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Feasibility Analysis for Power Generation from a Lab-made Intermediate Temperature-Solid Oxide Fuel Cell Using Liquid Alcohol Fuels

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Abstract

Liquid hydrocarbon fuels (HCf) have a high volumetric energy density, are easy to transport and safer in operation than hydrogen for SOFC power generation, and there is no carbon tax if the HCf is made from renewable sources. Bio-alcohol fuels and an understanding of the cost structure of the energy technology are necessary for validation of this important power generation system. This study gasified methanol and ethanol to prove syngas, in which the content of three small molecular fuels (H_2, CO, and CH_4) are studied after the gasification and the following, thermo-cracking/ reforming. One lab-assembled furnace and reforming catalyst, containing activated Ni/Sm-CeO$_2$/γ-alumina carrier was used for the reforming tests for SOFC operation. The raw material costs and optimizing the processing steps are used for an activity-based costing (ABC) system to estimate the costs of a lab-scale SOFC using liquid hydrocarbon as fuels. The operation of the power generation was based on an energy conversion efficiency of 50%, a 700 W SOFC, a total operational lifetime of 20,000 h, and a catalyst lifetime of 10 days. The costs are evaluated and compared with the electricity cost report of Taipower Co., Taiwan (TPC). This small-scale system is proposed as a potential alternative to that of combustion power generation might incur a carbon tax.

Keywords: Liquid fuel; Alcohol; Syngas; SOFC; Cost analysis; Feasibility; Carbon tax

Introduction

Energy, materials and information are three essential pillars of sustainable civilization [1]. Since the 2nd industrial revolution, the development of new technologies has been closely linked to energy issues. Electricity is an essential infrastructural energy element for economic development in modern cities, but as society continues to experience progress and convenience, there is an increase energy in demand as the population increases. But the use of fossil fuels results in environmental pollution, green house effects, global warming and extreme climates. The sustainable development of energy must consider more than the cost of power generation by combustion of fossil fuels [2].

Hydrogen has become a popular energy source. Hydrogen is the simplest element, the most abundant, and is the source of potential energy in the universe. It is obtained from biomass, thermal cracking of hydrocarbon fuels, such as fossil fuels, or the electrolysis of water [3]. Hydrogen can provide three times more energy than the same mass of fossil fuels, and has the highest energy density of all fuels. When hydrogen burns in air, only water is produced, and there is no methane, greenhouse gases or waste gases are produced. The concept of a hydrogen economy has been promoted in the last century to replace carbon-based fossil fuels [3-5].

About 80M tons of hydrogen was produced last year [4] as the first step in the hydrogen economy. The safe transportation and storage of hydrogen causes problems because gaseous hydrogen has very low density and must condensed to a liquid state before transportation or storage. The high pressure and low temperature conditions that are for H_2-condensationare expensive. Even in a liquid state, liquid H_2 has a low density (ca. 0.089 g*ml^{-1}) at room temperature [3]. So plenty improvements are needed before it is used in everyday life. Japan aims to be a hydrogen-powered society by 2030 [5], but is currently in a transition phase and has to reduce its reliance on fossil fuel gradually.

Hydrocarbon fuels are still the main source of the energy supply in the next 10 years in Japan.

Bio-hydrocarbon fuels (HC_f) that are produced from sustainable energy sources are an alternative to fossil fuels. The HC_f is using bio-mass widely distributed around the world, or is commercially synthesized from industrial and agriculture wastes [6-8]. If wastes are the raw materials, the biomass is virtually cost-free [9,10]. Plenty of biomass contains very little organic sulfur (<0.1%), and almost no sulfide emission are produced during the synthesis of syngas.

Solid oxide fuel cells (SOFCs) have a high energy conversion efficiency, low environmental pollution, and flexible acceptance for various fuels. The device can use hydrogen, CO, CH_4, and various HC_f sources, which are used for the production of gaseous H_2/CO fuels by evaporation, thermal cracking, and reforming. During the transition to a hydrogen economy, the main stream hydrogen production technology involves the use of renewable HC_f combined with SOFCs for power generation. The liquid renewable HC_f that is processed to syngas, and SOFCs are a potential power system for the near future [3,10].

This study uses several ceramic oxide carriers to produce catalytic Ni/CeO$_2$ on the submicron scale [10-12]. The synthesis of bio-alcohol is a mature process [8,9], so liquid alcohols are used for this study. The fraction of tree small fuel molecules (H2, CO, CH4) in syngas,

the furnace for thermo-processing, and SOFC power generation [13] are perform power generation. Activity-based costing (ABC) systems [14,15] is used to determine the cost of power generation to develop a sustainable and cost-effective method to produce electricity.

Experimental

Two anhydrous alcohols (C_2H_5OH and CH_3OH, 99.5% pure, King Chemical Co., Taiwan) and one aqueous alcohol (95% pure, King Chemical CO., Taiwan) were used as the liquid fuels for this study. After thermal reactions, a syngas of the highest hydrogen and lowest CH4 contents was used to fuel a SOFC for electricity production. The production steps were validated in the cost analysis of raw materials/ man power for the operation, including the furnace and reformer assembly, the operation of the furnace and SOFC. The details of the data are shown in the studies by Li [16] and Cheng [17], and is summarized in the following sections. Two attachments (furnace and catalyst) to the SOFC are described in the following.

Furnace Assembly and Test

Furnaces (F01) for heating cell stacks, a heat exchanger and a tubular reformer was assembled in the lab. One commercial 430

Figure 1: Schematic diagram of F01 furnace with heat exchanger, a burner of waste gas, a cell stack, and a reformer.
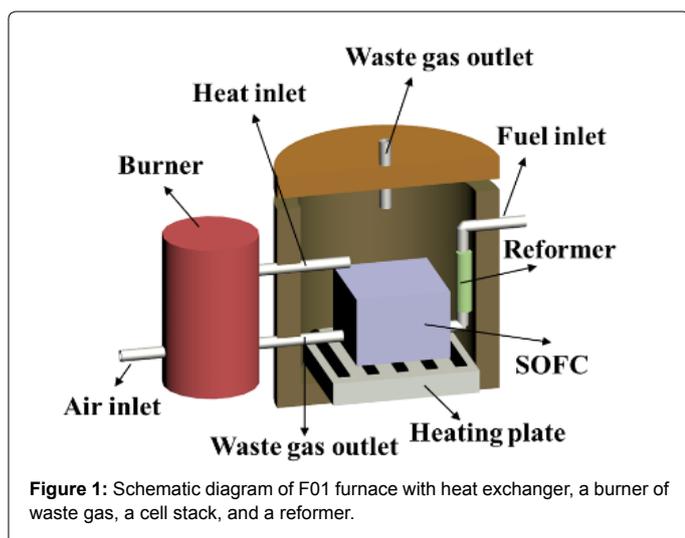
stainless steel (SS) cage with a diameter of 38 cm and a height of 36 cm was used as the furnace housing. A refractory clay (ICM-100, Kuan-Ho Co., Taiwan) for the preparation of a thermal insulator in 3.0 kg was casted into the bottom and the wall of the cage. In order to create flow channels for air inlet and temperature measurement, an inner-cylinder mold with a diameter of 28 cm was fixed by plastic straws and sealed with tapes. Several SS nuts were installed on the wall of the cage to strengthen the furnace refractory. After curing, demolding, and drying, the furnace was ready for testing. After drying of the furnace, the bottom was fitted with one 1600 W heating panel or two 720W heating panels. The thickness of the wall and cover was about 5.0 cm. The details of the F01 design are shown in Figure 1. The inner volume is 18 litters. The cost estimation is shown in Table 1, in which the steps of the furnace assembly are appraised in terms of materials usage and assembly labor. The furnace cost is US $923.95 per set.

The furnaces were operated using a programmable controller (CAHO P961, China), and the power dissipation rate (W) at different holding temperatures (500 – 800°C) was recorded.

The heating schedule for temperatures from 500 – 800°C is shown in Figure 2(a). The heating plate generates sufficient heat for a heating rate of 10°C.min^{-1}, except at 800°C. The furnace took about 120 min to reach 800°C. Therefore, one 1600W or two 720W heating plates are the minimal requirement to this furnace.

Figure 2(b) shows the test results off the heat dissipation for F01, which requires time to reach a set temperature, after which power is gradually reduced. The furnace radiates about 500W to 1440W of heat flow to space. So, the minimal heat to maintain the furnace at operation temperature is from 500W to 1440W for the temperatures of 500°C to 800°C.

If any parts, e.g. SOFC, are installed in the furnace, addition energy is needed to heat these parts to the operating temperature. One of the test results is shown in Figure 2(c). The SOFC requires an additional 1.25+0.03 MJ to reach 650°C, and 1.65+0.03 MJ to reach 800°C.

Preparation and Test of Catalyst/Reformer

Porous alumina balls (γ-Al_2O_3, First Chemical, Co., Taiwan) with a specific surface area (ca. 300 m^2/g) were used as a carrier material. Two chemicals, Ce $(NO_3)_3$.$6H_2O$ and Ni$(NO_3)_2$.$6H_2O$ (both 99% pure, Jing-

Item			Cost (US$)		
Furnace		Feedstock	1. SS cylinder (housing) 20 2.13 kg, ICM-100 Refractory clay 24.27 3. 20 sets screw and nut (diameter=2-3cm) 3.33 Subtotal $47.6		
		Labor	Sieving:5.27*13hr=68.51 Mixing:5.27*15/60=1.32 Casting:5.27*1hr=5.27 Subtotal $75.1		
Assembly	Demolding	Labor	5.27*5hr=$26.35		
	Integration	Component	1. Fuel inlet (10cm alumina tube) 0.83 2. Air inlet (10cm alumina tube) 0.83 3. Temperature controller(CAHO P961) 450 4. Stainless steel net 3.33 5. Heating plate 150 6. Catalytic and exhaust pipe 42.7 7. Custom furnace cover 116.67 Subtotal $764.36		
		Labor	5.27*2hr=$10.54		
Total			US$923.95		
※The curing time of refractory mud is not included in the cost calculation. ※The catalytic ball in the reformer is a consumable good. So it is not included in the cost of the fixed bed furnace.					

Table 1: Cost estimation of the furnace.
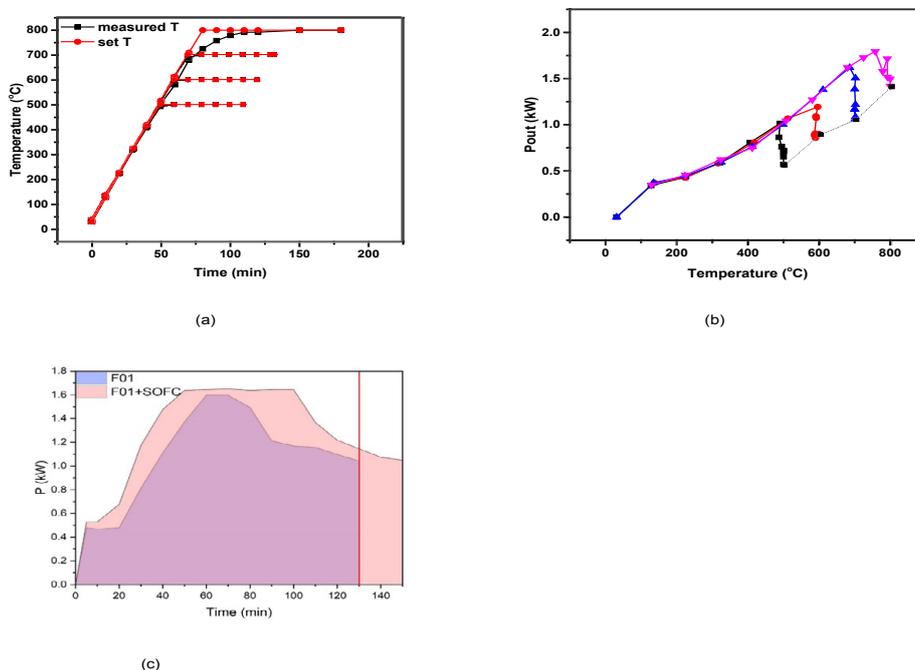
Figure 2: (a) Temperature distribution as a function of time, and (b) power dissipation of furnace F01 plotted against the temperature of the furnace equipped with two 720 W heating plates in parallel with the temperature setting at 500ºC to 800ºC, and (c) the power output profile plotted against heating time of F01 when the furnace install a SOFC stack and setting at 650ºC at a heating rate of 10ºC min^{-1}.

Ming Chemical Co., Ltd., Taiwan) were used to synthesize submicron NiO and CeO_2 particles in the porosity of the balls by immersion-precipitation [17]. 10 gm of the alumina carrier was immersed in 1.0 M 25 ml ceria nitrate solution, removed and dried in an oven. The carrier was then placed in a furnace at 500ºC and heated for 1 h at a rate of 5ºC.*min^{-1}. A similar process was used to coat NiO in the balls.

A combination of CeO_2 and Ni coating on γ-Al_2O_3 is basic catalyst to transform hydrocarbon gas to small molecules [10,17]. Ni is reduced from NiO at about 500ºC in strong reducing atmosphere, and is a low cost active metallic catalystif it is combined with CeO_2. This study uses the basic workable formulation NiO/CeO_2/γ-Al_2O_3 as the catalyst. The typical microstructure of the catalyst is shown in Figure 3. At submicron or nano-scale, Ni and CeO_2 particles have acceptable catalytic properties at 650ºC. The catalyst carrier has the porosity with bimodal distribution (Figure 3(a)), one shows around 20 μm and the other (Figure 3(b)) is less than 1 μm.

The content of NiO and CeO_2 were quantified using a lab-made standard. The constant EDS analysis parameters, were WD=10 mm, 20 keV, spot size= 40, and 200x magnification. The calibration factor, K, is between 0.8-0.9 [17], so the quantification analysis is significant. The EDS results* are shown in Figure 4. The variation in the NiO and CeO_2 contents is significant along the Al_2O_3 carrier. In general, the outer surfaces of the carrier have a higher Ce and Ni contents (more than 0.2 at%) than the center. The process for the reformer is described in the following. 200 g of ICM-100 refractory material was weighted, ground, and coarsely sieved, and a proper amount of water was added to form a paste. The outside of the alumina tube was then coated with the refractory material. In order to increase the diffusion path for alcohol gasification, the alumina tube with several holes was placed into a high-SiO_2 glass tube, containing 5.0

gm catalytic balls. The details of the material cost, the assembly cost and the processing cost for a reformer are shown in Table 2. One reformer costs US$52.2.

Activity Analysis of Power Generation

Gasification/Reforming of Liquid Alcohol

Figure 5 shows the gas composition of two alcohols that decompose at 400ºC – 800ºC. 99.5% ethanol with a very low water content (<0.5% water) was vaporized in anoxic condition, and decomposed thermally in the temperature region. The results* show that the alcohols did not fully decomposed, and H_2, CO and CH_4 formed at >500 ºC and gradually increased as the temperature was increased to 800ºC. The methanol transformed to H_2 in 64+2%, CO 32+2%, CH_4 2% at 800ºC (Figure 5(b)). Ethanol that did not decompose so well (Figure 5(a)) had a value of 35% CH_4, 33% CO and 19% H2. A high CH_4 content (35%) is not favorable for a syngas suppling to a SOFC, so reforming is required (Figure 5).

The dotted lines showing "H_2 calculated" in the figures are the calculation results for the measured carbon-containing species, $[H_2]_{cal}$=2*[CO]+2*[CO2]. LowCH_4 content result in a high H_2 calculated values. The values are consistent at 800ºC, no other products are formed. However, two carbon-containing products ($HCOOCH_3$ and HCHO) may be formed between 500ºC and 700ºC, in the following reactions.

$$2CH_3OH \rightarrow HCOOCH_3 + 2H_2 \tag{1}$$

$$\text{or} \quad CH_3OH \rightarrow HCHO + H_2 \tag{2}.$$

The composition of the syngas was determined using a gas chromatographer (GC/TCD, 8900GC, China Chromatography Co.,
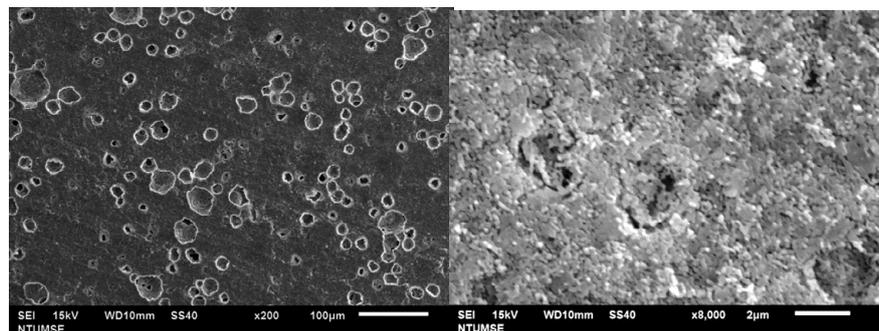
Figure 3: SEM micrographs of Al_2O_3 carrier (disk-shape) in different magnifications with 20 wt% MCMB (pore former) sintered at 1150 °C for 1 h. Note that all coating particles in (b) show that bright ones are CeO_2, the gay ones are NiO.
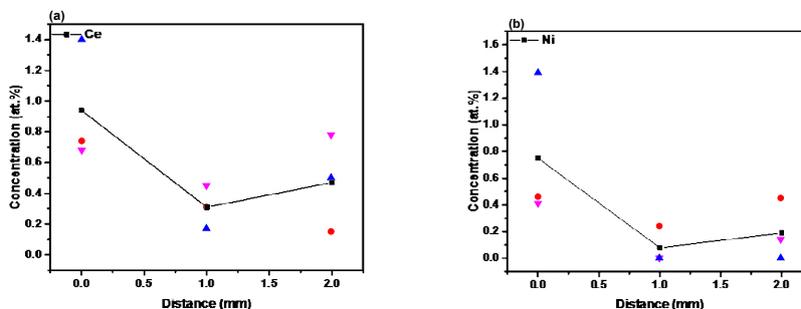
Figure 4: Average concentration (■) and the analyzed data (the other symbols) of the (a) Ce, and (b) Ni-containing particles on a few cross sections of the Al_2O_3 carrier (in 2.0 mm thick) with 20% MCMB addition from one side to another.

Item		Cost (US$)
Catalyst		1.Alumina ball (10 g) 0.13 2.Cerium nitrate aqueous solution (10.85 g) 3.63 3.Nickel nitrate aqueous solution (7.27 g) 0.17 Subtotal $3.93
Assembly	Material	1.Alumina tube (10 cm tube) 0.83 2.Quartz glass tube (inner diameter: 22 mm, length: 500 mm) 36.67 3. ICM-100 refractory clay (200 g) 0.4 4. Silicone plug 2.17 Subtotal$40.07
	Labor	The catalyst 1. Immersing cerium nitrate aqueous solution 5.27*20/60=1.76 2. Calcination 5.27*10/60=0.88 3. Immersing nickel nitrate aqueous solution 5.27*20/60=1.76 4. Calcination 5.27*10/60=0.88 5. Instrument 3.34kWh*0.094=$0.31 Subtotal $5.27
		The reformer 5.27*30/60=$2.64
Total		US$52.2 per piece
※The curing time of refractory mud is not included in the cost calculation. ※The catalytic ball in the reformer is a consumable, so it is not included in the cost of the reformer.		

Table 2: Cost estimation of the catalyst and the reformer.

Taiwan). Four gases, H_2, CO, CH_4 and CO_2, were analyzed.

The reactions reduce the H_2 content from 500°C to 700°C.

Figure 6 shows the syngas composition for 99.5% methanol passing through a reformer containing CeO_2-NiO/γ-Al_2O_3 or SDC-NiO/γ-Al_2O_3 catalyst at 400 °C~800°C. The amount of the catalyst was fixed at 5.0 g. The data (Figure 6(a)) for CeO_2-NiO/γ-Al_2O_3 reforming shows that only H_2 and CO are produced at 500°C, so the concentrations are 6262% H2 and 28% CO, with small amounts of CH_4 and CO_2., of which

the contents increase to 8.5% then reduce to 4.3% as the temperature changes from 600 to 800°C. The syngas content case in Figure 6(b) is slightly less in the temperature region because a dry-reforming reaction (2CO+2H2→CH4+CO2) is induced (Figure 6).

The syngas content was almost the same between 500°C and 8700°C. The H_2 content is almost 60+2%, CO 30+2%, so there is a similar thermal decomposition mechanism. CH_4 content can be reduced as low as 3% in this temperature region. The transformation rate from methanol to syngas is nearly 100% at temperatures higher than 500°C.
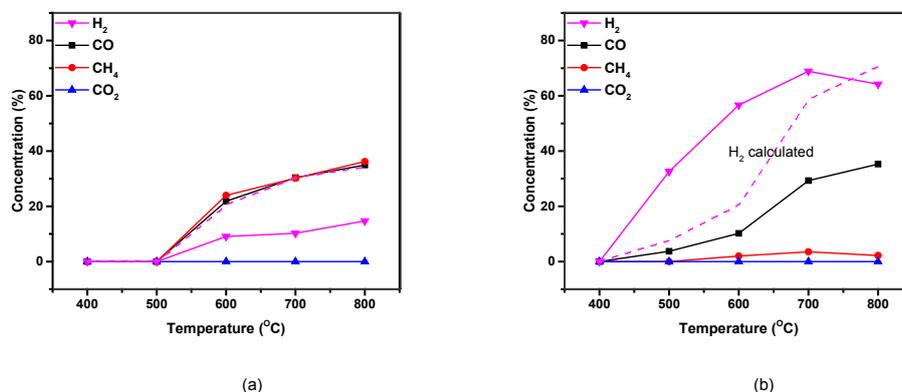
Figure 5: Syngas composition of 99.5% (a) ethanol (b) methanol through thermal decomposition at selected temperature.
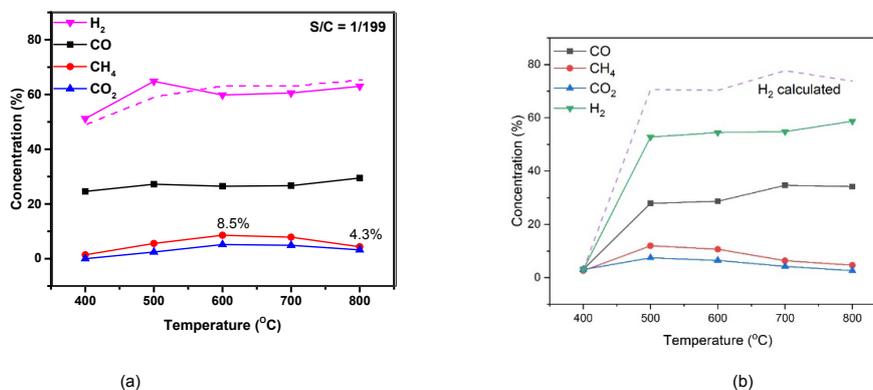
Figure 6: Reformed syngas composition of 99.5% pure methanol through 5.0 g γ-Al$_2$O$_3$ balls impregnated (a) CeO$_2$-NiO and (b) SDC10-NiO catalyst at selected temperature. The calculated H$_2$ concentration data has been plotted as dash line.

Category	Activity (operation)	Cost pool [17]	Costing driver
Batch level cost	(1) Heating	SOFC and furnace power needed	Cycling time,
Production level cost per kWh	(2) Temperature holding	SOFC and furnace	Input fuel, ml
		Depression of the furnace	Operation, hr
	(3) Fueling pump	Fueling electricity	Input fuel, ml
		Depression of pump	Pumping, h
		Replacement of catalyst	Life time of the catalyst, hr
	(4) SOFC operation	Depression of SOFC stack	Operation, h
		Cycling	man power for checking, 1 d/cycle

Exchange rate: US$1.00 = NT$30.0

Table 3: Operation activity, cost pool and costing driver of SOFC operation for SOFC power generation.

This data show that the syngas produced between 500 – 800ºC is well suited as a fuel for SOFC power generation between 500- 800ºC.

Activity Validation

This study identifies four activities based on the steps and processes for SOFC power generation using methanol as a fuel. An electric furnace is heated to, the temperature maintained by constant electric heating, fueling of methanol liquid uses a precision peristatic pump to an accuracy of 0.1ml.min^{-1}, and SOFC operation is manually controlled. The cost pools and drivers for each activity are shown in Table 3.

The heating for all units is assumed for each cycle using resistant heating panels (consuming electricity) in the early preparation stage.

When the furnace reached the set temperature, the SOFC began to generate electricity. Heating and thermal treatment, gasification, thermal cracking and reforming of alcohol syngas were performed in a separated heat recovery/exchange unit. During the thermal process, the syngas was analyzed using GC every 30 min before being fed to the SOFC stack. The composition results were almost constant (<1% variation) so the contents of H$_2$, CO and CH$_4$ were respectively close to 64+2%, 32+2%, 3+12% at 800ºC. When the syngas passed through the furnace, which was operated at 800ºC, the entire furnace (Figure1) was used to maintain the 700 W SOFC stack in operating conditions. The operation was almost labor-free, but the heating/cooling cycle counted in batch (200 h/cycle) was manually controlled. Table 4 shows the cost of the equipment and materials used for the activities Table 4.

Cost Analysis of SOFC Power Generation

The lower half of Table 4 shows the operating conditions, including the conversion efficiency 50% for the SOFC, the life time of the operation of 20000 h, the life time of catalyst lasting for 10 days and a cycle time of 200 h/cycle. The following analysis is based on the cost needed for power production of 1 kWh.

This study uses activity-based costing (ABC) to estimate the cost of using methanol for SOFC power generation [18]. The cost of liquid methanol and the purchase cost of the SOFC (purchased from Ningbo Institute of Material Engineering) and the assembly equipment are also summarized in the higher half of Table 4. The man power that is required for the assembly of the catalyst and the furnaces is shown in the previous tables.

Table 5 shows the details of the cost calculation of the power generation. The SOFC required 1.43 h to produce 1 kWh electricity, and needed 381 mL methanol for a conversion efficiency of 50%. In

term of depreciation of all devices, manpower and the batch operation, the cost of generating 1 kWh power generation was US$0.33 /kWh. The cost of electricity to keep the whole operating at 800°C is $0.22/kWh, which takes 66% (the main part) of the cost to produce 1 kWh by the SOFC, and can be improved by various modifications (Table 5)

The cost ($0.33/kWh) is greater than the cost that Taipower Co. charges, which are between $0.054 /kWh and $0.19/kWh for the power produced using fossil fuels (Table 6). If the government imposes an additional carbon tax of US$80 per tCO$_2$e for the TPC operation, the price of the local electricity increases to $0.119/kWh to $0.255 /kWh. The price of the electricity that is produced by this study is not competitive in the local market.

Several other options are currently under review by the authors. One is reducing the cost of the SOFC stacks from the current $1333 / set ($1904 /kW) to an expected price of $400 /kW if SOFC stacks can be mass produced [19,20] in future. The results of the subject and detail investigations will be reported in next future paper.

Item	Cost (US$) or variables	Sources
Methanol	0.175 /L	www.our-business/pricing of Methanex Co.
Fix-bed furnace, F01-1 and F1-2	924/ set	[17, 22]
SOFC	1333/stack	(purchased from NIMTE, Ningbo Institute of materials technology and engineering]
Fueling system	30 /set	[17]
Catalyst	9.53 /set	[17]
Conversion Efficiency of SOFC	50%	[19, 20] for stationary cells
Life time of SOFC at operation temperature	20,000 hr	[20] for stationary cells
Life time of catalyst	10 days	[17]
Cycling	100 times	[20] for stationary cells
Carbon tax	US$80 /tCO$_2$e	Referring to Appendix Table A1

Table 4: Costs of direct materials, processing assumptions, and processing equipment for the SOFC power generation by using methanol as a fuel.

(1) SOFC power (W)	−	700 W
(2) Energy conversion efficiency	−	50%
(3) Power required to run 700W SOFC 1.43 hr	(3)=(1)÷(2)	1400 W
(4) kWh required to run 700W SOFC 1.43 h	(4)=(3)÷1000×1.43	2.002 (kWh)
(5) Required methanol (MJ)	(5)=(4)×3.6MJ	7.21 (MJ)
(6) Required methanol (mL)	(6)=(5)÷0.767×40.55 mL	381 (mL)
(7) The cost of methanol required to generate 1 kWh of electricity (direct raw material)	(7)=(6)÷1000×0.175 USD	$0.067
(8) Feeding amount per hr (mL)	≥266 (mL)/hr	266.4 (mL)
(9) Feeding time required to generate 1 kWh of electricity (h)	(9)=(6)÷(8)	1.43 (hr)
(10) The power of fuel pump is 15 W.	15÷1000×1 h	0.015 (kWh)
(11) Pump operating cost required to generate 1 kWh of electricity	(11)=(9)×(10)0.094	$ 0.0037 /kWh
(12) The cost of electricity consumption of heating plate holding temperature to generates 1 kWh of electricity	(12)=1.6 kW×1.43 h×0.094	$ 0.22/kWh
(13) Fuel pump depreciation expenses that need to be shared when generating 1 kWh of electricity	$300÷43800hr×1.43 hr	$ 0.0098 /kWh
(14) Gasifier depreciation expenses that need to be shared when generating 1 kWh of electricity	$923.9÷43800hr×1.43 hr	$ 0.030 /kWh
Total		**US$ 0.33 /kWh**

Table 5: Cost estimation of a power operation by the SOFC with 50% energy conversion efficiency in first-stage analysis.

Item	Generation cost (USD/kWh)	CO$_2$ emissions (tCO$_2$e)	Total power Generation (kWh)	tCO$_2$e /kWh	Additional cost with US$5.0/tCO$_2$ tax	Additional cost with US$80/ tCO$_2$ tax
Coal	0.054	60,090,000	67,429,000,000	8.91x10⁻⁴	0.0046	0.073
Natural gas	0.086	27,200,000	68,723,000,000	3.96x10⁻⁴	0.00204	0.033
Oil	0.19	3,520,000	4,426,000,000	7.95x10⁻⁴	0.0041	0.065
Total	**0.074 (average cost)**	**90,810,000**	**140,578,000,000**	**6.46x10⁻⁴ (average)**	**0.0033**	**0.053**

Table 6: Cost of power generation with and without carbon dioxide emission, and possible cost of TaiPower Co. in consideration of the tax either US$5.0 or US$80.

Conclusions

This study uses methanol as a source fuel for a SOFC, and a cost analysis of the power generation is conducted to validate a lab-produced power generation system. One lab-assembled furnace and reformer containing Ni/CeO$_2$/γ alumina carrier were used for the syngas production for the SOFC operation. Methanol and ethanol were gasified, and the content of three small molecular fuels (H2, CO, and CH4) in the syngas after gasification, thermo-cracking and reforming through the furnace and reformer was measured. A syngas of 604+2% of H2, 32+2% of CO and 2% of CH4 was produced at 800°C.

Raw materials costs and optimization of the processing steps were used to determine the cost evaluation of each activity that is involve in using methanol fuel for a 700W SOFC. The study assumed an energy conversion efficiency 50 %, a 700 W SOFC costing US$ 1333 /set, a total operation lifetime of 20,000 h and a catalyst lifetime lasting for 10 days. The cost at US$0.33 /kWh is greater than the cost report of Taipower Co., Taiwan (TPC). If a carbon tax of US$80 per tCO$_2$e imposed for electricity which is produced using fossil fuels, this small-scale power generation system is still not commercially viable for operation in Taiwan. Additional efforts of cost-down are needed.

References

1. https://circularecology.com/sustainability-and-sustainable-development.html

2. Shafiee S, Topal E (2009). When will fossil fuel reserves be diminished? Energy Policy 37:181-189.

3. Wei WCJ (2013) Fundamental and technology of solid oxide fuel cells, Chapters 3, Ka-Li Pub., New-Taipei city, Taiwan, ROC

4. At the dawn of the hydrogen economy, Power Jun 30, 2020

5. https://www.s-ge.com/en/article/global-opportunities/20201-c5-japan-hydrogen-market

6. Inoue H, Horio H (2015) Method of biomass gasification. US patent no. 9.

7. Yemshanov D, McKenney D (2008) Fast-growing poplar plantations as a bioenergy supply source for Canada. Biomass Bioenergy 32:185-197.

8. Eaves J, Eaves S (2007) Renewable corn-ethanol and energy security. Energy Policy 35:5958-5963.

9. Kelfkens RC, Kosstrin HM (2016) Renewable carbon content in methanol and other products from gasification of biomass.

10. Ke SY, Chen YY, Wei WCJ (2017) Gasification and syngas reforming of city waste papers for solid oxide fuel cells. Innov. Energy & Research.

11. Sehested J (2006) Four challenges for nickel steam-reforming catalysts. Catalysis Today. 111: 103-110.

12. Hong YM (2011) Catalyst development of alcohol reforming, MOST report.

13. Ru YL, Sang JK, Xia CG, Wei WC, Guan WB (2020) Durability of direct internal reforming of methanol as fuel for solid oxide fuel cell with double-sided cathodes. Int. J. Hydrogen Energy 45:7069-7076.

14. Johnson T. (1981) Toward a New Understanding of Nineteenth-Century Cost Accounting. The Accounting Review 56:510-518.

15. Jasinski D, Meredith J, Kirwan K (2015) A comprehensive review of full cost accounting methods and their applicability to the automotive industry. J. Cleaner Production. 108:1123-1139.

16. Li KS (2020) Liquid alcohol fuels supplying for IT-SOFC, MS thesis, NTU, Taiwan.

17. Cheng YH (2018) (Bi,Mn,Fe)-doped Ceria electrolyte materials for IT-SOFCs, MS thesis, NTU, Taiwan.

18. https://www.taipower.com.tw/tc/page.aspx?mid=196

19. Wei WCJ (2014). Technology of solid oxide fuel cells, Shanghai Jiao Tong University Press, Shanghai, PRC

20. The requirements of SOFC, by Delphi and SECA, DOE project, USA (2010).