Advanced Combustion Engines for Power Generation and Propulsion Systems

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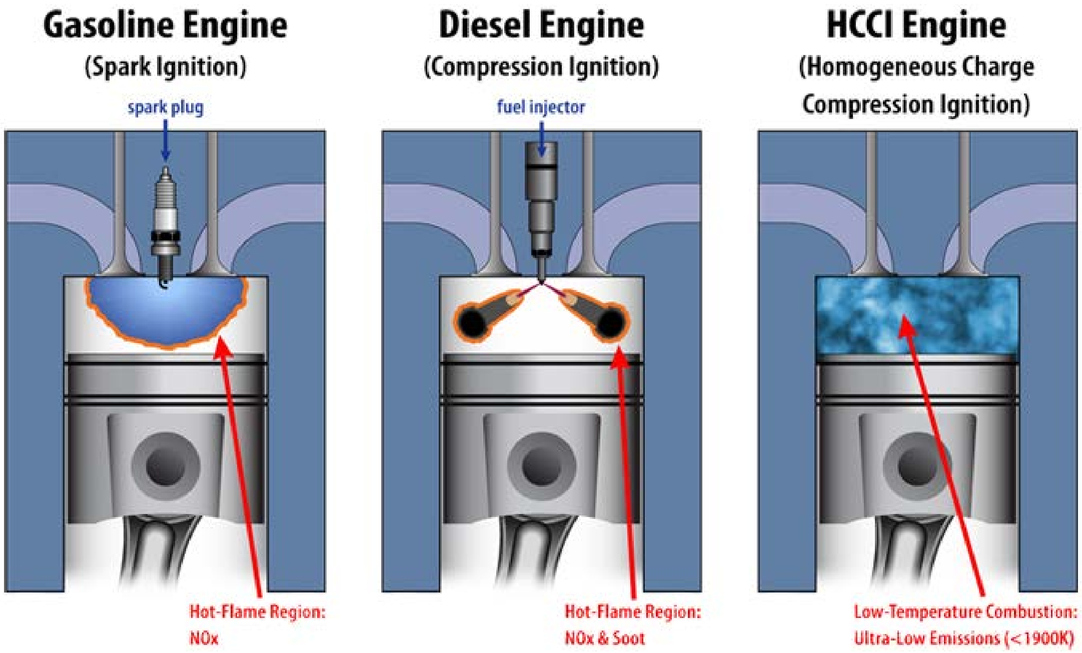
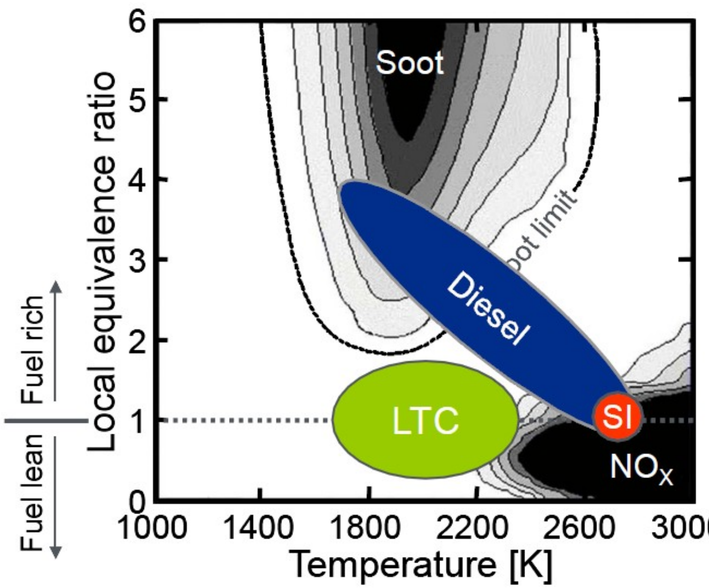
Outline

- What are advanced combustion engines?
- Discussion of two active research projects
  - Natural Gas HCCI Free Piston Linear Alternator: $2.7M for 3 years, ARPA-E, collaboration with Aerodyne Research, Inc.
  - Hybrid SOFC-ICE System, $2.325M for 2 years, Phase I, ARPA-E, collaboration with Nexceris LLC, Czero Engineering, and BNL
- Future Direction

Advanced Combustion Engines

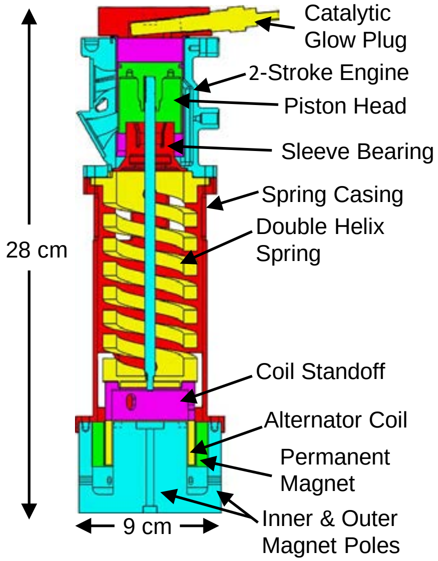




- Conventional engine concepts: Spark-Ignition and Diesel combustion
- Advanced or Low Temperature Combustion:
  - Combine benefits of SI and Diesel for high efficiency and low emissions
  - Many different concepts proposed, all with the same fundamental characteristics
  - Currently topics of active research for power generation and propulsion systems

Research Project 1: ARPA-E MICE

- Free-piston engine with natural gas HCCI combustion to achieve high thermal efficiency and low NOx, no soot emissions.
- Utilize spring for energy storage, high energy density, compact size, low weight, low cost, and good controllability.
- Employ a permanent magnet alternator for low active mass.
- Operate at fixed cycle frequency and optimize for low noise and vibration.
- Develop active piston lubrication system for high durability, and low VOCs from oil consumption.

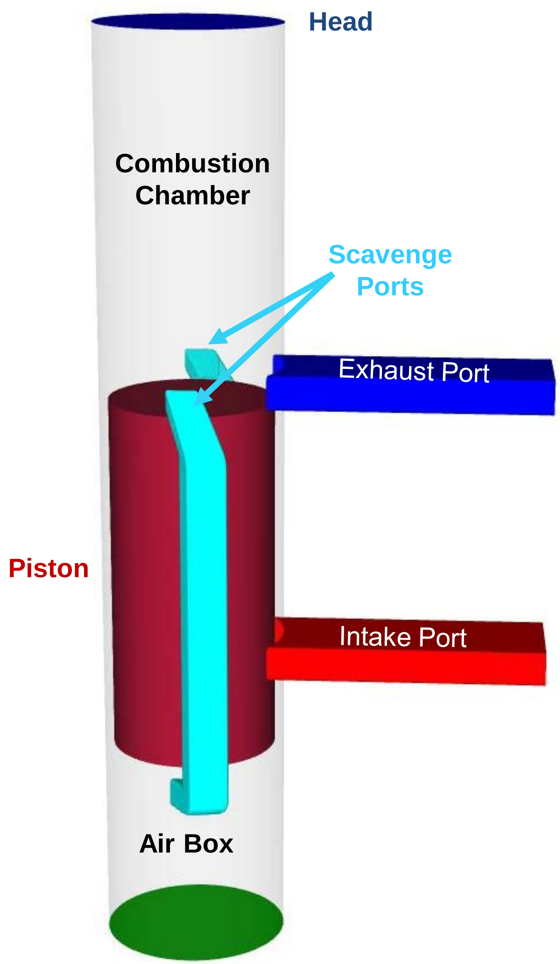


Double-helix spring

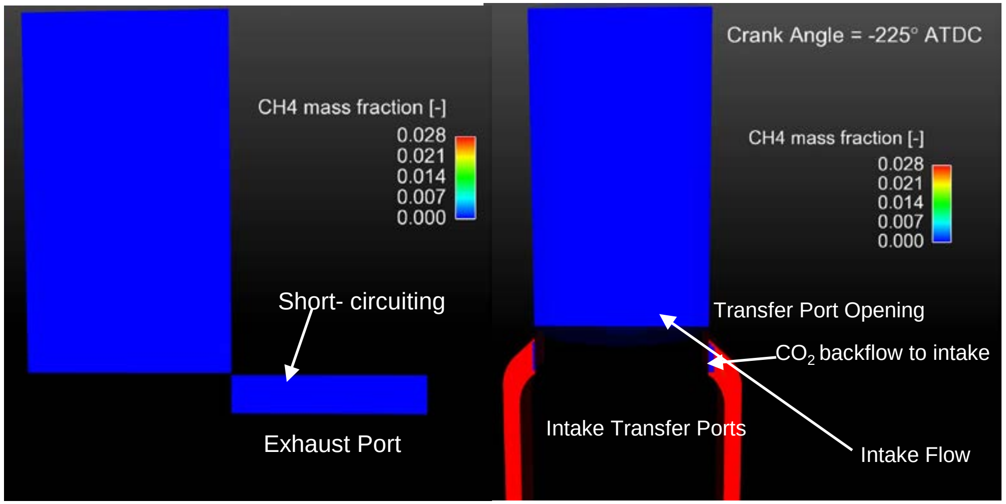
Metric	Proposed
Electrical conversion efficiency	≥ 40%
Useful heat output (> 80°C)	~1.1 kW/kWe
CARB 2007 emissions compliance	Yes
Aftertreatment	TWC + CH_4 oxidation
System cost	≤ $2,000
Operating $ Maintenance Cost	~$0.003/kWh
System Mass	30 kg
Noise (3 ft. away)	~ 50 dB

Images courtesy of Aerodyne Research Inc.

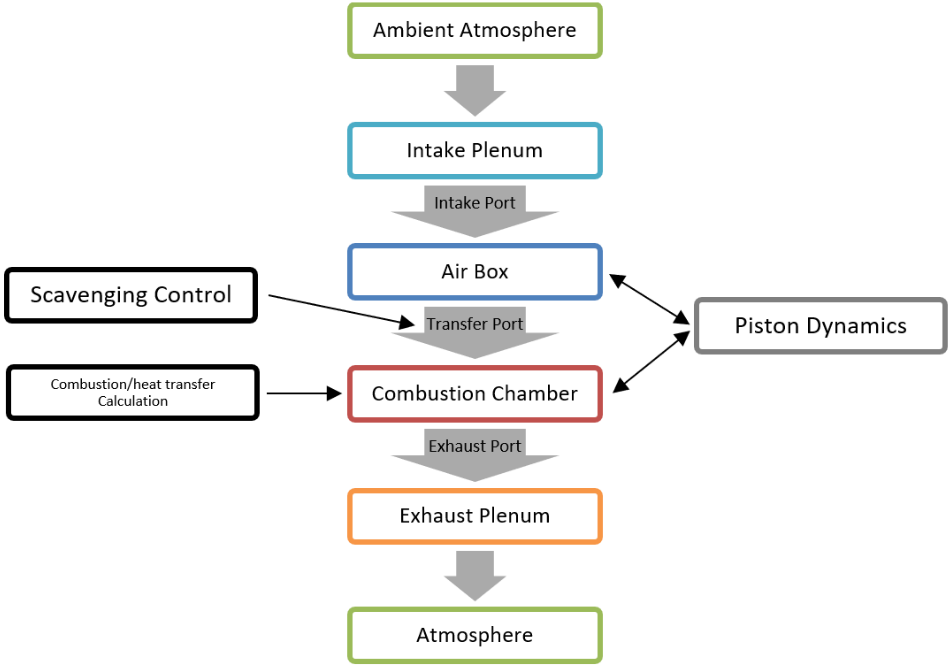
MICE CFD Modeling

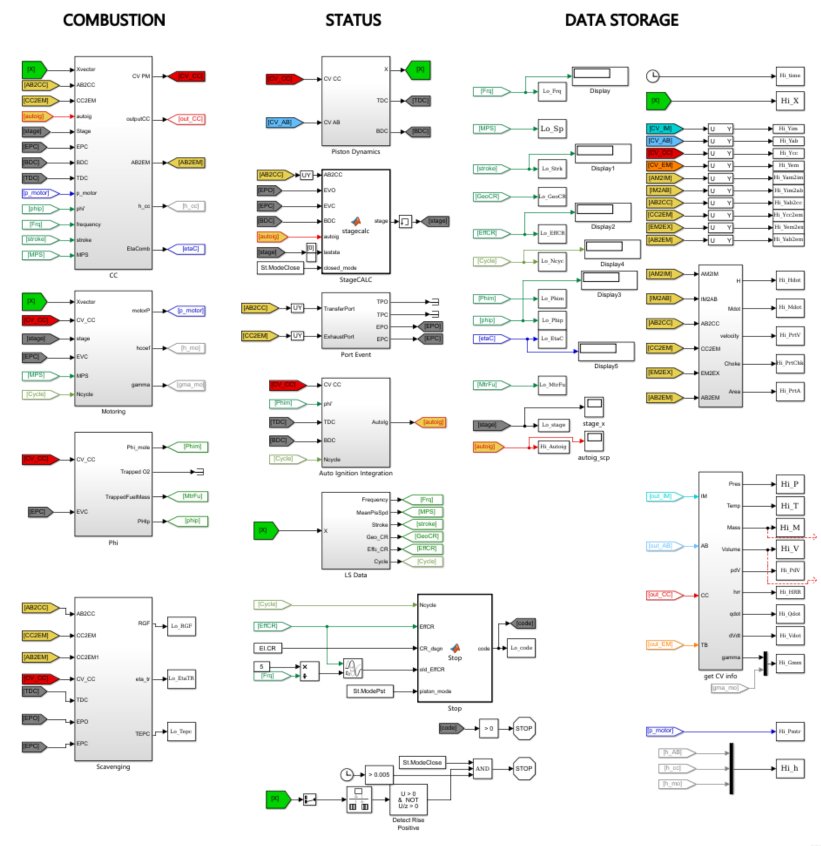


- CFD work focused on understanding the gas exchange and combustion processes of this free piston, 2-stroke engine
- Results were used to guide the design of the cylinder, airbox, and ports for prototype fabrication, as well as to guide experimental testing
- CFD simulations performed using RANS and LES with detailed chemistry over full engine cycles



MICE System Level Modeling

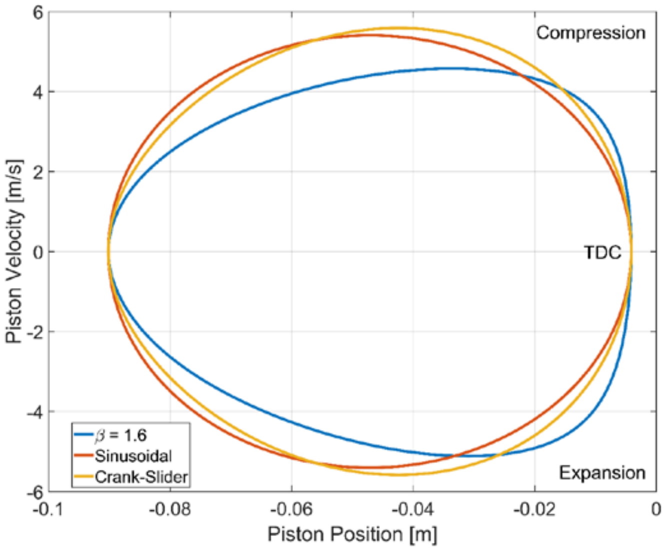


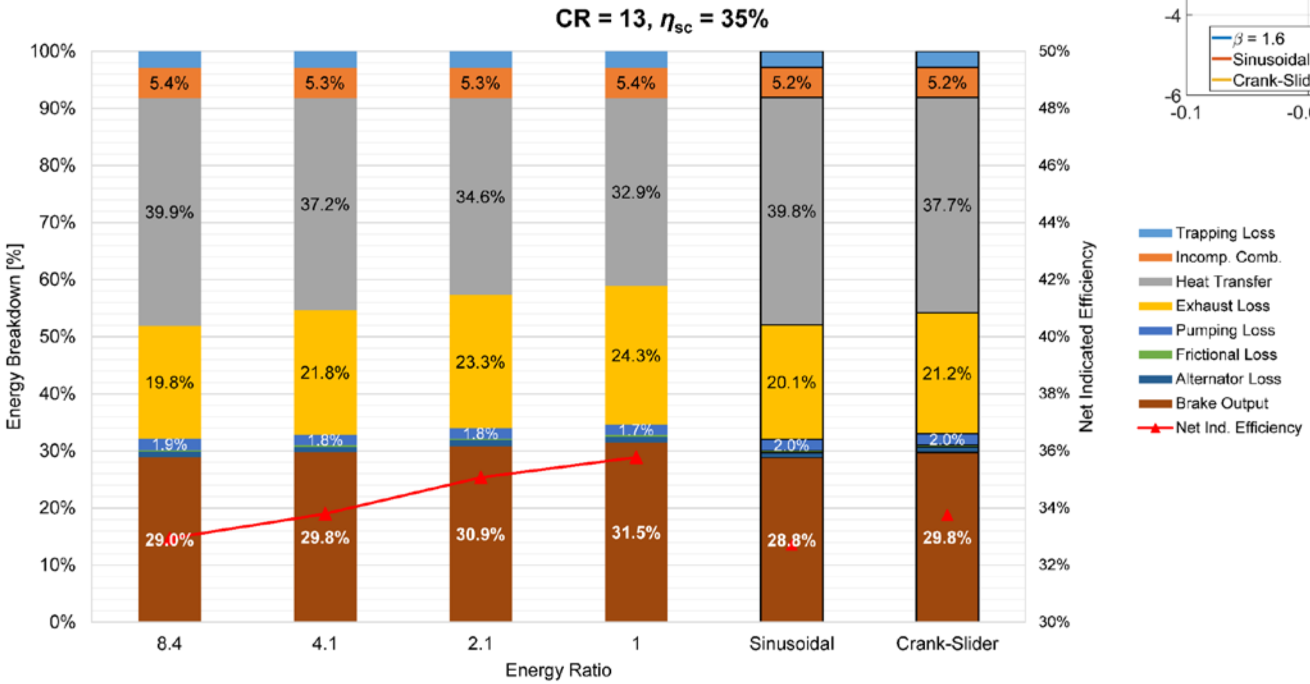


- System model includes: a thermodynamic submodel, a fluid dynamics submodel, a piston dynamics submodel
- Built using established correlations from the literature and validated against experimental data

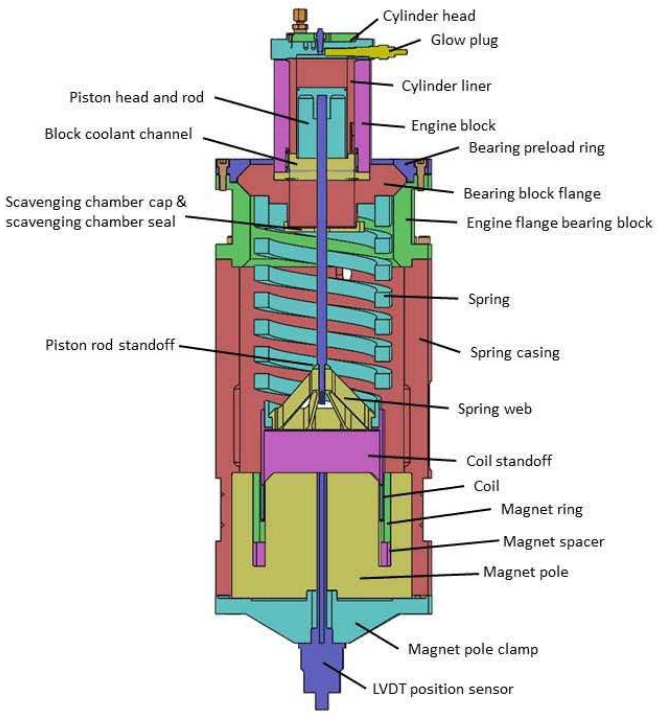
Results from System Modeling

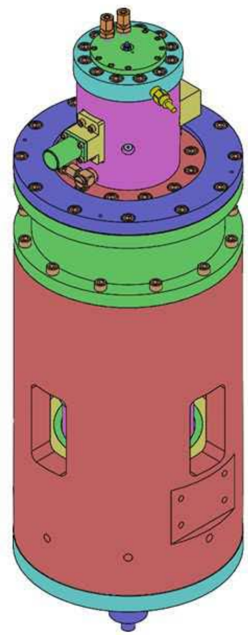
- Piston motion prediction based on dynamics
  - β: spring energy ratio
- Fuel energy distribution





MICE Experimental Testing

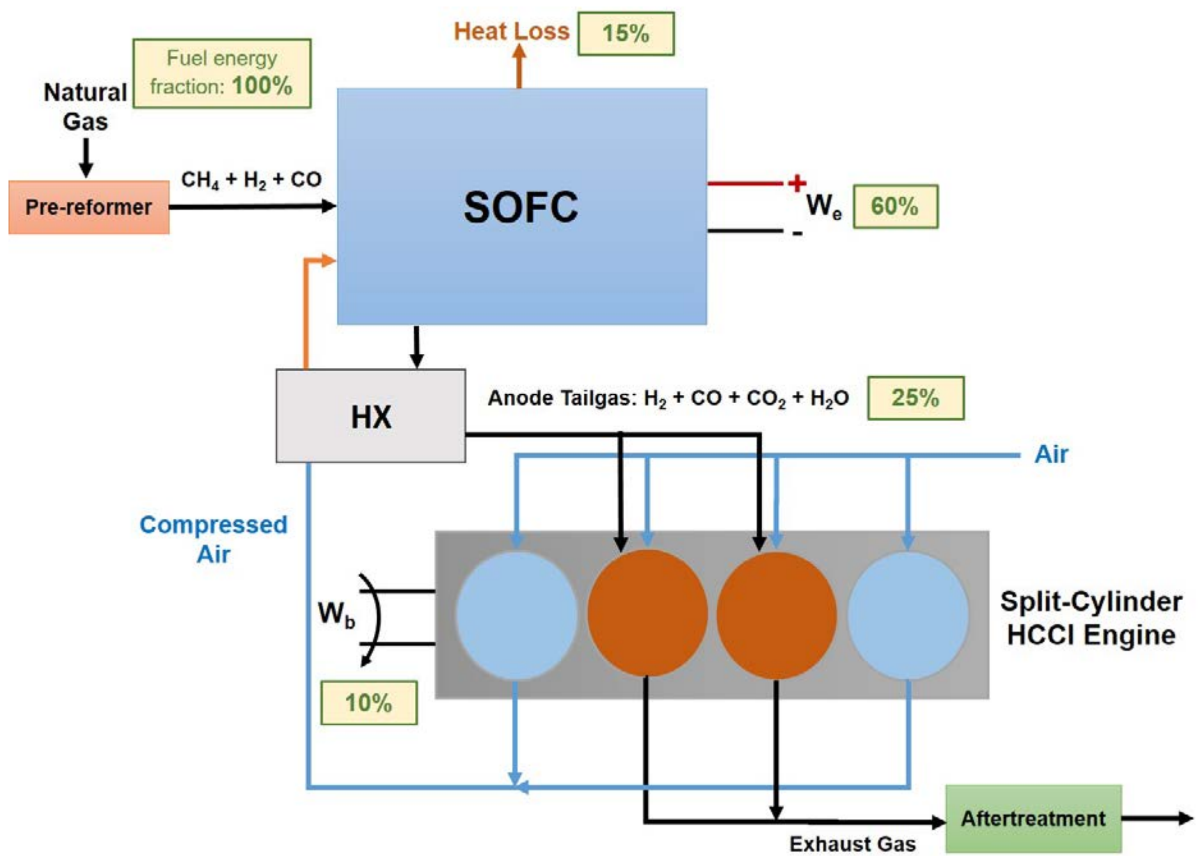




- Alpha prototype currently under testing to measure friction, pumping work, and subsequently perform SI and HCCI combustion experiments with natural gas
- Improved beta prototype to be delivered at the end of the project

Research Project 2: Hybrid SOFC-ICE

- Goal: Integrate SOFC with internal combustion engine to create a system that can achieve higher electric power conversion efficiency than current technology (70%+)
- How? Start with SOFC as the base and use the anode tailgas as fuel for an engine that can produce additional power
- The engine supplements the system power and also serves as *balance-of-plant* for the stack



Performance

METRIC	SOFC	ICE Generators	Microturbine Generators	Hybrid SOFC-ICE
Power	1~ 10 kW	100 ~ 1000 kW	50 ~ 300 kW	10 ~ 200 kW
Fuel	Natural gas, JP8	Wide range	Wide range	Natural gas
Net AC Efficiency	50-60%	35-45%	30-40%	≥ 70%
Manufacturing cost	~$6.00/W	~$0.50/W	~$1.00/W	≤ $0.90/W
Maintenance cost	≤ $0.01/kWh	~$0.05/kWh	~$0.05/kWh	≤ $0.02/kWh

- Competing and emerging technologies:
  - SOFC
  - ICE Generators
  - Microturbines
- Key: use the engine as a means to reduce the cost of the hybrid system
- Previous efforts have tried to hybridize SOFC with gas turbines or microturbines at higher power output levels

Thank you!