Low-Cost Intermediate-Temperature Fuel-Flexible Protonic Ceramic Fuel Cell Stack

Prof. Ryan P. O'Hayre[1], Neal P. Sullivan,[2] Bob Kee[2], and Robert Braun[2]

[1]Metallurgical & Materials Engineering Department

[2]Mechanical Engineering Department

Colorado School of Mines

Eric Tang, Michael Pastula, Tony Wood, and Hossein Ghezel-Ayagh

Fuel Cell Energy/Versa Power Systems

Fuel Cells are Ideal for Distributed Generation: Clean, Compact, Powerful, Efficient, Silent

Domestic DG Market > 200 GW (>$200B USD)
International DG Market > 1 TW

Current DG technologies:
Gas/Micro turbines
Diesel/Internal Combustion Engines
Batteries
Fuel Cells

Diesel Generators in India

Bloom Box Fuel Cell "Energy Server"

?
OR
?

Backup Battery Pollution in the Daintree Rainforest, Australia

Fuel Cell Vs. Batteries for Backup Power

Tesla Powerwall: 3.3kW, 7 kWh, $3000

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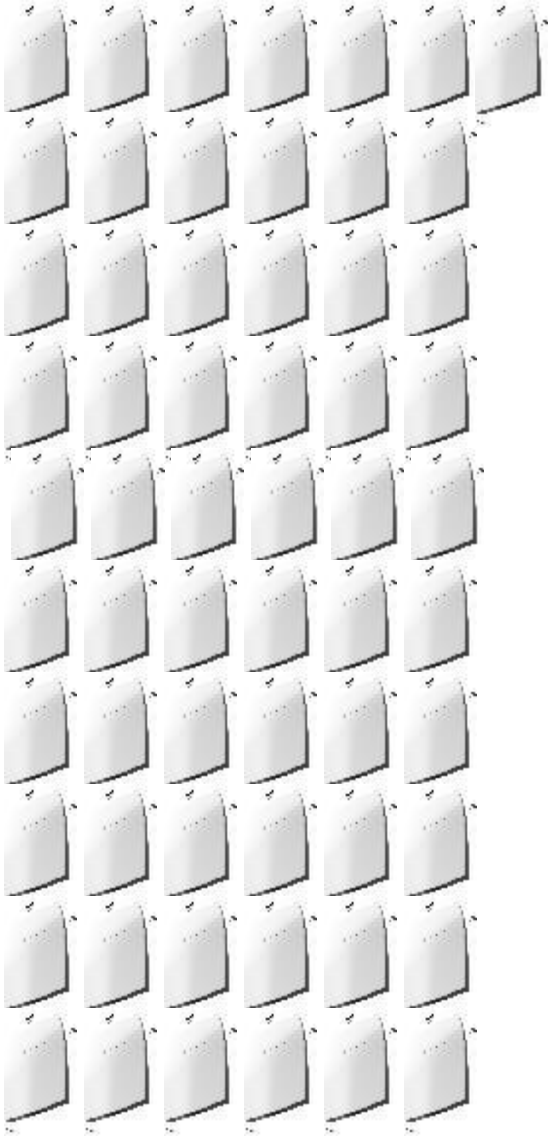

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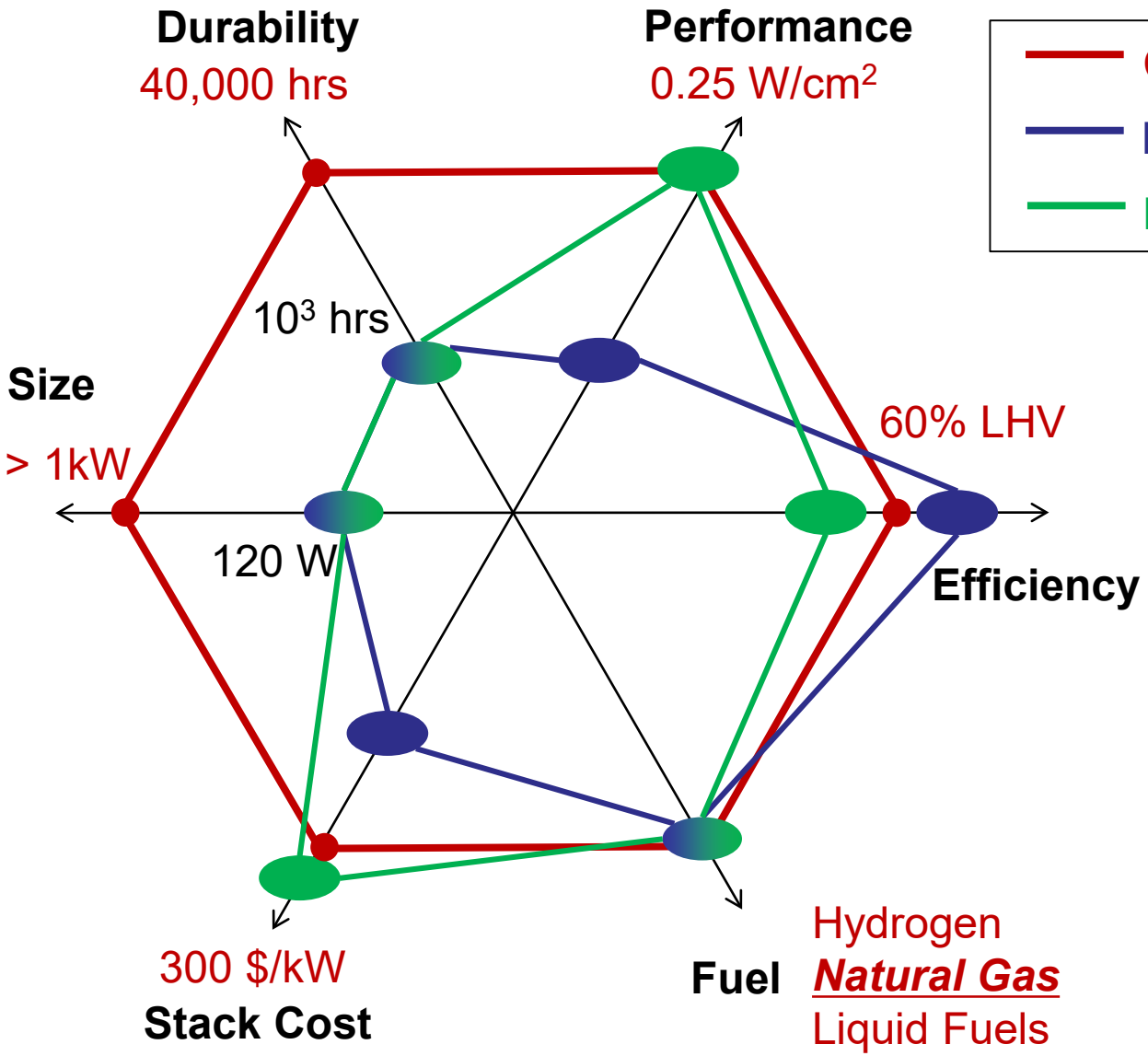
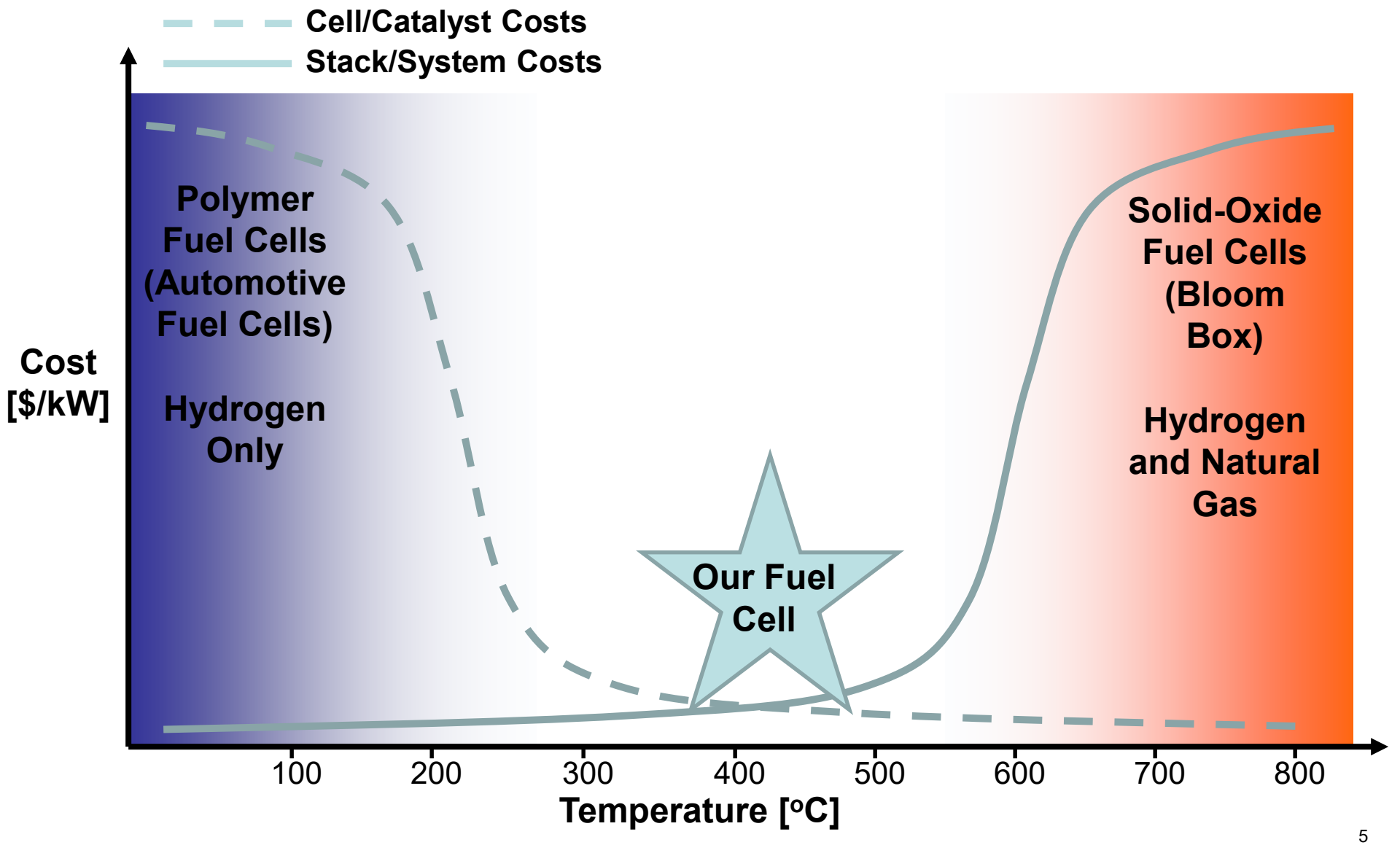
One 200 kW Bloom Box Fuel Cell Energy Server

Our Fuel Cell Technology Aims to Address Multiple Market-Relevant Performance Metrics



- PCFC technology has achieved many of the commercialization goals
- Durability and size goals are ongoing via development at FCE, with promising results

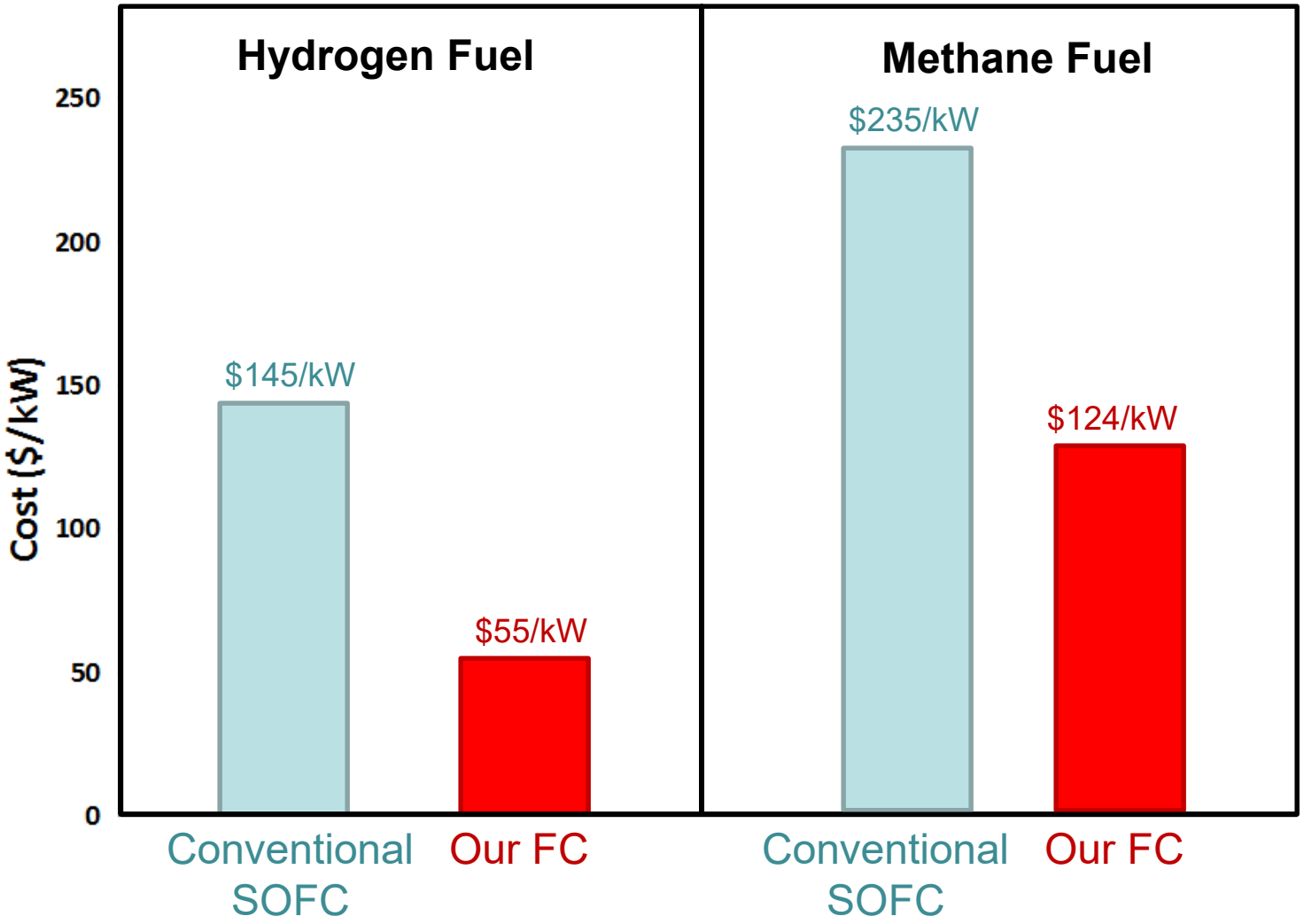
Our Fuel Cell: Greater Versatility, Lower Cost



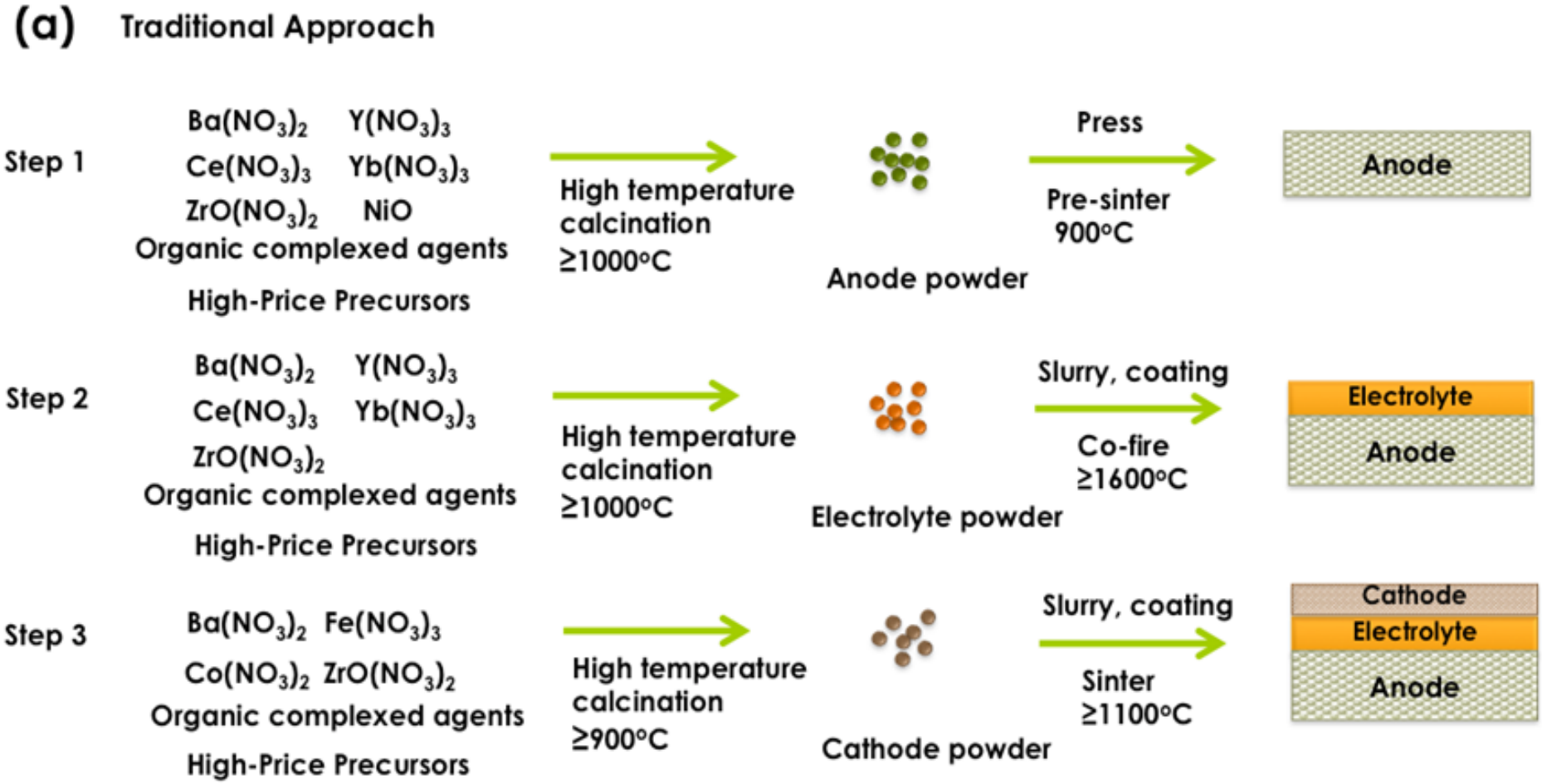
Cost Projections of Our Fuel Cell Technology

Estimated Stack Costs (10kW stack, 10,000 units/yr)

(assuming comparable per-cell power densities)



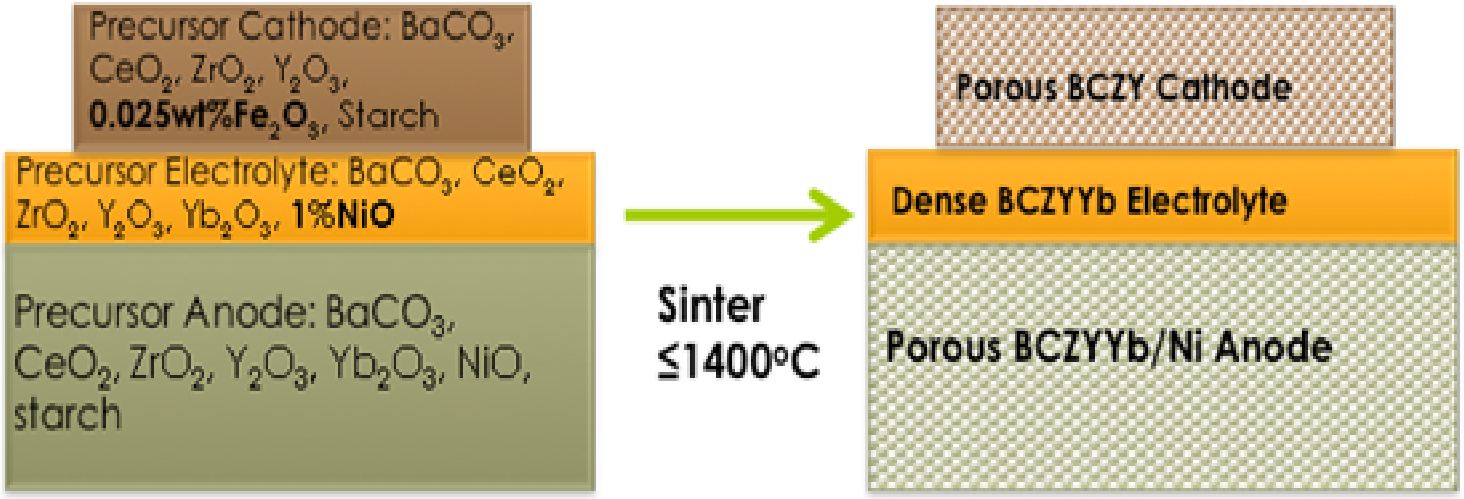
Manufacturing Cost is a Key Issue with Conventional Solid Oxide Fuel Cells



Multiple time-consuming and expensive manufacturing steps are required to produce a cell

Patented Colorado School of Mines Technologies [1,2] Eliminate Fuel-Cell Market Barriers

- CSM's single-step reactive sintering [1] overcomes cost obstacles
  - Combines steps of materials synthesis and device fabrication
  - Greatly reduces manufacturing costs

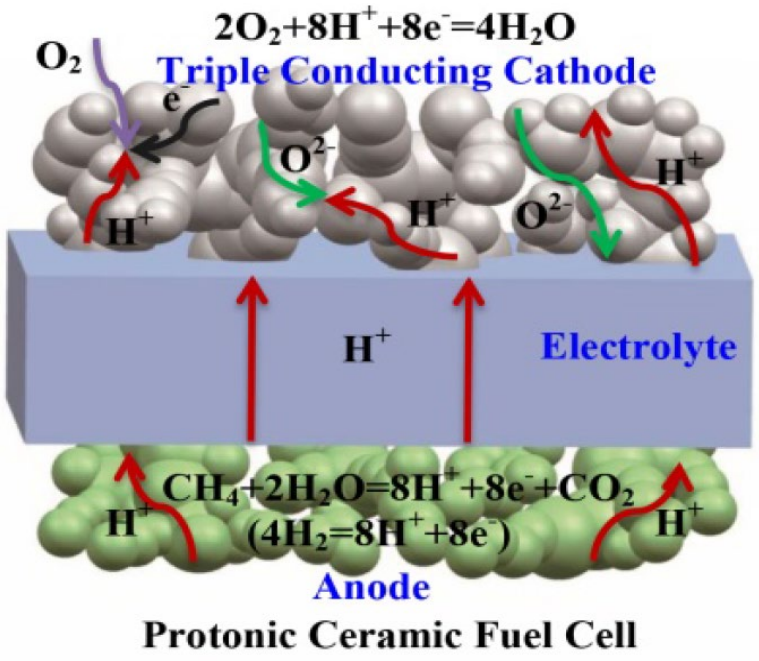


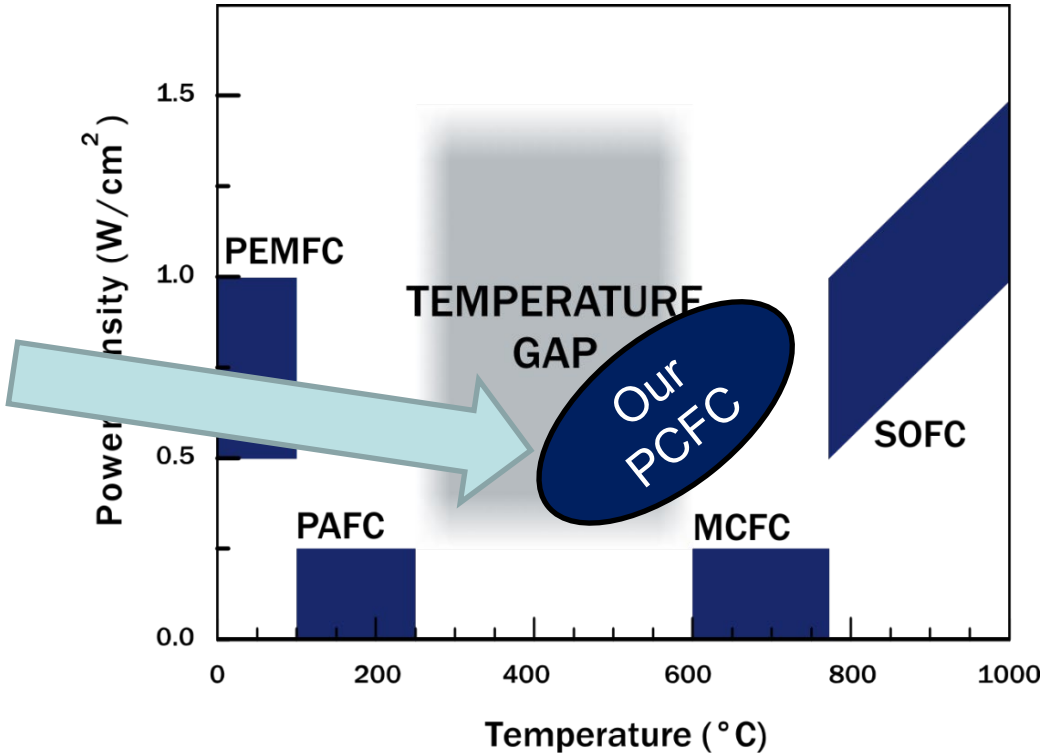
Complete fuel cell is directly manufactured from inexpensive precursors in one or two steps

[1] J. Tong R. O'Hayre, et al., US Patent application 14/621,091, 2015 (fabrication).

Patented Colorado School of Mines Technologies [1,2] Eliminate Fuel-Cell Market Barriers

- CSM's patented "triple-conducting" electrode [2] boosts performance
  - World-record power density (Watts / cm^2)
  - Reduces materials usage and device cost



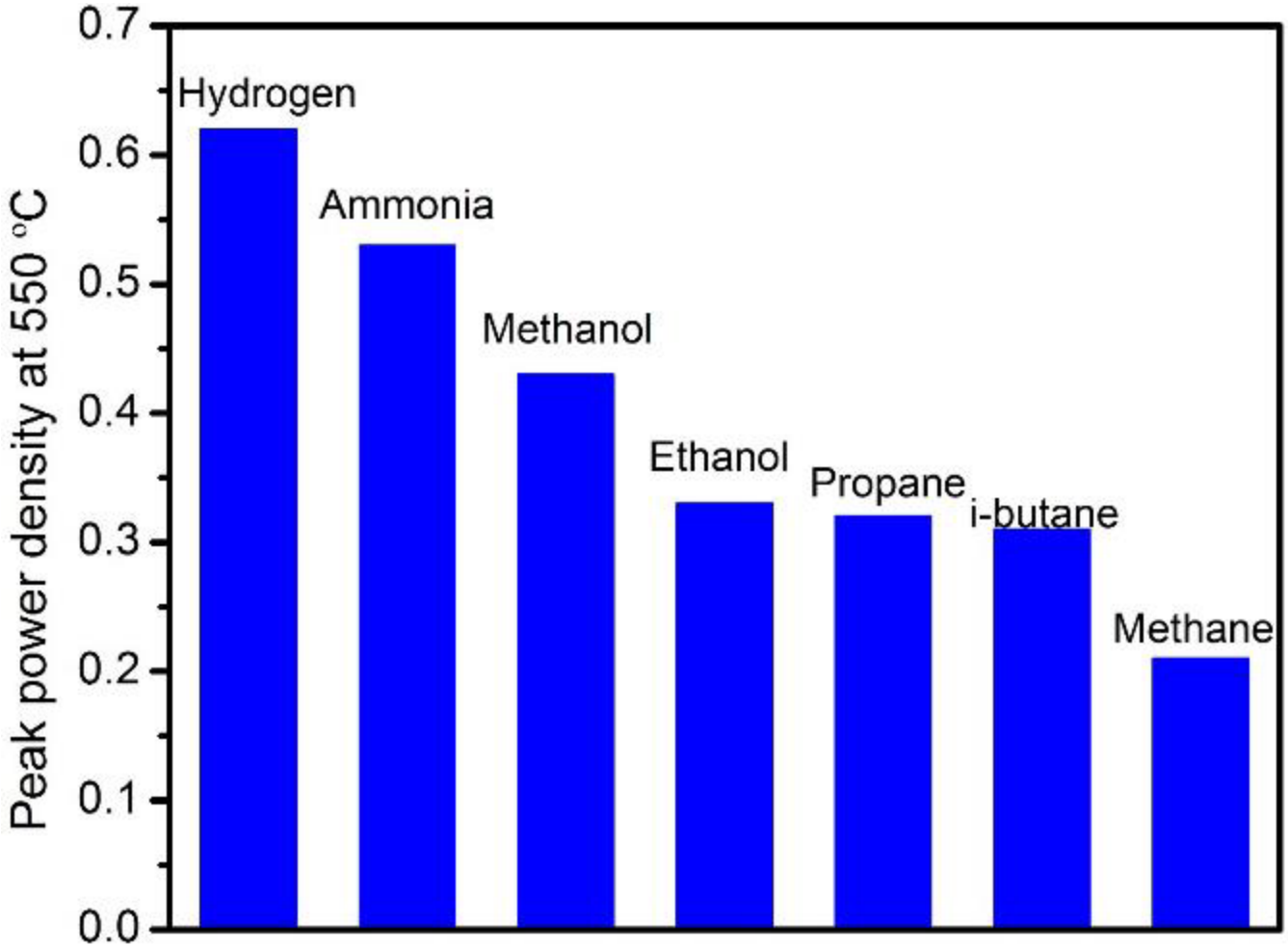


Operation at temperatures 200-300 °C below SOFC

We project <$0.07/kW LCOE for 10 kW PCFC system

[2] J. Tong, R. O'Hayre et al, *US Provisional Patent,* 62101285.

PCFCs demonstrate tremendous fuel flexibility

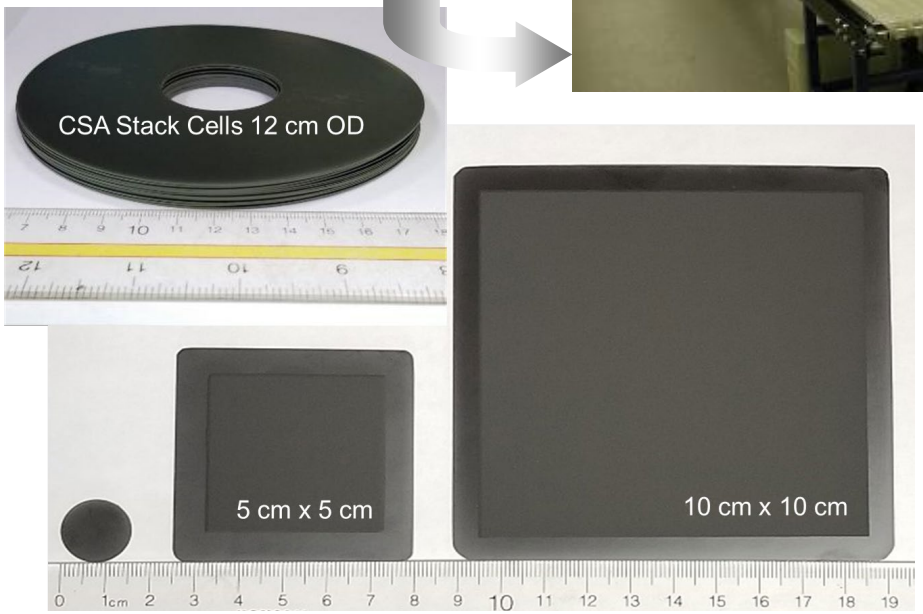


Peak power density of the FlexPCFC at 550 °C on 7 fuels

C. Duan, R. O'Hayre et al., *Nature,* **557**, 217–222 (2018)

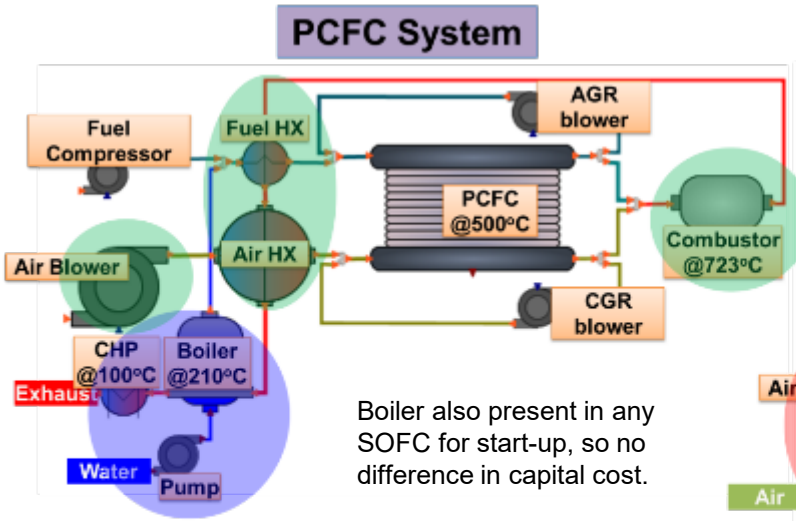
PCFC Manufacturing and Scale-up

- PCFC cell fabrication process with solid-state sintering demonstrated via adapting FuelCell Energy's solid oxide manufacturing process
- Processes are flexible & scalable to high volume and low cost

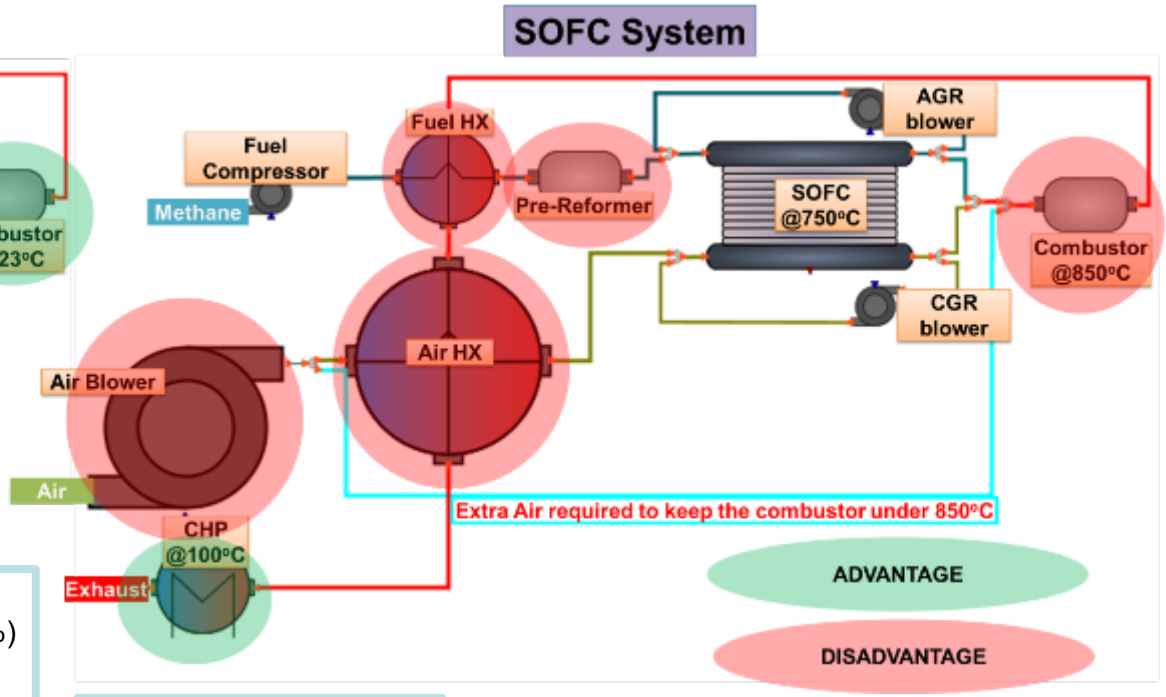


Cells have been scaled up to 10 cm x 10 cm and 12 cm OD stack cells

Lower temperatures and simpler system requirements make PCFCs ideal for small (<10 kW) DG applications



Boiler also present in any SOFC for start-up, so no difference in capital cost.



- $P_{sys,Net\ AC}$ = 25 kW
- Gas Recycle: Anode (66%) and Cathode (50%)
- Counter-flow Fuel Cell Stack Configuration
- Cross-flow Heat Exchangers
- System Fuel Utilization = 80%
- Steam/Carbon = 2.0
- CHP heat recovery = 100°C

Scale is representative of relative size of components

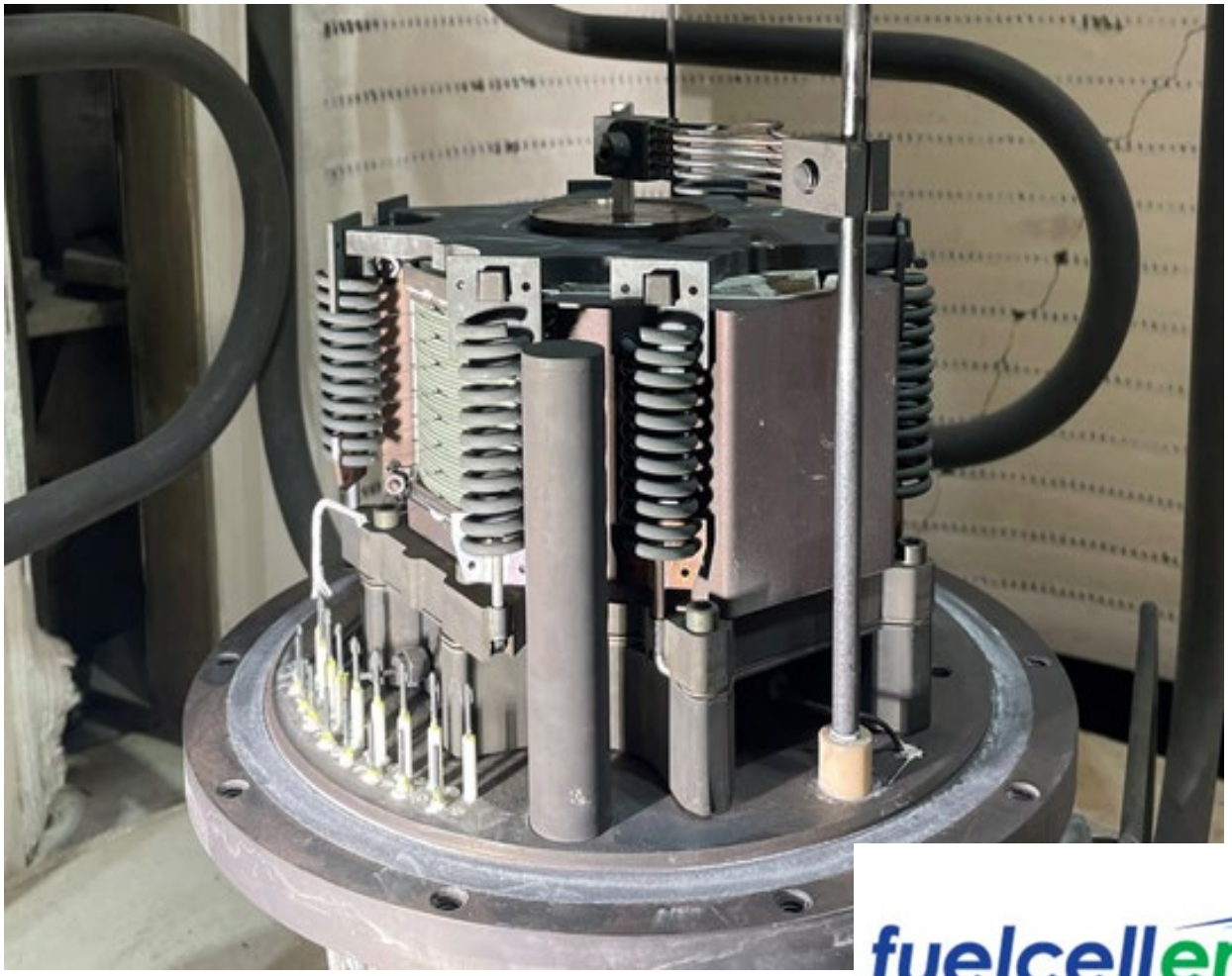
PCFC balance of system potentially simpler than SOFC

Value proposition: Versatility, lower cost, lower-temp/ simpler system amenable to smaller-scale applications

- Drivers to system cost savings
  - Novel, low-cost manufacturing
  - Lower-temperature operation
- Target markets
  - End users & early adopters
  - Data centers
  - Automotive range extender
  - Distributed power generation
- Technological extensions
  - Energy storage
  - Hydrogen production
  - Fuels synthesis: NH_3, CO_2 upgrading, MDA

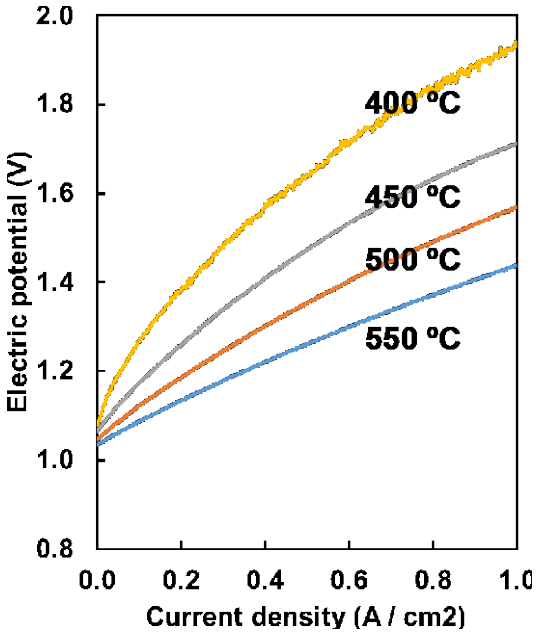
Datacenter at Microsoft Advanced Energy Lab

500W stack demonstration prototype underway; provides scale-up pathway to commercial products

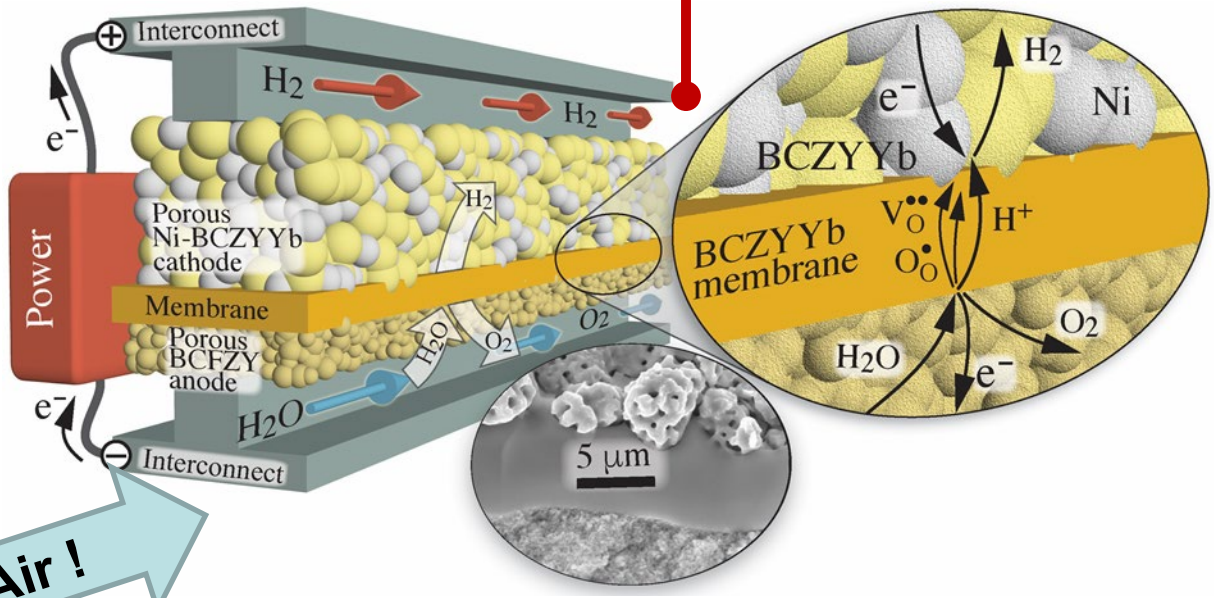


fuelcellenergy

Run in reverse as an Electrolyzer, PCFCs can produce pure pressurized dry H_2

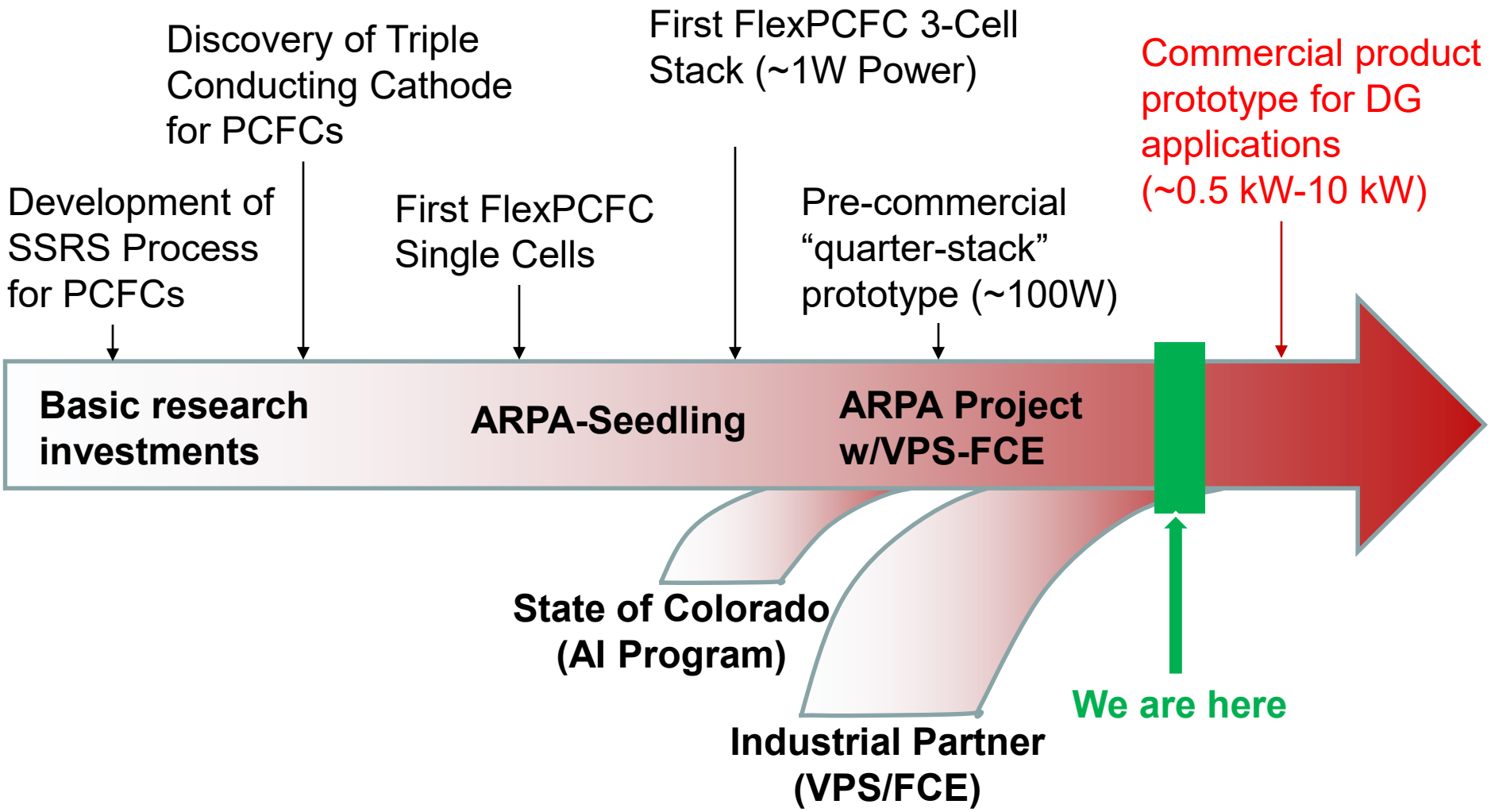


Produces dry H2 at ultra-high efficiency that can be utilized for numerous applications



H2O in Air !

Roadmap to Commercialization



Please contact us for more information!

Project Lead: Prof Ryan P. O'Hayre; rohayre"at"mines"dot"edu

Tech-to-Market Lead: Prof Neal P. Sullivan; nsulliva"at"mines"dot"edu