High Temperature Fuel Cell Tri-Generation of Power, Heat & H_2 from Biogas

DOE/ NREL Biogas Workshop – Golden, CO

National Fuel Cell Research Center

UCIrvine | University of California

Outline

- Introduction and Background
- Tri-Generation/Poly-Generation Analyses
- OCSD Project Introduction

Introduction and Background

- Hydrogen fuel cell vehicle performance is outstanding

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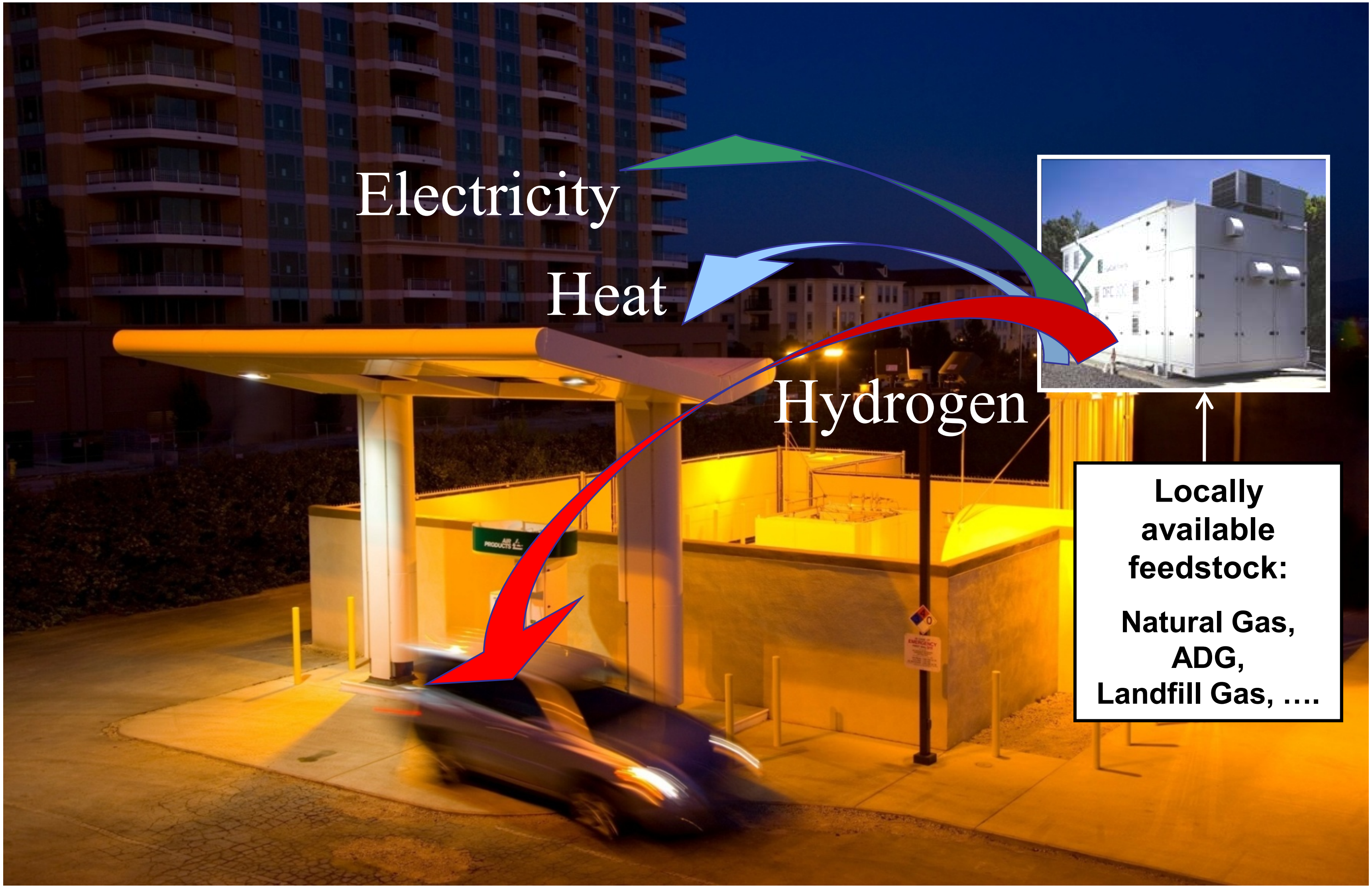
There is a need for a distributed, high-efficiency, low emissions hydrogen production method able to use a variety of feedstocks

An emerging strategy is poly-generation of hydrogen, heat and power from a high-temperature fuel cell (HTFC)

Introduction and Background

Tri-Generation Energy Station Concept [1, 2, 3]



[1] Brouwer et al., 2001; [2] CHHN Blueprint Plan, 2005; [3] Leal and Brouwer, 2006

Introduction and Background

Poly-generation of Power, Heat and H_2

- **Advantages:** [4, 5, 6]
  - H_2 production is at the point of use averting emissions and energy impacts of hydrogen and electricity transport
  - Fuel cell produces sufficient heat and steam as the primary inputs for the endothermic reforming process
  - Synergistic impacts of lower fuel utilization increase overall efficiency (i.e., higher Nernst Voltage, lower polarization losses, lower cooling requirement and associated air blower parasitic load)
- **Potential Disadvantage:**
  - Distributed production may not be compatible with carbon sequestration

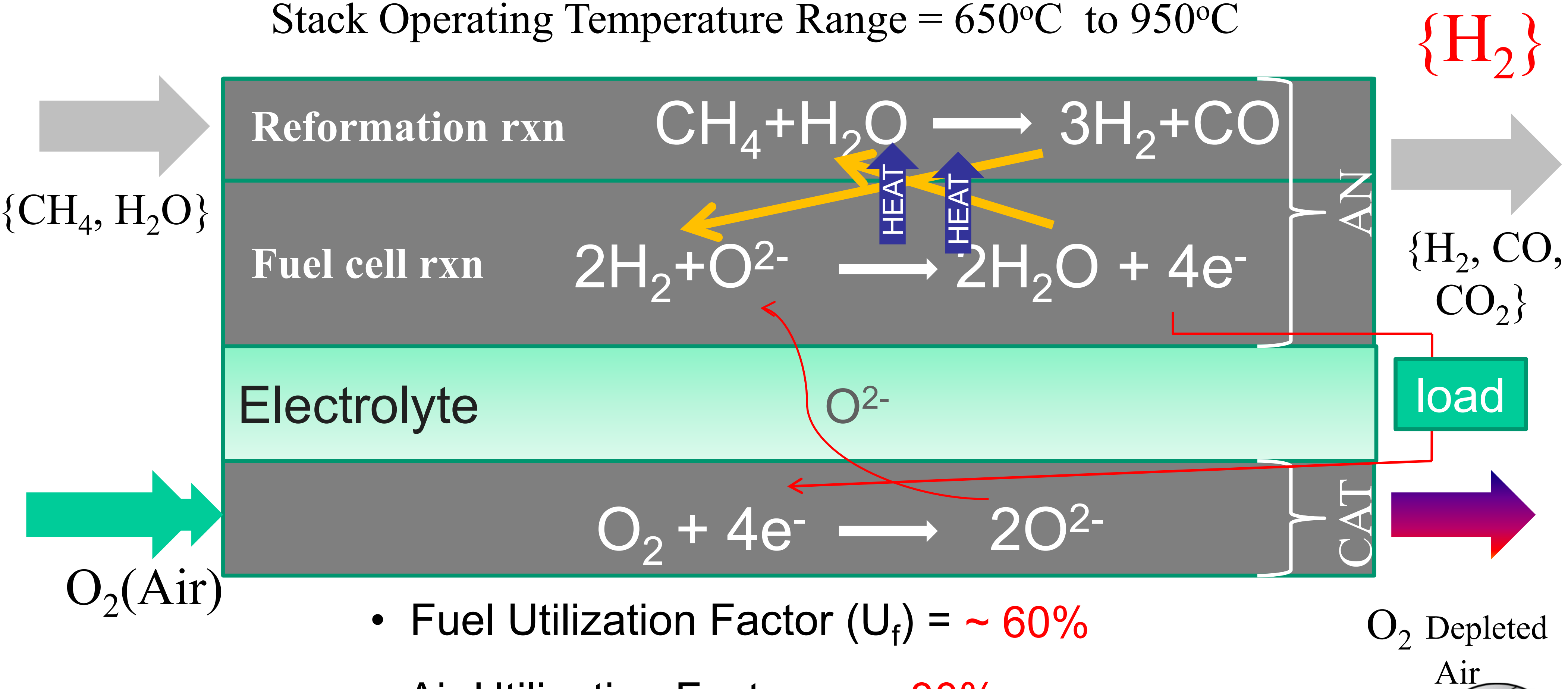
[4] Leal and Brouwer, 2006; [5] O'Hayre, R., 2009; [6] Margalef et. al, 2008

Introduction and Background

High Temperature Fuel Cell (HTFC) Stack

- **Solid Oxide Fuel Cell Example**

Stack Operating Temperature Range = 650°C to 950°C



- Fuel Utilization Factor (U_f) = ~ 60%
- Air Utilization Factor = ~ 30%

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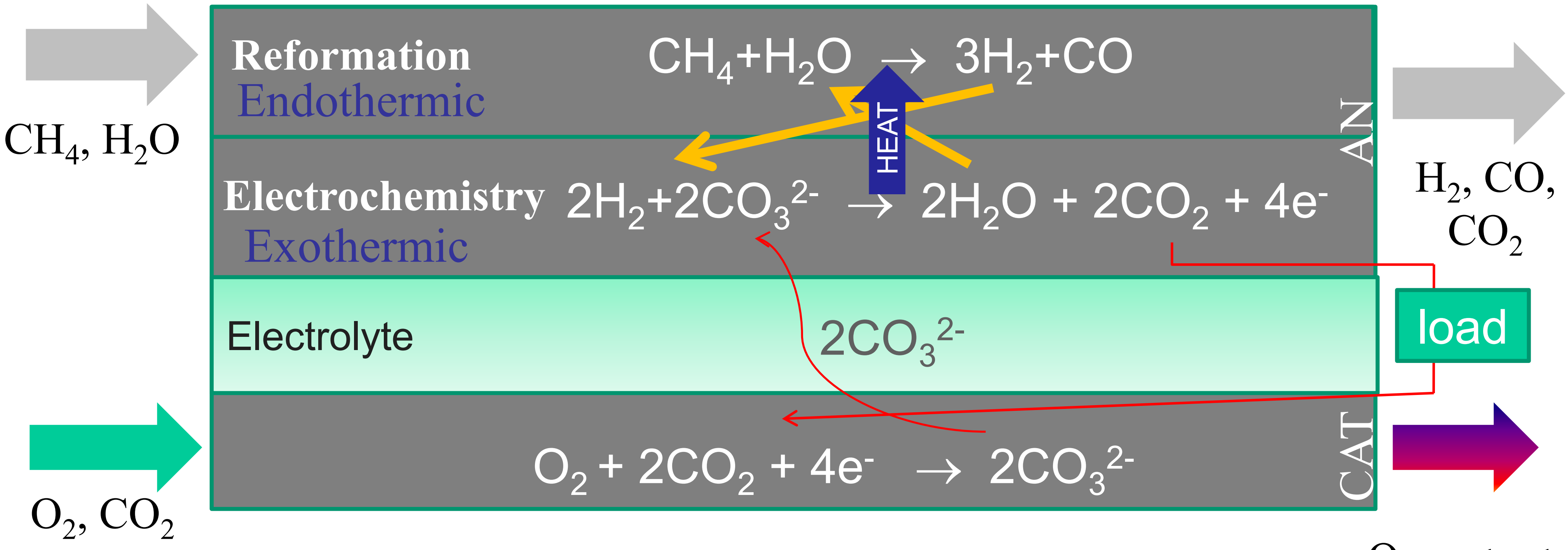
Analyses of Synergies

Recall: High Temperature Fuel Cell (HTFC) Stack

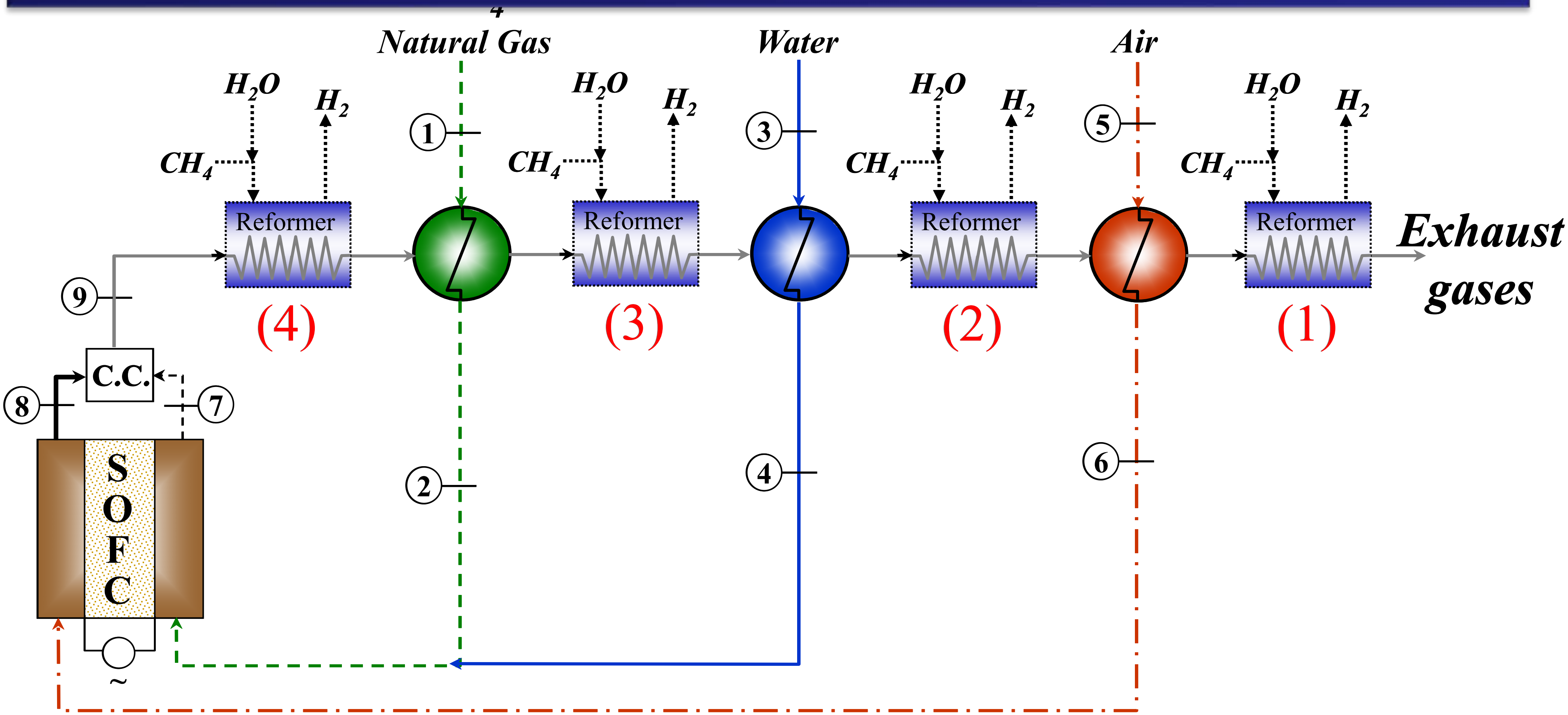
- **Molten Carbonate Fuel Cell Example**

Stack Operating Temperature Range = 550°C to 650°C



Air Flow and parasitic blower power can be reduced

Cycle Configurations



Placement of a reformer in different locations:

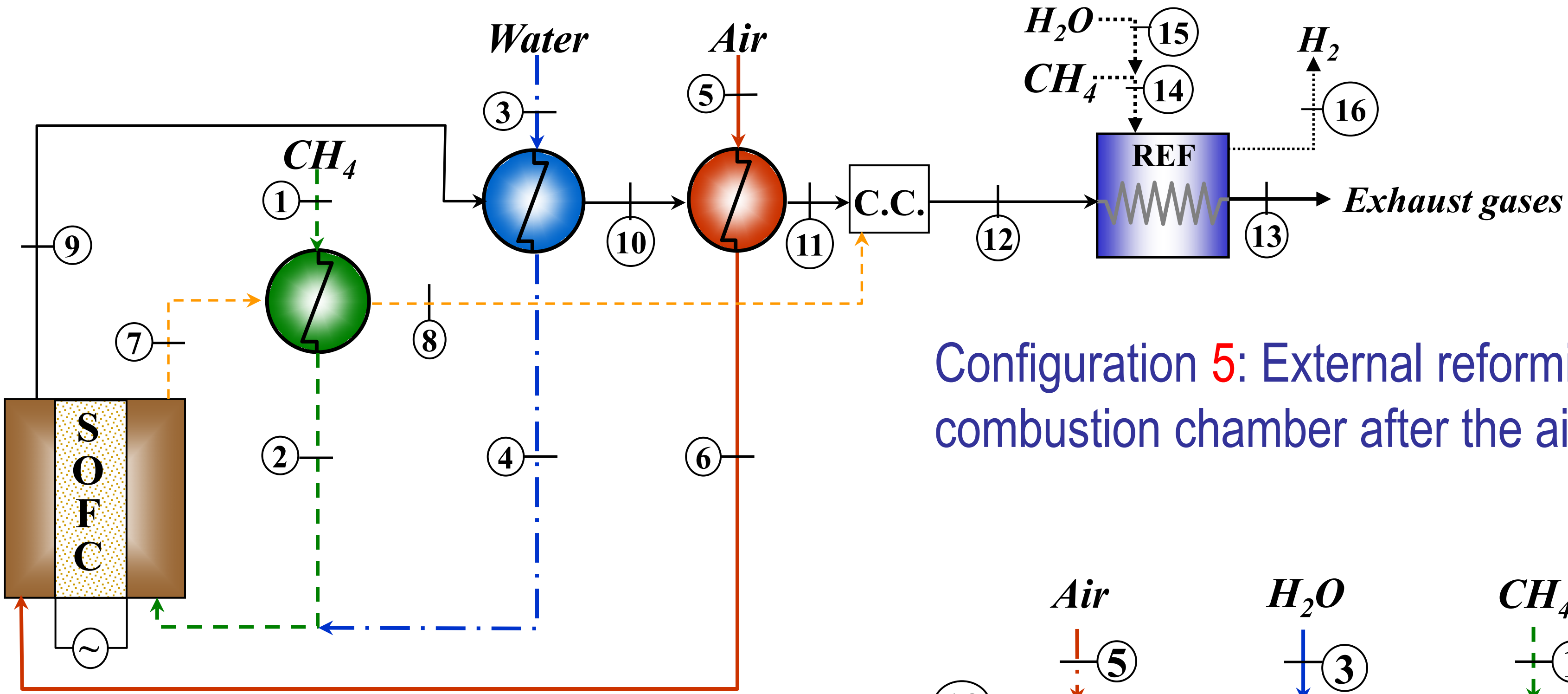
Configuration 1 ⇨ reformer after the air preheater,

Configuration 2 ⇨ reformer after the water preheater,

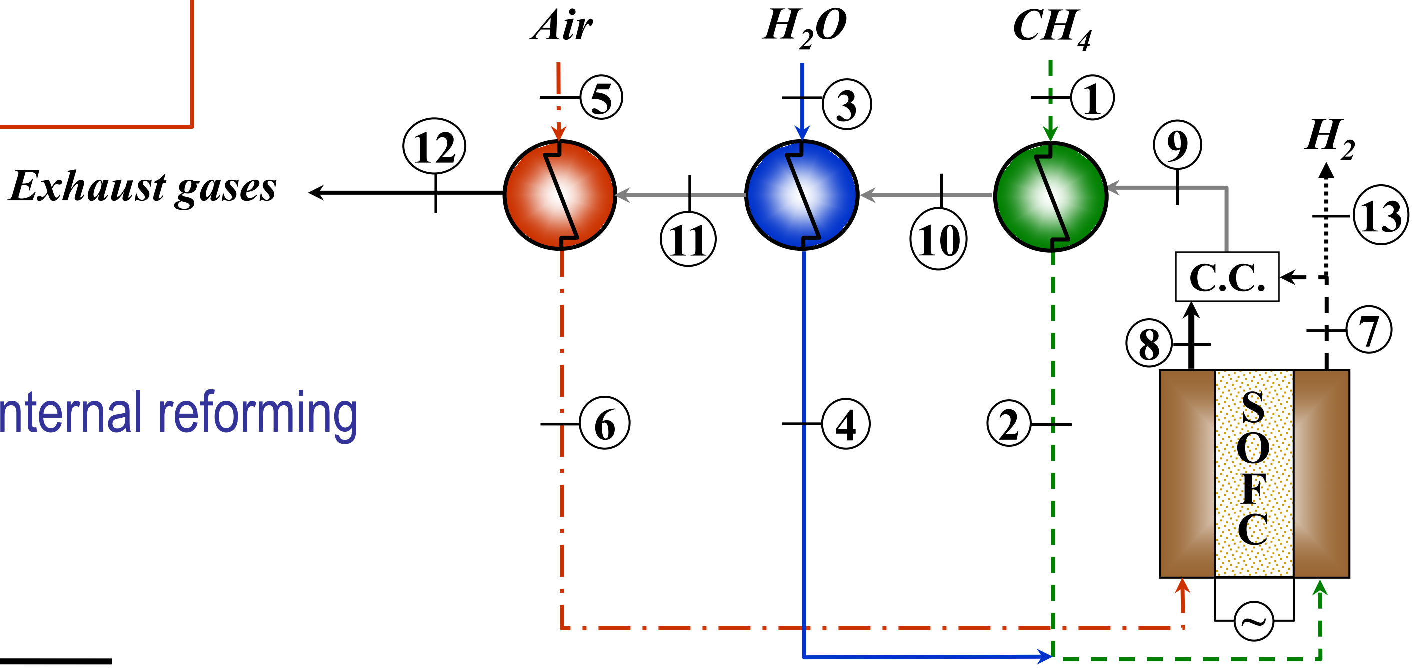
Configuration 3 ⇨ reformer after the natural gas preheater,

Configuration 4 ⇨ reformer after the combustion chamber.

Cycle Configurations



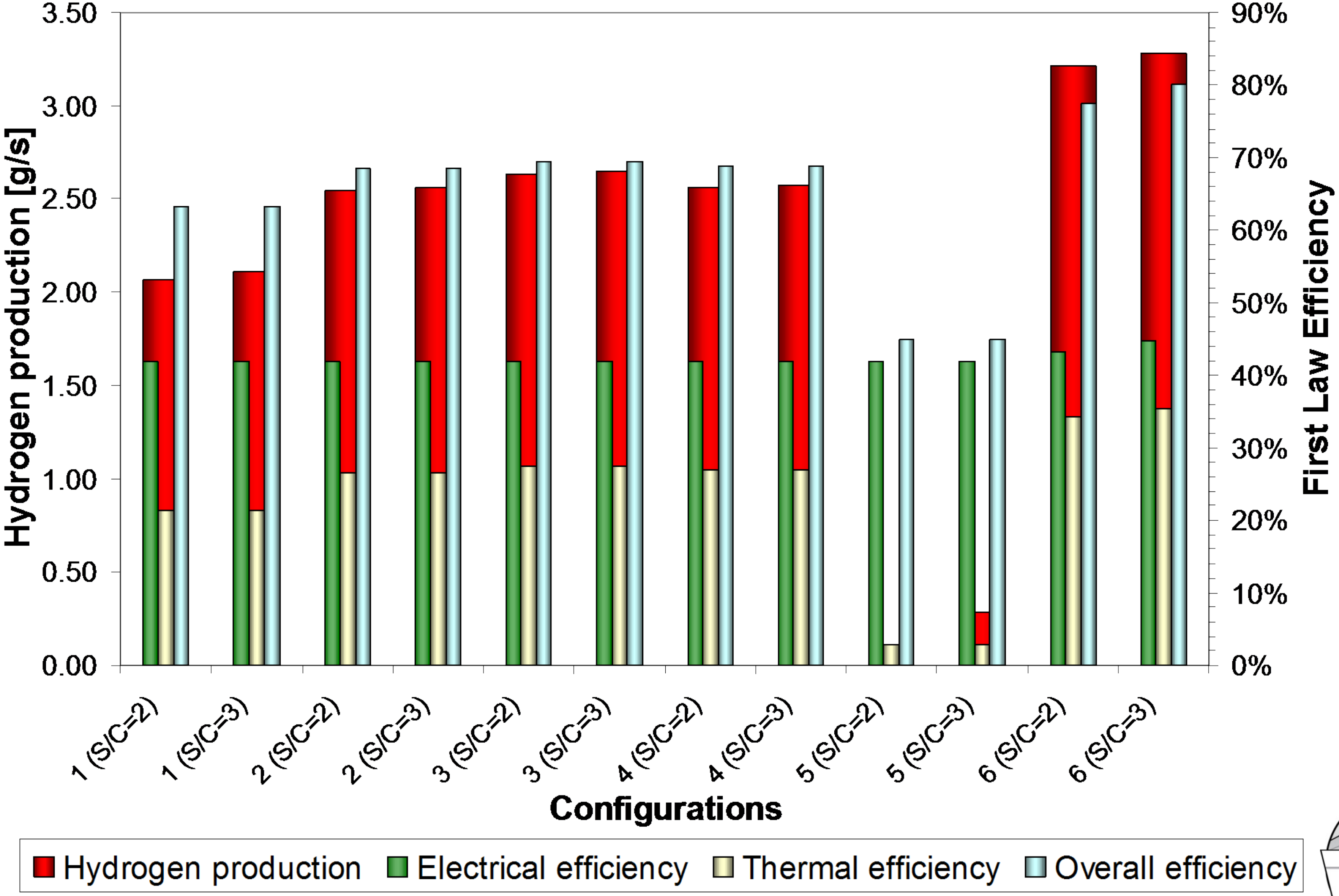
Configuration 5: External reforming with combustion chamber after the air preheater.



Configuration 6: Internal reforming

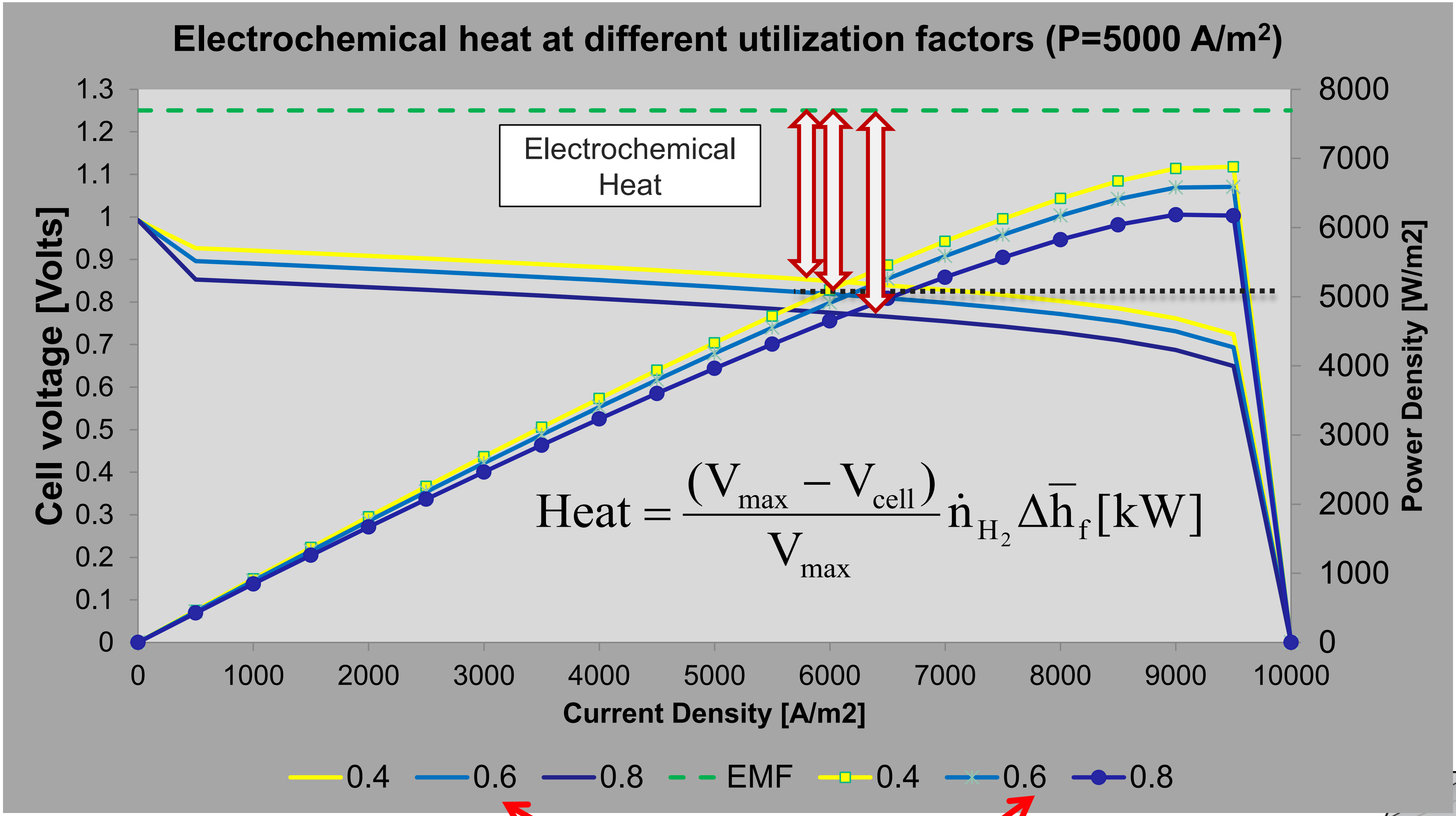
Thermodynamic Analyses

- **Energy performance analysis**



Poly-Generation Analyses

- **Synergy #1: Electrochemical heat & voltage**

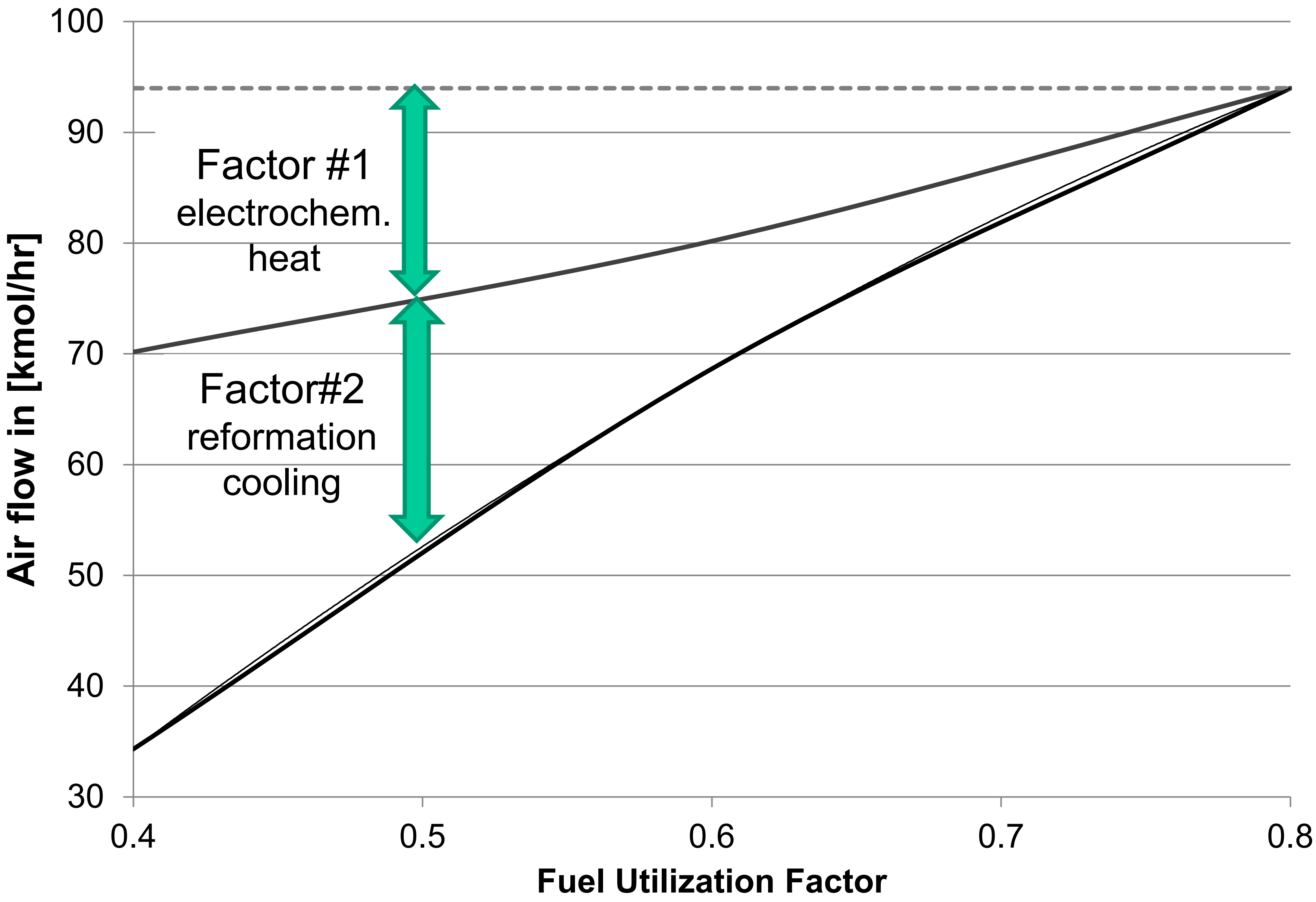


$$\text{Heat} = \frac{(V_{max} - V_{cell})}{V_{max}} \dot{n}_{H_2} \Delta \bar{h}_f [kW]$$

Fuel Utilization Values

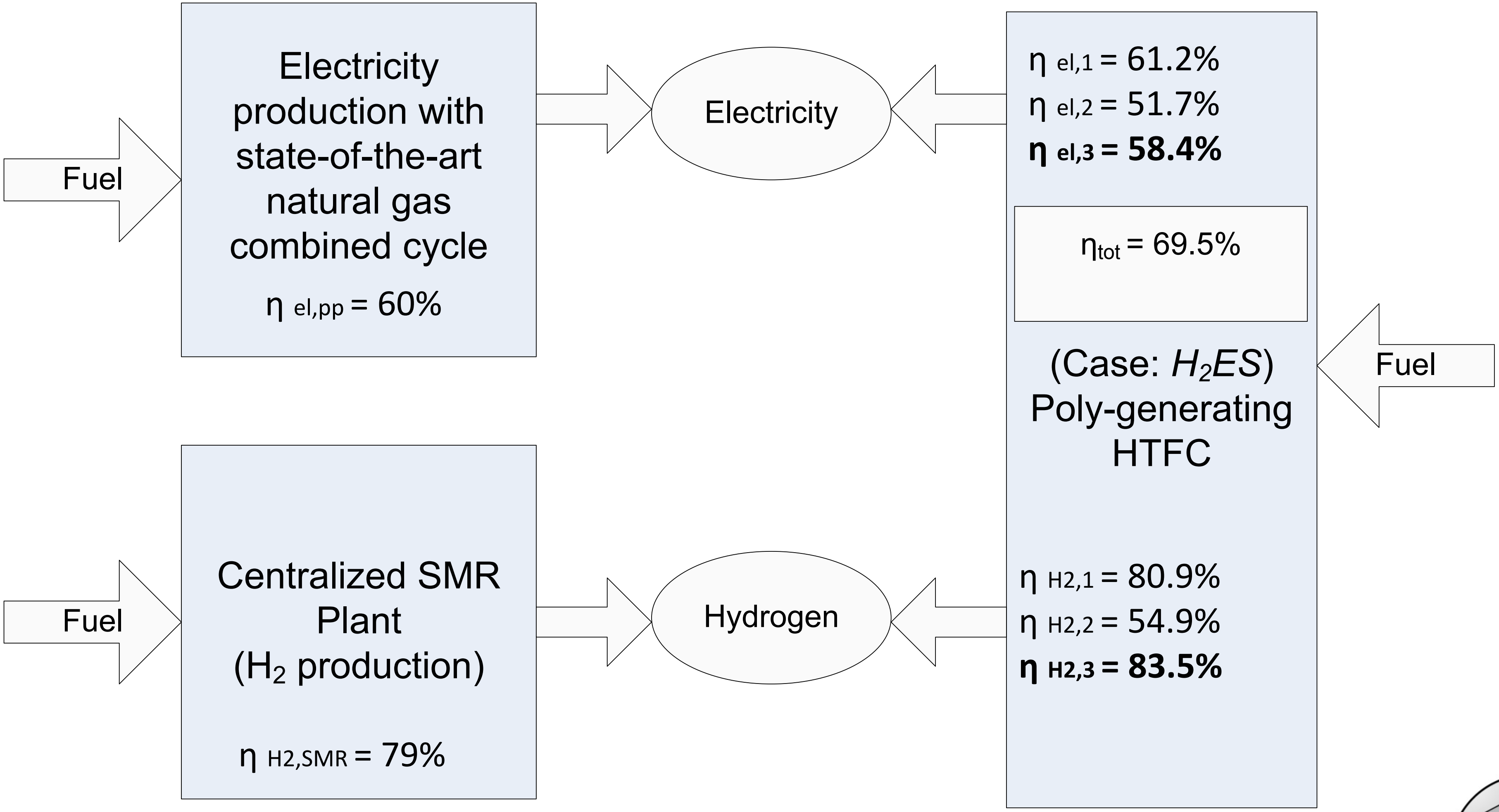
Poly-Generation Analyses

- **Electrochemistry & Reformation Synergy #2 – Air Flow**



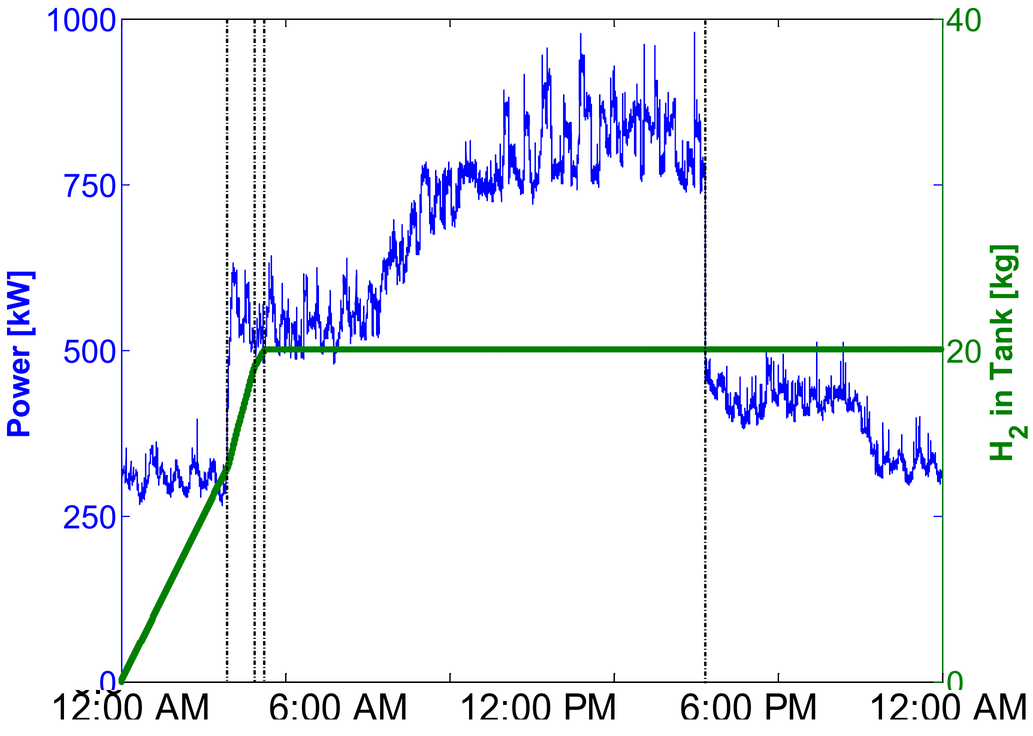
Poly-Generation Analyses

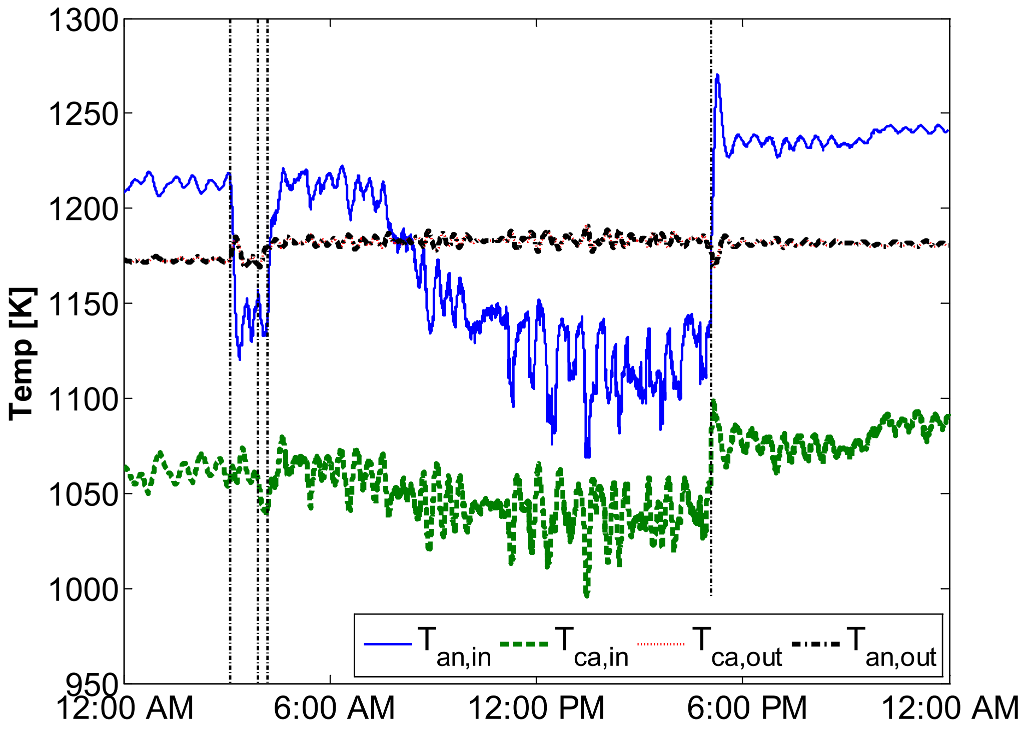
- **<u>EXAMPLE:</u> Efficiency of a Poly-Generating Hydrogen Energy Station (H_2ES) without valuing heat**



Poly-Generation Dynamic Analyses

- Diurnal dynamic operation of SOFC
- Hydrogen tank fills forcing end of tri-generation
- Control of system temperatures during transient is possible





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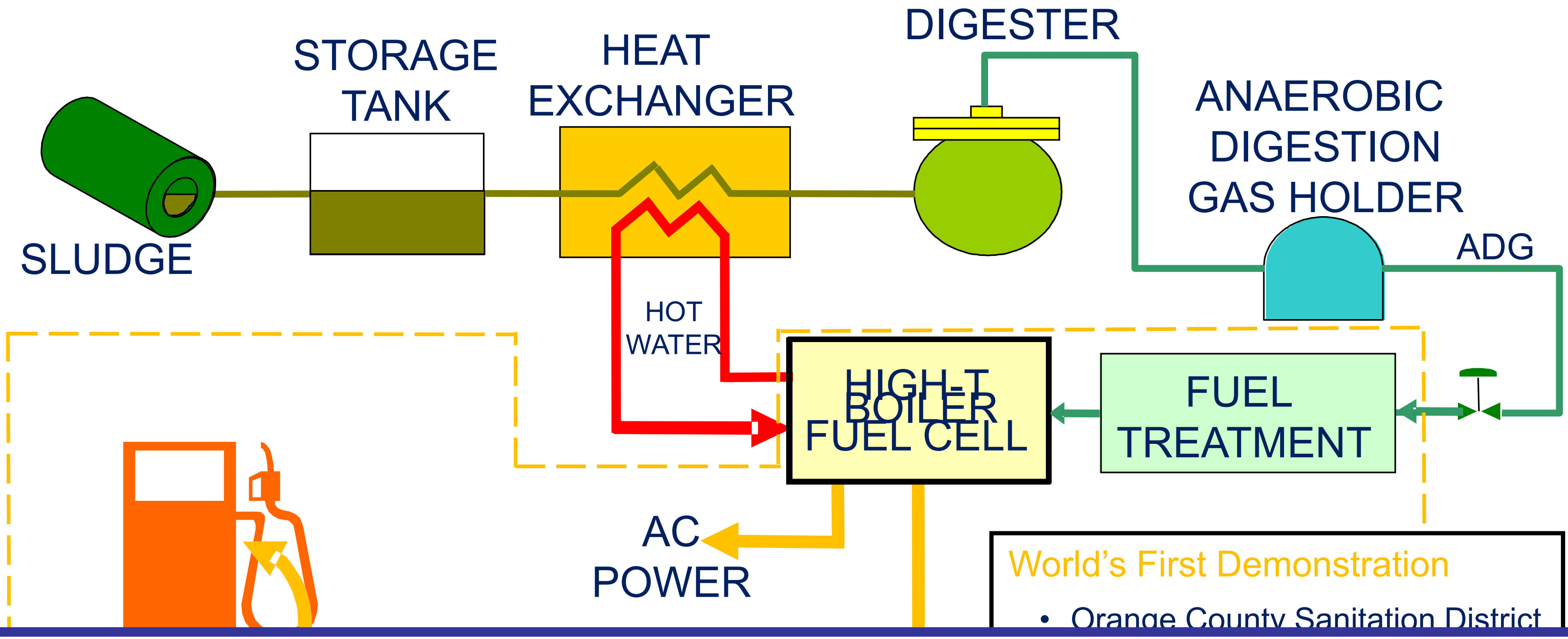
Renewable Tri-Generation of Power, Heat & H_2



Sponsors/Participants:

AIR PRODUCTS

FuelCell Energy

AQMD

U.S. DEPARTMENT OF ENERGY

NATIONAL FUEL CELL RESEARCH CENTER
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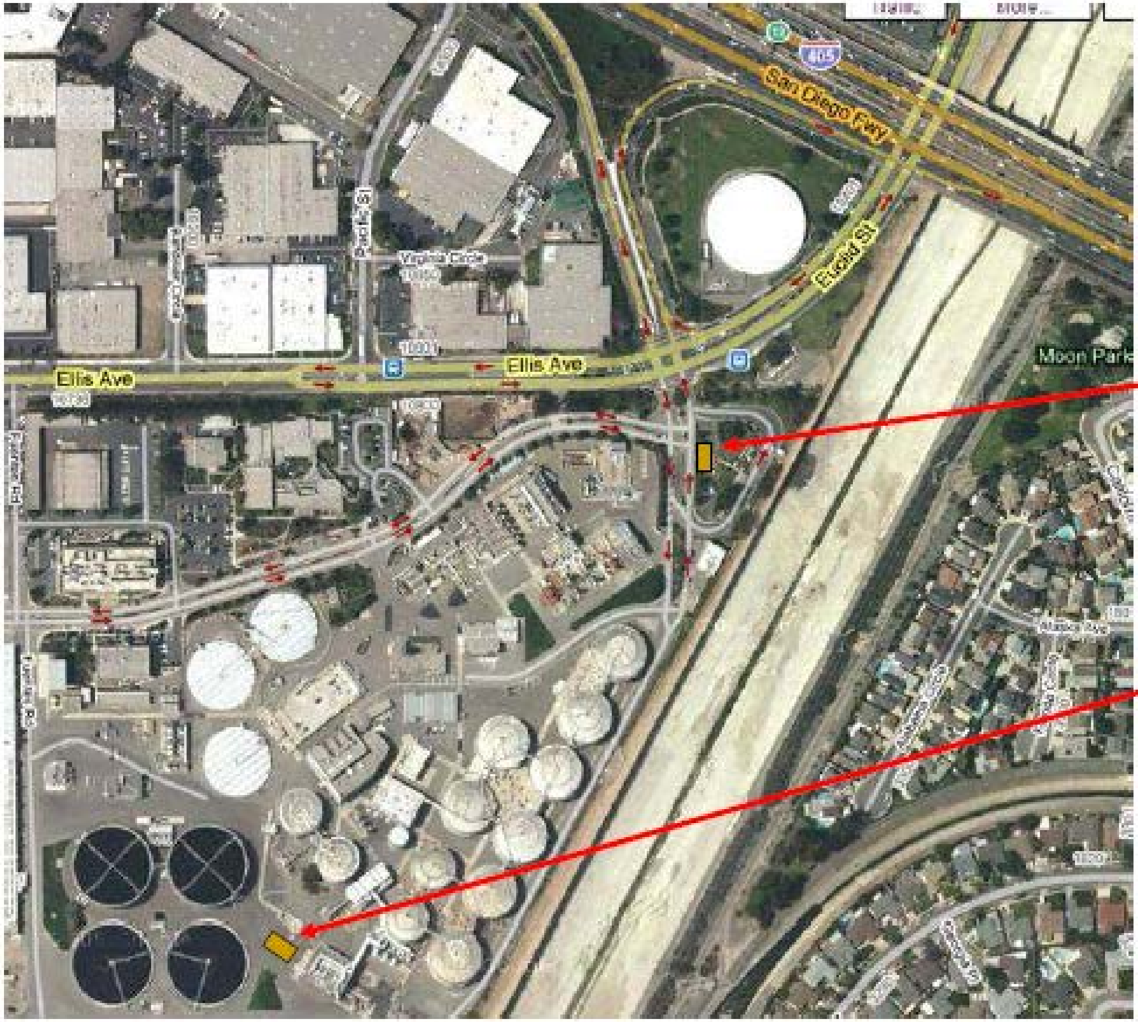
OCSD Project – World's First

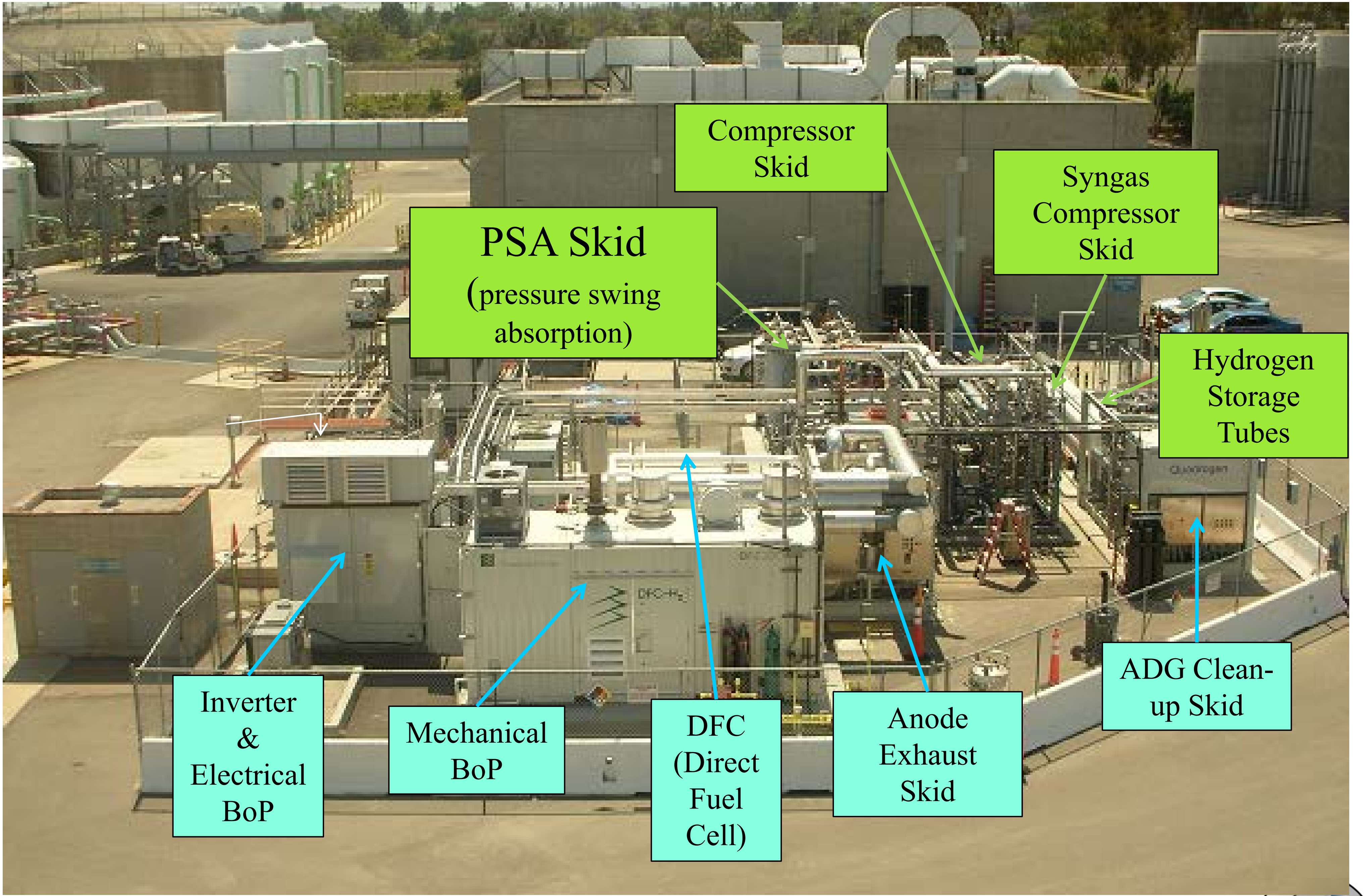
- **Installation complete, Operation on natural gas (6 months), ADG operation underway for ~1 year**



Orange County Sanitation District (OCSD)

Renewable H_2 Filling Station

ADG fueled DFC-H2 ® Production Unit



Air Products Equipment

FCE Equipment

OCSD Project – Status Update

As of December 31, 2011:

- Operation on natural gas from January 1, 2011
- Installation completed in June, 2011 (including ADG skid)
- Operation on ADG: 3,522,591 SCF processed & used
- Electricity produced: 605,512 kWh
- Hydrogen produced: 6,400 lbs (2,902 kg)
- Steady-State performance demonstrated

Method	Efficiency
Total Efficiency *(Elec. + H_2)*	53.2%
Eq. Hydrogen Efficiency	87.0%
Eq. Electrical Efficiency	37.4%

- Significant challenges with grid interconnection, power quality, inverter trips that adversely affect performance

The UC Irvine Team

Thank You For Your Attention!

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