# Fuel Cells for Transportation: Fuel Processing Technology


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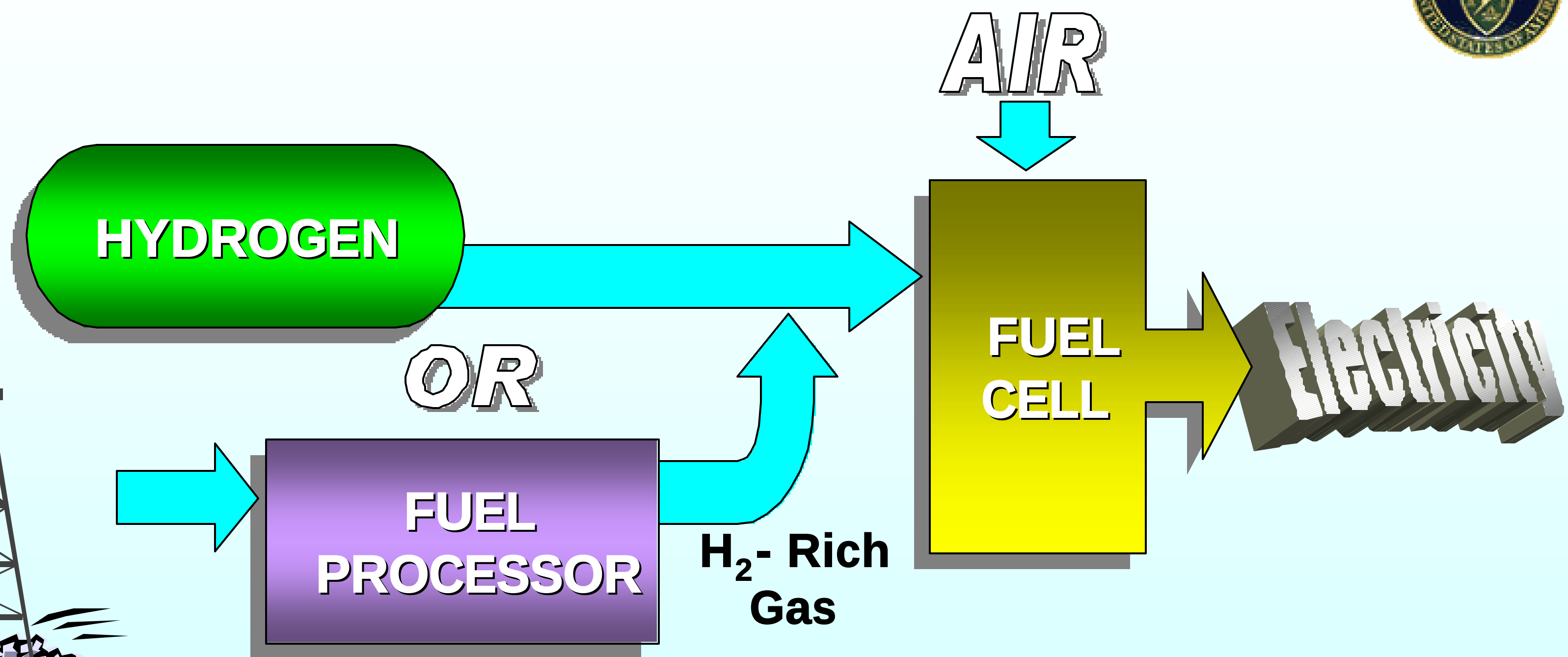
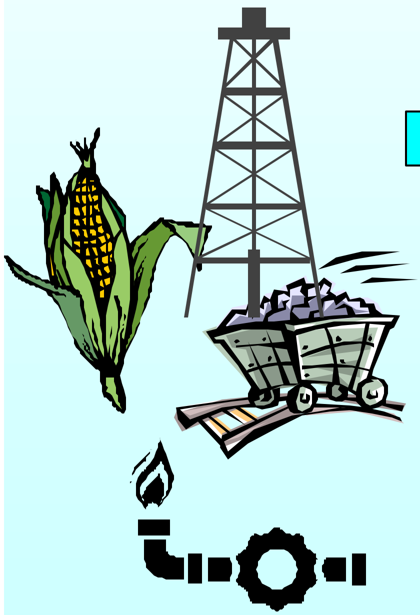
SECA Workshop
February 14-15, 2001
Atlanta, Georgia

# Fuel Options for PEM Transportation Systems



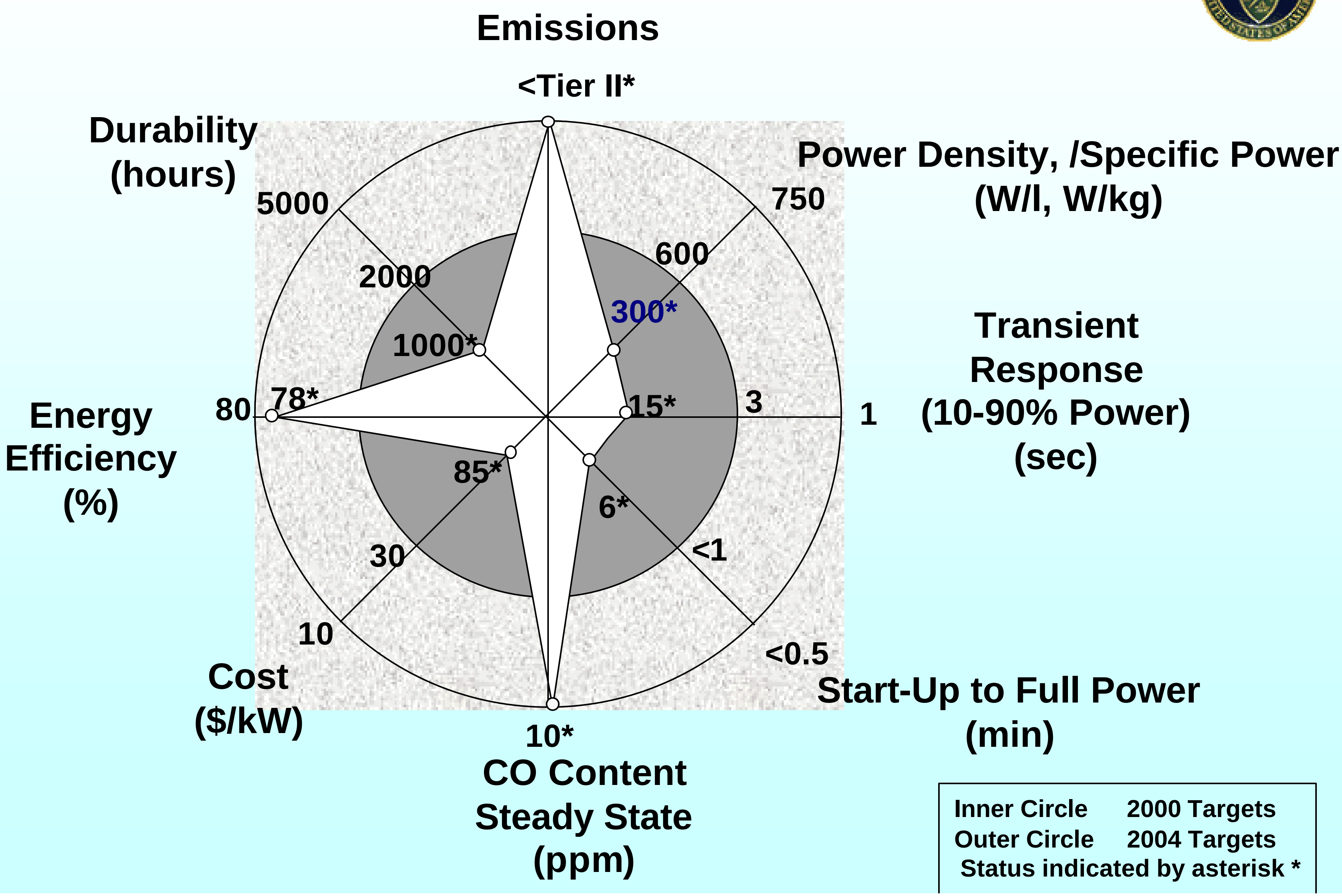



- Hydrogen can be stored and supplied directly to the fuel cell: *Storage and Infrastructure Issues*

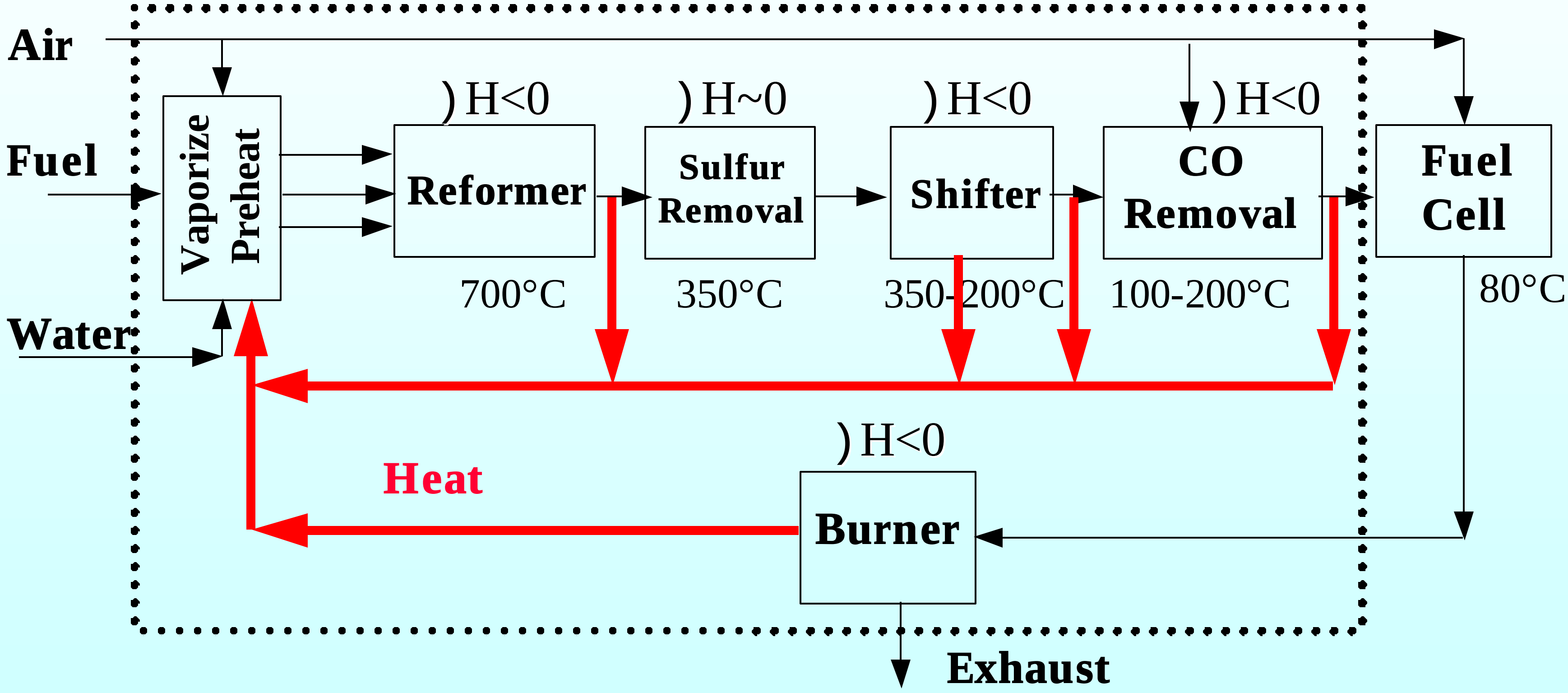
- Hydrogen can be derived from fuels such as ethanol, methanol, natural gas, gasoline or FT fuels: *Complexity, Cost, and Start-up Issues*

# Status vs Technical Targets

## 50-kW Gasoline Fuel Processor for PEM Fuel Cells

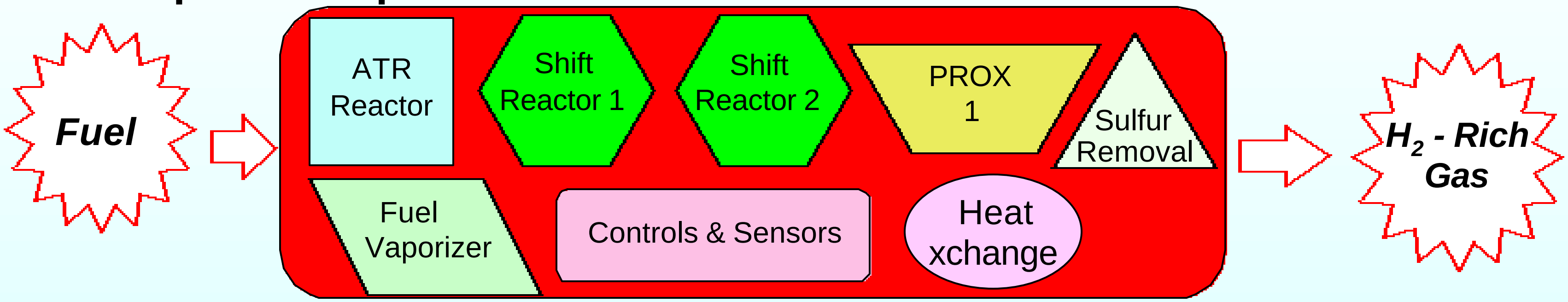


# The PEM System Gasoline Fuel Processor



# Challenges to On-Board Fuel Processing

- Complexity – Complete reformer includes multiple steps.




- Cost – complexity, sophisticated catalysts, control technology and high temperature operation combine to make the cost goal of $10/kW difficult.

- Fuel – "Gasoline" may have to be tailored for the fuel cell application - a moderate infrastructure challenge.

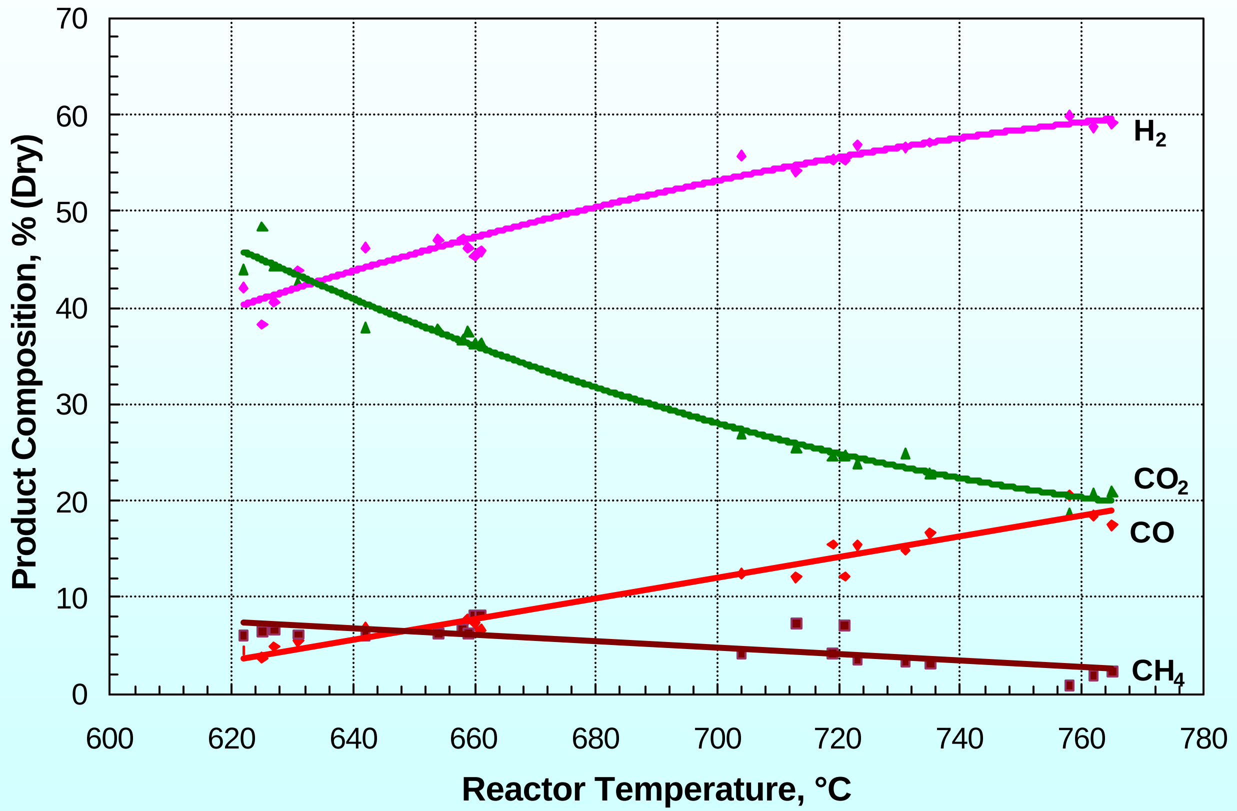
# Autothermal Fuel Processing

***Fuel Flexible & Thermally Favorable***

$$C_nH_mO_p + x(O_2+3.76N_2) + (2n\text{-}2x\text{-}p)H_2O =$$
$$nCO_2 + (2n\text{-}2x\text{-}p+m/2)H_2 + 3.76xN_2$$

- Process control thermodynamics is a function of the oxygen-to-fuel ratio ($x$). $\Delta H = 0$ at $x = 5.86$
  - Lower heat exchange requirements, reducing the size and weight of the fuel processor
  - improved cold starting – initially using high oxygen to fuel ratio
  - Improved transient response – only requires adjustment to feed rate while maintaining constant feed proportions (oxygen-fuel and water-to-fuel)

# Autothermal Reforming of Gasoline Using an ANL Catalyst




- Theoretical maximum hydrogen percentage = 66%
- No performance degradation: 1700 hrs. on gasoline containing 0.01 wt% sulfur

*[1]on a nitrogen-free basis*

# Projects and Funding by Budget Category

## Systems

- Plug Power/NUVERA
- IFC
- Energy Partners, Honeywell
- ANL

**FY01: $7.6M**

## Fuel Processing

- NUVERA
- IFC
- McDermott
- Plug Power
- Honeywell
- Arcadis
- U. Michigan/Nextech
- ANL, LANL, PNNL

**FY01: $21.5M**

## Stack Subsystem Components

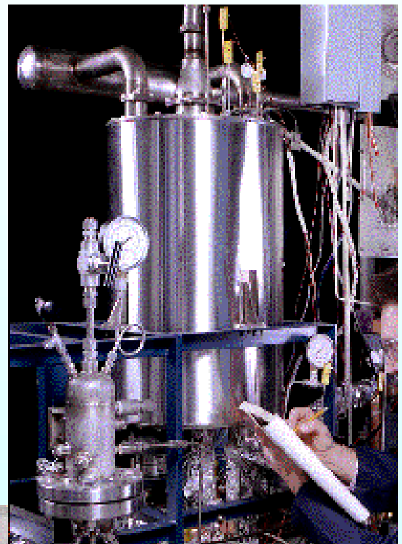
- Energy Partners, AlliedSignal, IFC, Plug Power
- IGT, Electrochem
- 3M, SwRI/Gore, Foster-Miller
- Vairex, A.D. Little, Honeywell, Meruit
- Spectracorp
- LANL, LBNL

**FY01: $12.4M**

**Total FY 01 Budget: $41.5M**

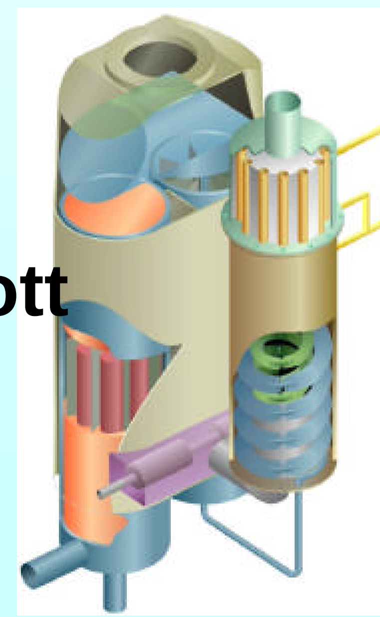
# Fuel-flexible Fuel Processors Under Development

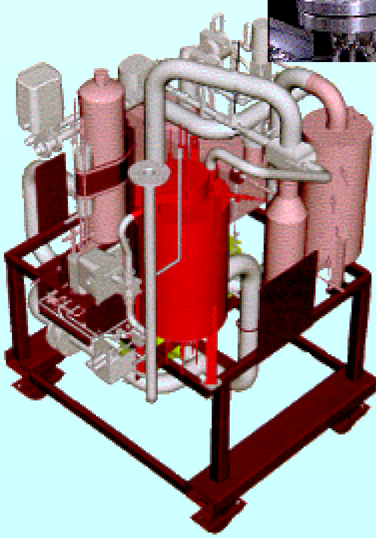
Nuvera



Argonne

McDermott

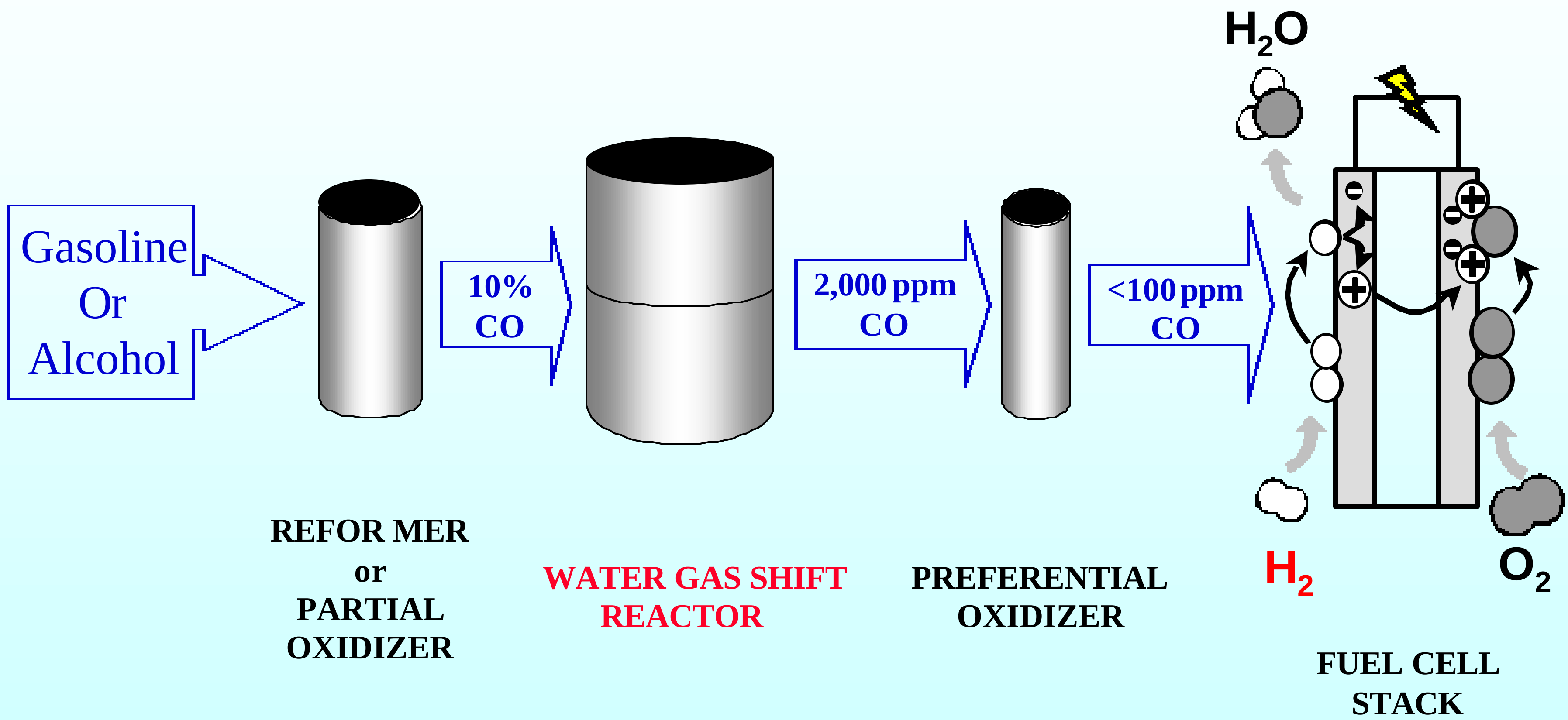




International Fuel Cells

# Shift Catalyst Work

## *U. of Mich – Nextech – NUVERA – IFC - McDermott*

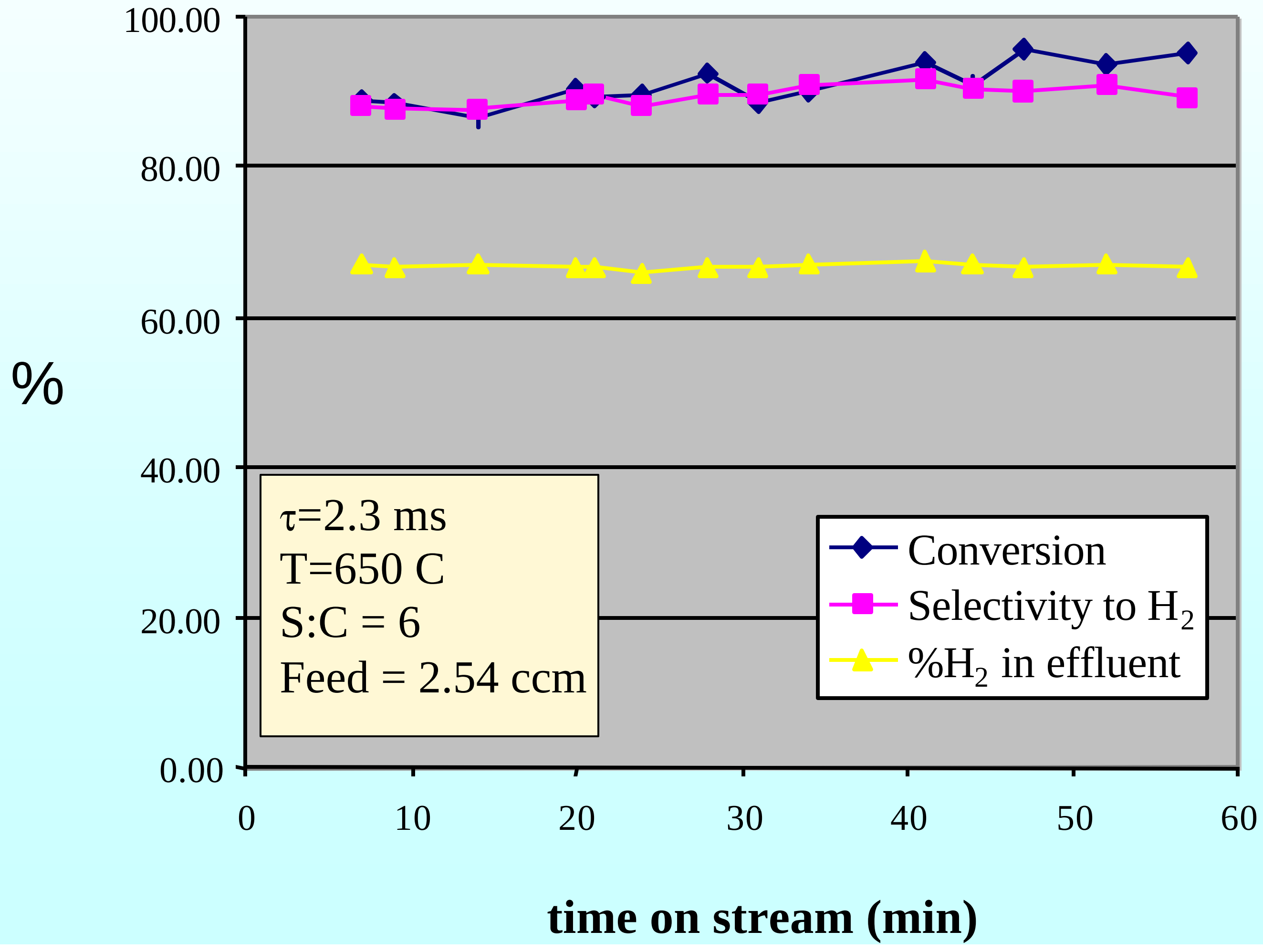



$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H = -9.7\ \text{kcal/mol}$$

# Microchannel Iso-Octane Steam Reforming
# PNNL

***Technical feasibility of microchannel steam reforming established***

**Complete fuel processor system: < 1 ft³**

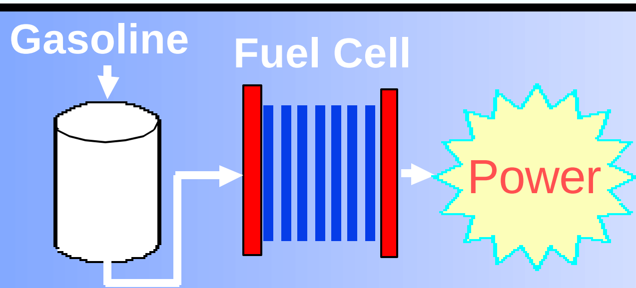



- **13kW Achieved**
- **98.6 Fuel Conversion**
- **2100 W/L**

# Progress in Fuel-Flexible Fuel Processing

***Full Scale Fuel Processing Being Demonstrated***

**1997:**

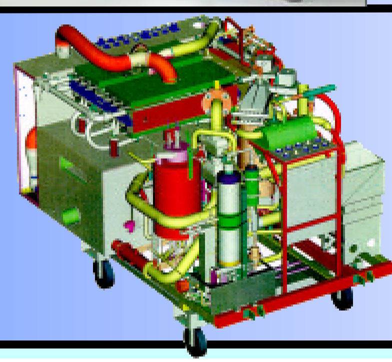



**World's First Demonstration of PEM Fuel Cell Power from Gasoline - <1kW**

**1999:**

**Plug Power & Epyx (NUVERA) Demonstrate 10kW System on Multiple Fuels Including Gasoline, Methanol, and Ethanol**

**2000:**



**IFC Demonstrates 50 kW, Automated System on Gasoline. Plug Power/NUVERA System Demonstrated.**

# The Program Supports Diesel Reforming in Two Ways

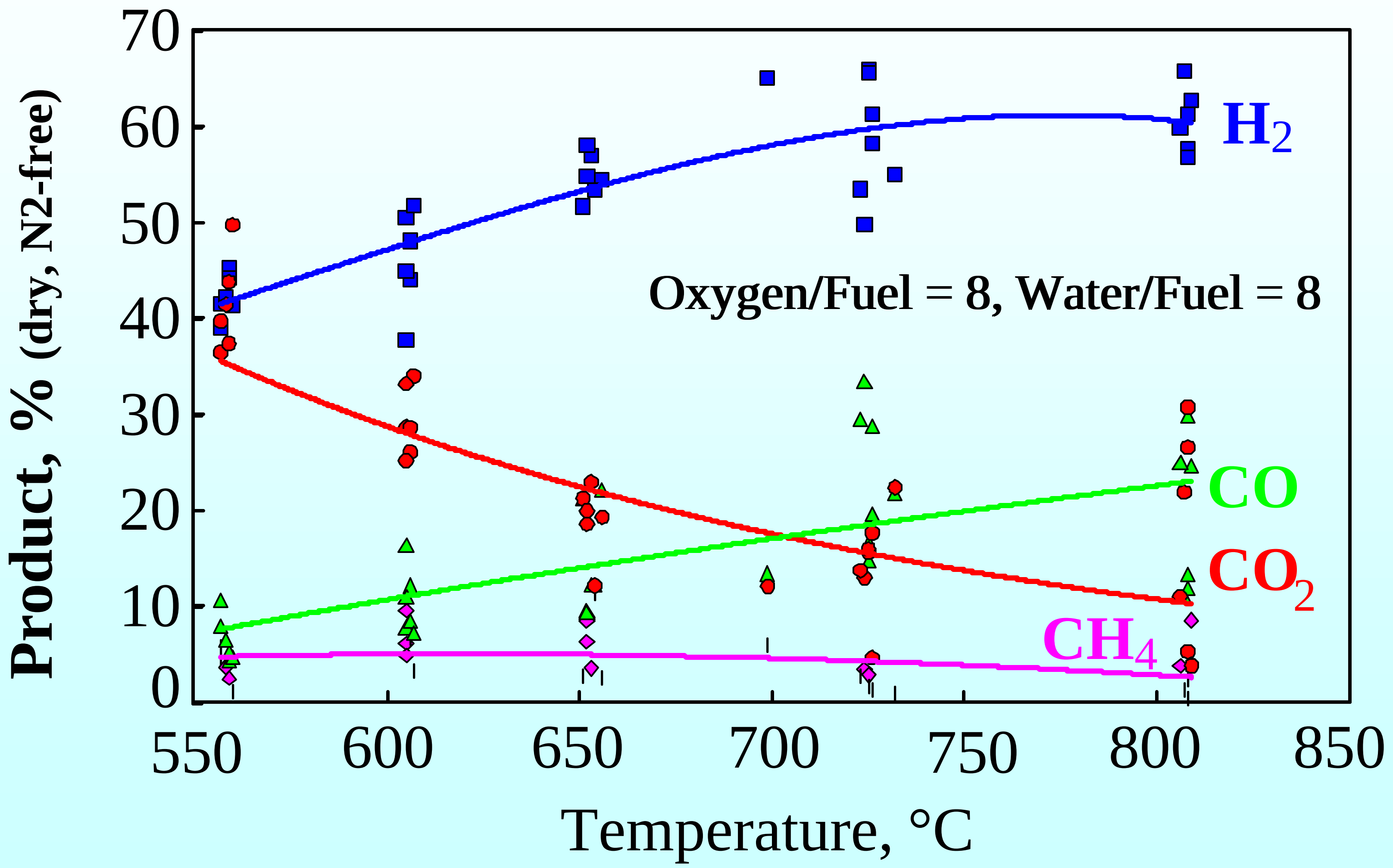
## PEM Reformers Indirectly Support Diesel:

- **CO clean-up projects all directly applicable to diesel reforming.**
- **ANL autothermal catalyst, Nextech and U. of Michigan shift catalysts applicable to a diesel reformer.**
- **Initiating a significant sensors effort necessary for control of all types of reformers.**
- **A large part of our program focuses on reformate tolerant stacks, necessary for any type of reformed fuel PEM system.**

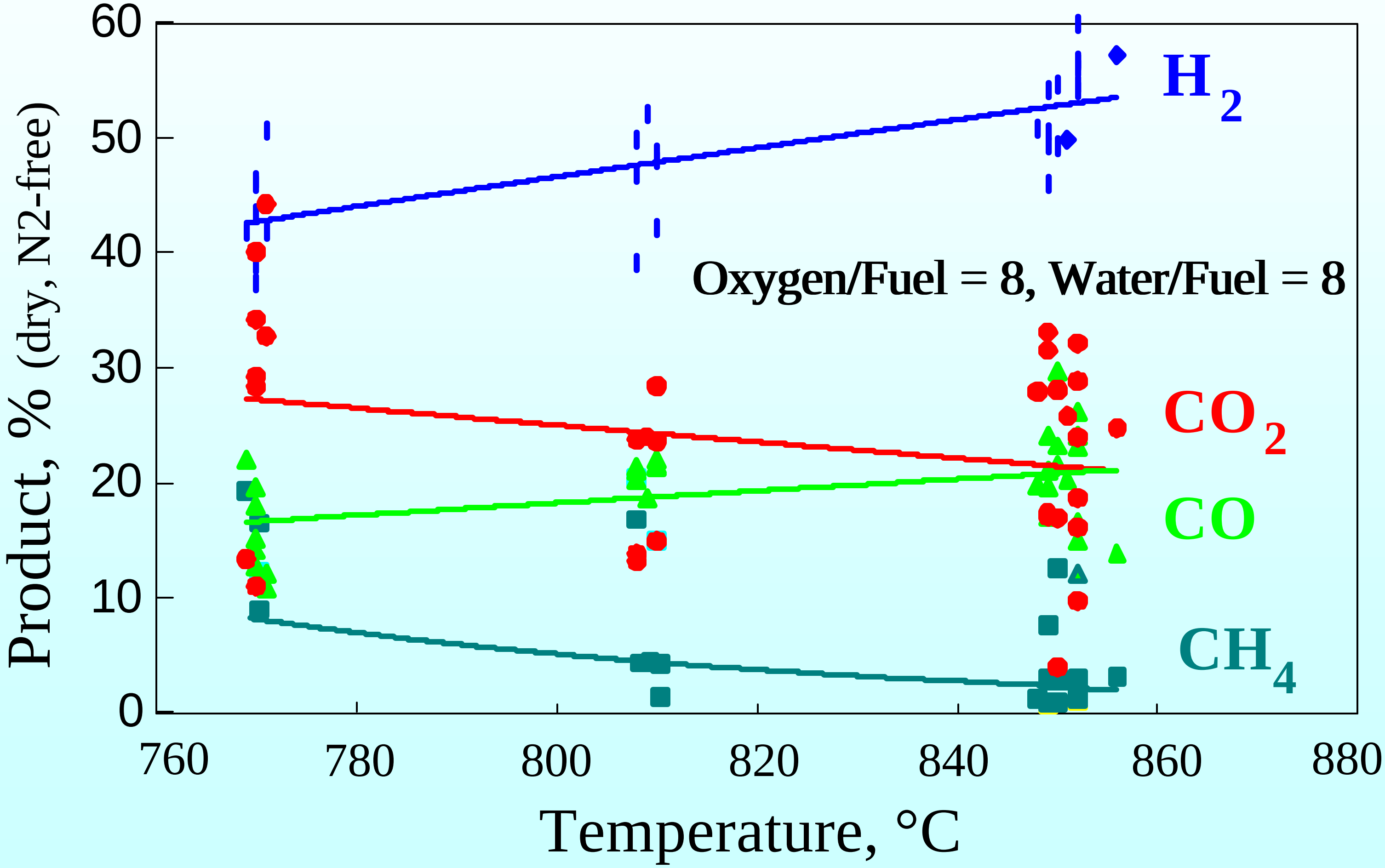
## Direct Support of Diesel for Solid Oxide:

- **Diesel reforming work at ANL initiated by DOE Hydrogen program being continued for solid-oxide applications.**
- **Work at LANL being initiated**

# Suitable process temperature for hexadecane is 750°C



# Autothermal reforming of diesel (D-2) fuel yielded 50% $H_2$



# Issues in Diesel Processing for SECA

- Fuel vaporization
  - Solution: liquid fuel injection
- Coke formation
  - Solutions: catalyst, high temperature, excess water
  - Would like to reduce the amount of water used
- Sulfur poisoning
  - Solution: S-tolerant catalyst, scrubber
  - High temperature sulfur removal is a potential issue
- Byproduct hydrocarbons
  - Solution: catalyst selectivity, high temperature
- Solid Oxide reformer potentially 1/10th the size of a PEM reformer, except for sulfur removal issue

# Current Solicitation Addresses Key Fuel Processing Barriers

**Solicitation Website:**
**www.doeal.gov/cpd/readroom.htm**

- Advanced fuel processing technology
- Water-gas shift catalysts
- Balance of plant (sensors, actuators, heat exchangers)

**Solicitation Closes February 15**