Techno-Economic Analysis of Scalable Coal-Based Fuel Cells

The University of Akron, Akron, OH 44325

FirstEnergy Advanced Energy Research Center

Steven S. C. Chuang (PI), Tritti Siengchum, Felipe Guzman, Jelvehnaz Mirzababaei, Seyed Ali Modjtahedi, Nader Hedayat, Azadeh Rismanchian

Objective

Demonstrate the technical and economic feasibility of building a kW scale pilot-plant coal-based fuel cell with participation by industries. This project will address initial development, scaling, and manufacturing of the core technology. Objectives for 2012 include the following:

- Design and fabricate a preliminary fuel cell stack
- Demonstrate the operation of fuel cell stack with hydrocarbon and solid carbon fuels
- Study the effect of different types of carbonaceous fuels on the performance of the fuel cell
- Evaluate the efficiency of the carbon fuel cell

Evaluation of Carbon Fuel Cell Efficiency-1

Definitions of Fuel Cell Efficiency

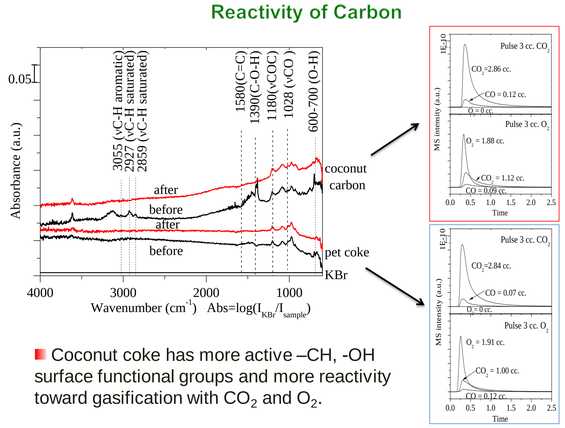
Efficiency	Definition	Range *
Operating efficiency	$\xi_{operating} = {}^{W_e}/_{\text{energy input}}$	30-35% (coal-fired power plant)
Thermodynamic efficiency	$\xi_{thermo} = {}^{\Delta G}/_{\Delta H}$	Depends on choice of fuel
Load efficiency	$\xi_{load} = {}^{E(i)}/_{E_R^0}$	70-75 %
Fuel efficiency	$\xi_{fuel} = {}^{(i/nF)}/_{\nu_{fuel}}$, $^{\text{mass}_{reacted}}/_{\text{mass}_{feed}}$	< 0.90
Effective efficiency	$\xi_{eff} = \xi_{ideal} \times \xi_{load} \times \xi_{fuel}$	27-40 %

Fuels	Reaction	Thermodynamic eff. at 800°C
Hydrogen	$H_2+0.5O_2 \rightarrow H_2O$	82.6%
Propane	$C_3H_8+5O_2 \rightarrow 3CO_2+4H_2O$	104.2%
Decane	$C_{10}H_{22}+15.5O_2 \rightarrow 10CO_2+11H_2O$	106.2%
Carbon monoxide	$CO + 0.5O_2 \rightarrow CO_2$	75.2%
Carbon	$C + 0.5O_2 \rightarrow CO$	164.6%
Carbon	$C + O_2 \rightarrow CO_2$	100.4%

A. L. Wolf Vielstich, Hubert A. Gasteiger, *Handbook of Fuel Cells, Vol. 2*, WILEY, (2003)

IR Study of Carbon Fuel Cell-2

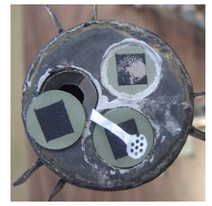
Reactivity of Carbon

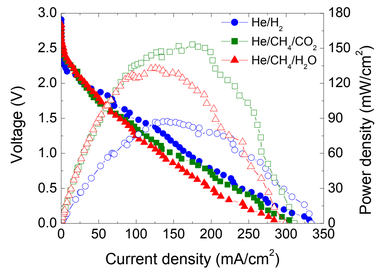


- Coconut coke has more active –CH, -OH surface functional groups and more reactivity toward gasification with CO_2 and O_2.

The Integration of Individual Fuel Cell-1

Three Cells in Series Configuration



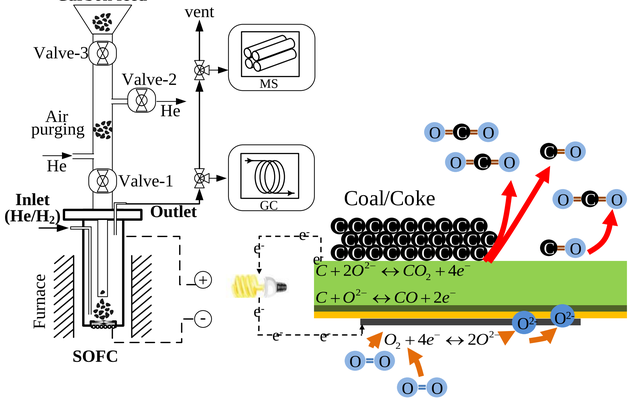


Testing Conditions

H_2/He :
100 sscm, 50 vol% H_2
He/CH_4/CO_2
100sccm,25 vol% CH_4, 25 vol% CO_2
He/CH_4/H_2O
100sccm,50 vol% CH_4, 3 wt% H_2O
Temp: 750 °C

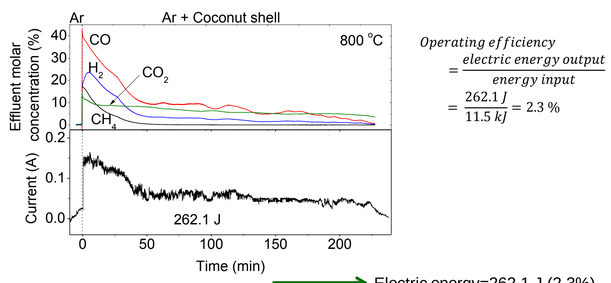
- Integration of fuel cells in series resulted in voltage close to the expected Nernst potential (3 V).

Carbon Fuel Cell: Operating Principle

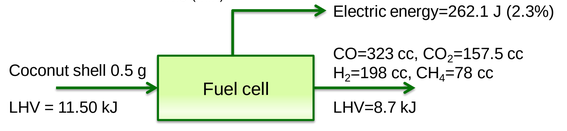


Evaluation of Carbon Fuel Cell Efficiency-2

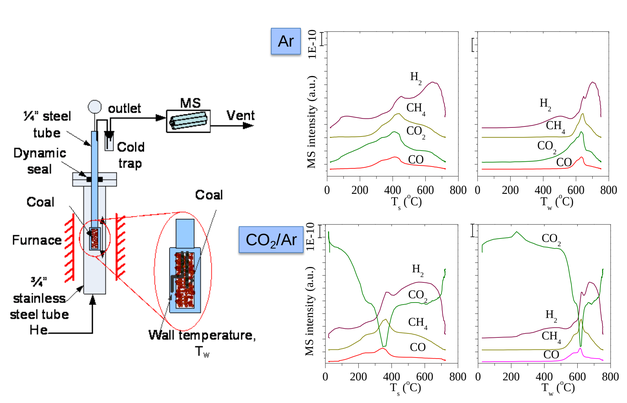
Performance in Coconut Shell at 800°C



$$Operating\ efficiency = \frac{electric\ energy\ output}{energy\ input} = \frac{262.1\ J}{11.5\ kJ} = 2.3\ \%$$

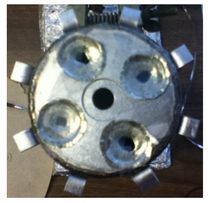


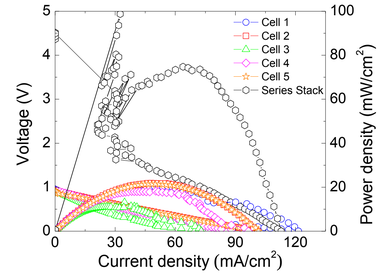
Fast Pyrolysis of Mansfield Coal in Ar and CO_2



The Integration of Individual Fuel Cell-2

Five Cells in Series Configuration



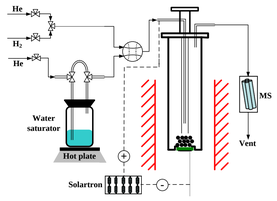


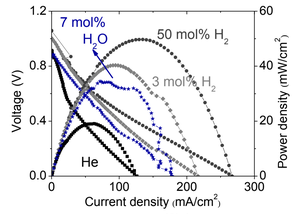
Testing Conditions

H_2/He : 100 sscm, 50 vol% H_2
Temp: 750 °C

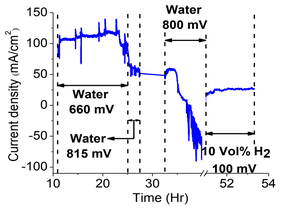
- Integration of cells in series resulted in voltage close to the expected Nernst potential (5 V).

Effect of Steam on Performance of Carbon Fuel Cell





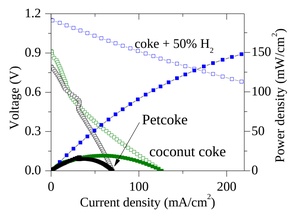
$$C + 2O^{2-} \longrightarrow CO_2 + 4e^- \quad (1)$$
$$C + O^{2-} \longrightarrow CO + 2e^- \quad (2)$$
$$CO_2 + C \longleftrightarrow 2CO \quad (3)$$
$$CO + O^{2-} \longrightarrow CO_2 + 2e^- \quad (4)$$
$$C + H_2O \longleftrightarrow CO + H_2 \quad (5)$$



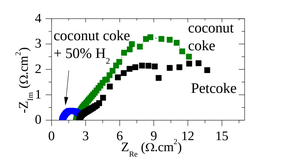
- Addition of 7 mol% H_2O increased the maximum power density of the carbon fuel cell 1.7 times.

IR Study of Carbon Fuel Cell-1

Carbon Fuel Cell Performance

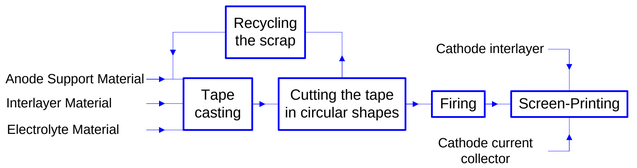


- Maximum current density of the fuel cell operated with coconut coke was 19% of that with H_2, while Petcoke produced 9% of that with H_2.



- Ohmic resistance and polarization losses of the fuel cell with Petcoke were higher than those with coconut coke.

Cost Analysis of Fuel Cell



Components	Cost ($/kW)
Anode support	333
Anode interlayer	30
Electrolyte	146
Cathode interlayer	30
Cathode current collector	28
Total cost	**567**

- Fuel cell cost for generation of 1 kW electricity is about $ 570.

Future Work

- Modification of the anode catalyst to increase the activity toward carbonaceous fuels and its gasification products
- Evaluating the efficiency of the fuel cell stack in carbonaceous fuels
- Integration of multiple fuel cell stacks and design a kW scale pilot plant
- Cost analysis of a kW scale fuel cell stack

Publication

Tritti Siengchum, Felipe Guzman, Steven S.C. Chuang, Analysis of Gas Products from Direct Utilization of Carbon in a Solid Oxide Fuel Cell. *Journal of Power Sources* **2012,** *213* (0), 375-381.

Acknowledgements

US Department of Energy, DE-FE000528
Ohio Coal Development Office, OCDO
FirstEnergy Corp.