Development of a kW Prototype Coal-based Fuel Cell

DE-FG36-06GO86055

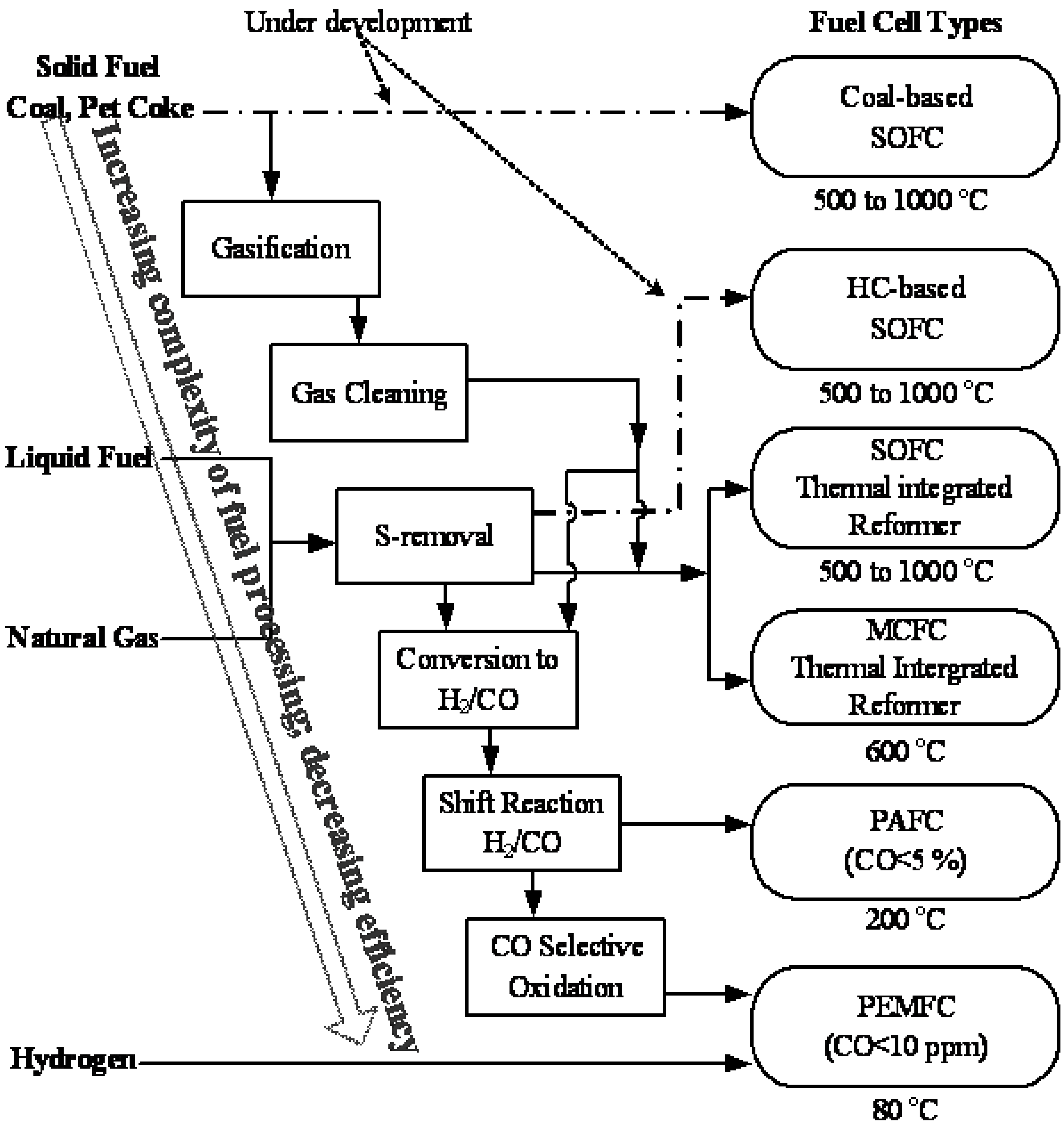
Steven S. C. Chuang
Department of Chemical and Biomolecular Engineering
The University of Akron
Akron, OH 44325-3906 USA

FCP 41

Acknowledgement: US Department of Energy, Ohio Coal Development Office, Ohio Board of Regents; Univ. of Akron

Students: J. Fisher, D. Miller, F. Guzman, R. Singh, and Z. Yu,

Relationship between fuel processing and fuel cells

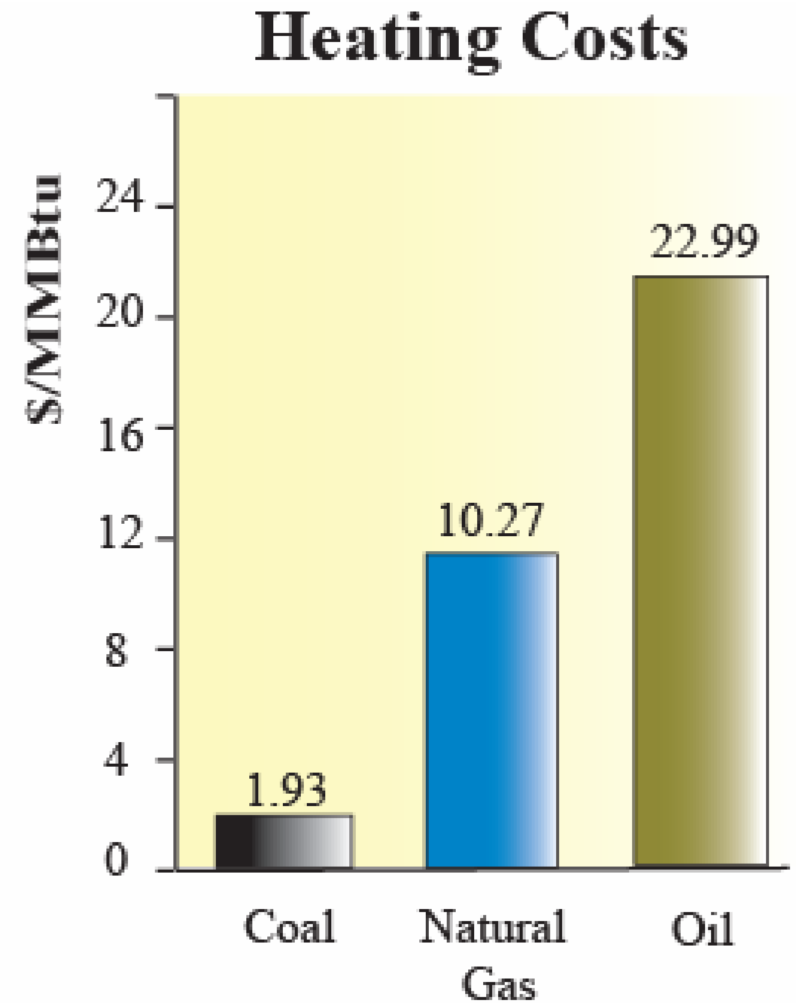


Ref: N.F. Brandon, S. Skinner, B.C.H. Steele, *Annu. Rev. Mater. Res.* **2003. 33:183-213**

Coal is Important

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

- Economic prosperity
- Energy security

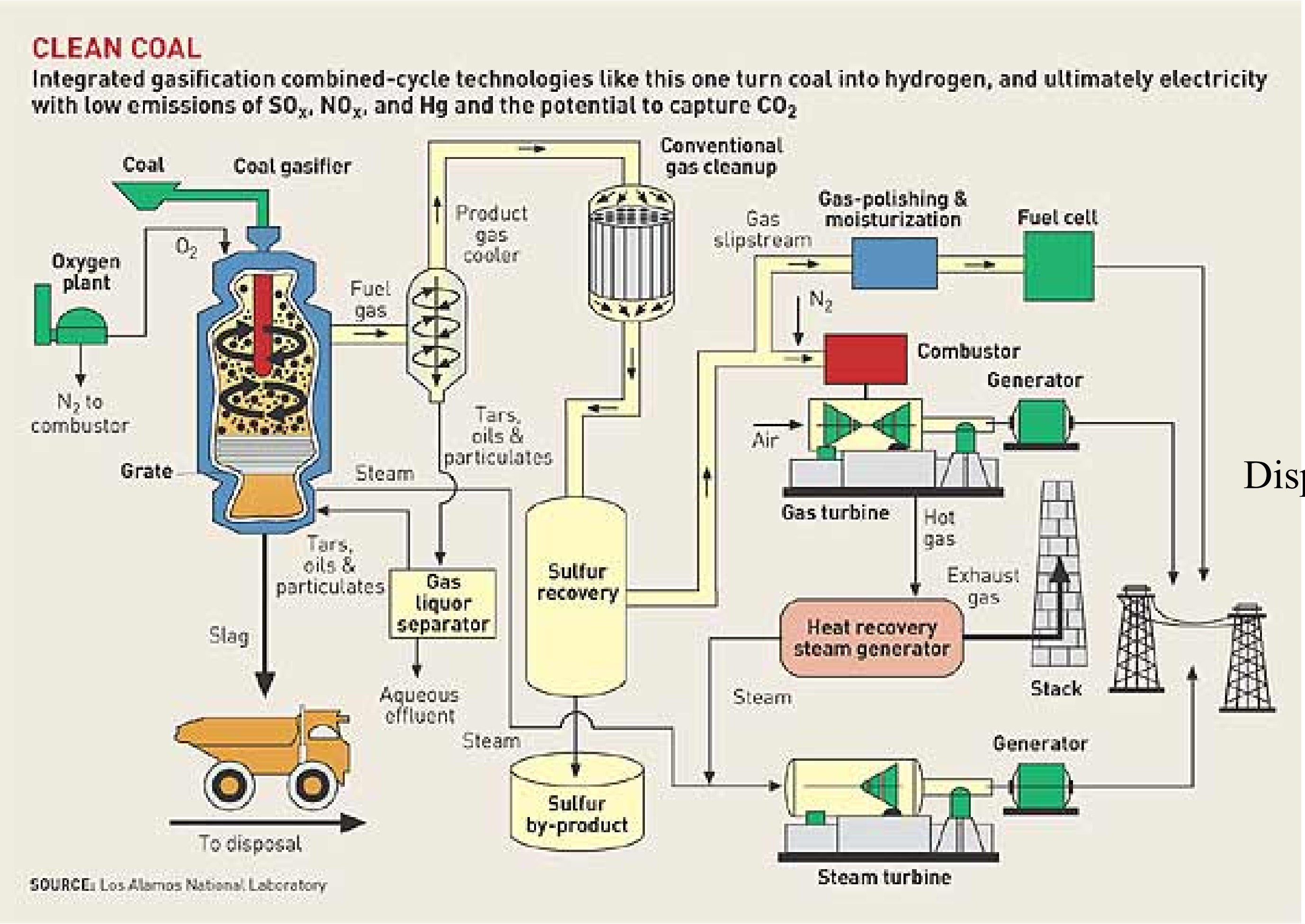


1. Prices current as of Jan-March 2005 (www.eia.doe.gov)
2. Natural Gas prices DOE (Average Commercial Prices)
3. Gasoline & Diesel Fuel Prices (tonto.eia.doe.gov)

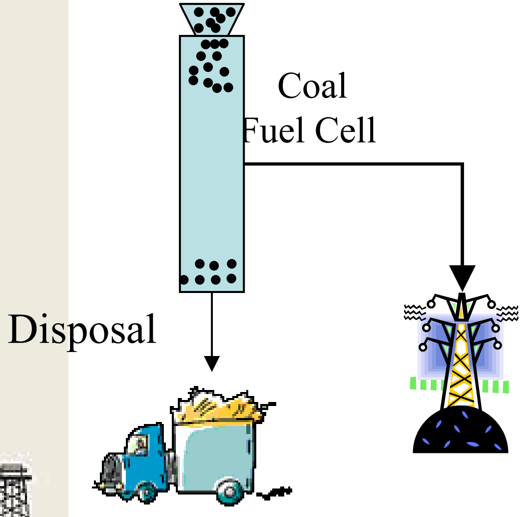
NETL

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

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

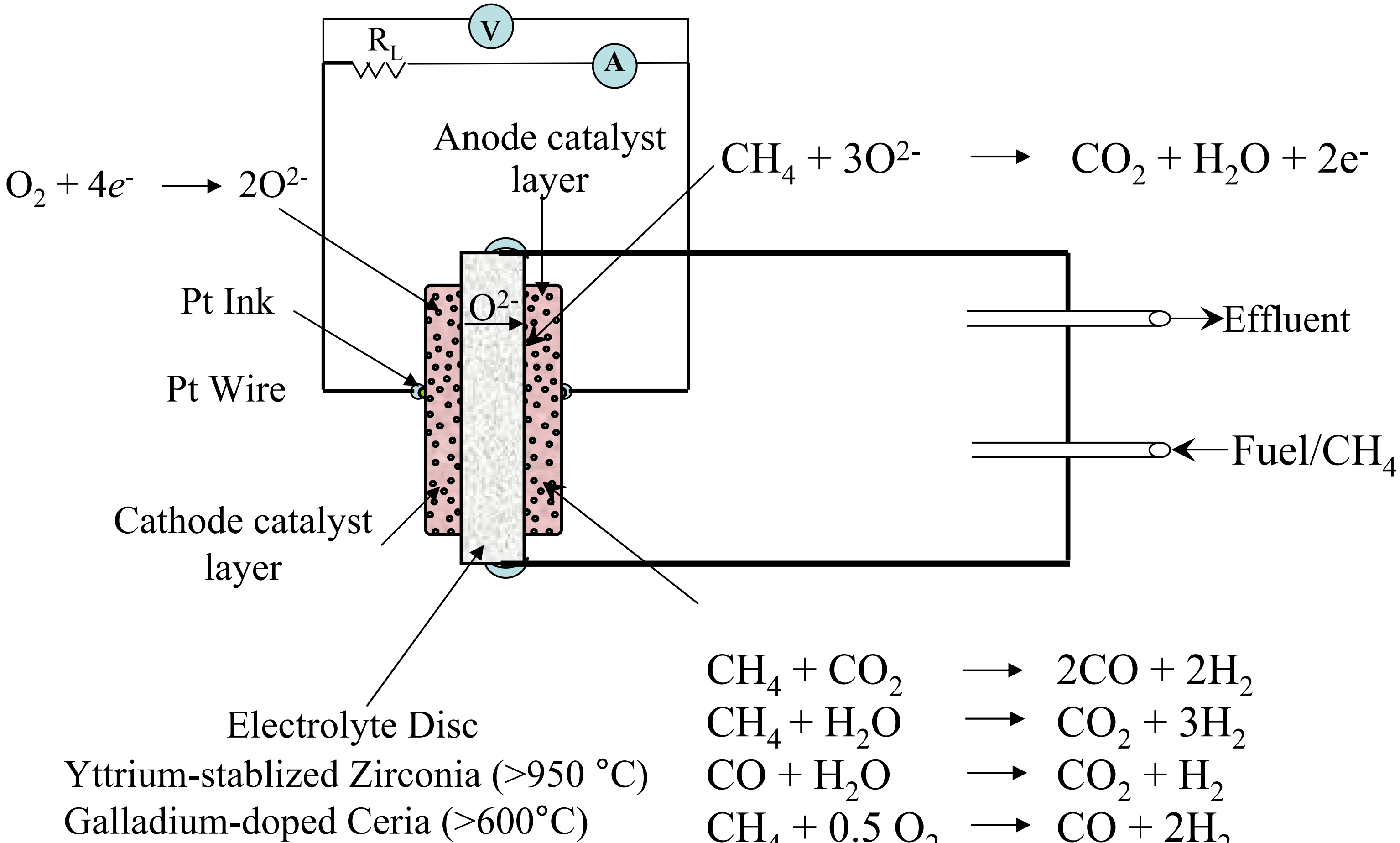


Coal-based Fuel Cell



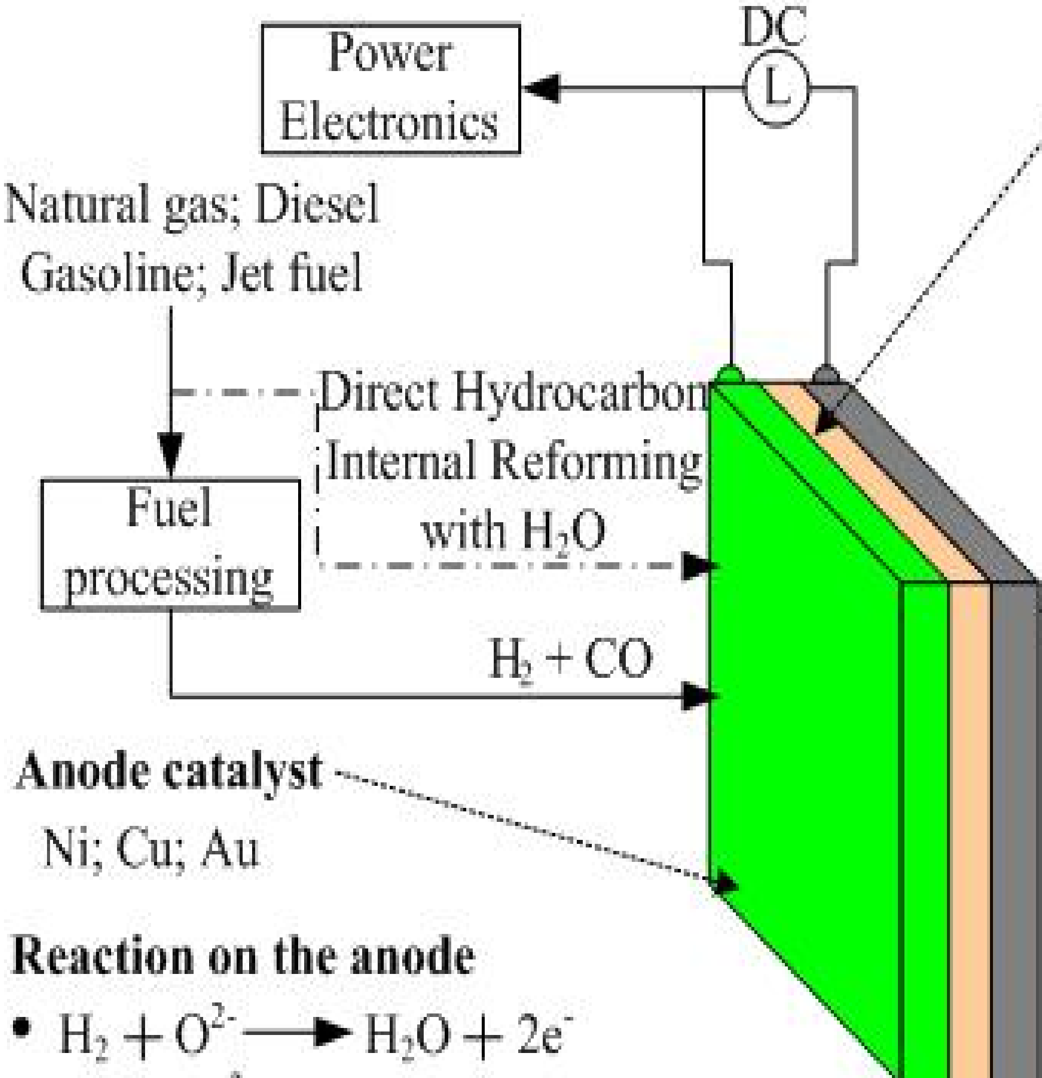
Source: The University of Akron

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	$\mathbf{O_{ad} \rightarrow CO_2}$	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

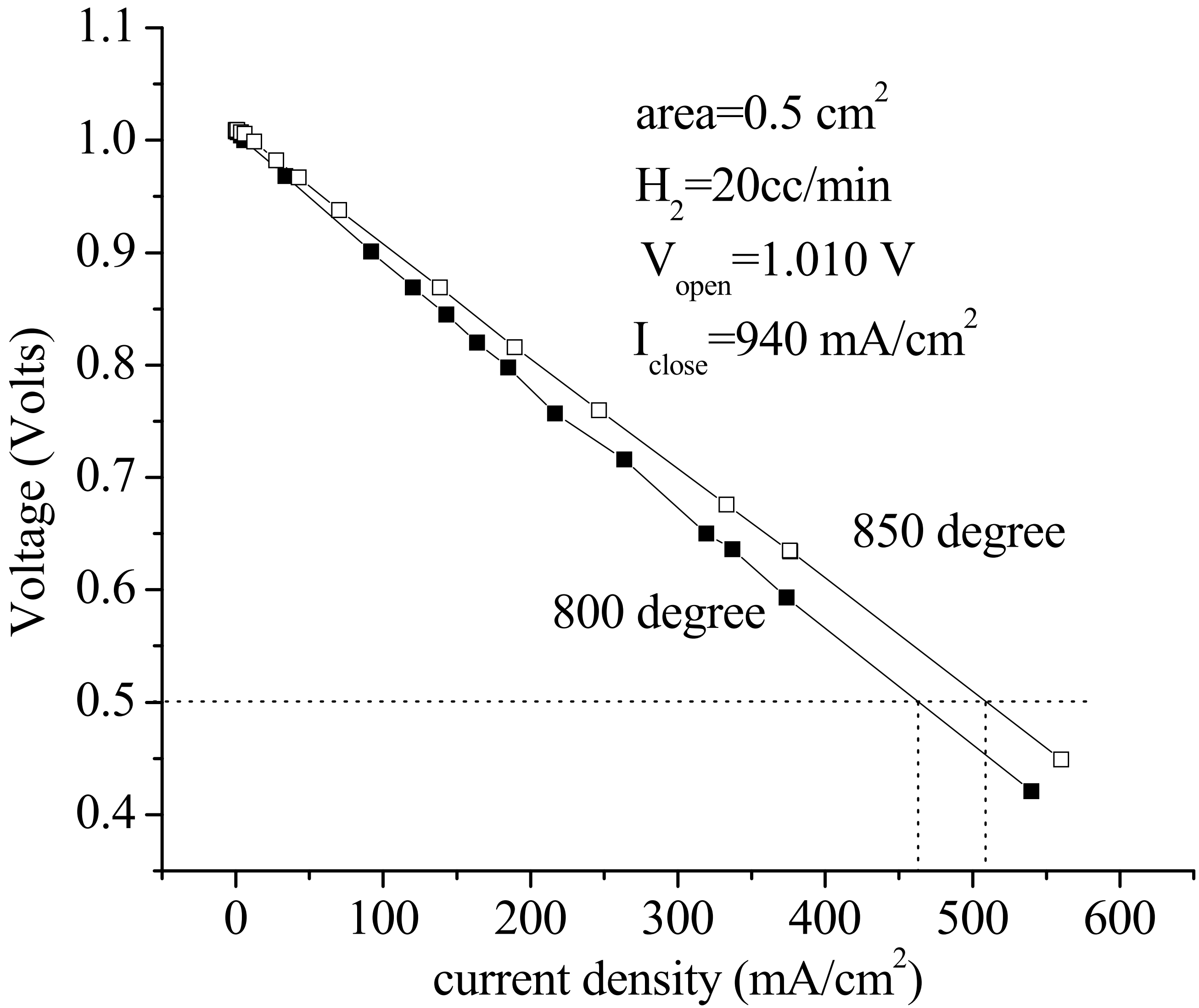
Reaction on the anode

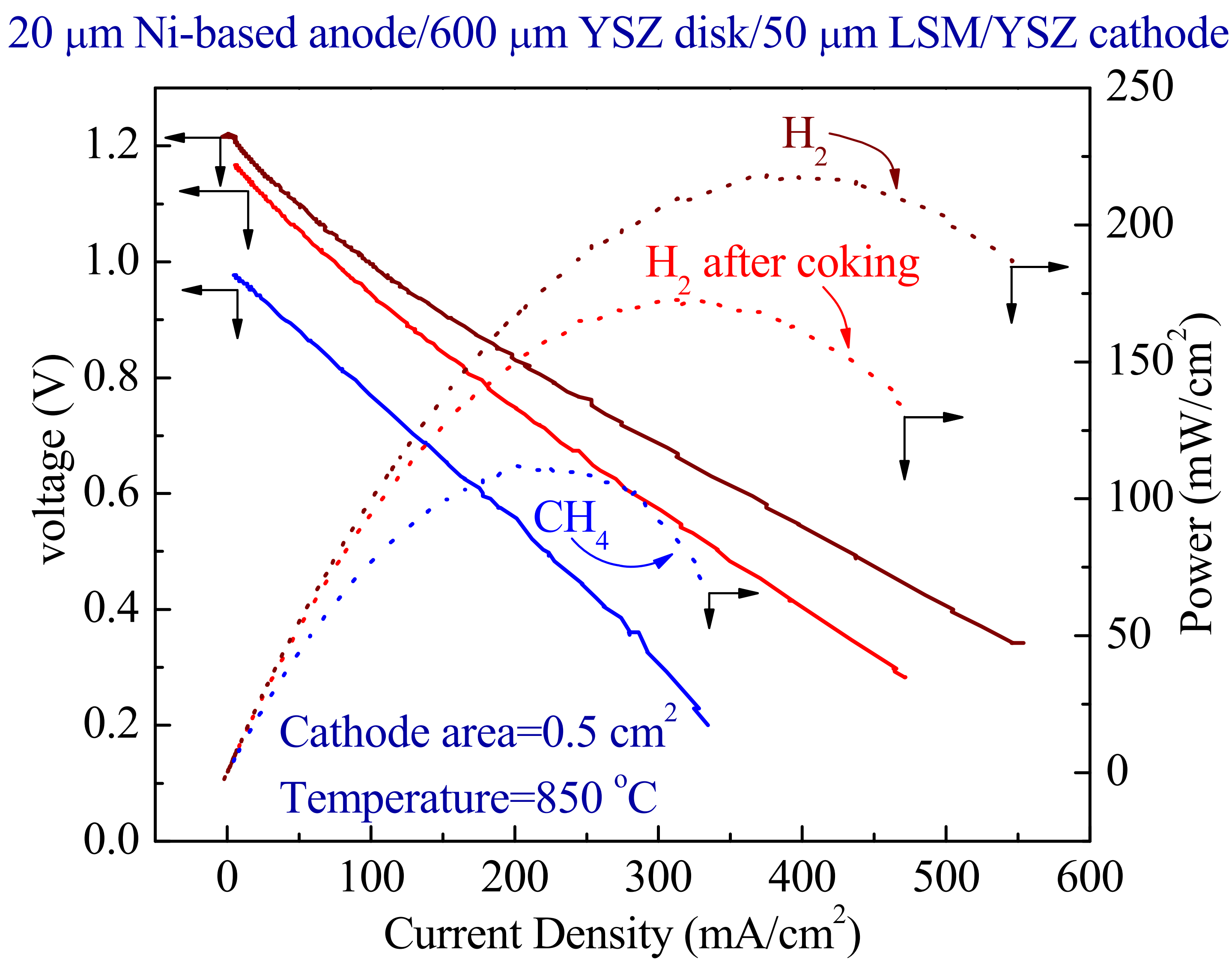
- $H_2 + O^{2-} \longrightarrow H_2O + 2e^-$
- $CO + O^{2-} \longrightarrow CO_2 + 2e^-$
- $CH_4 \longrightarrow C$ (anode deposit) $+ 2H_2$
- $C + 2O^{2-} \longrightarrow CO_2 + 4e^-$

Reaction on the cathode

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

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

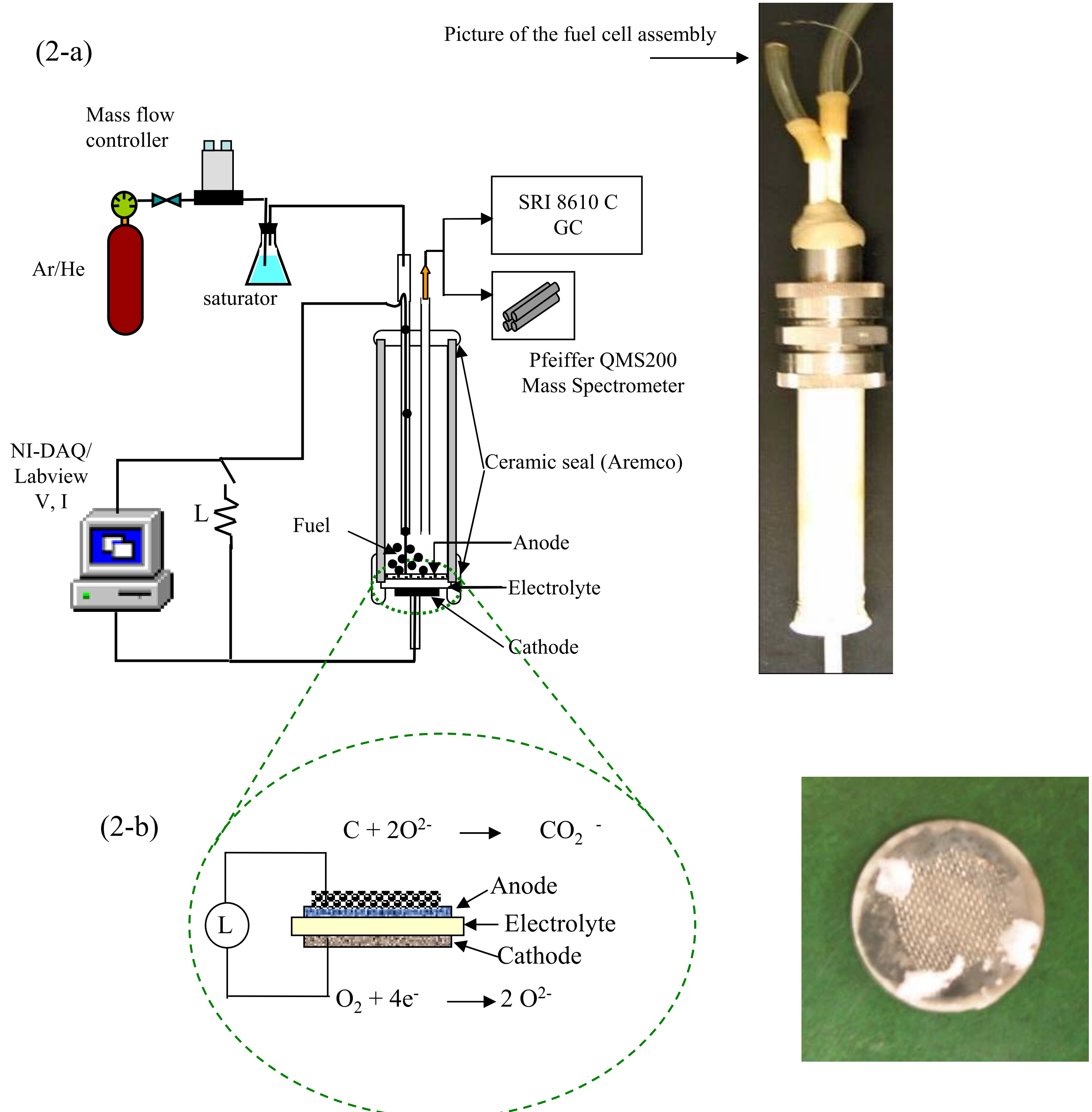




20 μm Ni-based anode/600 μm YSZ disk/50 μm LSM/YSZ cathode
voltage (V)
Power (mW/cm2)
Current Density (mA/cm2)
H2
H2 after coking
CH4
Cathode area=0.5 cm2
Temperature=850 oC
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200
250
0
100
200
300
400
500
600

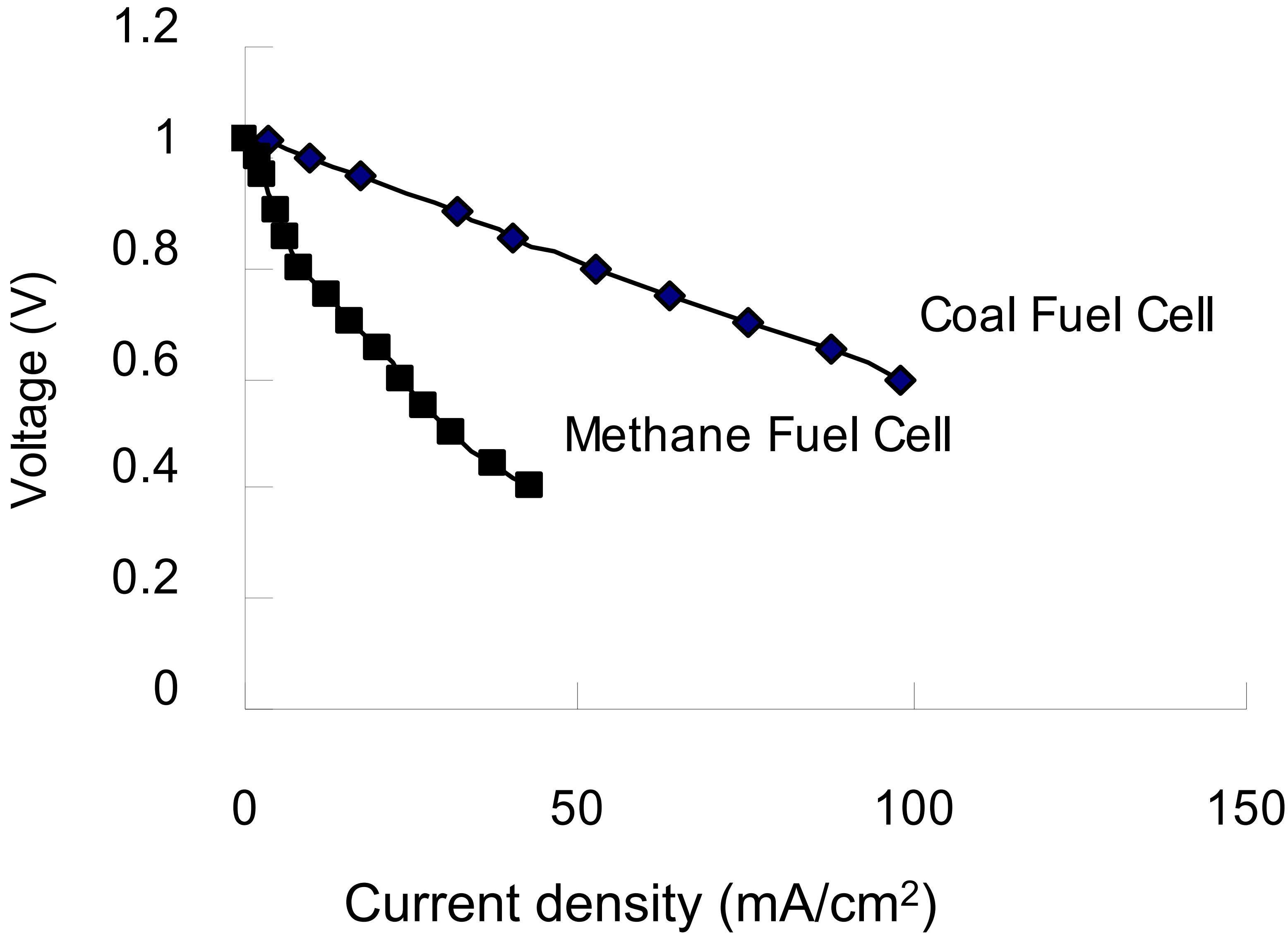
Ohio Coal no. 5

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		

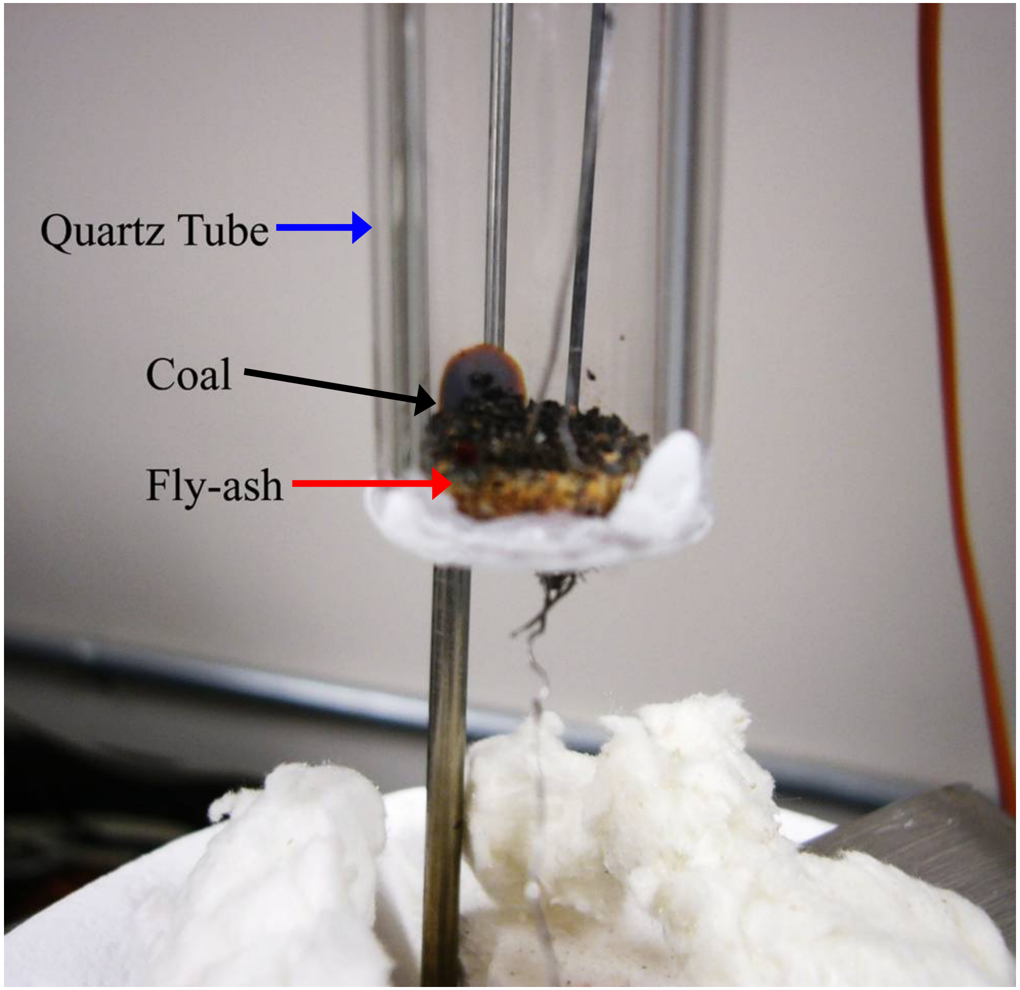


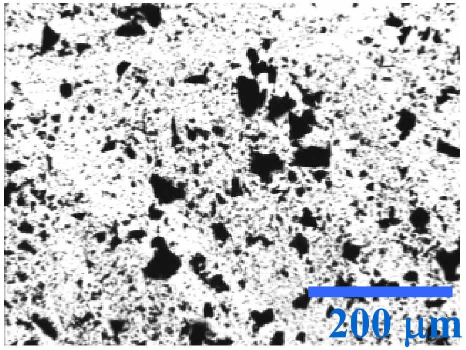
(2-a)
Picture of the fuel cell assembly
Mass flow controller
Ar/He
saturator
SRI 8610 C GC
Pfeiffer QMS200 Mass Spectrometer
NI-DAQ/ Labview V, I
L
Fuel
Ceramic seal (Aremco)
Anode
Electrolyte
Cathode
(2-b)
$C + 2O^{2-} \rightarrow CO_2$ -
L
Anode
Electrolyte
Cathode
$O_2 + 4e^- \rightarrow 2\ O^{2-}$

Comparison of IV curves for Promoted-Metal Anode SOFC at 900 ^oC

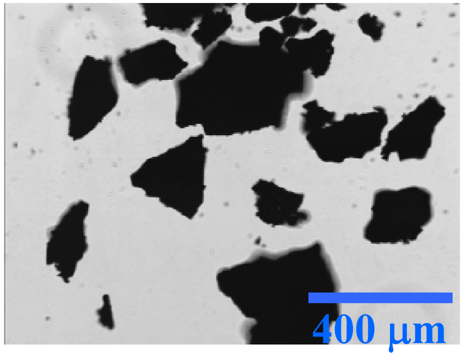


Coke and fly ash after the SOFC reaction in the reactor

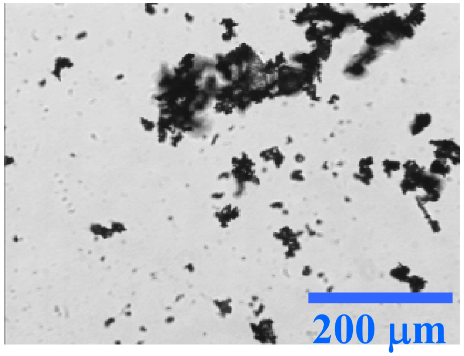




Coke before reaction

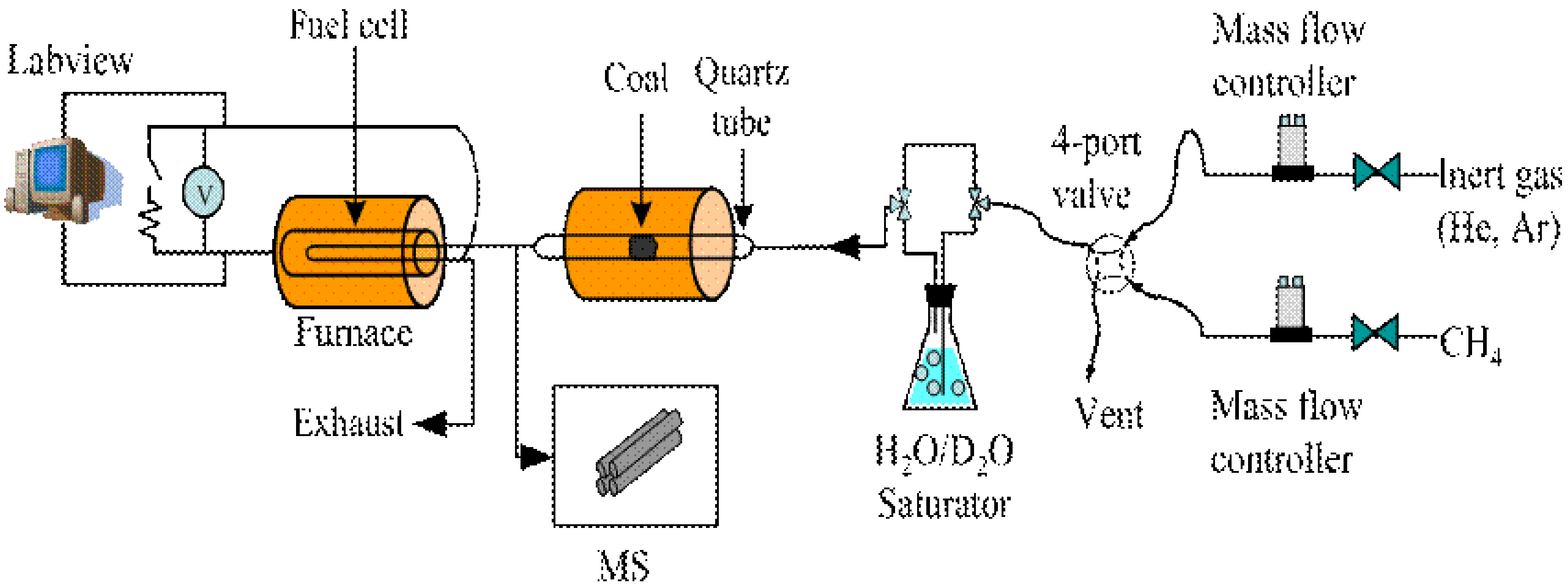


Coke after reaction

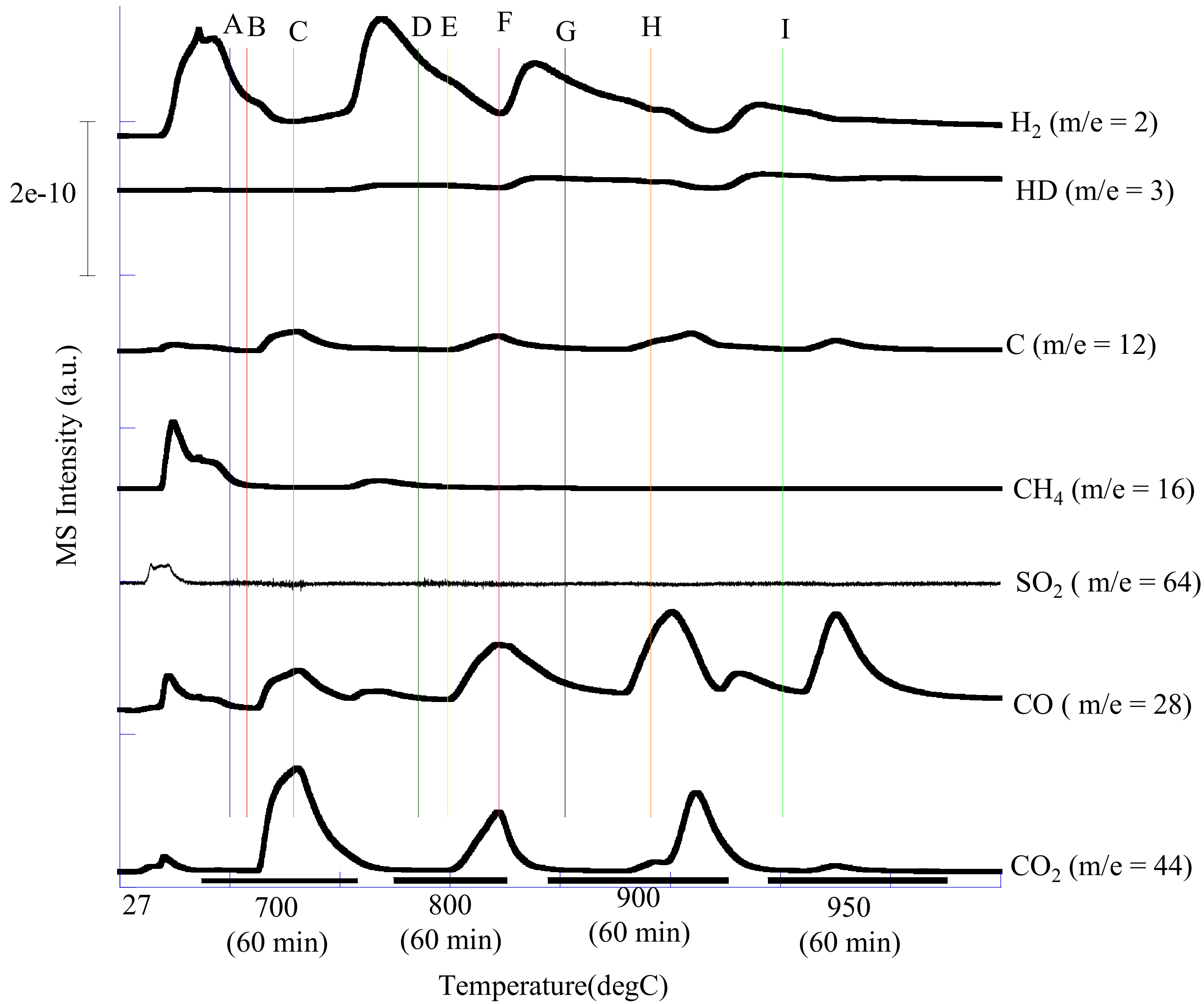


Fly ash after reaction

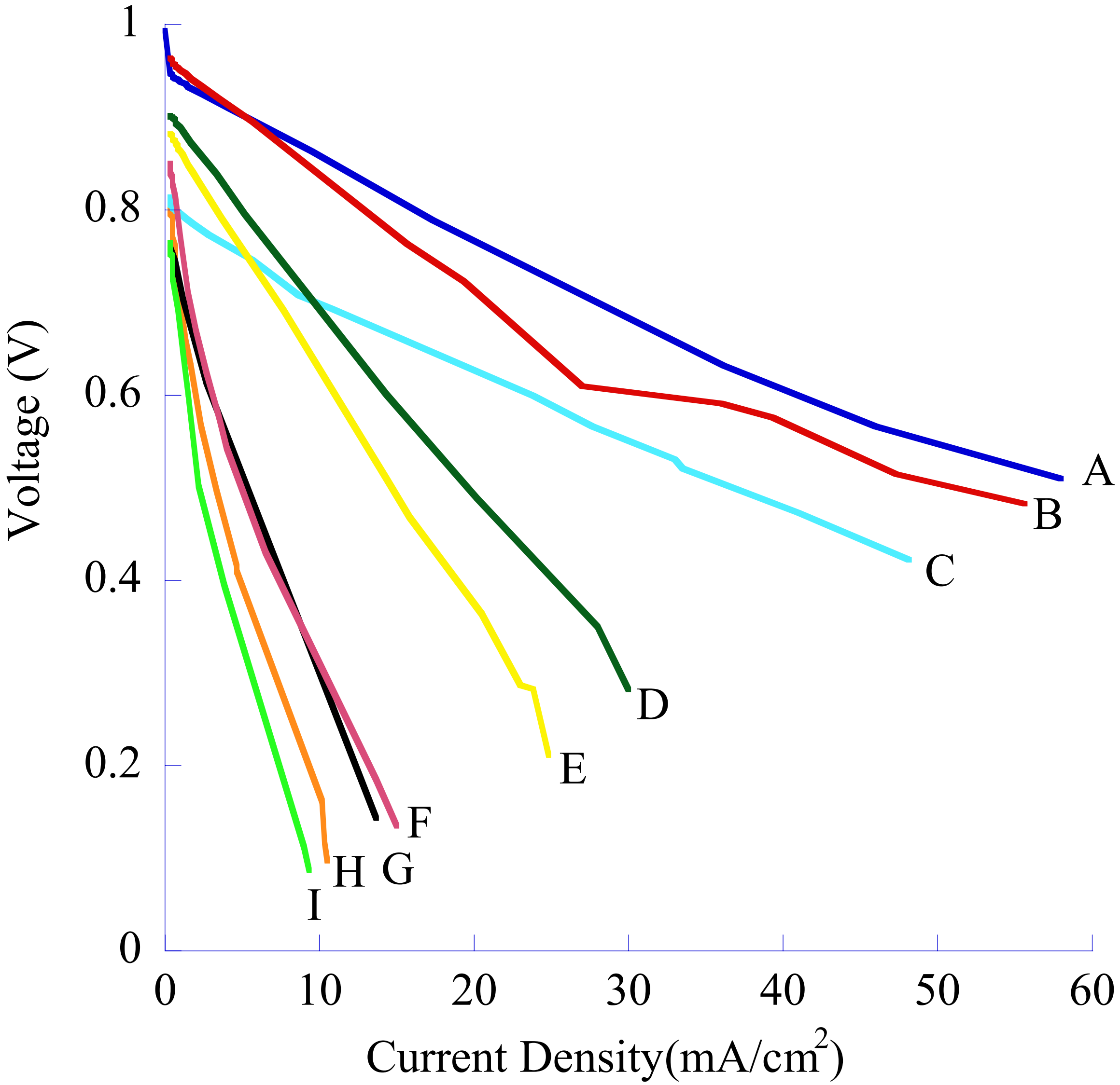
Coal Gas Fuel Cell



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, μ	V(i)/V(i=0) = ε_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:

≡ **(electrical energy out) / (Heat of combustion (HHV) of fuels input)**

= [theoretical efficiency G/H][utilization fraction μ][voltage efficiency ε_v]

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

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

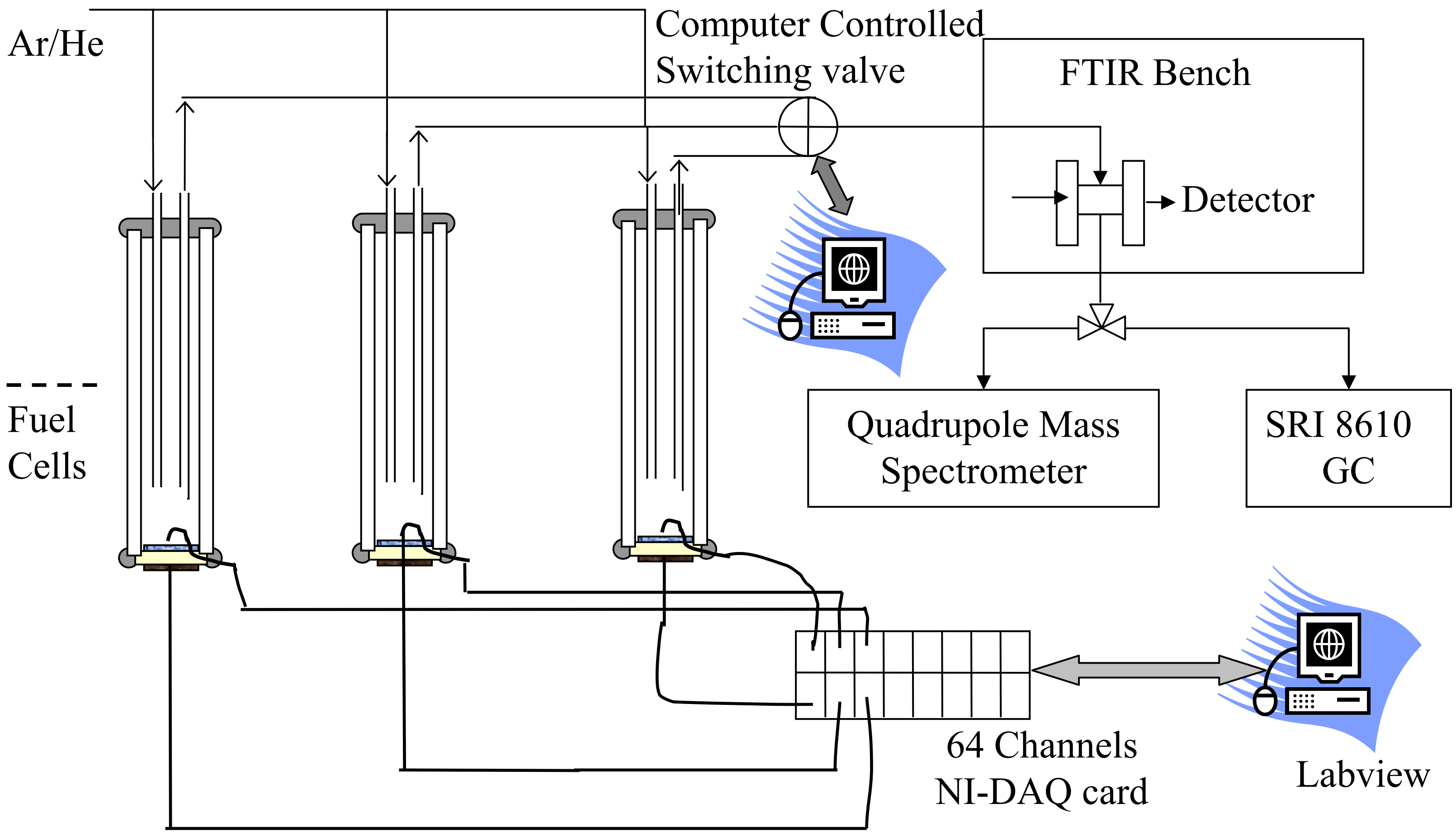
Typical C/air efficiency is 80%
Must adjust for Energy Cost of Fuel Production

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.