PCI
Precision Combustion

Recent Fuel Processor Development at PCI

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DOE Phase II SBIR (Joe Stoffa)

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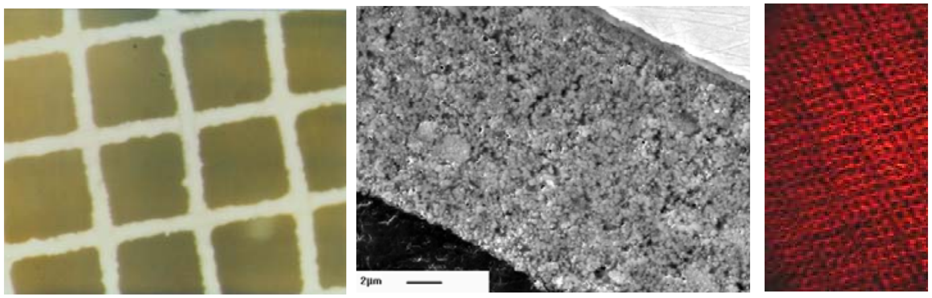
Clean Power Solutions for the 21st Century®

Precision Combustion, Inc.

- Established in 1986; Privately held; 30 employees; Located in North Haven, CT
- Develops advanced catalytic reactors & systems; manufactures limited-volume catalytic products
- Two major platform technologies under development
  - *RCL® catalytic combustors for gas turbines and downhole applications*
  - *Microlith® catalytic reactors for multiple markets*

Microlith® Technology



Small, durable, catalytically coated metal mesh with very high surface area

Continuous catalyst coating line with batched furnace and rigorous QA, QC in place

Microlith® Catalytic Reactors

Ultra compact

Short contact time

Rapid thermal response

High heat & mass transfer

High surface area/unit volume

Low catalyst usage & small size ⇒ Low cost

PCI holds multiple patents on catalyst structure, reaction methods, and apparatus

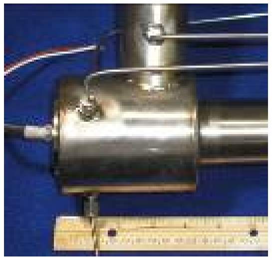
Reforming Areas Under Development At PCI

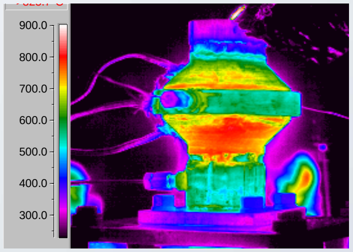
Reforming Processes:
Auto-thermal reforming
Catalytic Partial Oxidation
Steam Reforming

Reforming reactors:
WGSR, PROX
Burners (startup, AGB, purge)
Scales: 50 We – 250 kWe

Fuels:
Liquids: Diesel, JP-8, Jet-A, E-85
FT fuels, Methanol, Gasoline
Gases: Natural Gas, Propane

BOP:
Pumps, Blowers, Nozzles
Igniters, HX, Steam generation,
F/A/S mixing, Controls
Sulfur Cleanup, System Integration

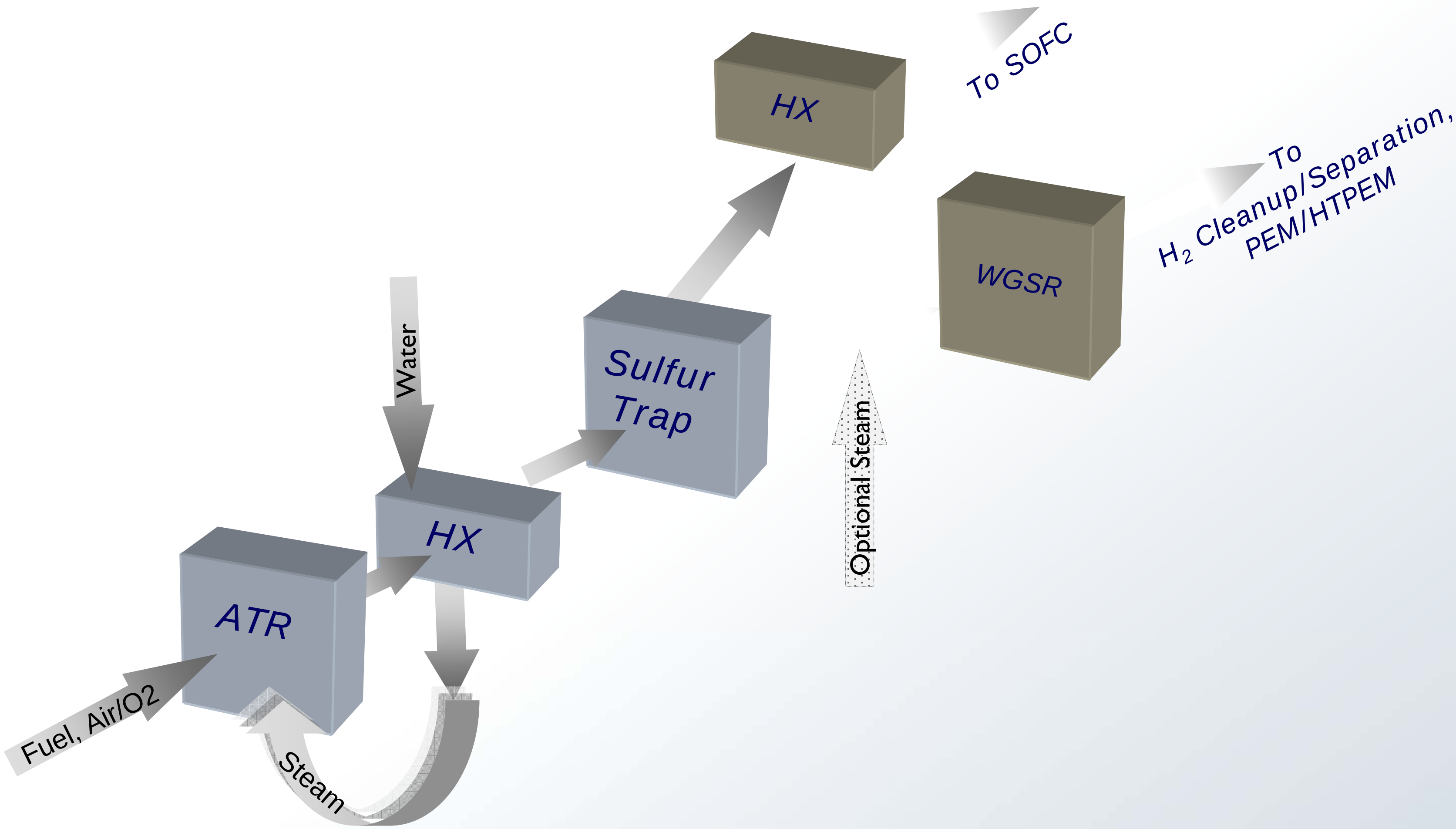




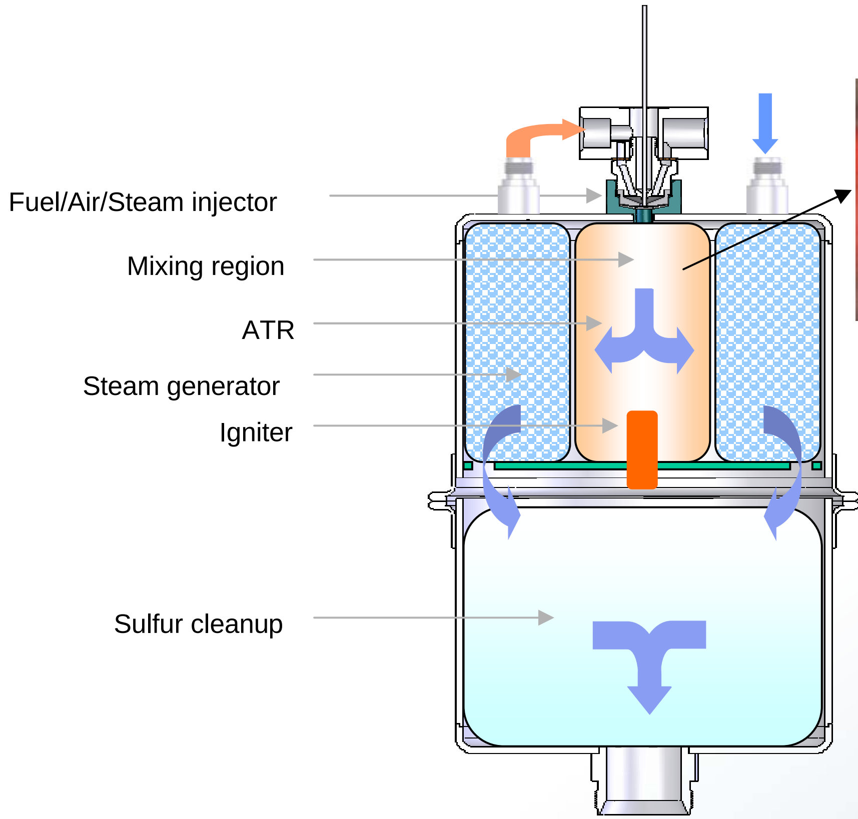
Significant Results

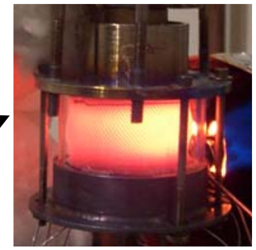
- Microlith® Auto Thermal Reformer
  - Operation w. SOFC stack
  - Sulfur Tolerance
  - Operation on AGR
- Microlith® Steam Reformer
- Reformer Scale-up

System Design Approach (E.g. Water Recycle)



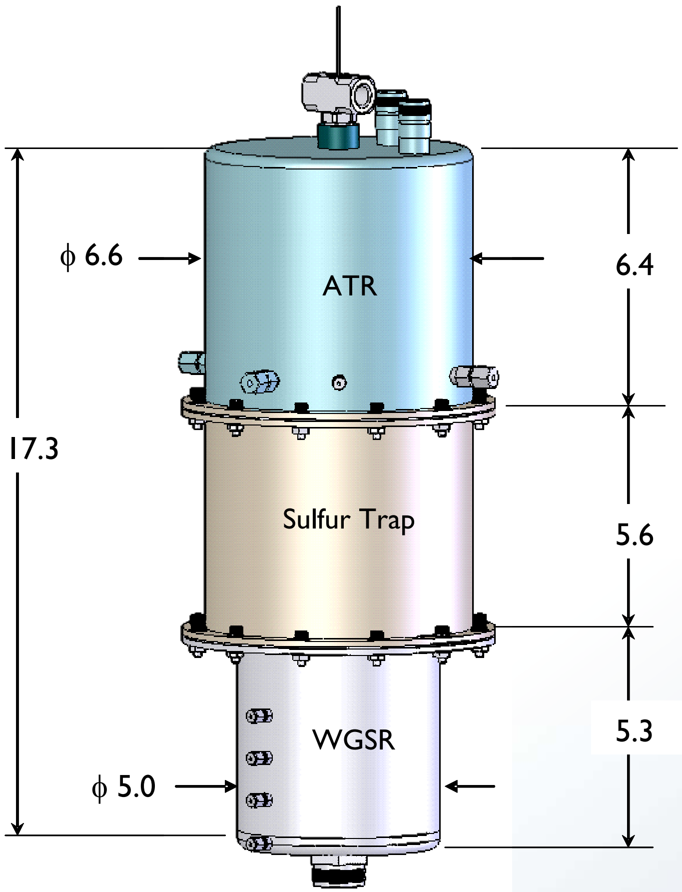
Standalone Fuel Processor (SOFC)





5 – 10 kW_{th} reformer integrated w. fuel/air/steam injector, igniter, steam generating HX, sulfur trap

Standalone Fuel Processor (HT-PEM/PEM)



25 kW_{th} ATR w. fuel/air/steam injector, igniter, steam generating HX, sulfur trap, WGSR

Standalone Fuel Processor Metrics

- Reforming efficiency: ~85% (ratio of LHV)
- Size: 3 liters; Weight: 5 kg (for 5 kW_{th})
- Operate at low S:C ratios (AGR/water)
- Start up in CPOX (1 min), transition to ATR (7 min)
- Modular, readily-serviceable components
- Stand-alone pumps & blowers implemented
- 12 V battery for startup & controls
- Readily integrated w. SOFC, PEM, H_2 generation systems
- Durability: 1000 hrs w/o failure w. JP-8 (~400 ppm_w sulfur)

Convert JP-8[*]/Diesel[+] into sulfur free (<1 ppm_v) reformate

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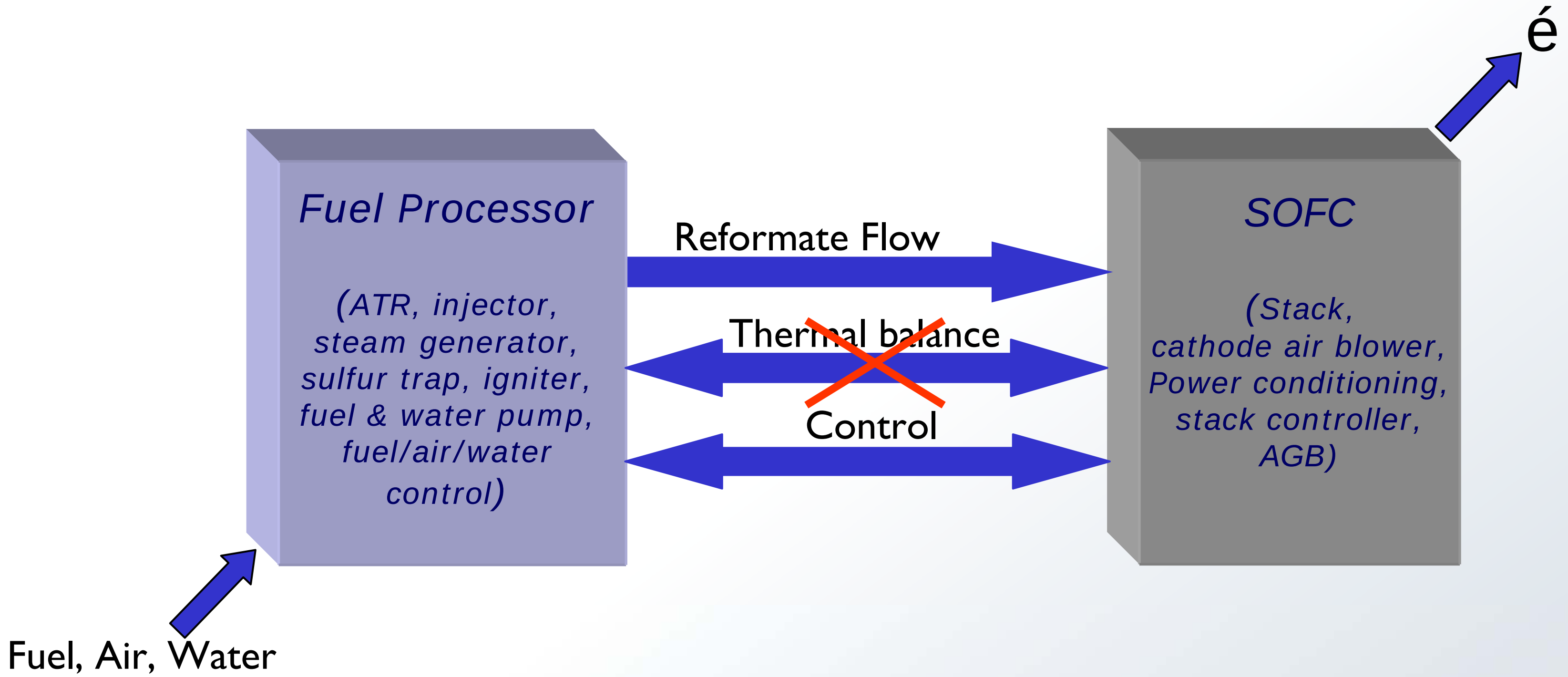
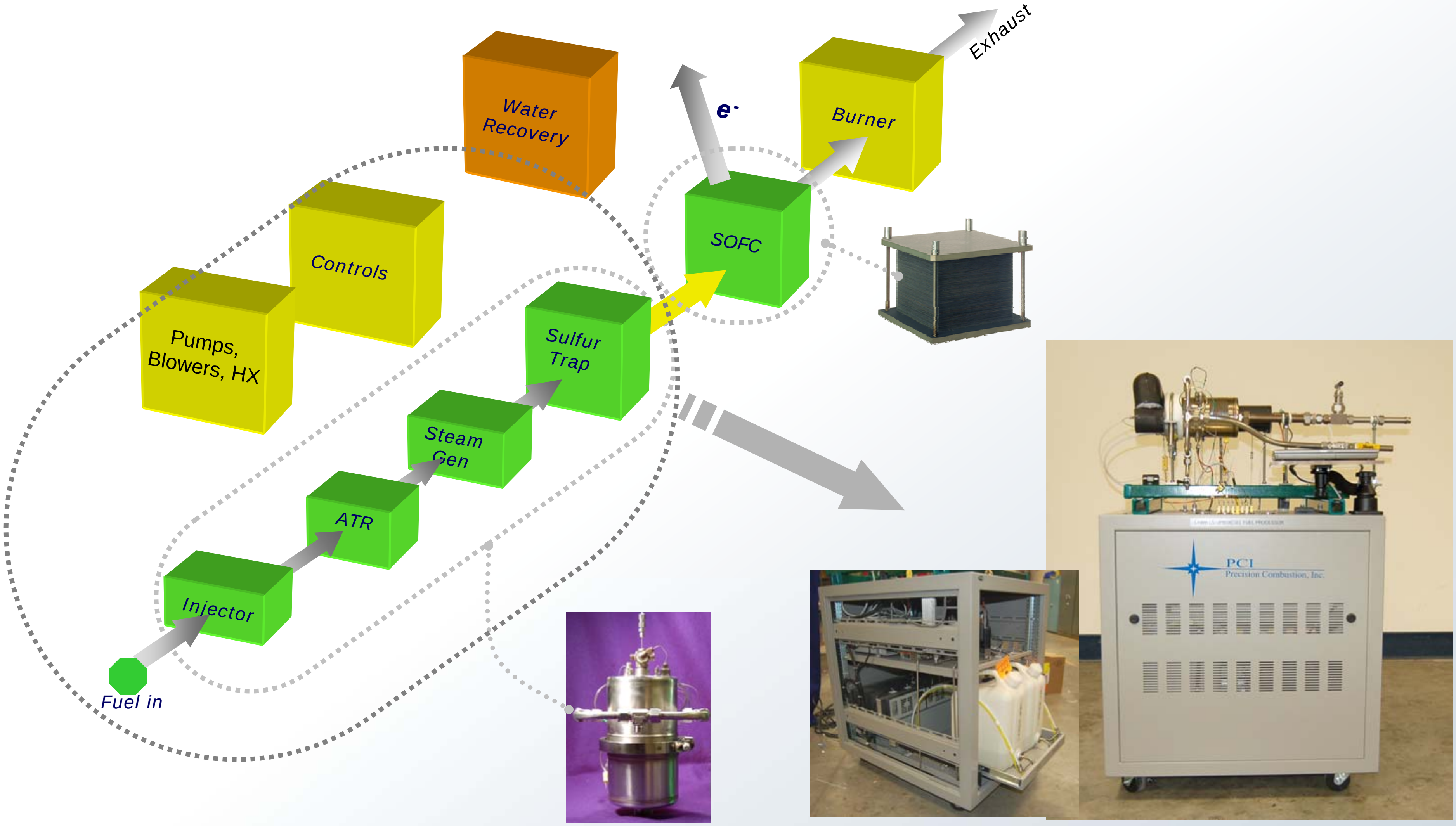
Stack Interface (SOFC)



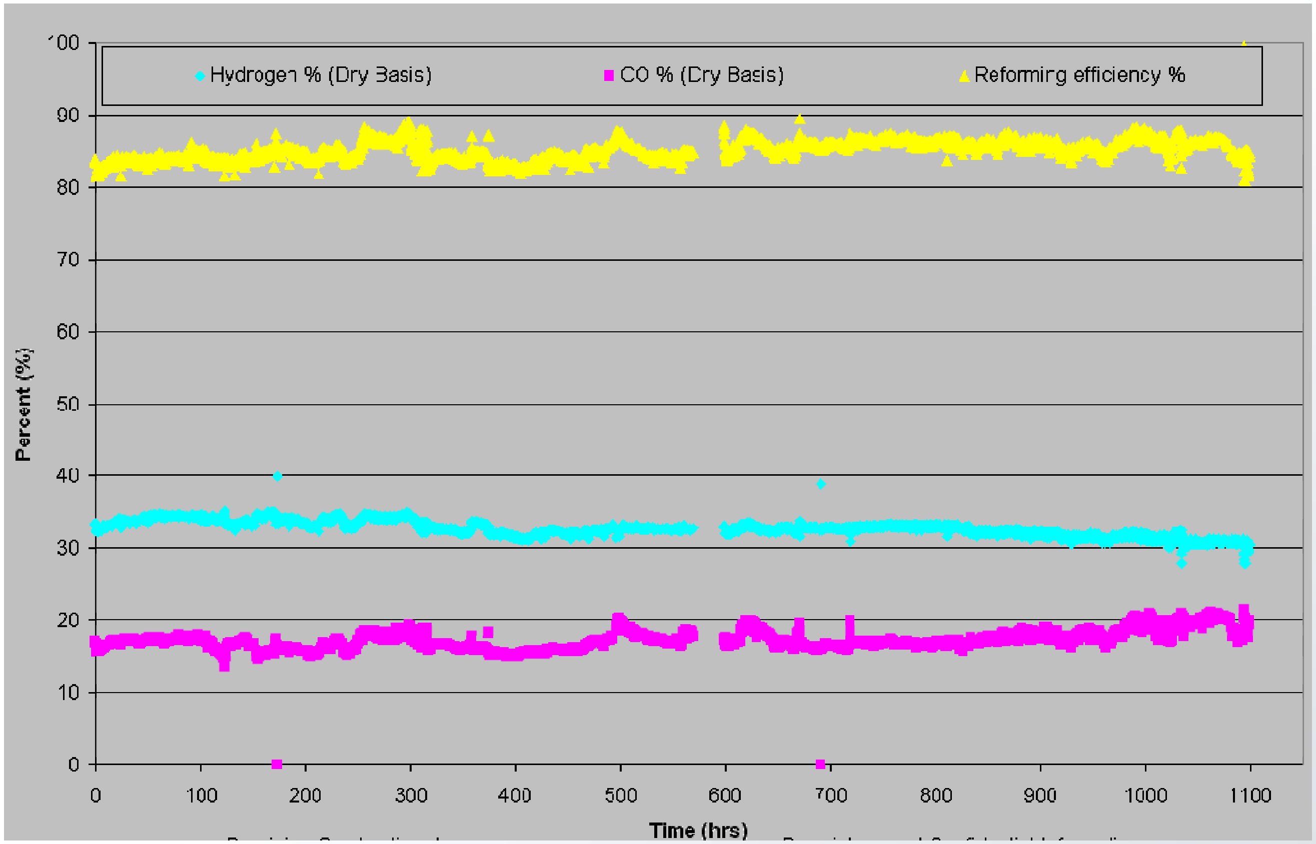
Towards Integrated System (ATR + BOP)



Fuel Processor Controls

- Automated start, shutdown, load changes
- Closed loop feedback control w. safety interlocks
- Real-time air/fuel/water flow control
- Control logic/algorithm implemented via PC-based interface
- National Instruments interface hardware, programmed in *Labview*

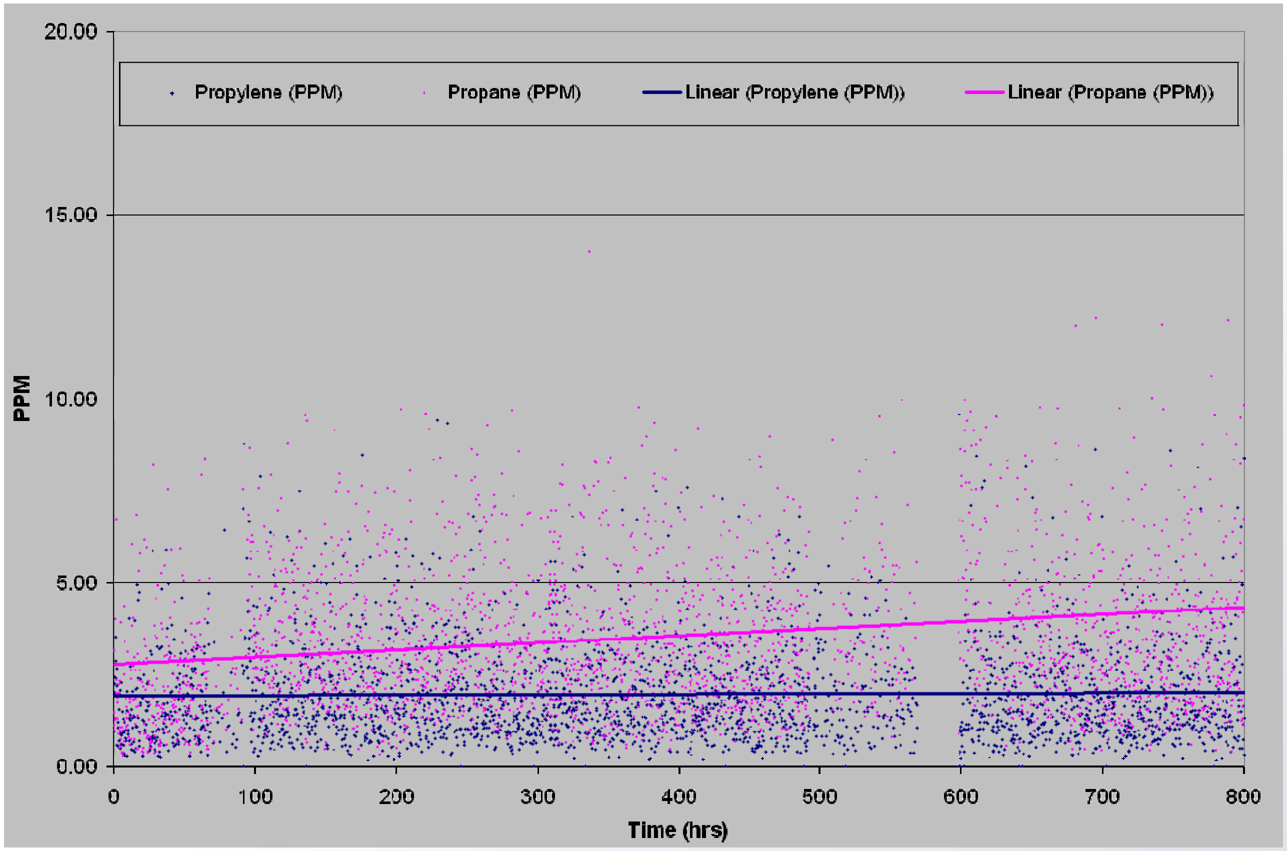
Reformer Performance (1100 hrs)



JP-8 w. low S (Average ~15 ppm_w S)

Operated with 1 kW_e SOFC stack – Stable Operation w/o coking for 1100 hours

Higher Hydrocarbon Formation with ~15 ppm_w S



Propylene and propane <10 ppm_v for up to 1100 hrs;

Ethylene and ethane were not detected by GC (<5 ppm_v)

Results From Stack Interface Testing

- 6 thermal cycles
- 1100 kW-hr produced
- DC Gross efficiency of 34% achieved
- Maximum power of 1.5 kWe obtained
- Successful startup/operation/shutdown demonstrated
- 1100 hrs total testing- 370 hrs longest steady-state period
- Successfully tested manual load-following (order of seconds)
- On post inspection, no carbon was found or deleterious effects on stack observed
- No fuel cell performance difference beyond expected compositional changes observed

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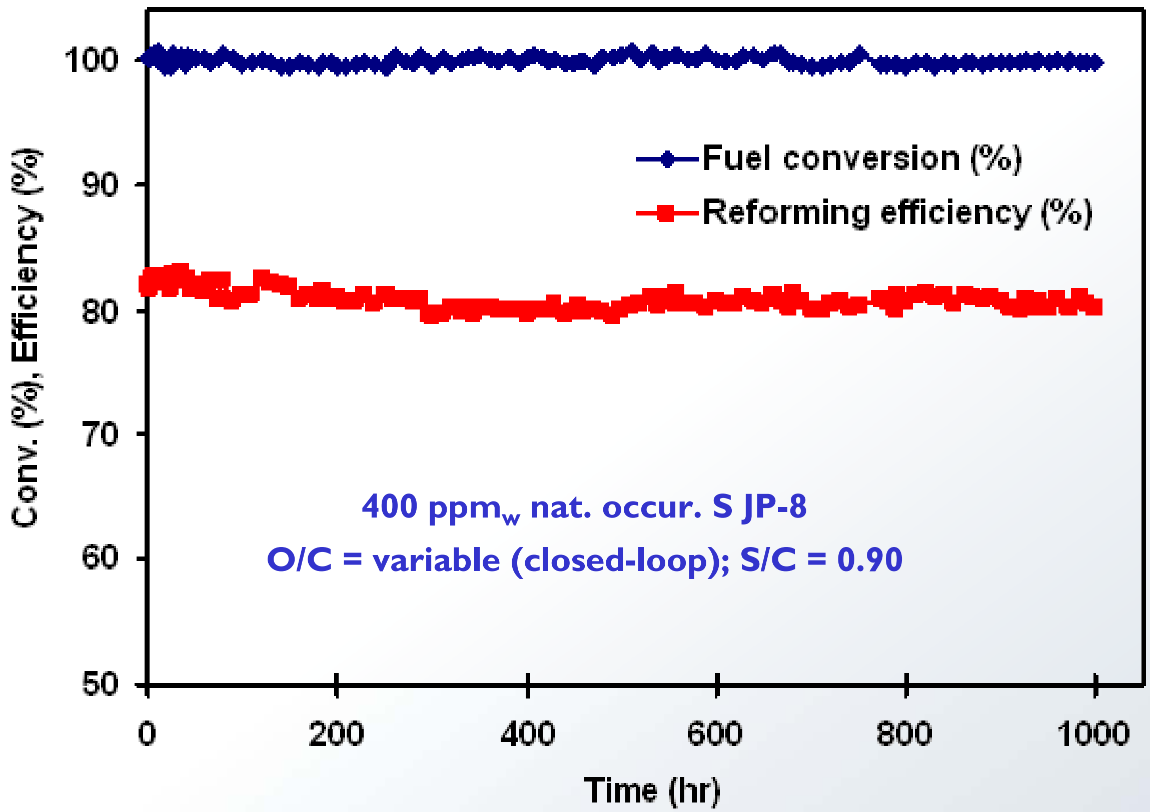
ATR Sulfur Tolerance Tests

- Performed 1700 hrs of testing on ATR catalyst w. the following fuels:
  - 4 ppm_w naturally occurring JP-8 (Baseline)
  - 50, 100, 250, 500, 1000, 2000 and 3000 ppm_w Sulfur JP-8 (doped with DBT)
  - 400 ppm_w Sulfur JP-8 (naturally occurring/21% aromatics, DBT-doped, and BT-doped)

- Evaluated ATR catalyst performance for:
  - Fuel conversion to C1 products (CO, CO_2, and CH_4)
  - Reforming efficiency (ratio of LHV of H_2 and CO in reformate to the feed fuel)
  - Reformate composition for organics (C2 or >) via GC/TCD analysis
  - Reformate composition for H_2S/COS via GC/FPD analysis

Effect of 400 ppm_w "Real S" for 1000 hrs



- Stable/complete fuel conversion, Reforming efficiency, H_2+CO mole % over time
- Total organics (primarily C2, C3) <100ppm at end of test.

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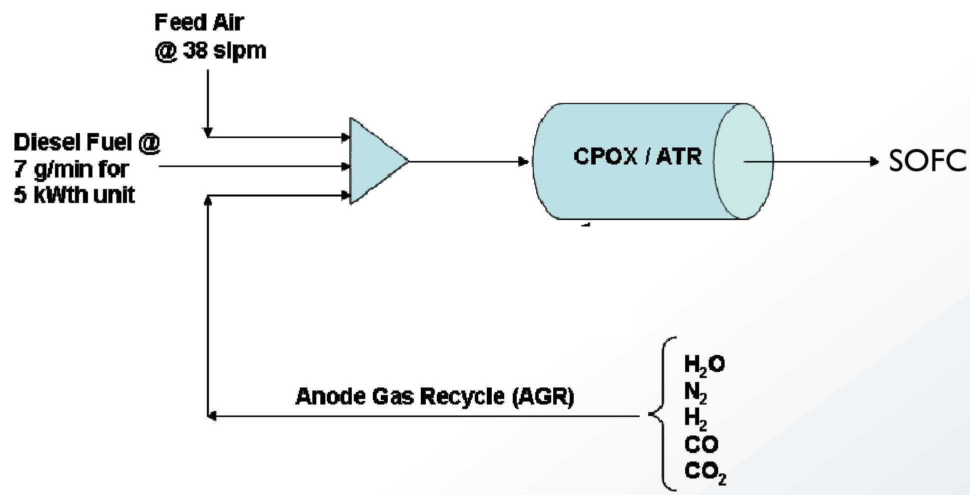
Anode Recycle for Water Neutrality



- Used surrogate gas mixture to simulate AGR composition and flow rate
  - (Assumptions: 60% SOFC FU; 50% AGR split to achieve target O/C and S/C)
- Reactor startup under CPOX (waterless); then transitioned to ATR (w. AGR, S/C = 0.7)
- Stable reactor operation w. no temperature excursions
- Successfully demonstrated feasibility of using AGR for water neutral operation

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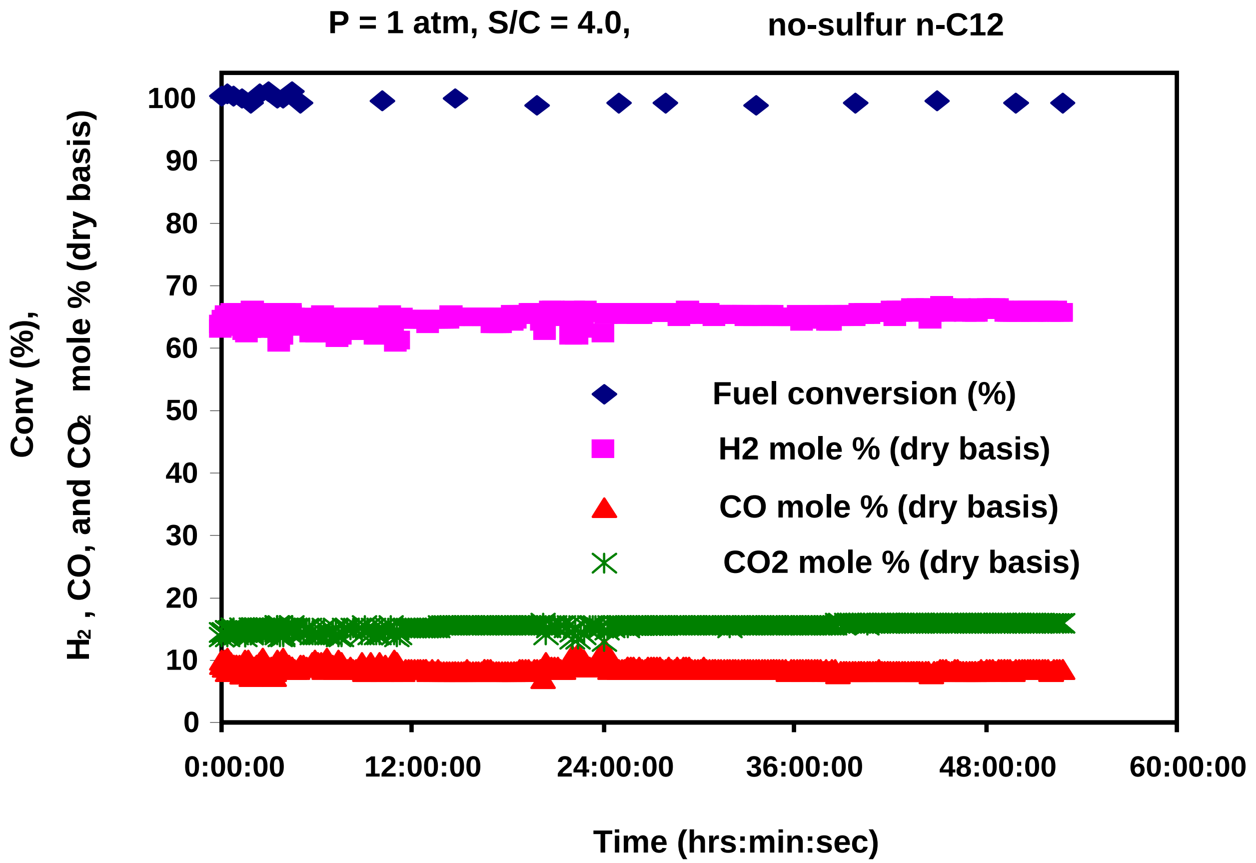
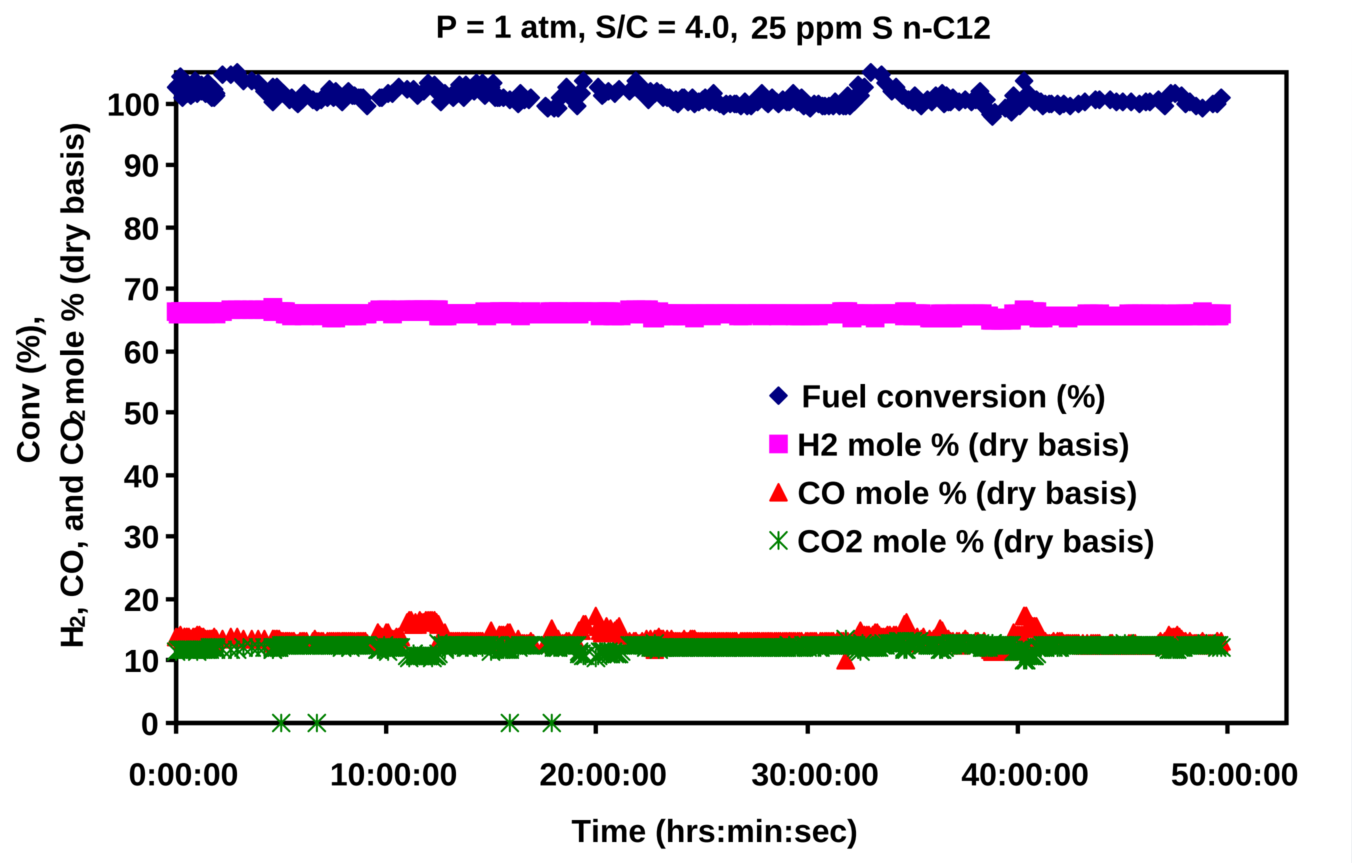
Steam Reforming: Performance w.o sulfur



Steam Reforming: w. 25 ppm Sulfur



W. 25 ppm_w S n-C12 (DBT-doped), conversion was stable at 100% & H_2 conc. was steady.

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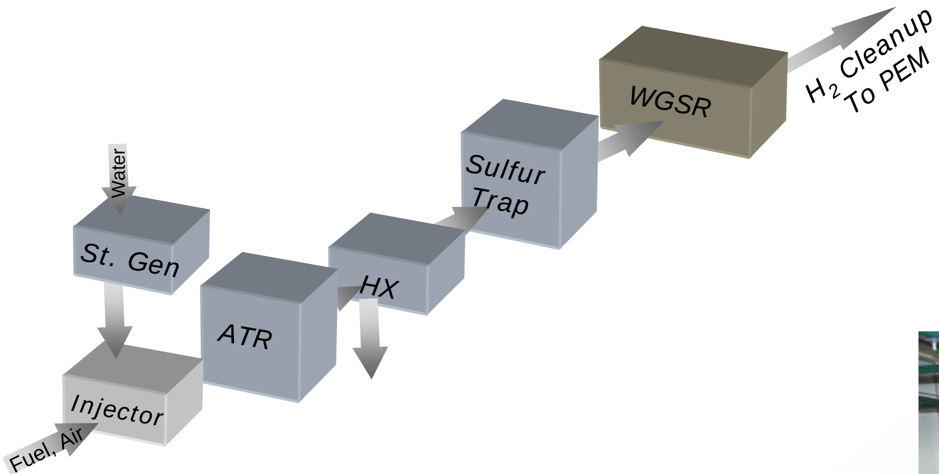
200 kW$_{th}$ ATR + Sulfur Trap + WGSR – ONR



- Simple layout
- Compact footprint
- ATR Size: 3 liters
- Operating pressure: 7 atm
- Reforming efficiency: 70% - 80%
- 1 mkWe scale-up ongoing

Summary

- Demonstrated stand alone ATR integrated w. 1 kW_e SOFC stack
  - Compact system
  - High reforming efficiency (~85%) with JP-8
  - Stable ATR and stack operation over 1100 hours
- Demonstrated sulfur tolerance of ATR catalyst
  - Catalyst can tolerate 3000 ppm S; Performance degrades w. >500 ppm_w sulfur
  - However, catalyst performance recovers after operation w. low-sulfur JP-8
  - Stable (high conversion & efficiency) with up to 400 ppm_w sulfur in JP-8
  - Tested for 1000 hrs to confirm viability
- Demonstrated sulfur tolerance of steam reforming catalyst
  - 25 ppm_w S in n-C12 for 50 hrs. w/o degradation
- Demonstrated AGR capability for water neutrality
- Scale-up to 200 kW_{th} demonstrated; 1mW_{th} ongoing

Acknowledgment

We are grateful to the DOD & DOE for their support,

And

The engineers and technicians at PCI.