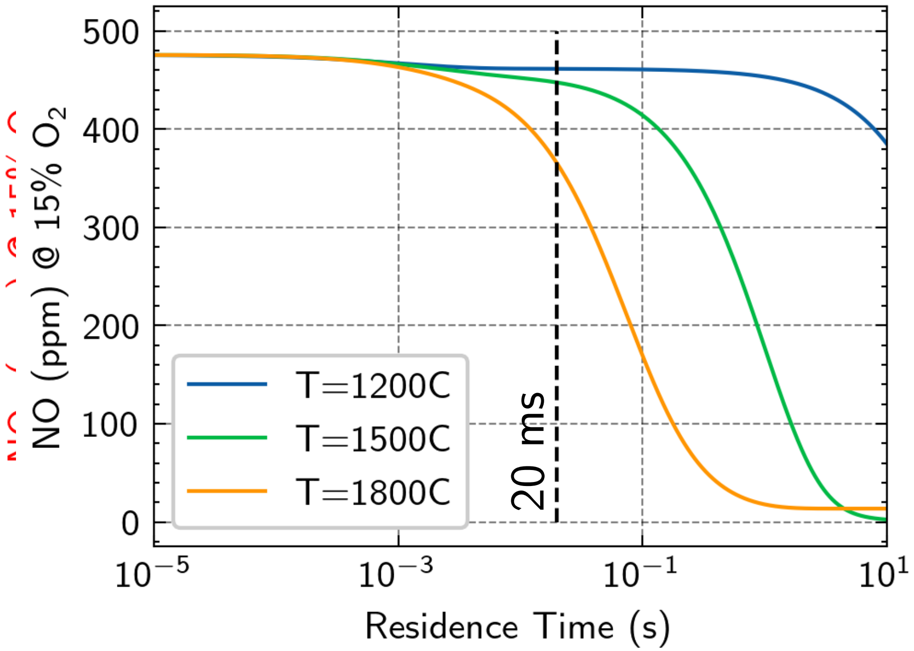
But flameless combustion requires:
- Preheated reactants
- Rapid mixing
- Larger volumes

Making it unsuitable for gas turbines



Excess ammonia reacts with NO$_x$

SNCR time at ϕ=1.2



Excess fuel

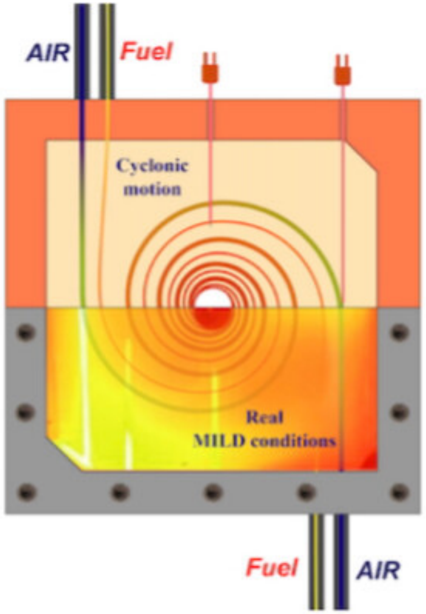
$$4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$$

Ammonia SNCR needs:
- Long residence time at high temperatures

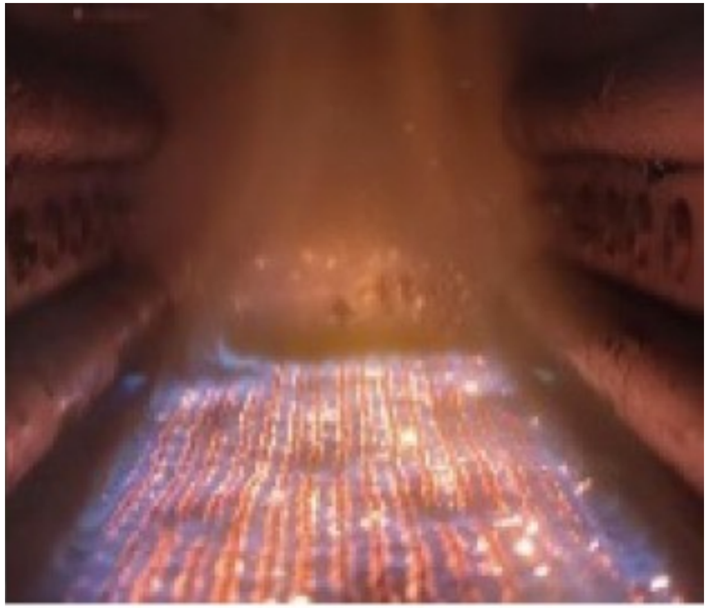
Which lowers efficiency of gas turbines

Flameless combustion + SNCR incompatible with turbines

Prior flameless + SNCR works had no power generation



Sorrentino et al. (2019)



Shi et al. (2022)

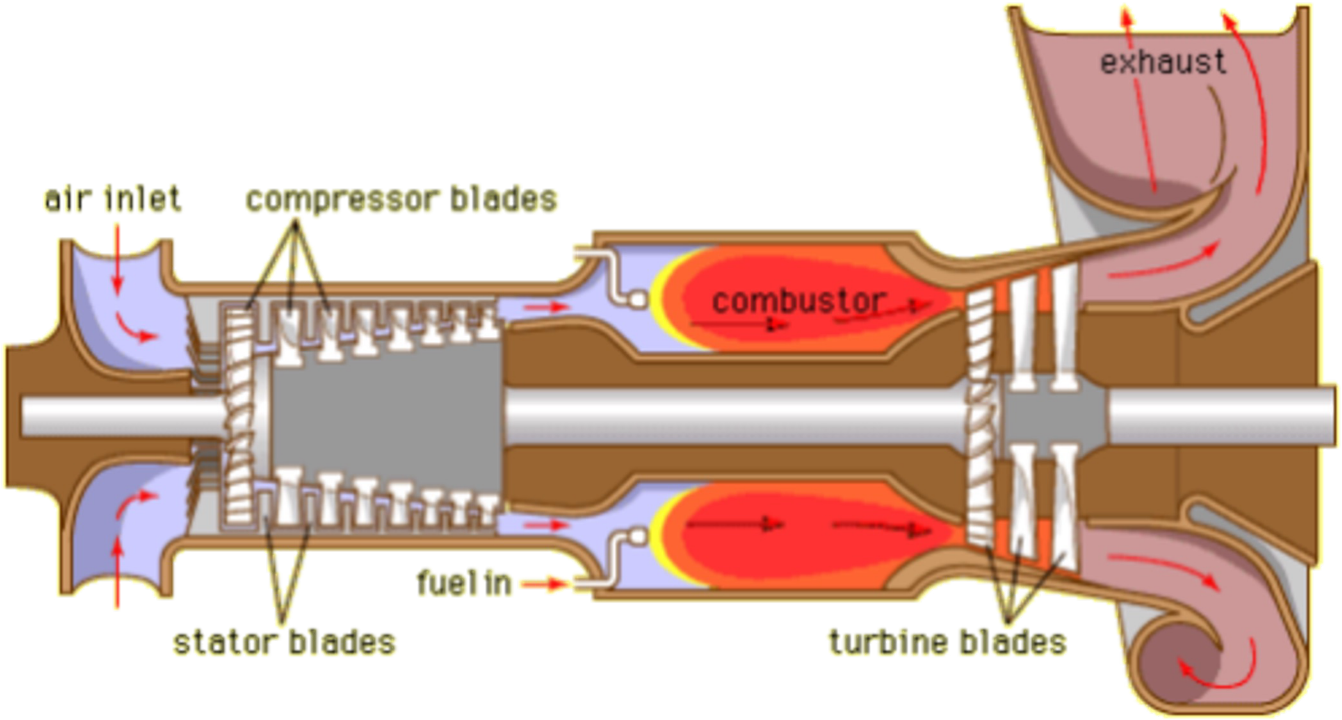
Low NO_x (10 ppm)

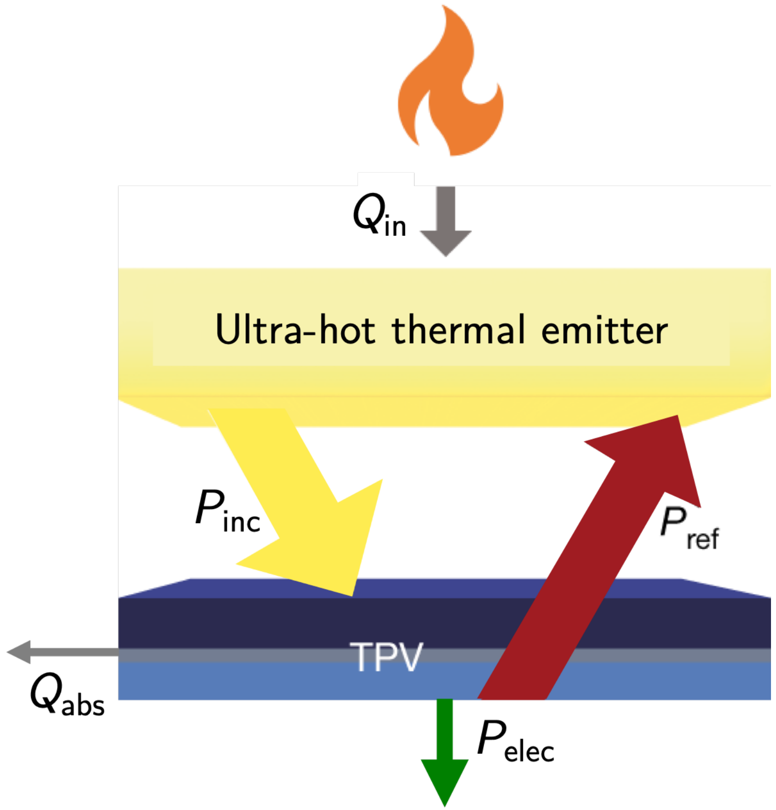
No power generation

Can an alternative heat engine enable power extraction from low-NOx ammonia combustion?

Mitsubishi Power, Energy Fuels 39, 19512—19525 (2025)

TPV *decouples* heat generation from power extraction





~95% of heat transfer is radiative at >1500°C

Britannica

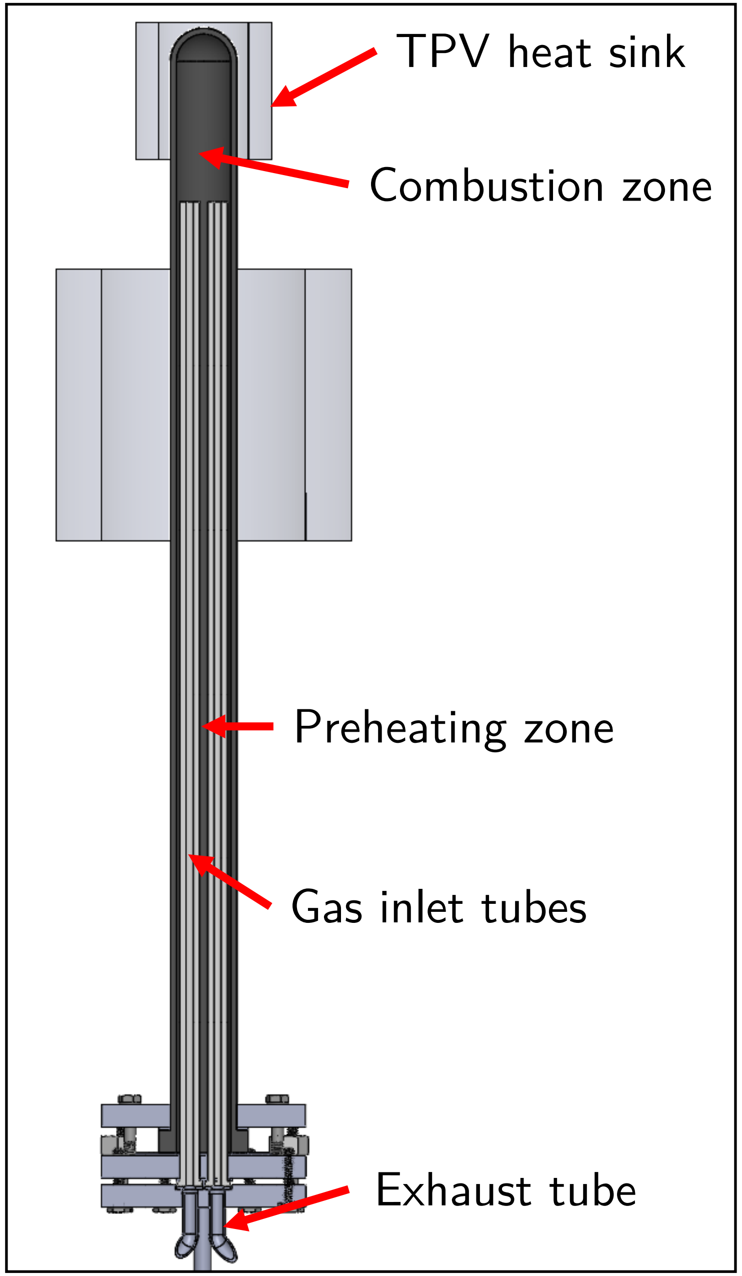
Low-NOx ammonia combustor + TPV power generation

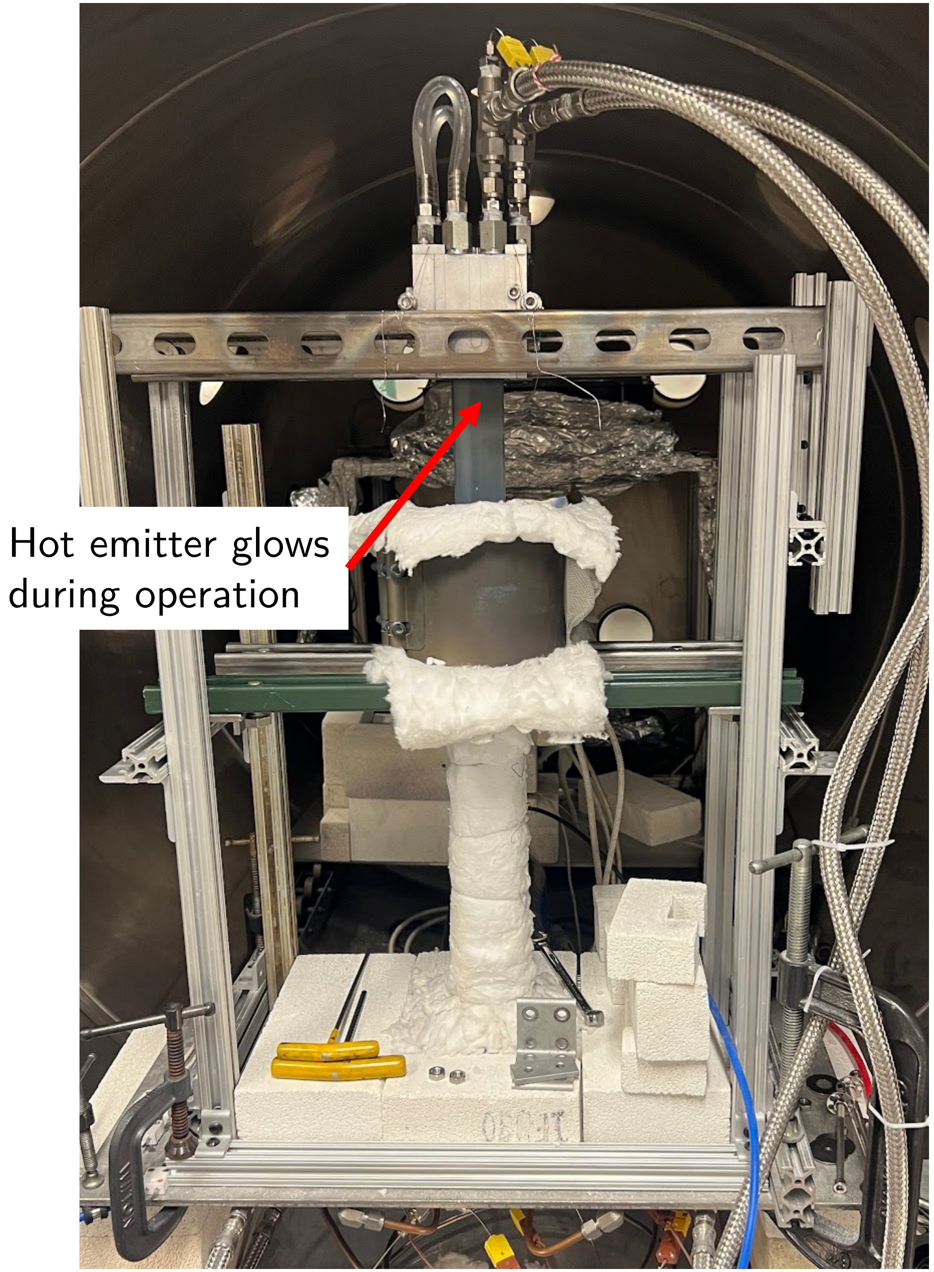
NO_x reduction

- Preheated reactants & well-mixed combustion zone
- Long residence time recuperator
- Target: 15 ppm

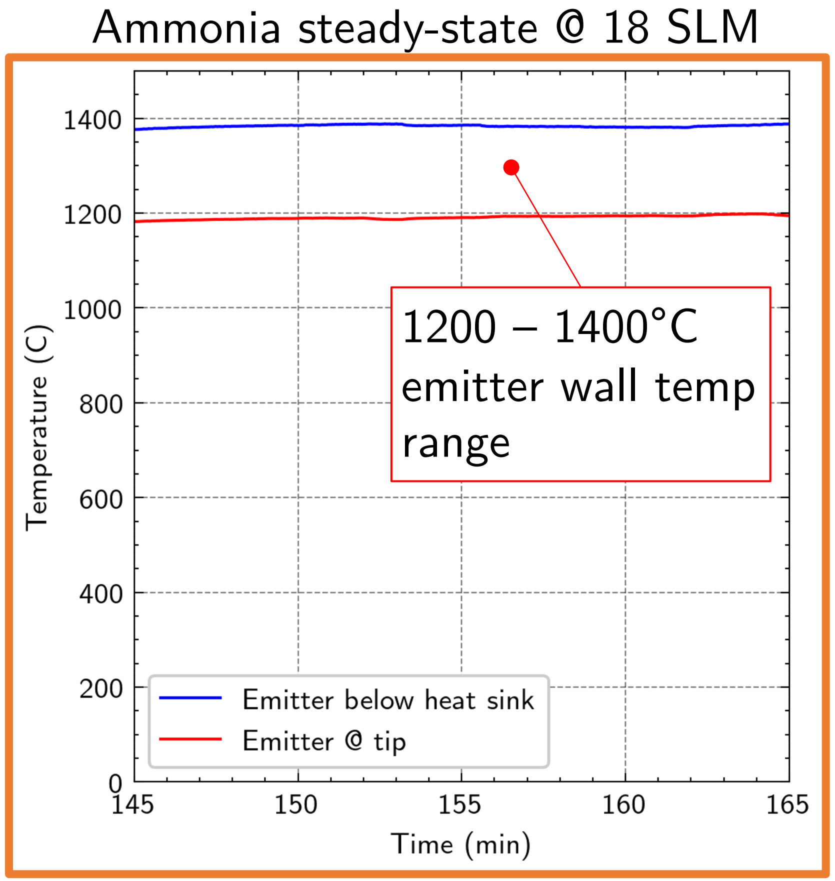
Performance

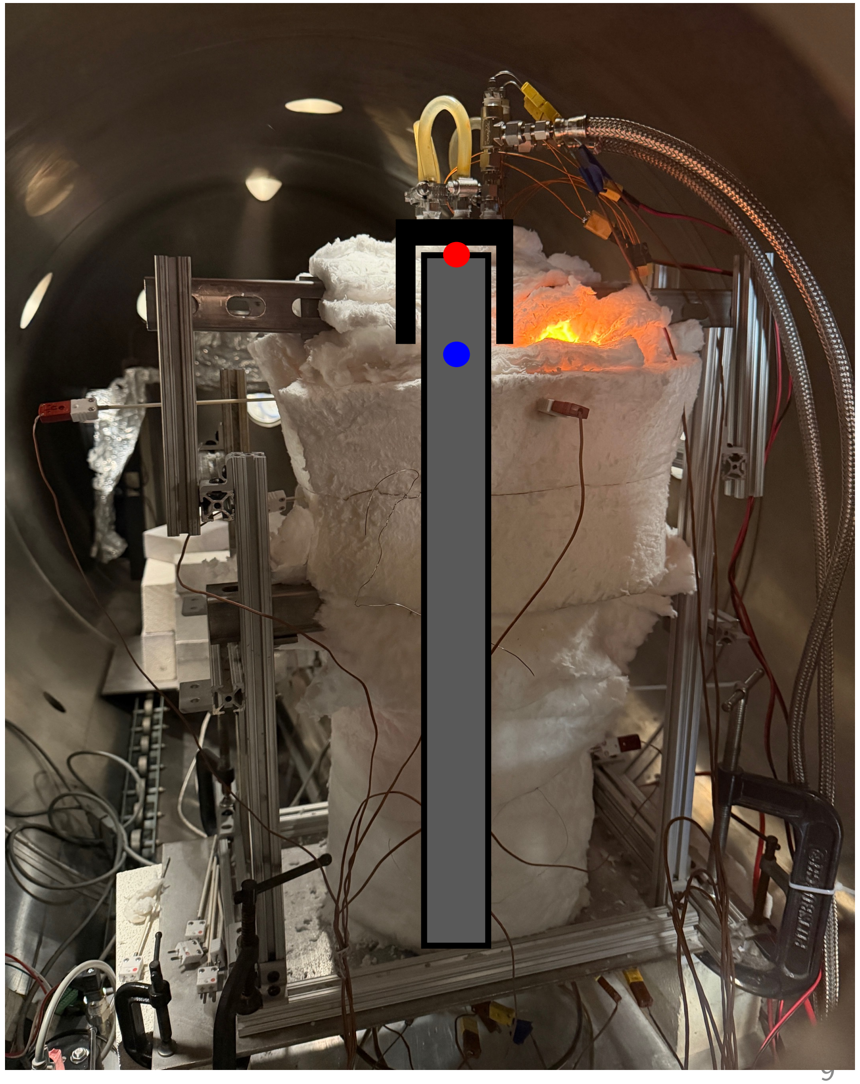
- High-effectiveness recuperator
- High-temperature emitter
- Target: 5 W/cm^2



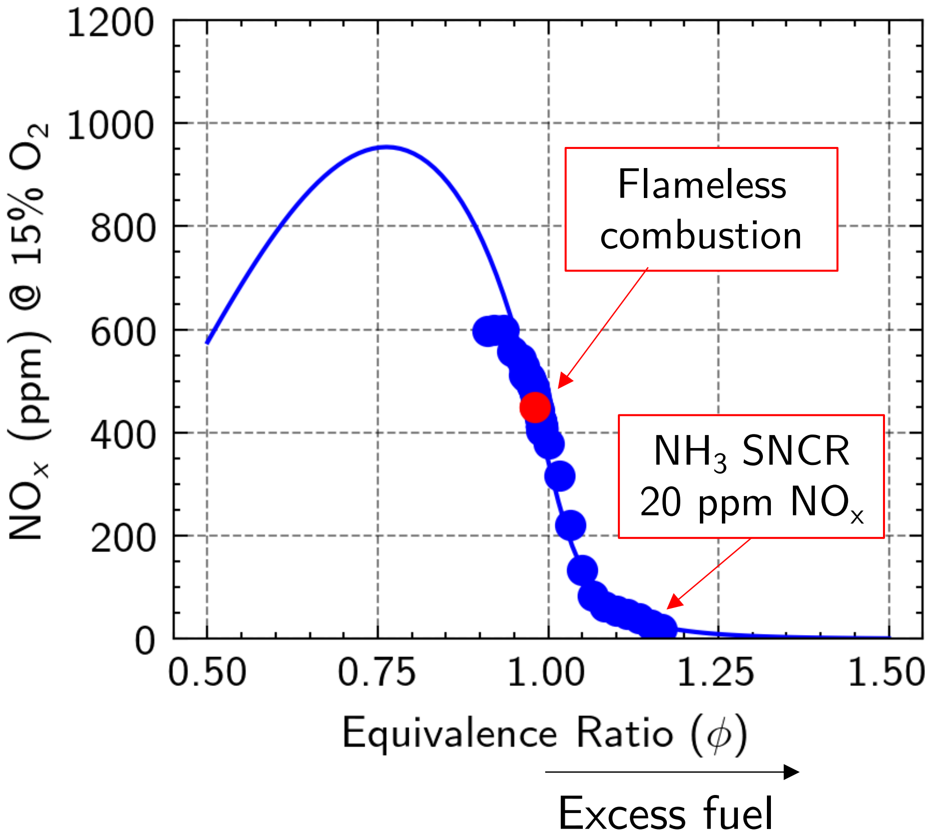


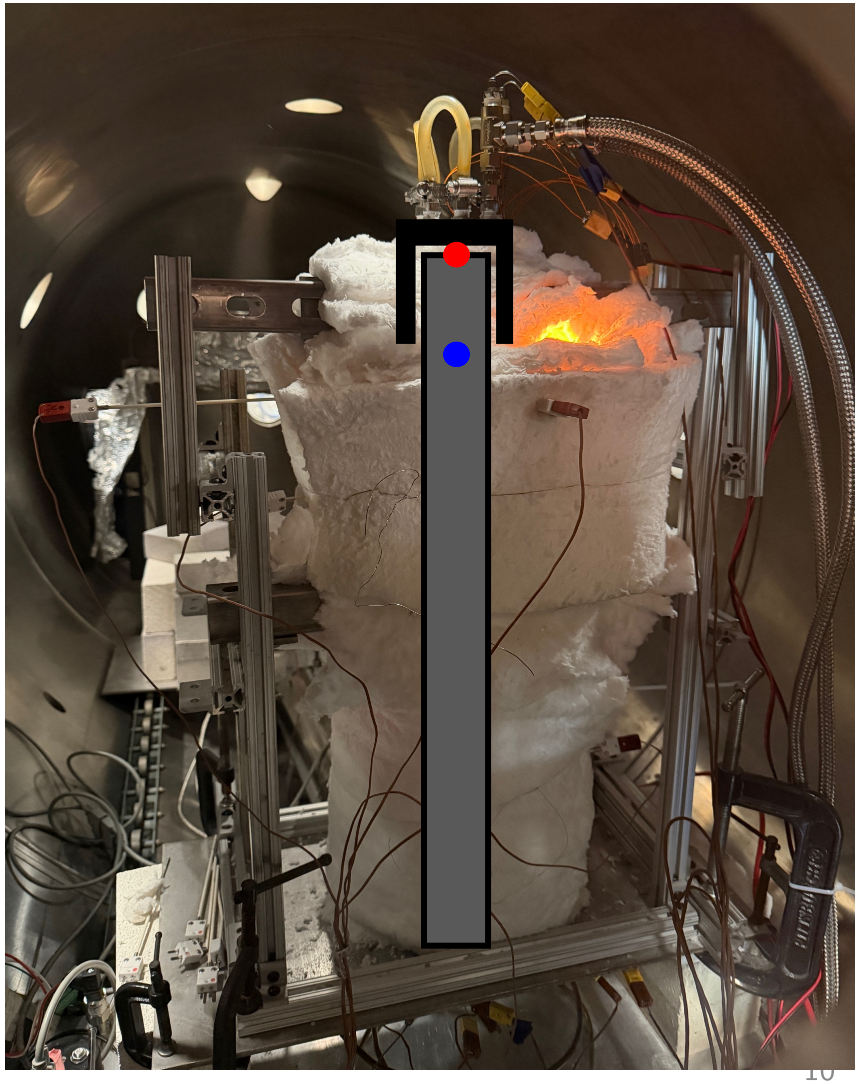
High temperatures achieved with ammonia combustion





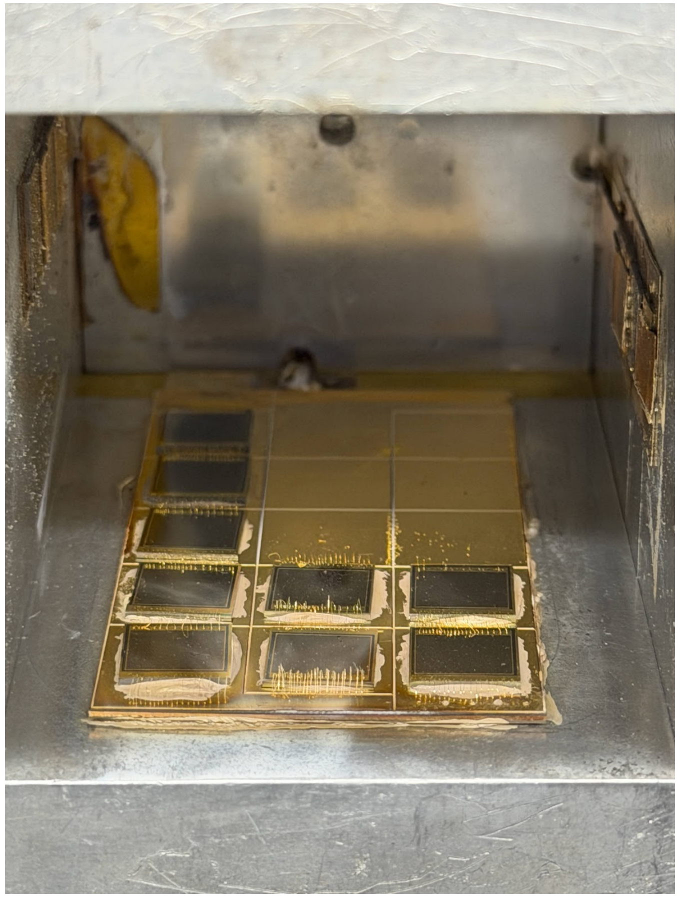
Low NO_x emissions at these temperatures





Low NOx (20 ppm) ✓

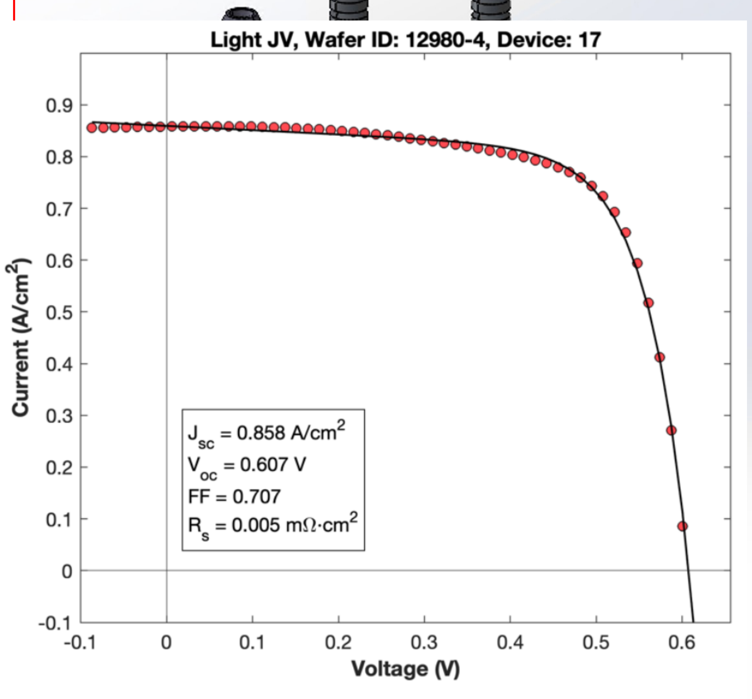
TPV cell integration into combustor system



String of 9 Heat2Power cells wirebonded in series

Datasheet from H2P

1200°C emitter with VF=1



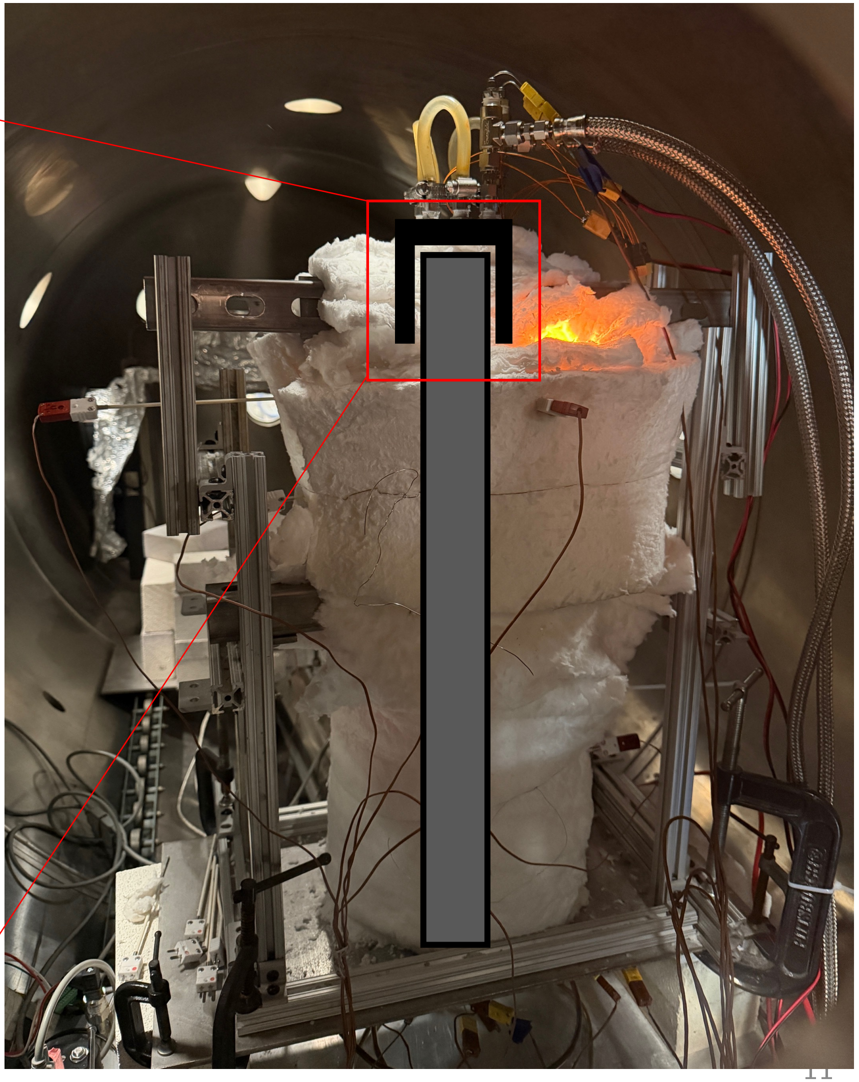
0.9 eV InGaAsP

98% sub-bandgap reflectance

Heat sink

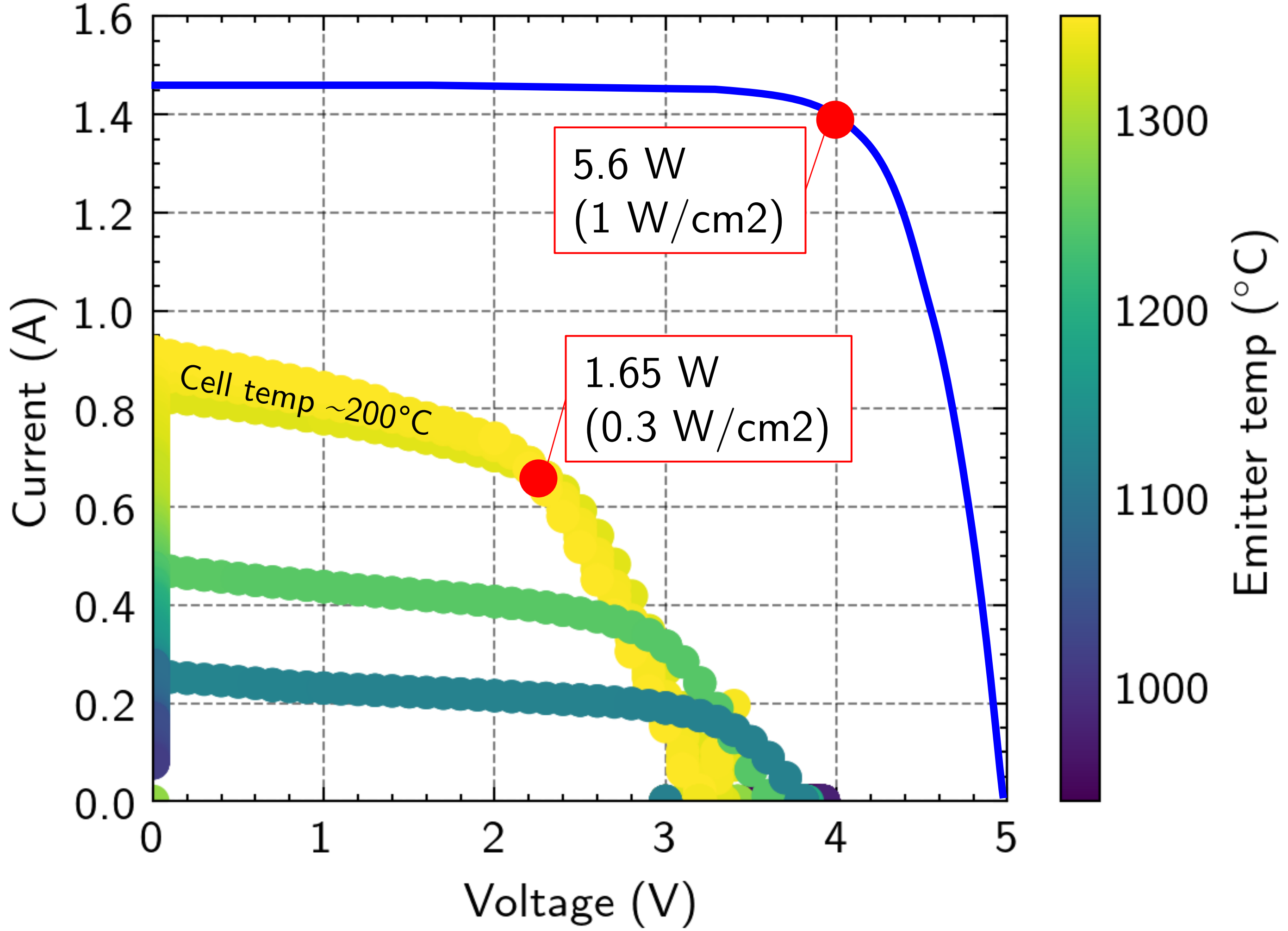
Record 44% efficiency

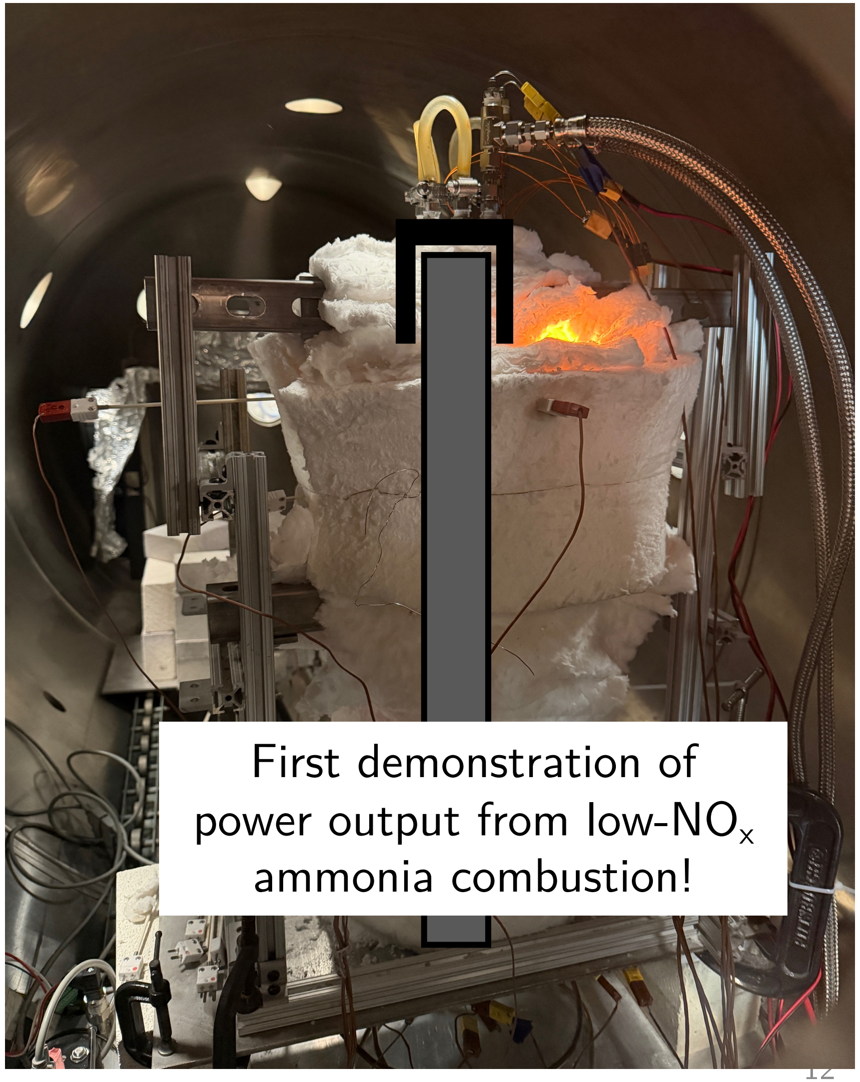
Roy-Layinde et al. *Joule* (2024)



TPV power output using combustor light

Better cooling + configuration

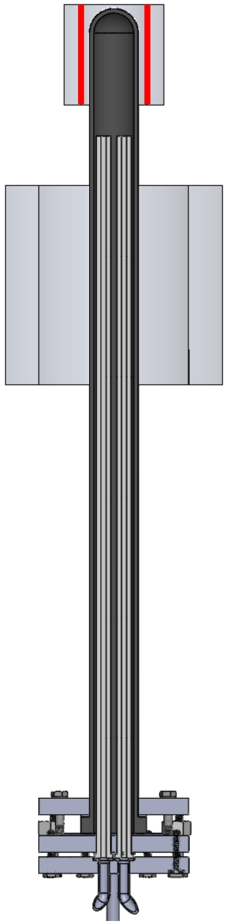




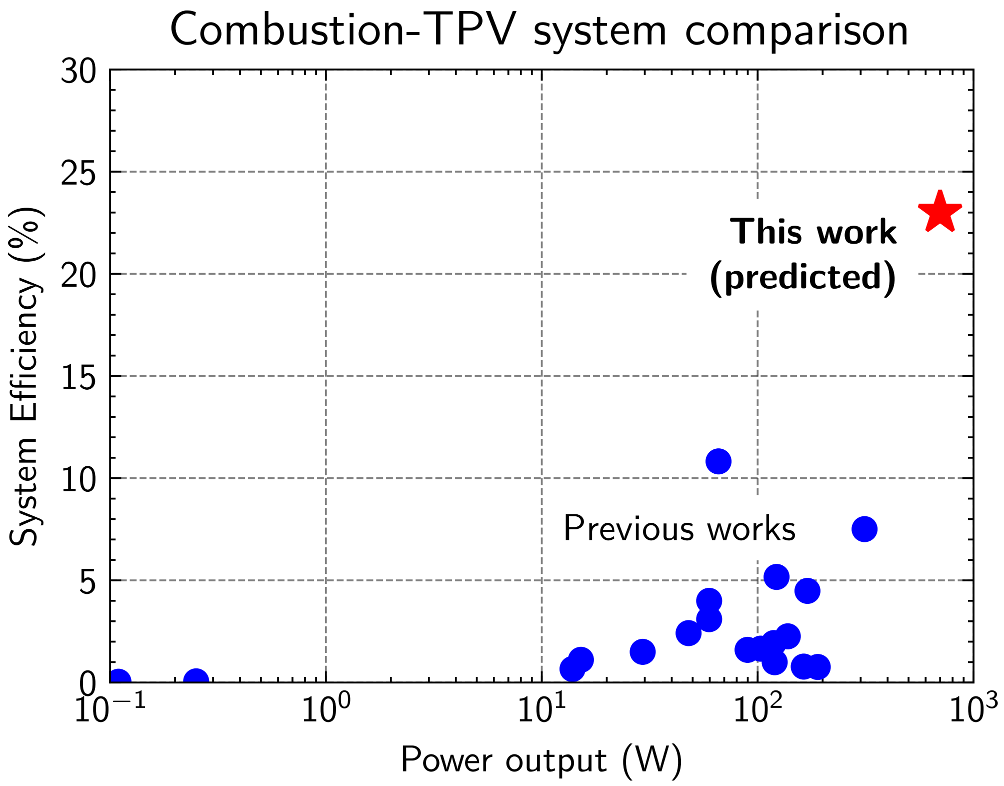
First demonstration of power output from low-NO_x ammonia combustion!

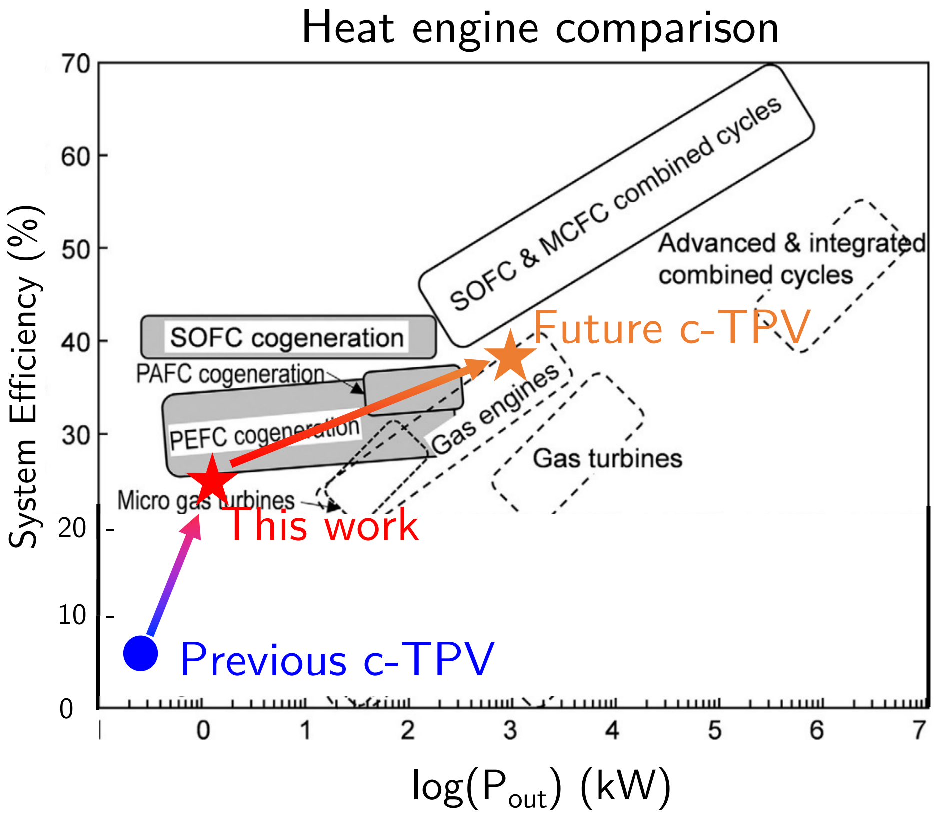
TPV power output (1 W/cm^2) ✓

Scaled-up performance of TPV combustor



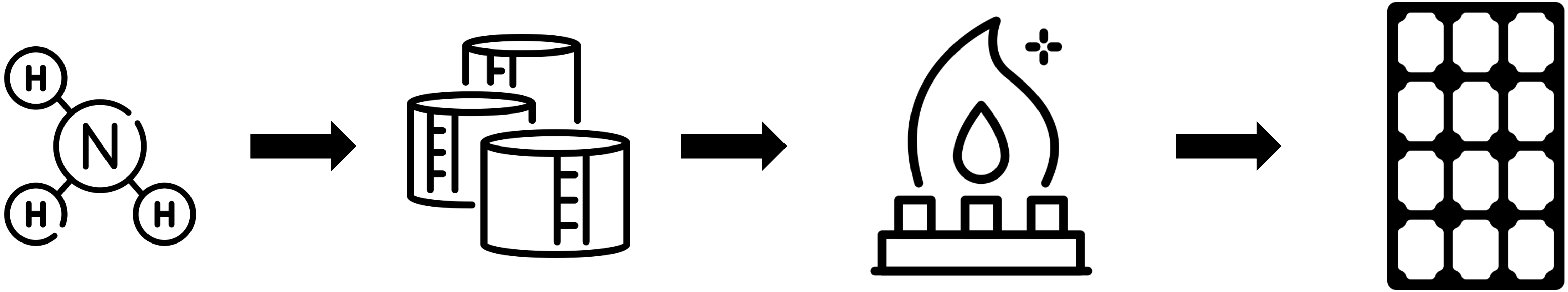
700 W e⁻ output from
3 kW NH_3 power input





- Higher-effectiveness recuperator
- Larger scales → better insulation
- Higher TPV coverage
- Multijunction cells

Techno-economics (LCOE) for NH_3 combustion-TPV



Fuel cost

Ammonia
\$0.50/kg

→ 20 ¢/kWh

Storage cost

Tanks, compressors, etc.

→ 1 ¢/kWh

Combustor cost

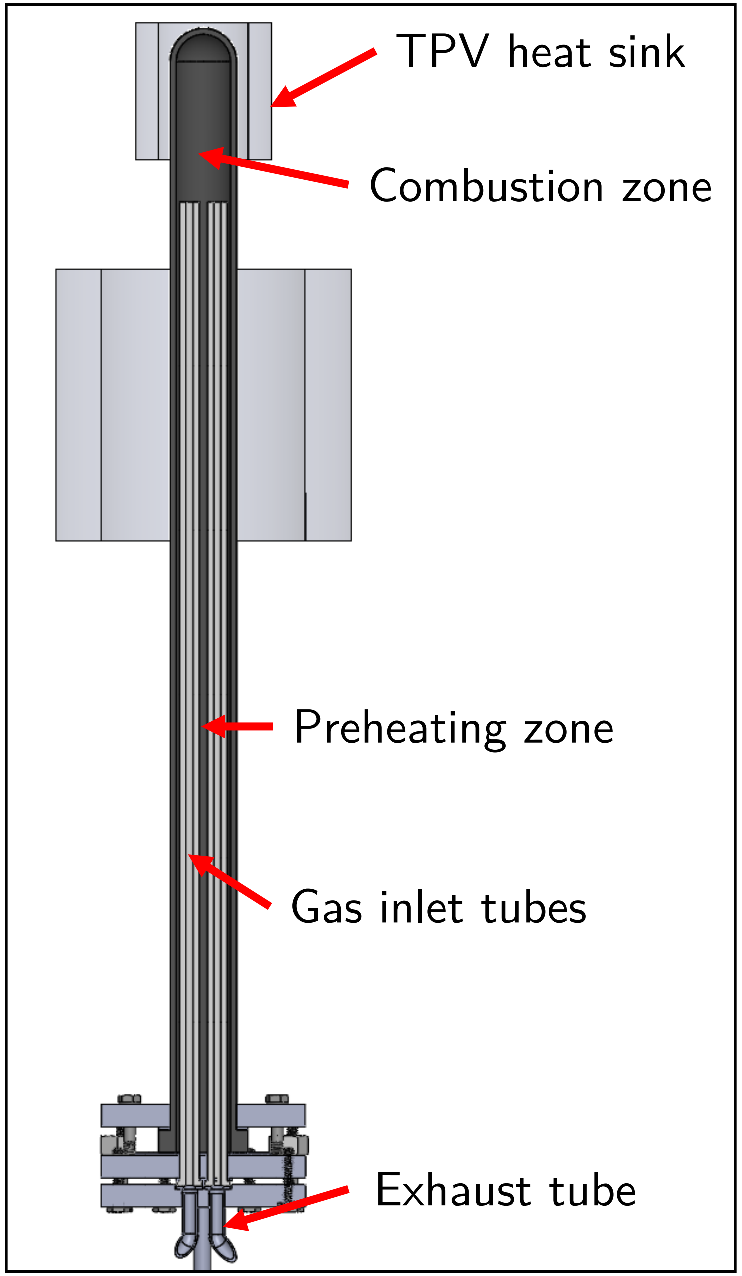
Sum of components:
Ceramics, insulation, tubing, etc.
\$0.50/W
→ 2.5 ¢/kWh

TPV cost

Cells, heat sink, etc.

\$1/W
→ 5 ¢/kWh

Electricity cost (LCOE): ∼30 ¢/kWh
Competitive with NG peaker plants ✓
Provides cheap, clean, and reliable electricity for grid decarbonization



- Flameless combustion + ammonia SNCR limits NOx to 20 ppm
- First demonstration of power output (0.3 W/cm2) from low-NOx ammonia combustion
  - Predictions indicate 23% efficiency at small scale and 40% at large scale
- Electricity costs of 30 ¢/kWh competitive with NG peaker plants

Interested in collaborating!

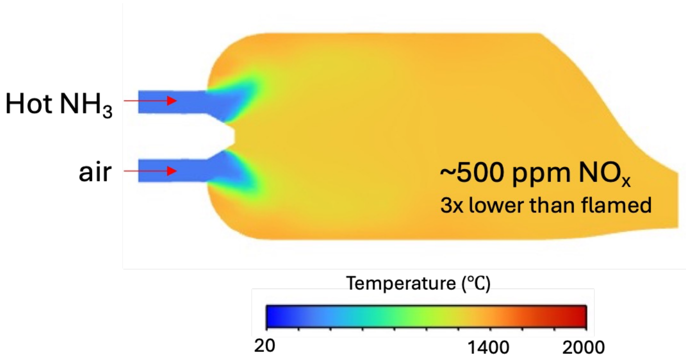
- Bringing large-scale combustion-TPV systems to reality
- Incoming assistant professor at Rice MECH
- Research program in high-T materials for energy conversion
  - TPVs, thermionics, thermoelectrics, heat pumps, etc.

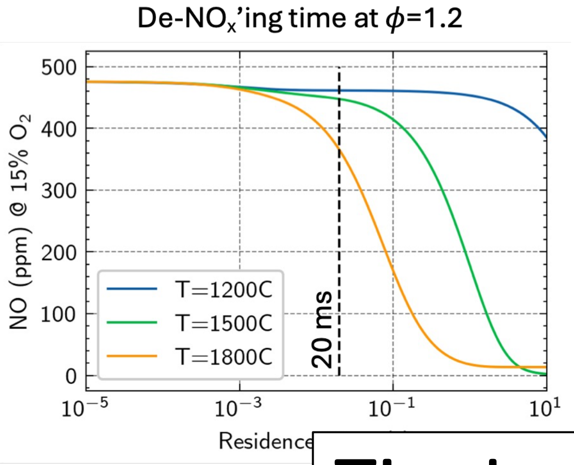
RICE ENGINEERING AND COMPUTING

Department of Mechanical Engineering

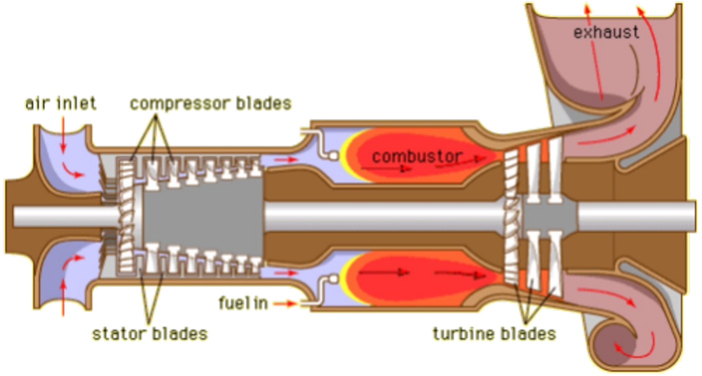
skverma@rice.edu

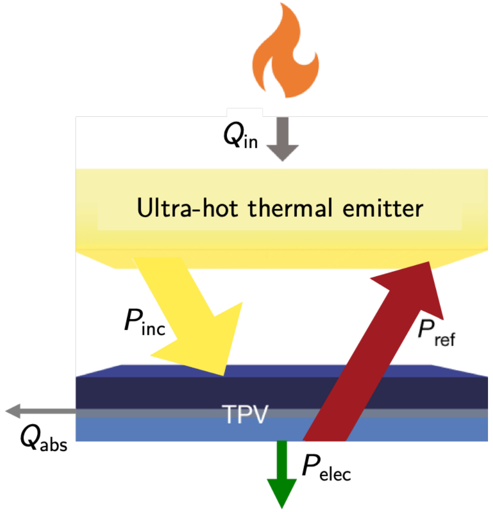
Ammonia combustion results in high NOx
Flameless combustion + SNCR can solve NOx problem





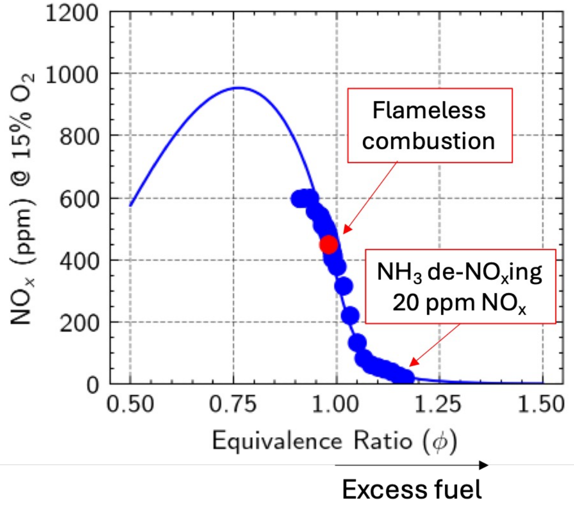
TPVs uniquely suited for power conversion

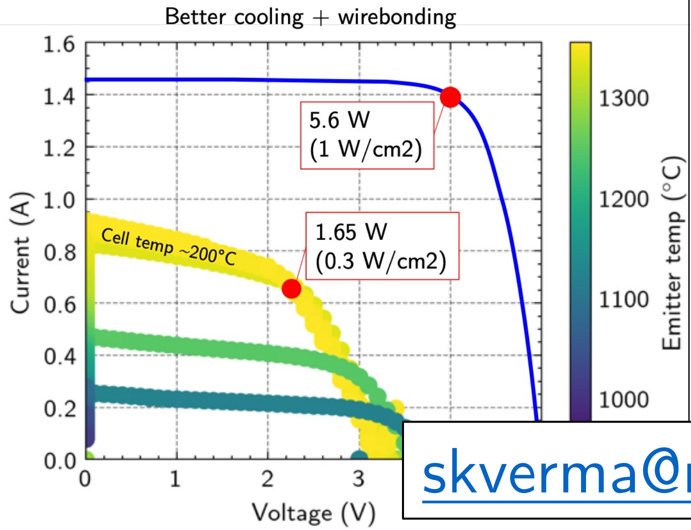




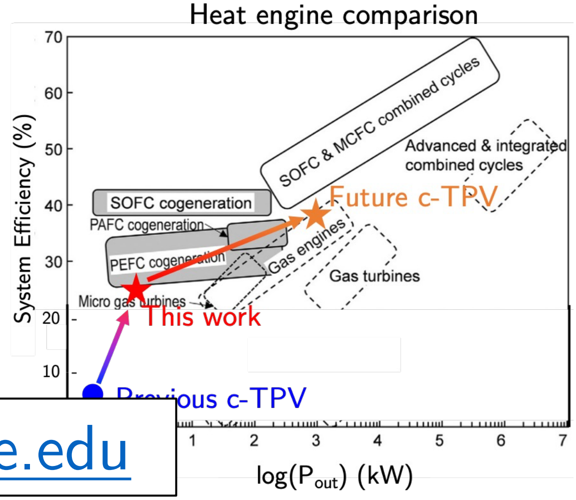
Thank you! Q&A

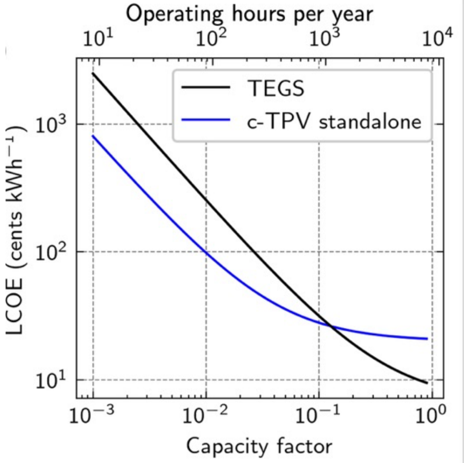
First experimental demonstration of power conversion from low-NOx ammonia combustion





Predictions indicate at-scale efficiency (~40%) and cost (<30 ¢/kWh) competitive with gas turbines





skverma@rice.edu