

Reversible Solid Oxide Fuel Cells for Power Generation and Hydrogen/Chemical Production

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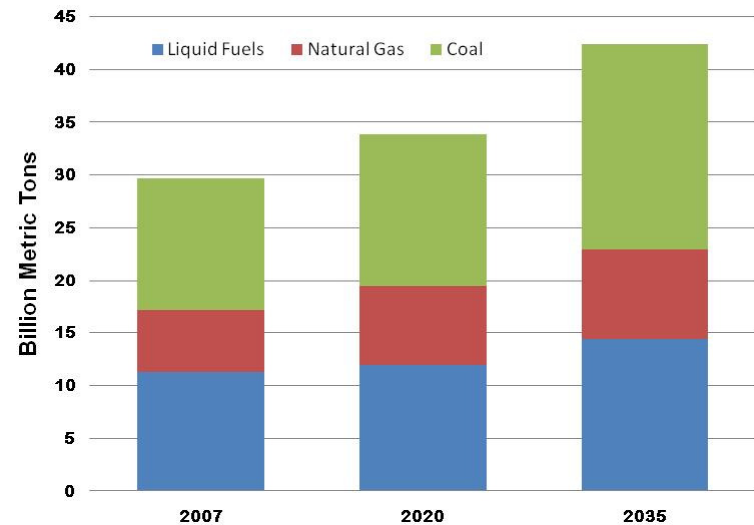
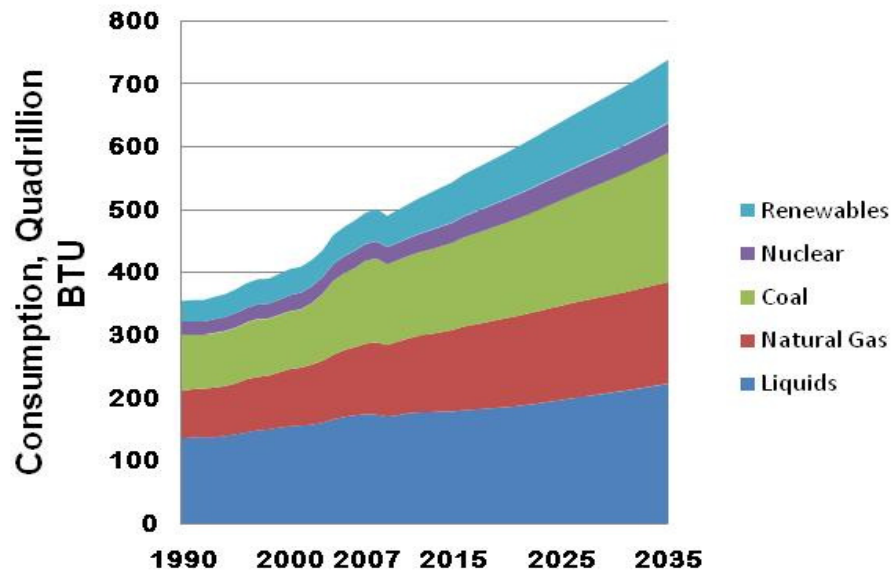
**Fuel Cell Seminar and Exhibition
Orlando, FL
November 2, 2011**

Advanced Energy Concept

- Direct and reversible solid oxide fuel cells (DR-SOFCs)
- Base technology for future advanced energy systems

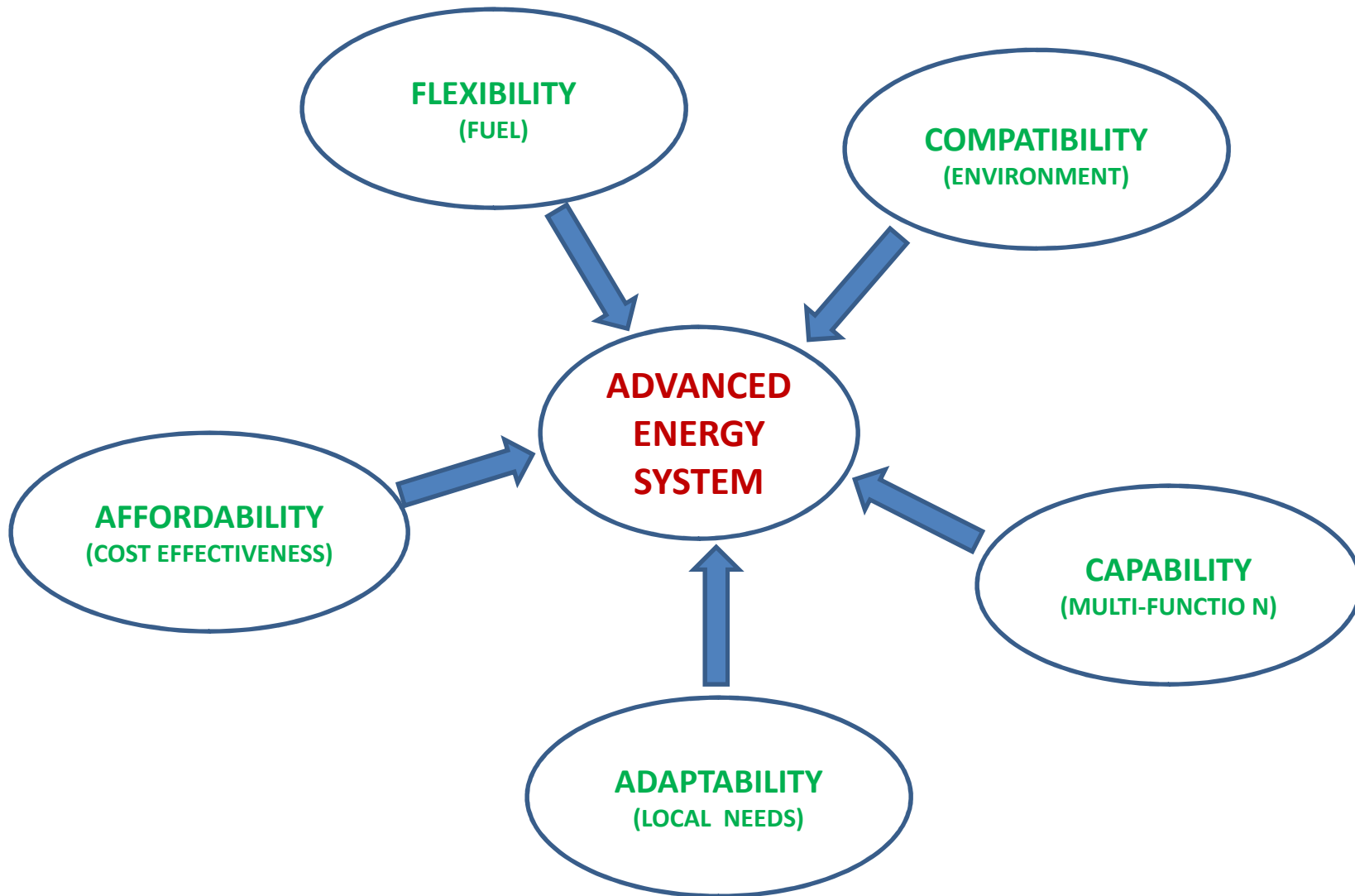
World Energy Consumption and CO₂ Emissions

History and Projection



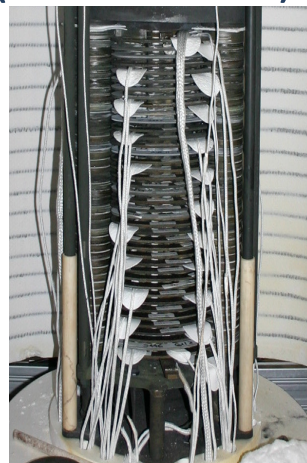
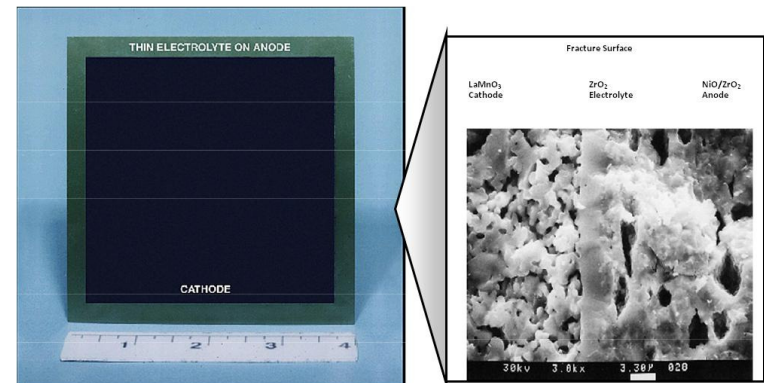
Source: EIA 2010

Future Energy Systems



Solid Oxide Fuel Cell (SOFC) Technology

- Fuel flexible (FLEXIBILITY)
- Environmentally friendly (COMPATIBILITY)
- Suitable for a broad spectrum of practical applications (ADAPTABILITY)
- Projected to be cost competitive (AFFORDABILITY)
- Capable of operating reversibly for power generation and chemical production (CAPABILITY)



PORTABLE



AUTOMOBILE AUXILIARY POWER UNIT (APU)



RESIDENTIAL



DISTRIBUTED GENERATION (DG) POWER

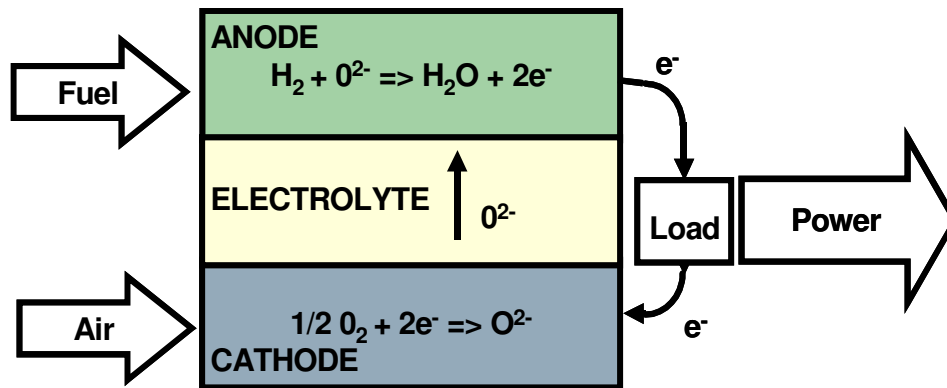
Universal Reversible Fuel Cell (URFC) System Concept

- Based on DR-SOFCs
- Single unit capable of functioning in two operating modes
 - Power generation (fuel cell) mode: Directly generate power from a broad spectrum of fuels
 - Hydrogen/chemical production (electrolysis) mode: Produce hydrogen or chemical (e.g., syngas) from steam (or mixture of steam and carbon dioxide) when integrated with an energy source

Operating Modes of DR-SOFC

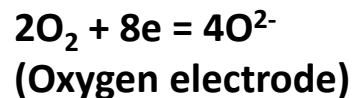
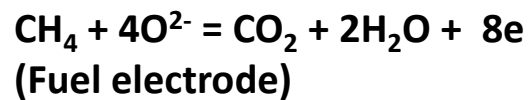
POWER GENERATION

HYDROGEN FUEL



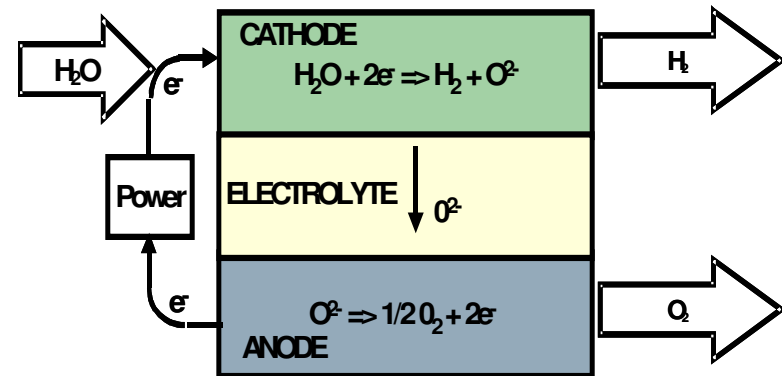
HYDROCARBON FUEL

(WRITTEN FOR METHANE)



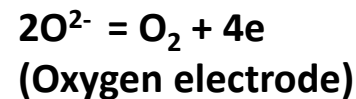
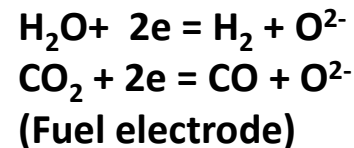
HYDROGEN/CHEMICAL PRODUCTION

HYDROGEN FROM STEAM



CHEMICAL PRODUCTION

(WRITTEN FOR SYNGAS)



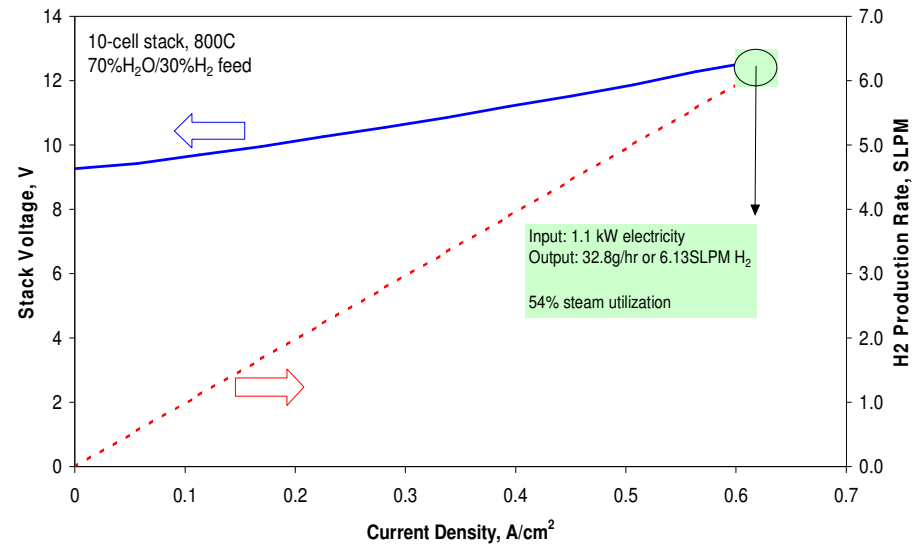
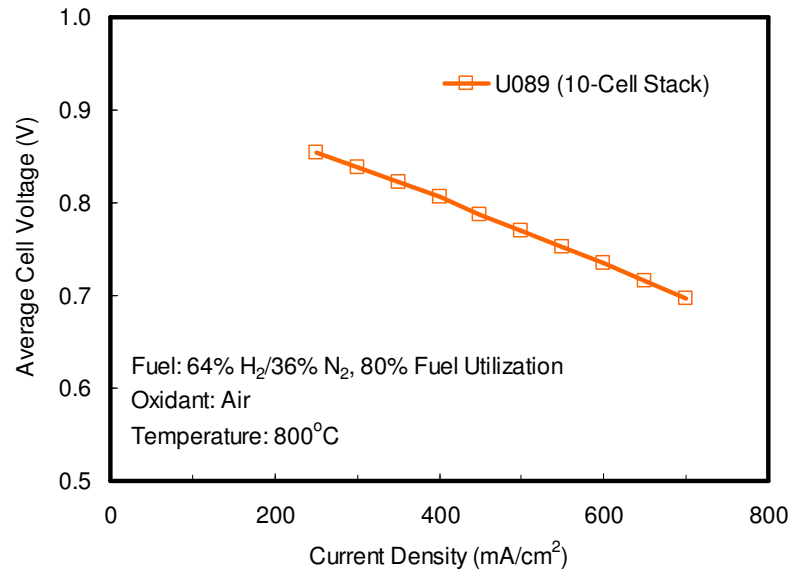
Key Requirements for DR-SOFC Direct and Reversible Operation

- Stable, high-performance single cells in both operating modes
 - Oxygen electrode performance reversibility
 - Direct -utilization fuel electrode without coking
- Efficient and stable cyclic operation

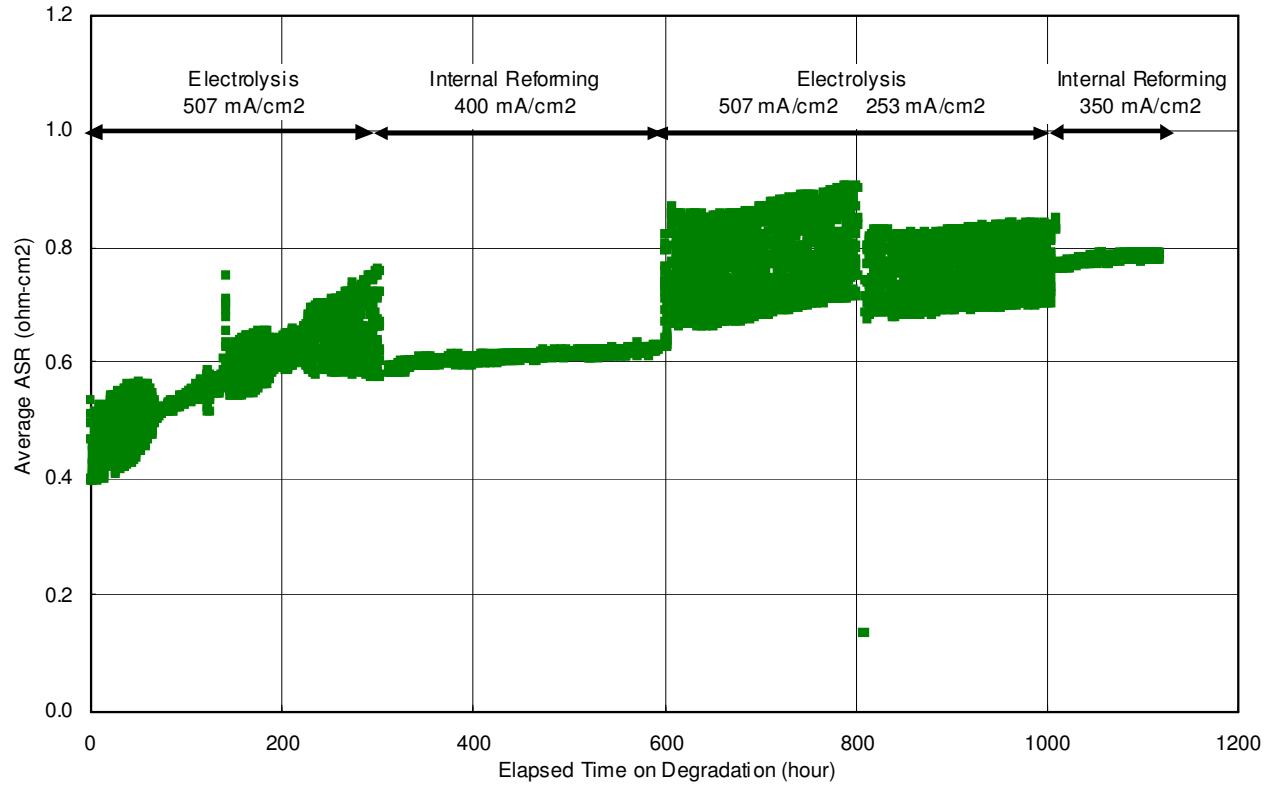
Ten-Cell RSOFC Stack



Performance of Ten-Cell RSOFC Stack

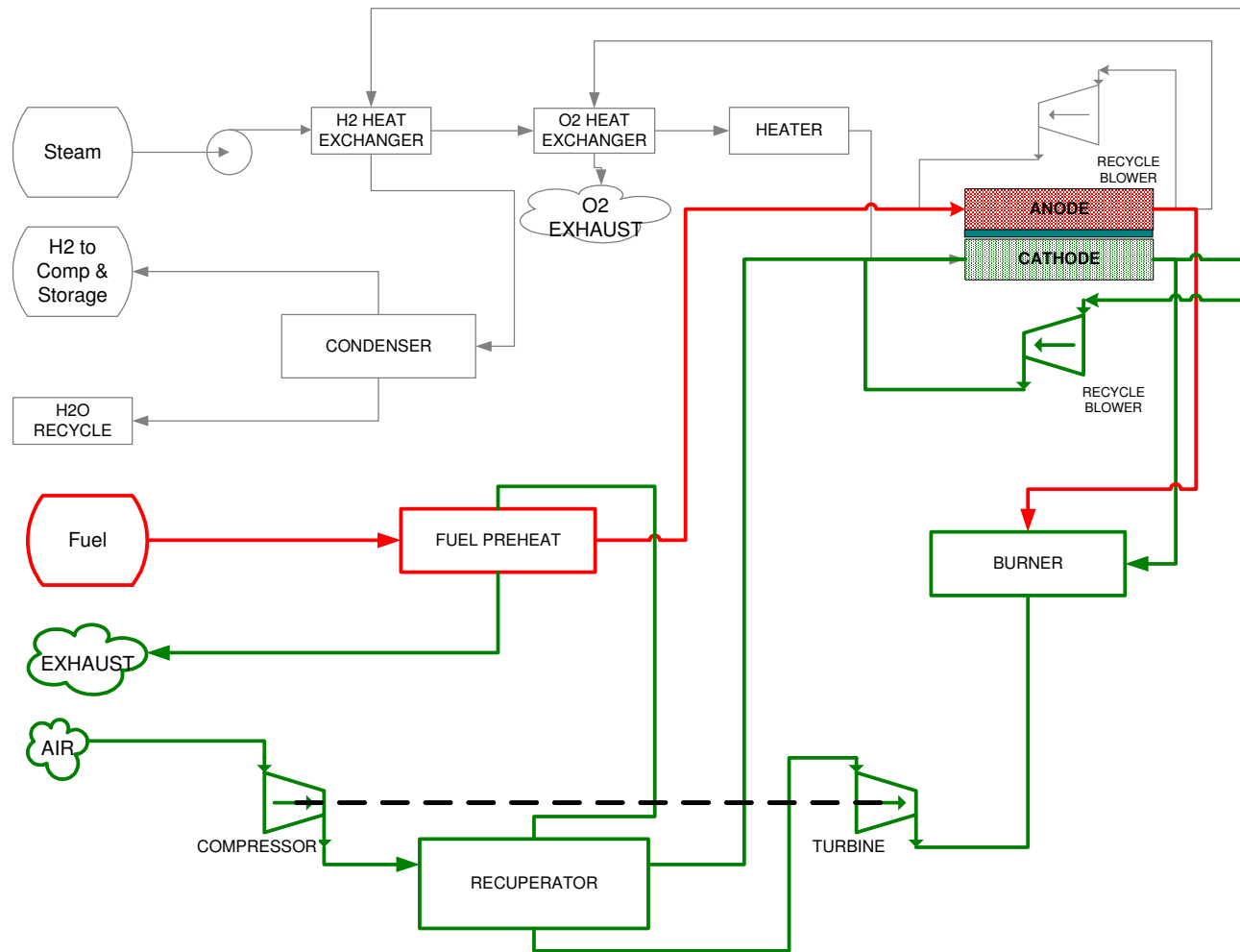


Cyclic Operation of RSOFC Stack



System Configuration

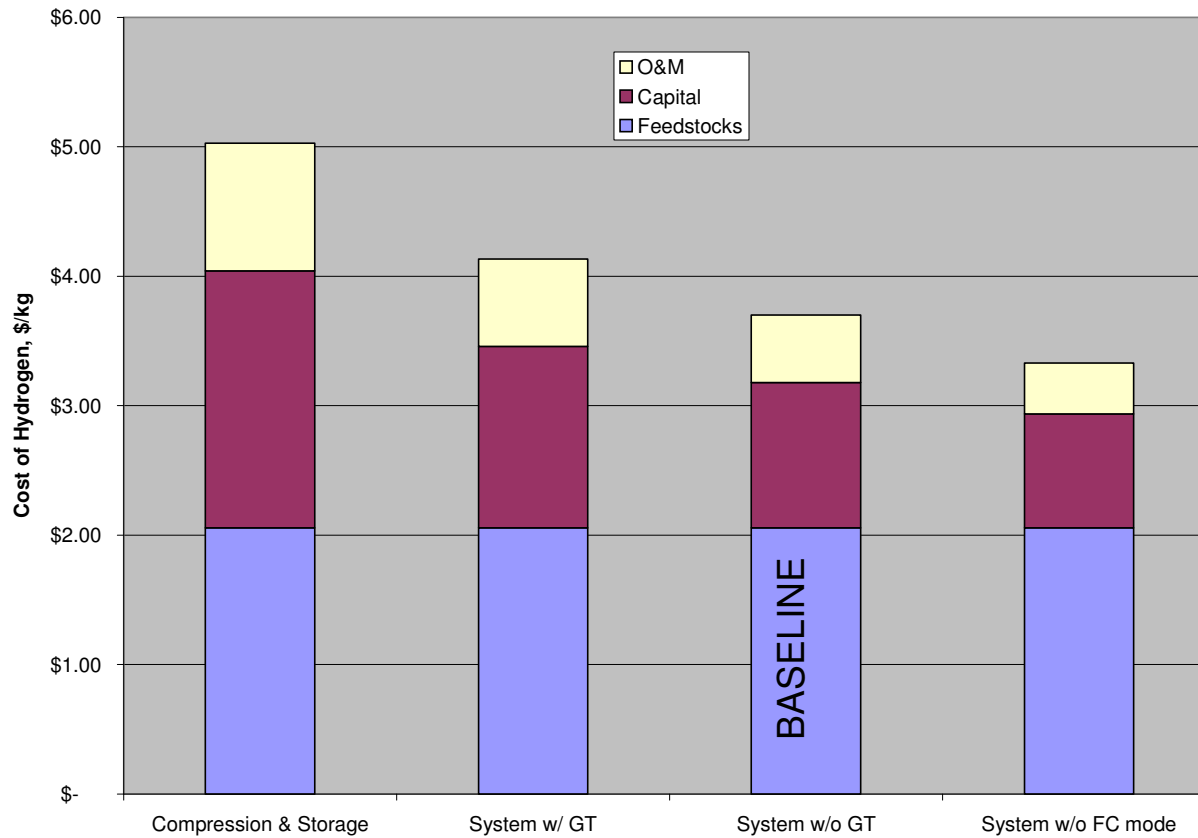
Fuel Cell Mode



Estimated Cost of Hydrogen (CoH)

for Distributed Systems

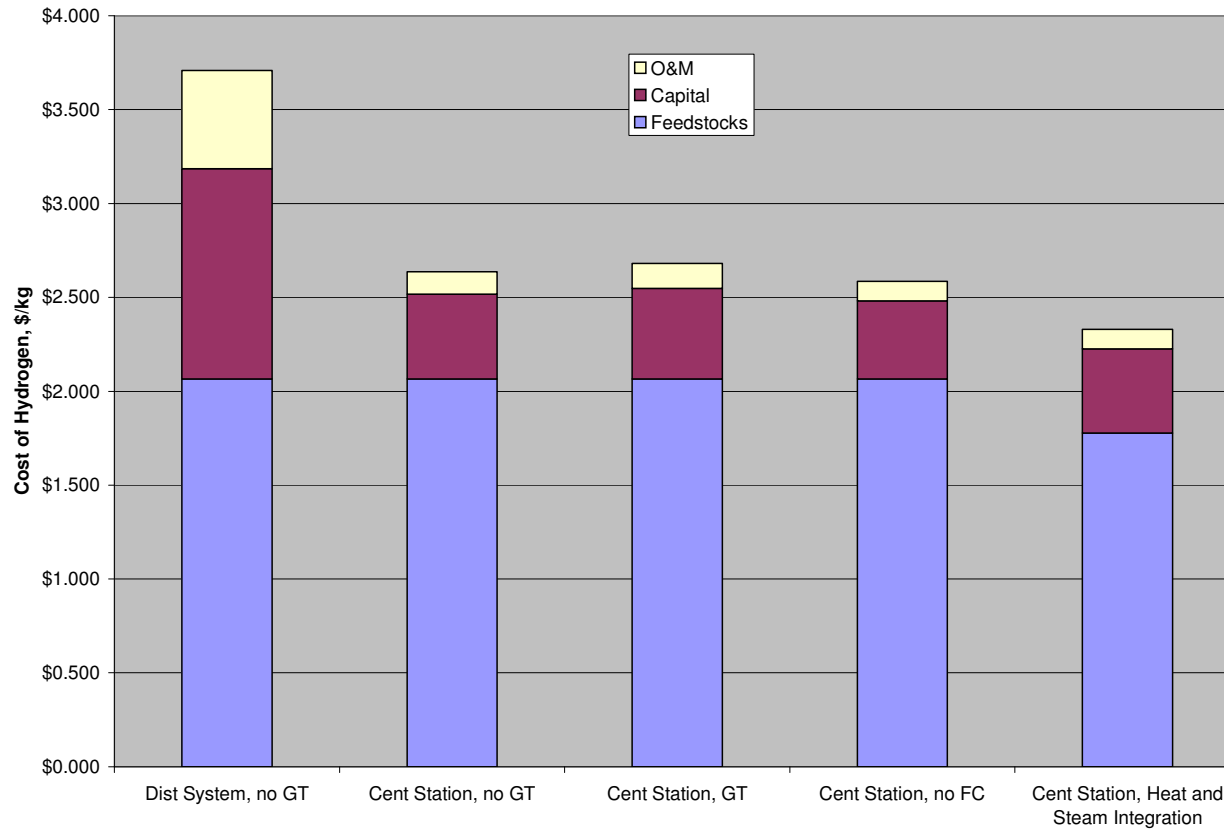
Distributed CoH with Various System Configurations



Estimated CoH

for Central Systems

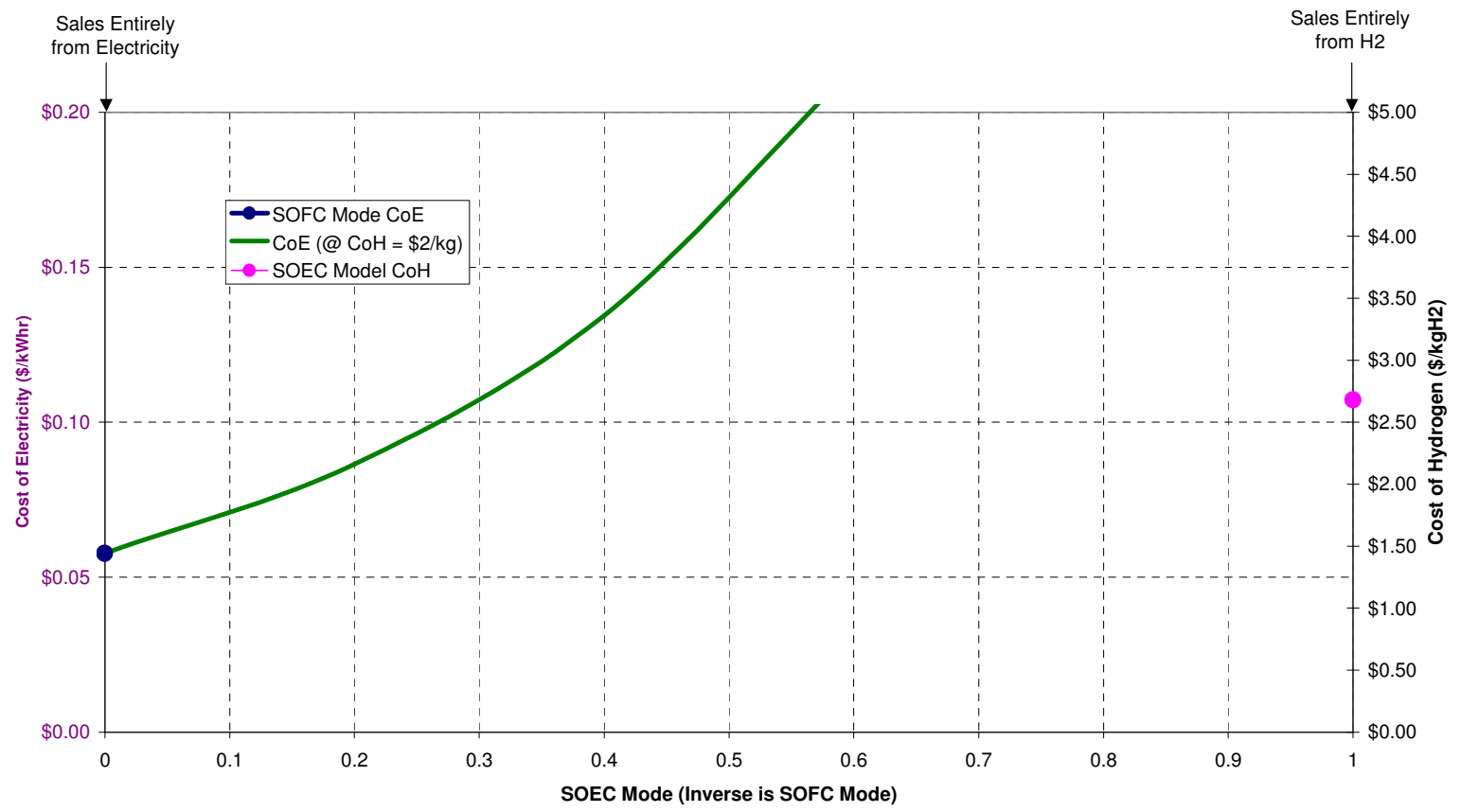
Central CoH with Various System Configurations



Impact of Reversible Operation on CoH

for Central Systems

RSOFC Mode of Operation Impact



Key Technical Elements

(for URFC Technology Feasibility Demonstration)

ELEMENTS

- Fabrication of DR-SOFC cells with required configurations and microstructures
- High performance under direct fuel utilization fuel cell, electrolysis and cyclic operating modes
- Performance stability in long-term operation (including no carbon deposition in direct fuel utilization in fuel cell operating mode)
- Dual operation stack design

APPROACHES

- Develop fabrication processes and engineer processing/structure/property relationships
- Develop appropriate hydrogen electrode and oxygen electrode material sets and required structures
- Identify causes for performance degradation
- Define operating parameters and develop other approaches to mitigate carbon deposition
- Develop stack designs with simplified seals

Summary

- URFC system concept based DR-SOFCs
- Concept feasibility
- Critical technical elements to demonstrate technology feasibility