# Development of a kW Prototype Coal-based Fuel Cell

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FCP 41

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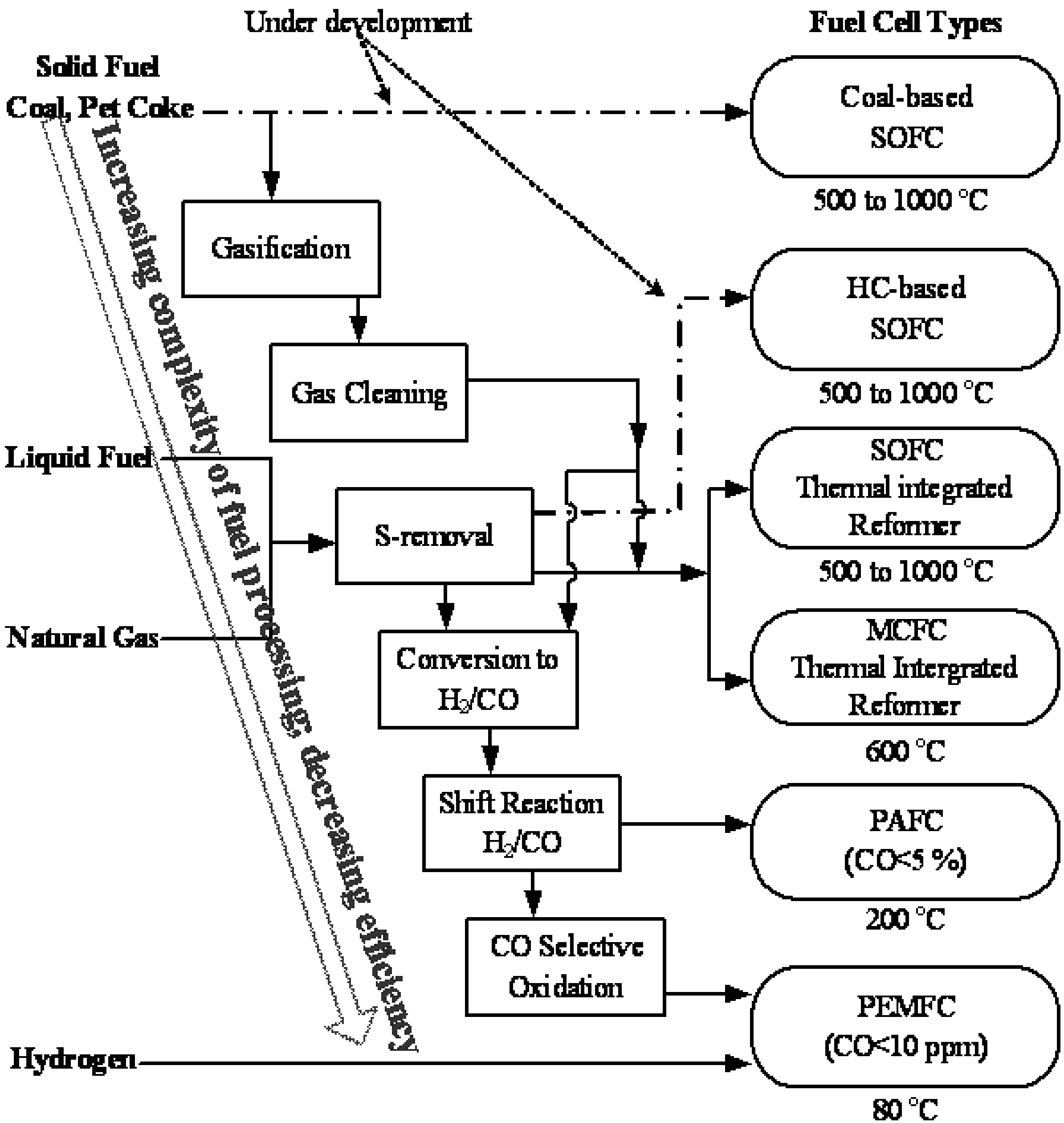
This presentation does not contain any proprietary or confidential information

# Relationship between fuel processing and fuel cells

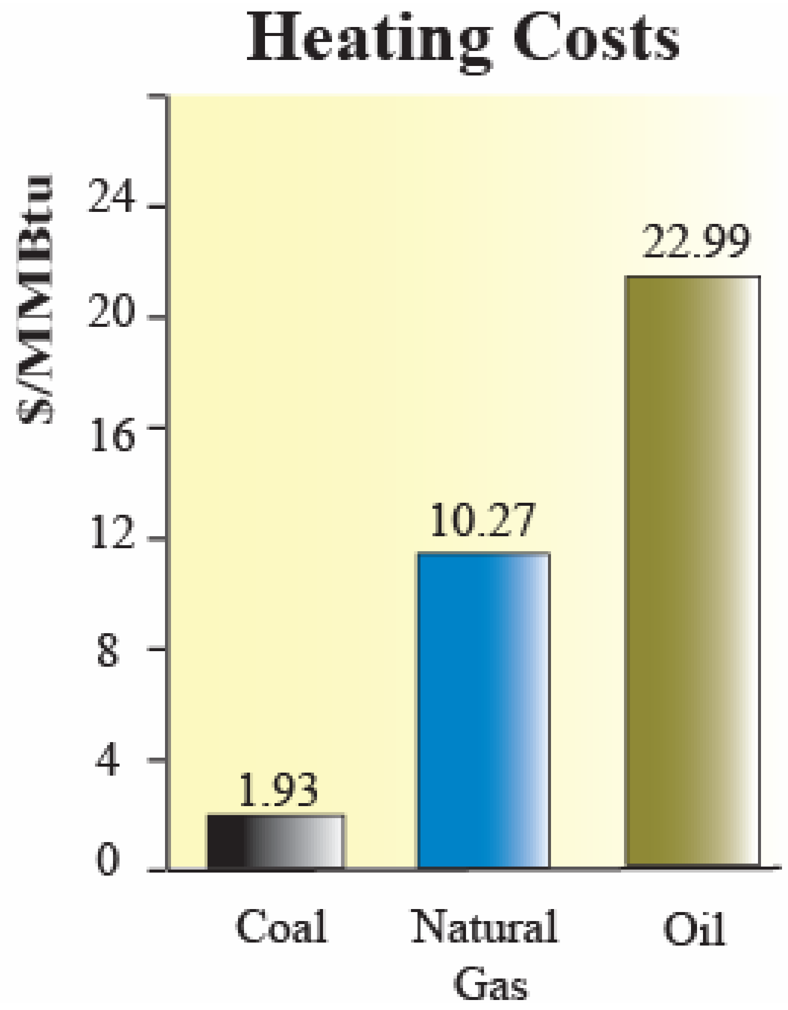



Ref: N.F. Brandon, S. Skinner, B.C.H. Steele, *Annu. Rev. Mater. Res.* **2003. 33:183-213**

# Coal is Important

- Abundant domestic reserves
- Low and stable prices
- Provide > ½ nation's electricity
- Future source of $H_2$

- Economic prosperity
- Energy security

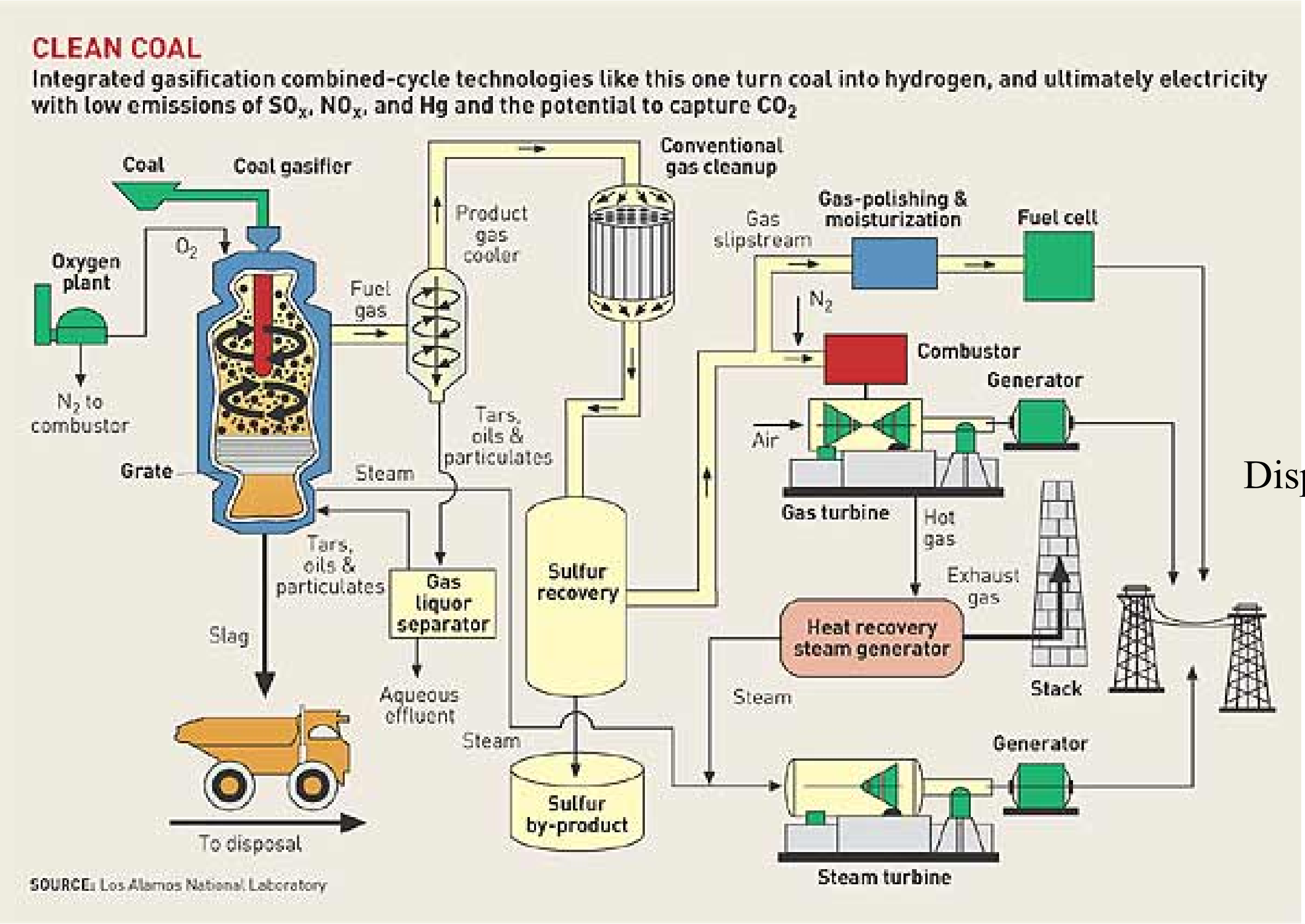



1. Prices current as of Jan-March 2005 (www.eia.doe.gov)
2. Natural Gas prices DOE (Average Commercial Prices)
3. Gasoline & Diesel Fuel Prices (tonto.eia.doe.gov)

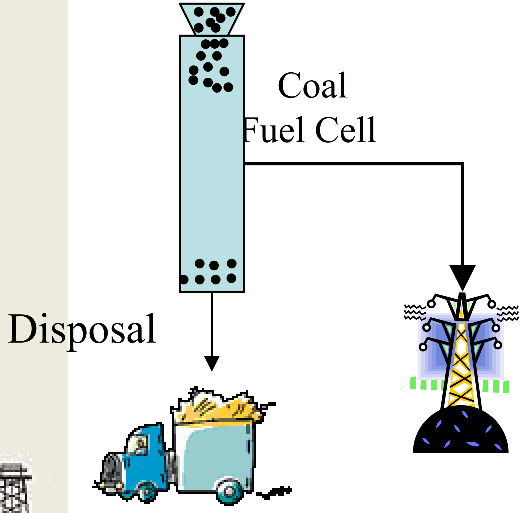
NETL

Rita Bajura, CCPI-Round 2, Planning Workshop, Aug. 23, 2003_

# Coal Gasification + Cleaning + Syngas Fuel Cell and Turbine/ Generator

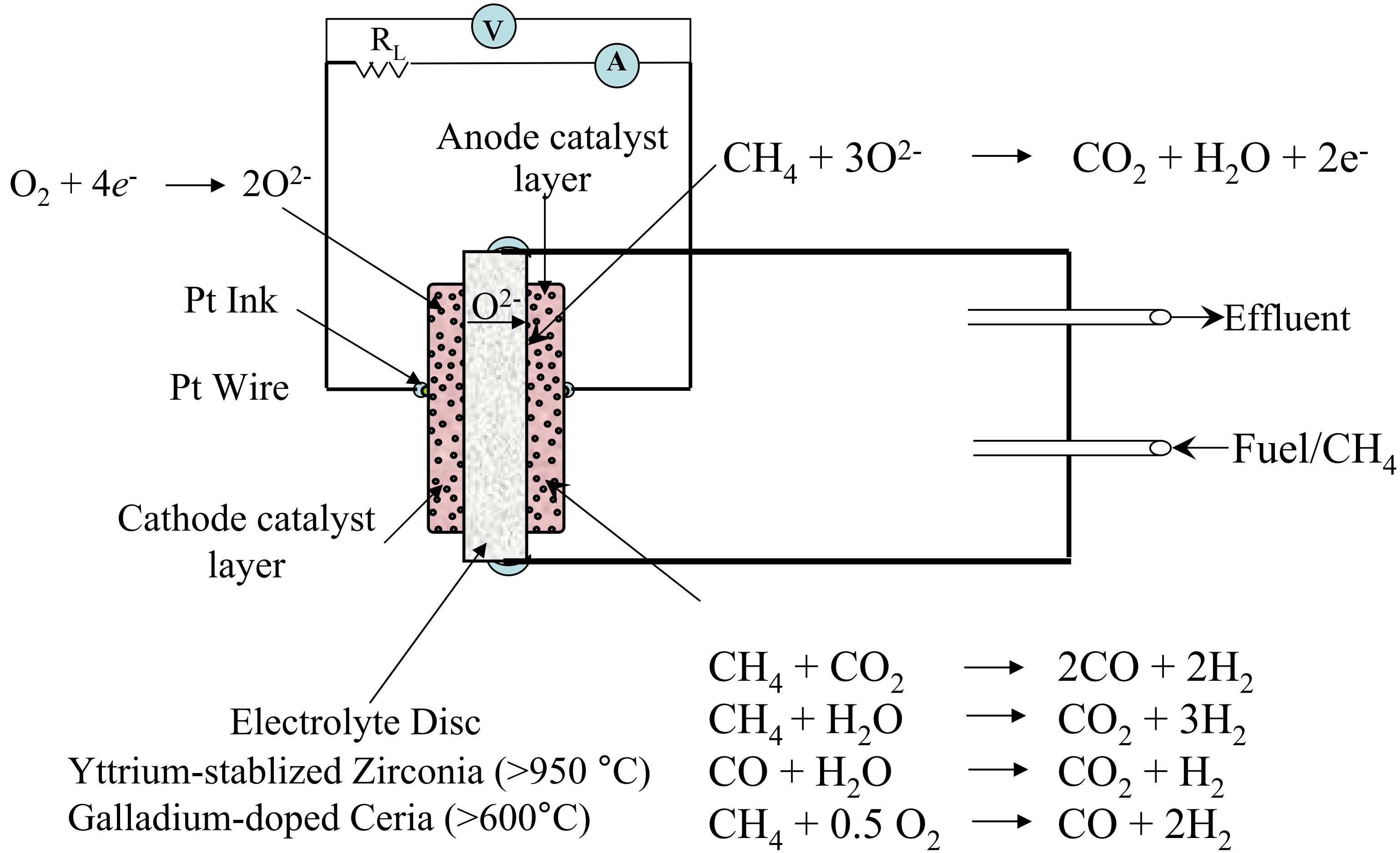



## Coal-based Fuel Cell



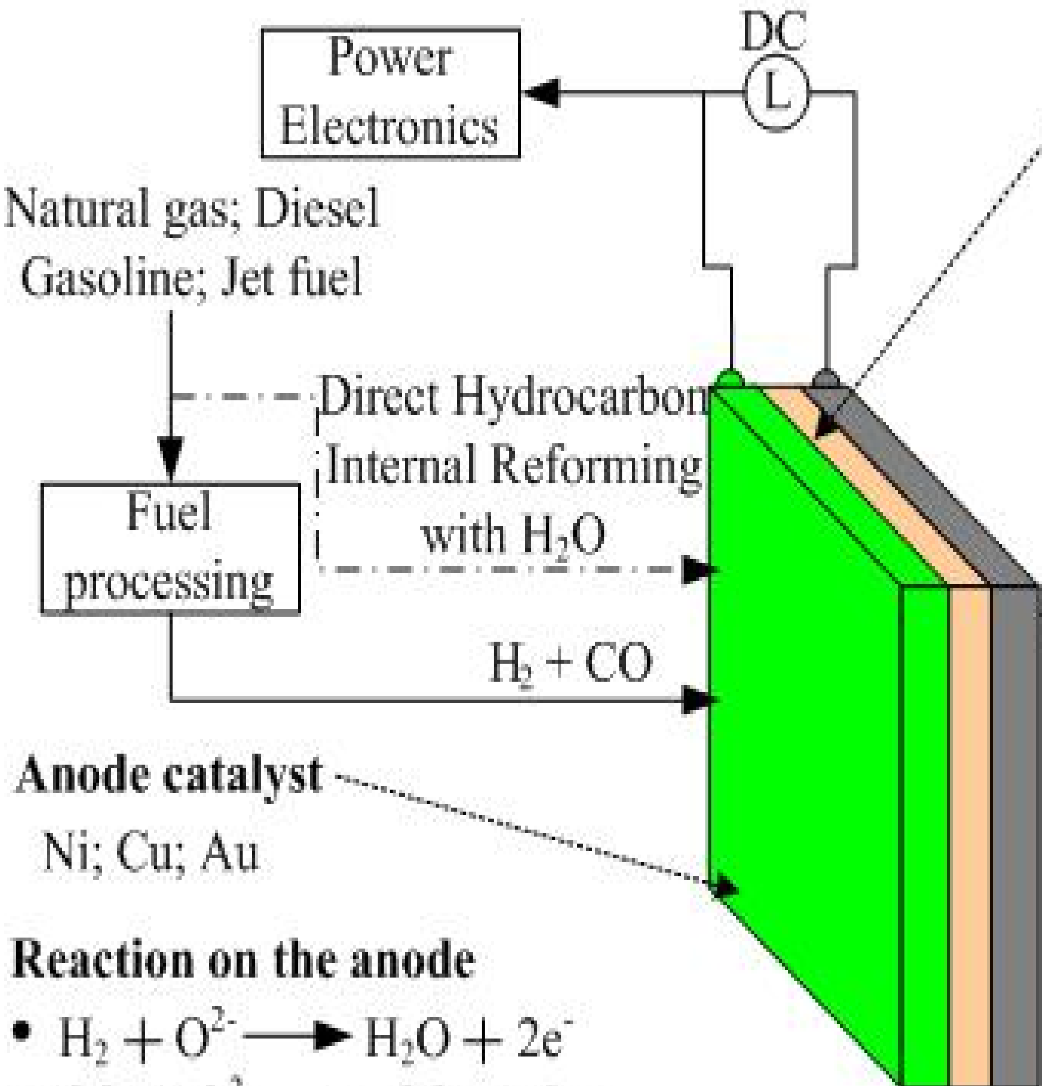

Source: The University of Akron

J. Johnson, Volume 82, Number 08, Chemical & Engineering News, February 23, 2004




| A | $O_{ad}$ | Products | T (°C) |
|---|---|---|---|
| $CH_4$ | $O_{ad} \rightarrow$ | $CO, H_2, CO_2, H_2O$ | 600-1200 |
| $C_nH_{2n}$ | $O_{ad} \rightarrow$ | $C_nH_{2n}O, CO_2, H_2O$ | |
| **C** | **$O_{ad} \rightarrow$** | **$CO_2$** | 550-950 |

# SOFC Materials and Reactions




**Electrolyte**

$(ZrO_2)_{0.92}(Y_2O_3)_{0.08}$ (YSZ)

$Sc_2O_3$; $Y_2O_3$; $Yb_2O_3$; $Bi_2O_2$

$(Bi_2O_7)_{0.75}(Y_2O_3)_{0.25}$

$(La_2O_3)_{0.95}(SrO)_{0.05}$

$BaTh_{0.9}Gd_{0.1}O_3$; $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$

$(Ce_2)_{0.8}(GdO_{0.5})_{0.2}$; $(ZrO_2)_{0.9}(Sc_2O_3)_{0.1}$

$(ZrO_2)_{0.9}(Y_2O_3)_{0.1}$; $(ZrO_2)_{0.87}(CaO)_{0.13}$

**Cathode catalyst**

$La_{0.95}Sr_{0.05}MnO_3$ (LSM); $LaMnO_3$

$La_{0.8}Sr_{0.2}FeO_3$ (LSF); $La_xSr_yMn_3$

$La_{0.6}Sr_{0.4}Fe_{0.8}Co_{0.2}O_3$ (LSCF)

$Sm_{0.5}Sr_{0.5}CoO_3$ (SSC); $La_{0.99}MnO$

$YBa_2Cu_3O_y$; $La_xCa_yMnO_3$

**Anode catalyst**

Ni; Cu; Au

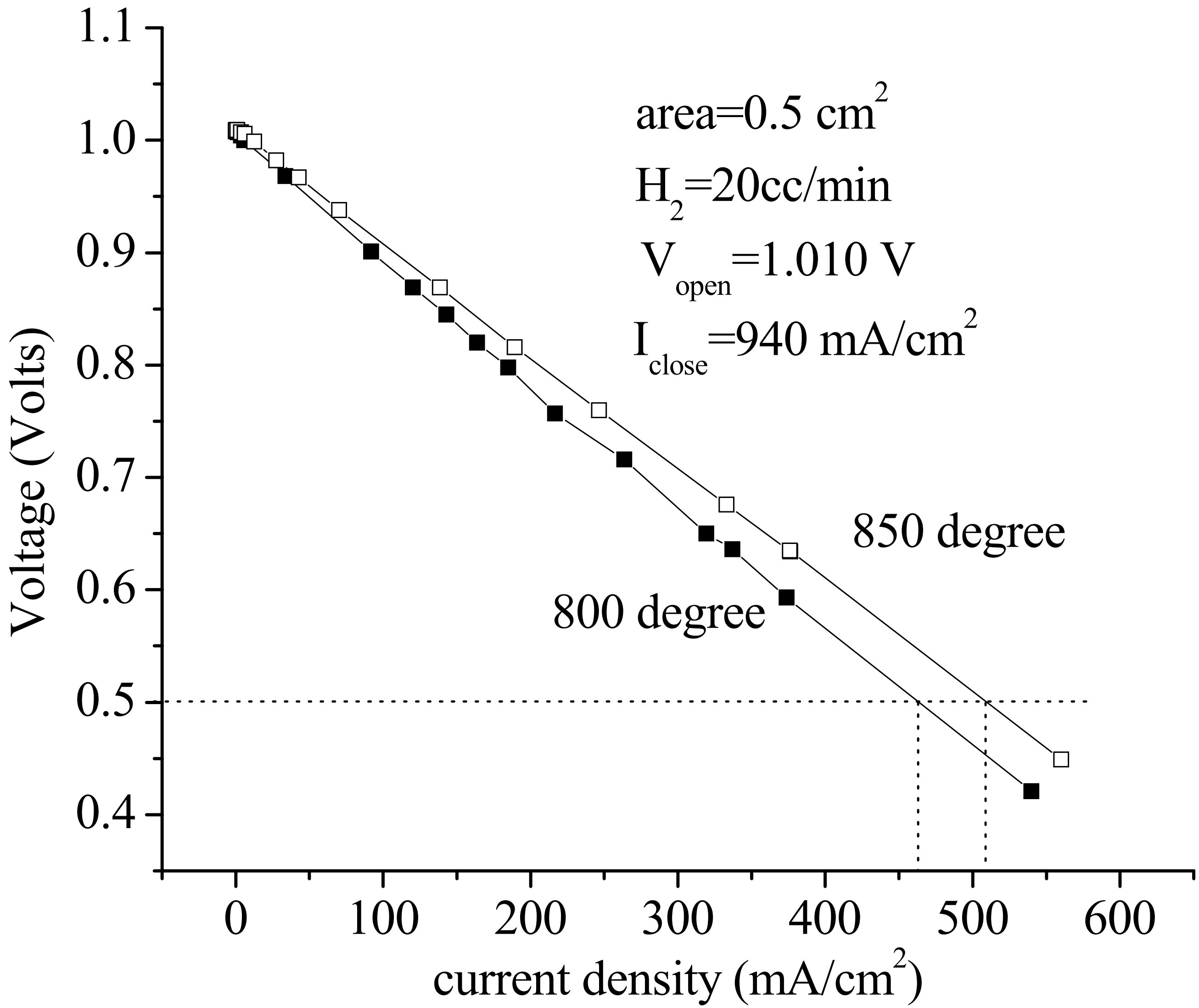
**Reaction on the anode**

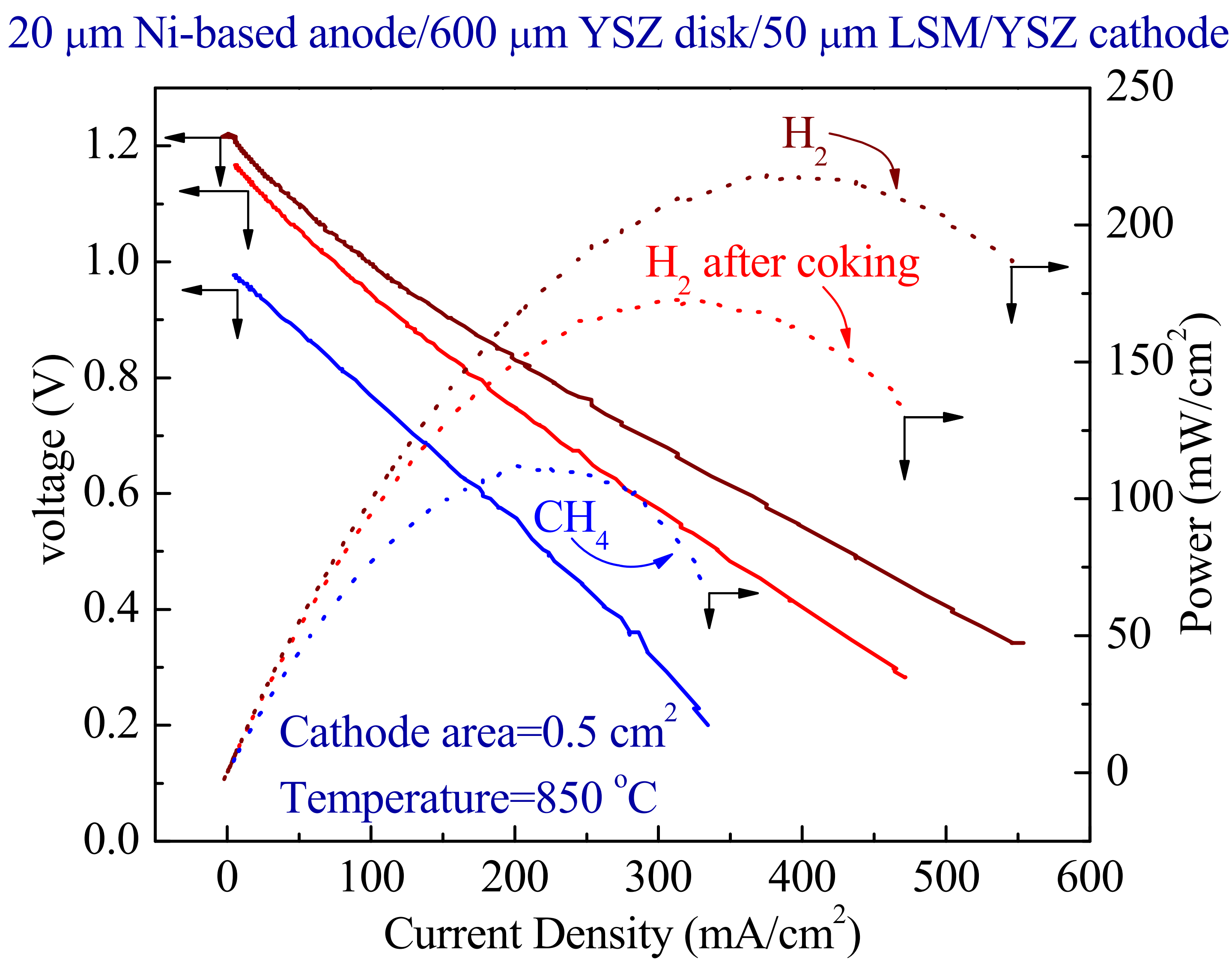
- $H_2 + O^{2-} \longrightarrow H_2O + 2e^-$
- $CO + O^{2-} \longrightarrow CO_2 + 2e^-$
- $CH_4 \longrightarrow C \text{ (anode deposit)} + 2H_2$
- $C + 2O^{2-} \longrightarrow CO_2 + 4e^-$

**Reaction on the cathode**

- $2e^- + O_2 \longrightarrow 2O^{2-}$

# Ni/YSZ-Anode-supported fuel cell with $H_2$ feed



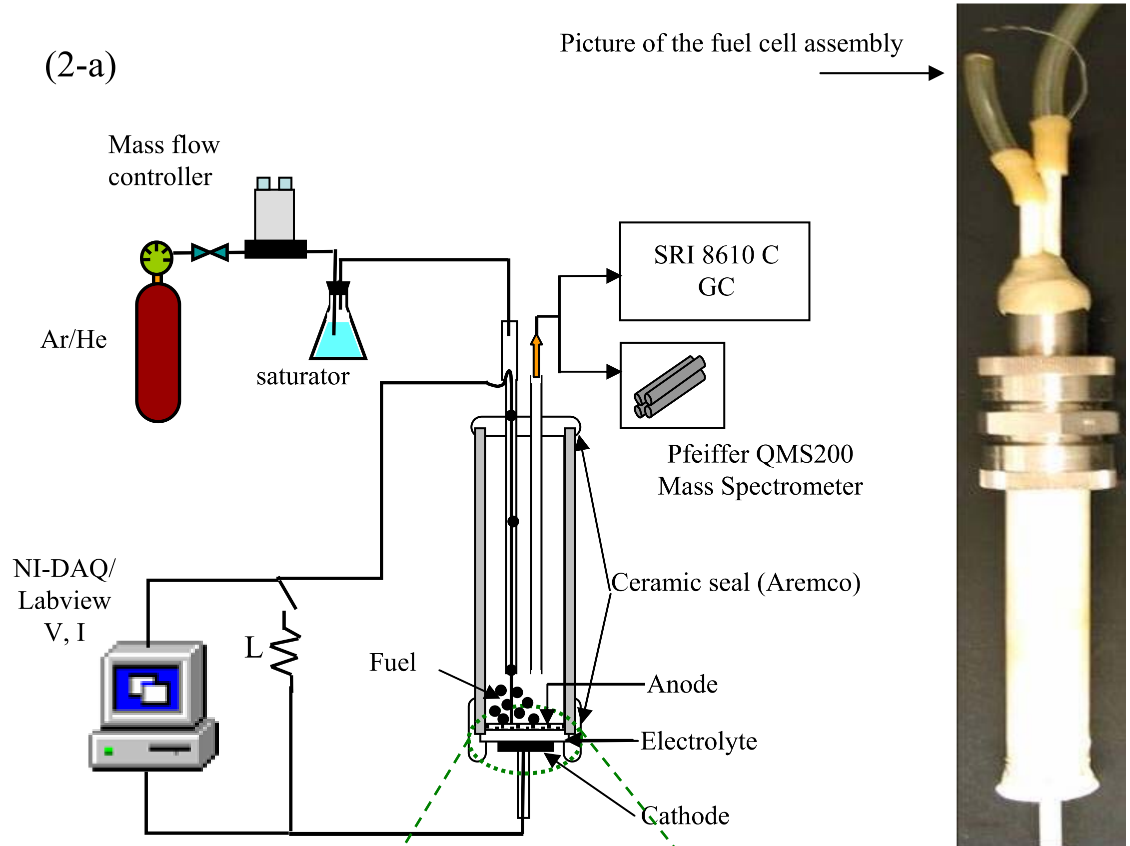


20 μm Ni-based anode/600 μm YSZ disk/50 μm LSM/YSZ cathode
$H_2$
$H_2$ after coking
$CH_4$
Cathode area=0.5 cm$^2$
Temperature=850 °C
voltage (V)
Power (mW/cm$^2$)
Current Density (mA/cm$^2$)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200
250
0
100
200
300
400
500
600

# Ohio Coal no. 5

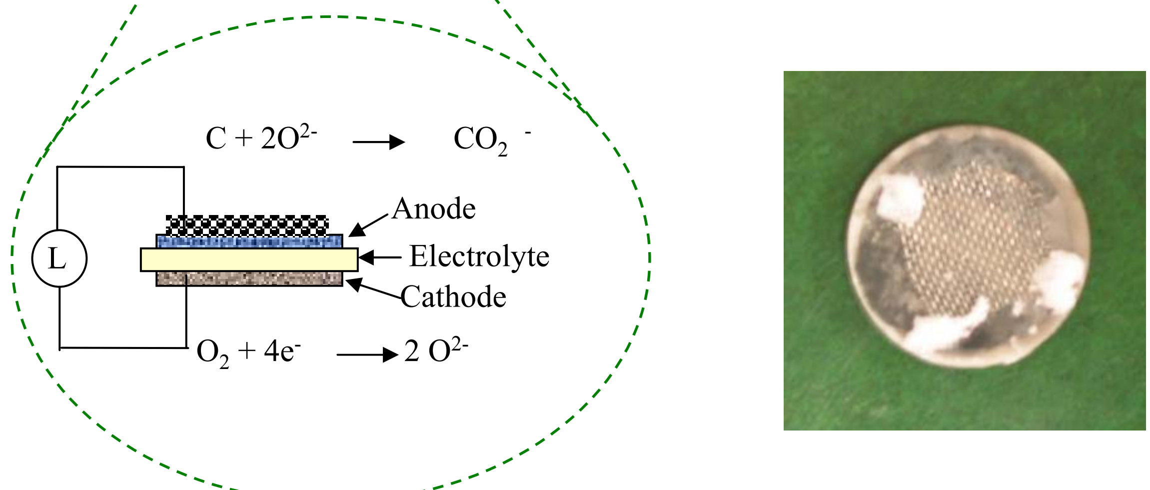
| PROXIMATE ANALYSIS | | ULTIMATE ANALYSIS | |
|---|---|---|---|
| % Moisture as received | 4.15 | % Carbon | 83.99 |
| Dry % ash | 4.80 | % Hydrogen | 5.50 |
| Dry % volatile matter | 37.98 | % Nitrogen | 1.88 |
| Dry % fixed carbon | 57.22 | % Oxygen | 8.63 |
| SULFUR FORMS | | CALORIC VALUE (BTU/lb) | 14258 |
| % Pyritic 0.70 | % Organic 1.21 | EQULIBIRUM MOISTURE (%) | 7.98 |
| % Sulfate 0.01 | % Total 1.92 | | |

(2-a)



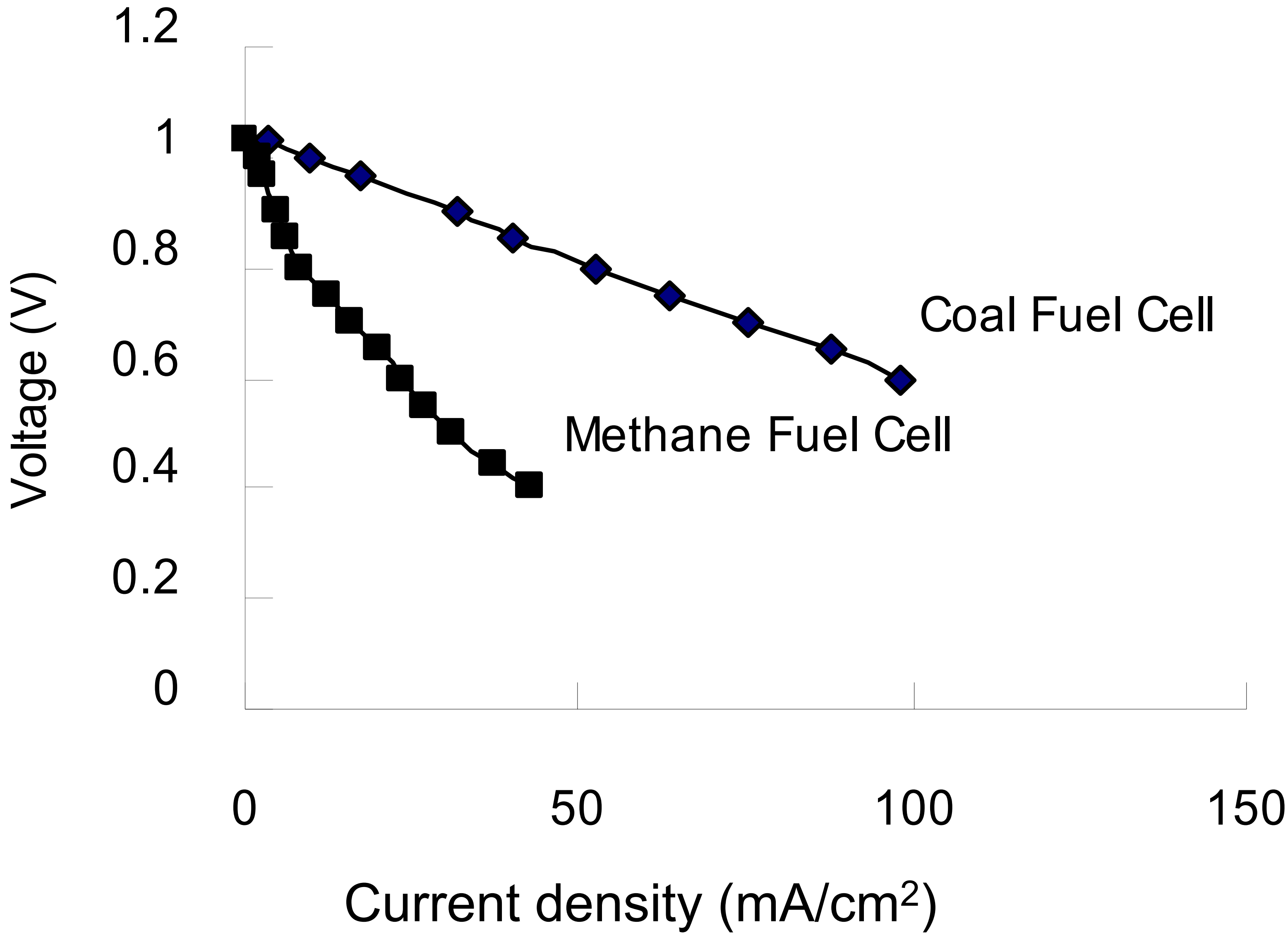
Picture of the fuel cell assembly
Mass flow controller
Ar/He
saturator
SRI 8610 C GC
Pfeiffer QMS200 Mass Spectrometer
NI-DAQ/ Labview V, I
L
Fuel
Ceramic seal (Aremco)
Anode
Electrolyte
Cathode


(2-b)

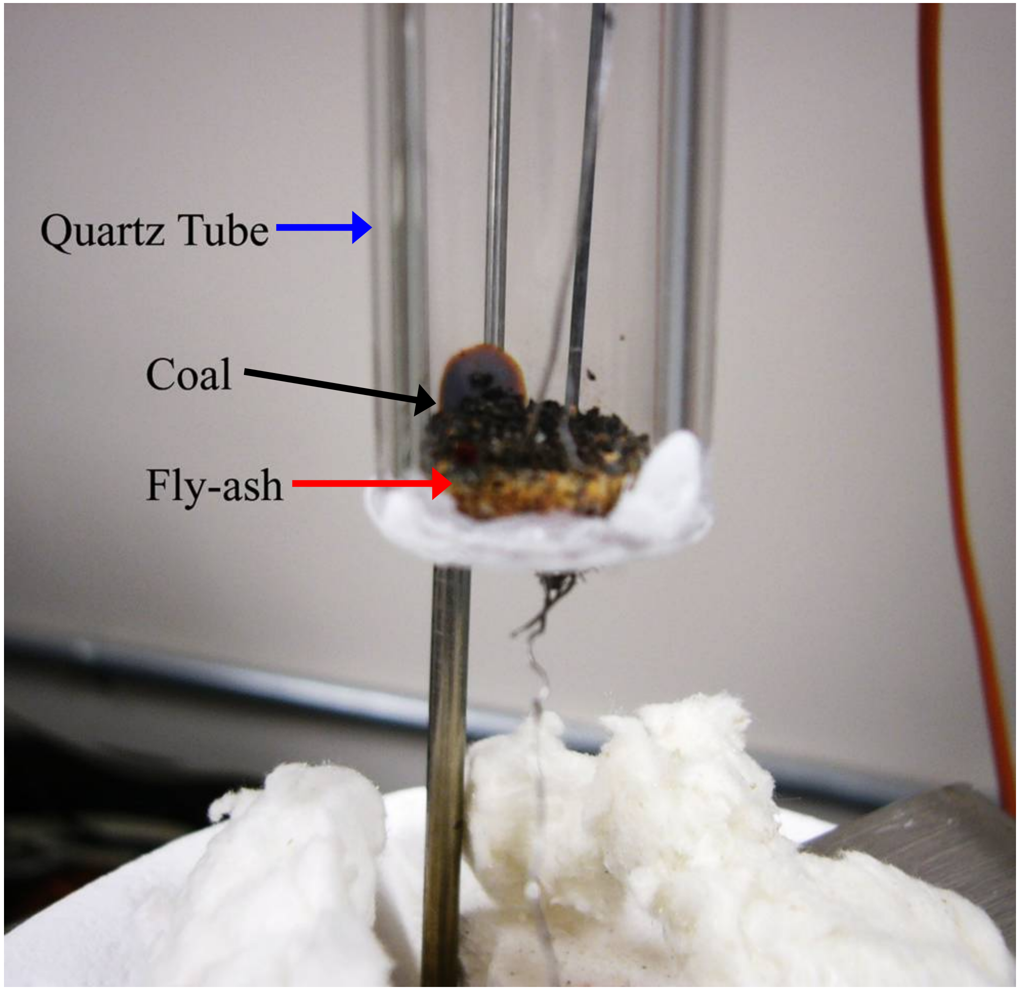


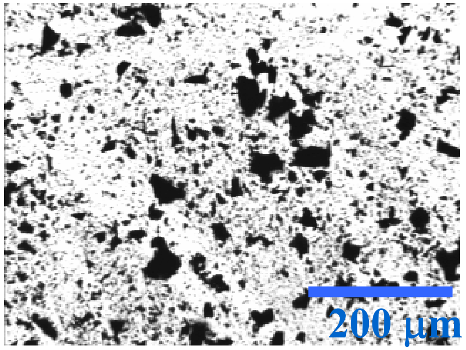
$C + 2O^{2-} \rightarrow CO_2$ -
Anode
Electrolyte
Cathode
L
$O_2 + 4e^- \rightarrow 2\ O^{2-}$

# Comparison of IV curves for Promoted-Metal Anode SOFC at 900 $^{o}C$

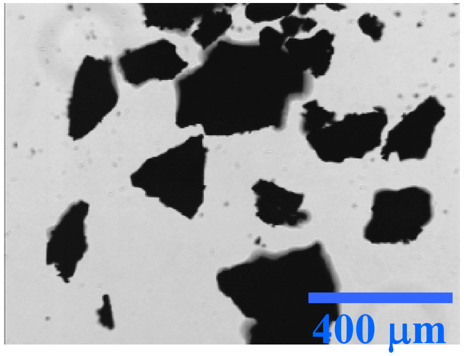


# Coke and fly ash after the SOFC reaction in the reactor

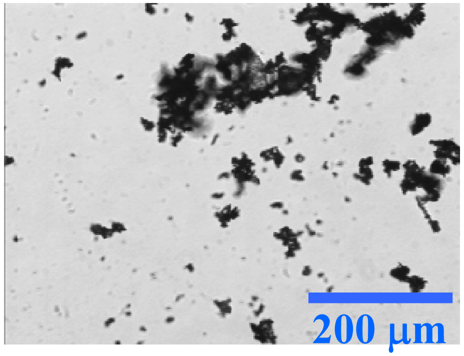



Coke before reaction

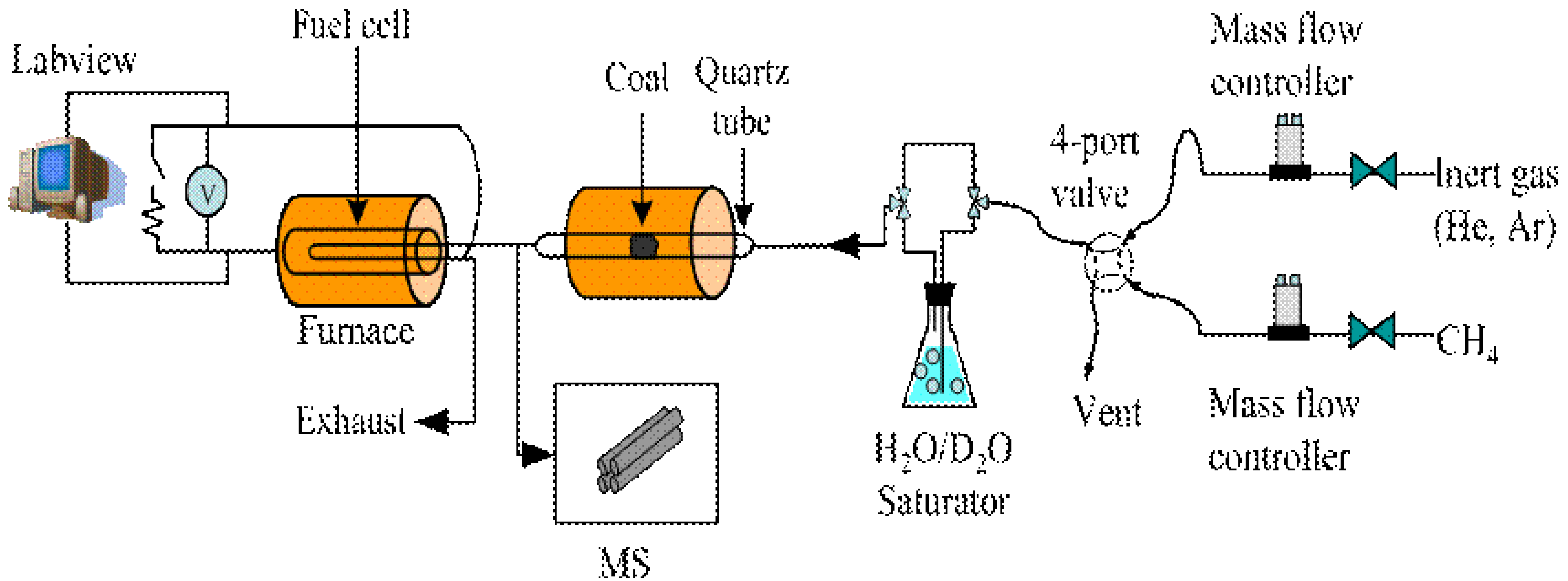



Coke after reaction

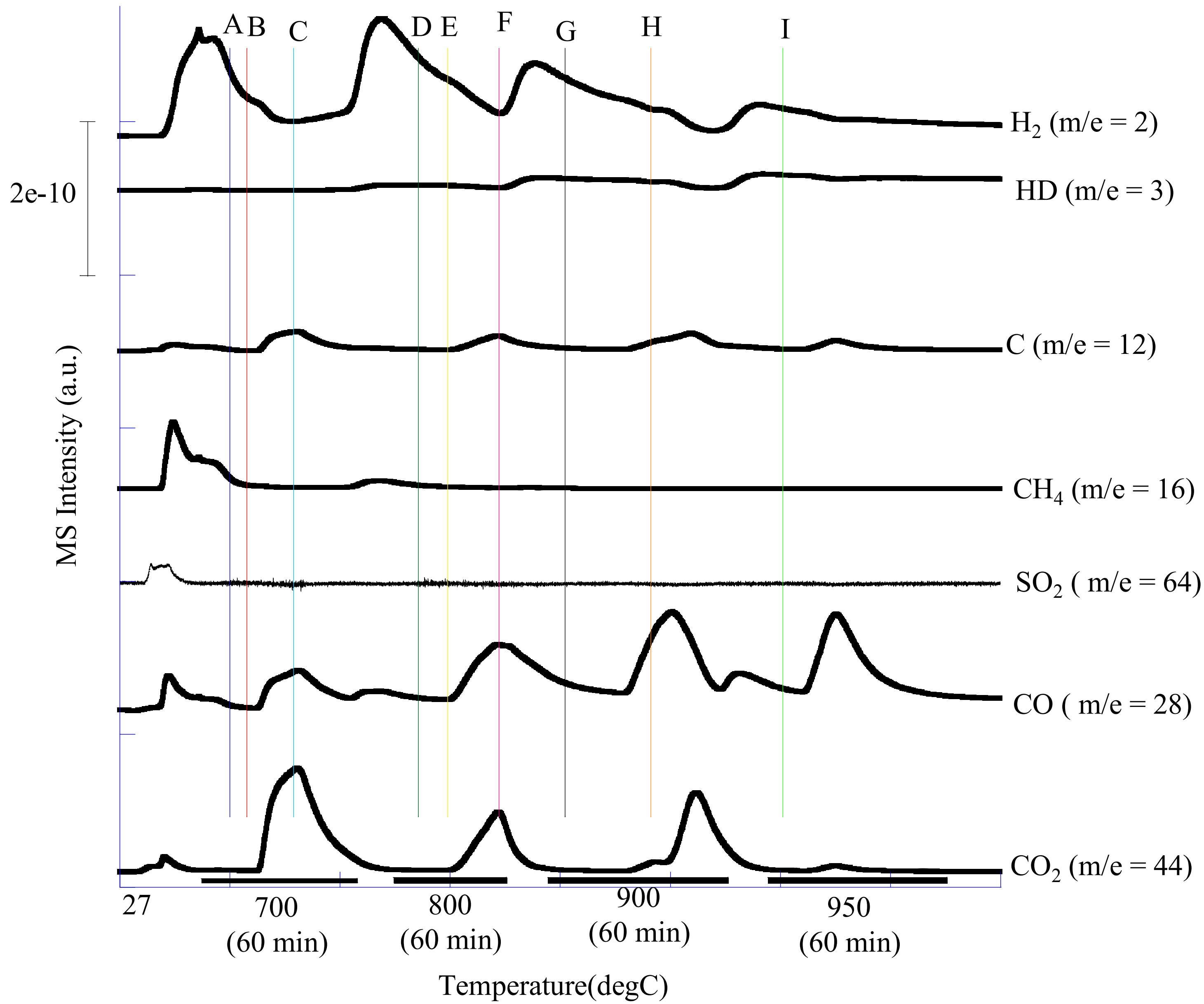



Fly ash after reaction

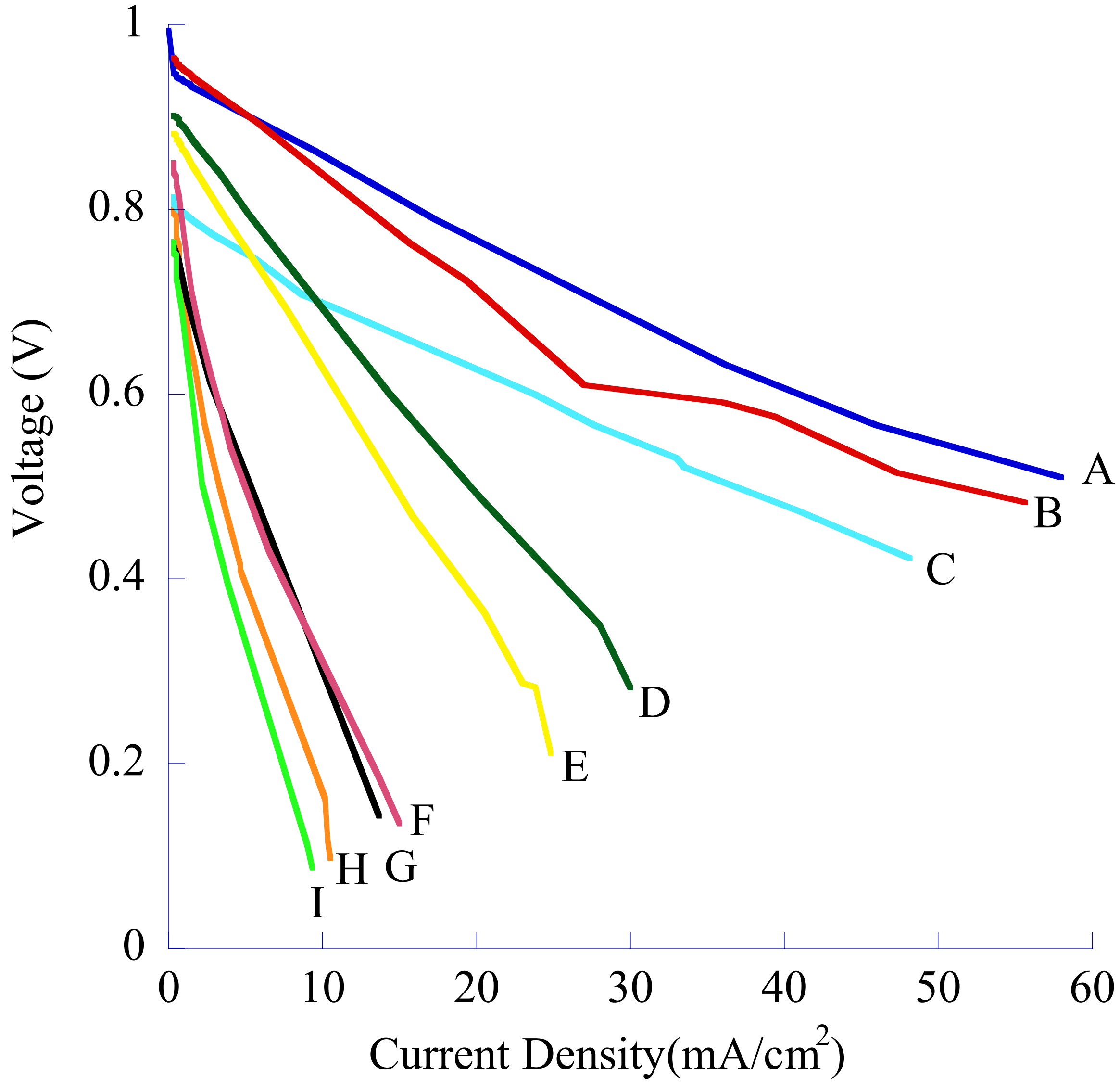
# Coal Gas Fuel Cell



# MS Profiles during Gasification of Ohio Coal # 5



# V-I Curves of Coal Gas Fuel Cell



# Efficiency of Fuel Cells

| Fuel | Theoretical limit = $\Delta G(T)/\Delta H^o_{std}$ | Utilization efficiency, $\mu$ | $V(i)/V(i=0) = \varepsilon_v$ | Actual efficiency = $(\Delta G/\Delta H^o_{std})(\mu)(\varepsilon_v)$ |
|---|---|---|---|---|
| C | **1.003** | **1.0** | **0.80** | **0.80** |
| $CH_4$ [a] | 0.895 | 0.80 | 0.80 | 0.57 |
| $H_2$ | 0.70 | 0.80 | 0.80 | 0.45 |

**Efficiency of a fuel cell or battery is defined:**

$\equiv$ **(electrical energy out) / (Heat of combustion (HHV) of fuels input)**

**= [theoretical efficiency G/H][utilization fraction $\mu$][voltage efficiency $\varepsilon_v$]**

$= [\Delta G(T)/\Delta H^o][\mu][V/V^o] = [\mu][nFV]/\ \Delta H^o$

--where $\Delta G(T) \equiv -nFV^o \equiv \Delta H - T\Delta S$

**Typical C/air efficiency is 80%**

**Must adjust for Energy Cost of Fuel Production**

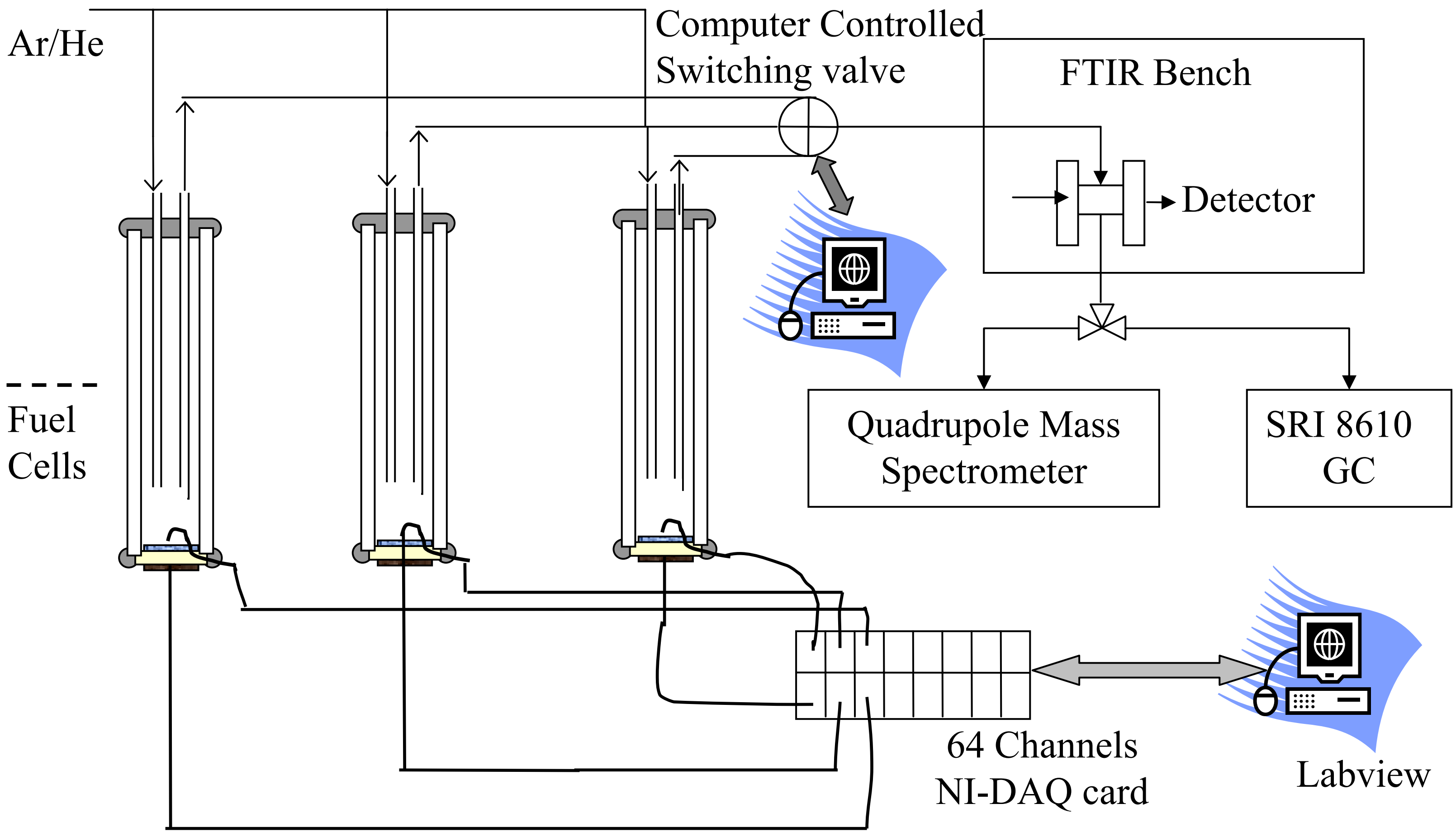


John F. Cooper, Direct Caron Fuel Cell Workshop, NETL, July 30, 2003

# Research in Coal-based Fuel Cells

- The performance of all the fuel cells is limited by the rate of ion diffusion across the membrane.
- Solid Oxide Fuel Cell
  - Long Term Catalyst Activity (poisoning of anode catalyst)
  - Material compatibility
  - Robustness (Strength of the fuel cell assembly)

# Fuel Cell Testing System



# Summary

- Power density: Petcoke> Coal > Coal gas > $CH_4$
- Fly ash produced from coal at 950 $^0$C did not foul the anode catalyst surface.
- Future Tasks:
  - Task 1: Improvement of the anode catalyst structure and the interface between electrode and membrane.
  - Task 2: Refinement of the techniques for fabrication of the fuel cell assembly
  - Task 3: Selection and testing of interconnect materials for the coal-based fuel cell.
  - Task 4: Investigation of the design factors for the coal injection and flyash removal systems.
  - Task 5: Design and fabrication of a 5 kW prototype coal fuel cell.