REFERENCES

Amphlett, J.C., Creber, K.A.M., Davis, J.M., Mann, R.F., Peppley B.A., and Stokes, D.M. (1994) Hydrogen production by steam reforming of methanol for polymer electrolyte fuel cells. International Journal of Hydrogen Energy, 19, 131–137.

Bensalem, A., Bozon–Verduraz, F., Delamar, M., and Bugli, G. (1995) Preparation and Characterization of highly dispersed silica supported ceria. Applied Catalysis A: General, 121, 81–93.

Bond, G.C., Louis, C., and Thompson, D.T. (2006) Catalysis by Gold, London: Imperial College Press.

Carrettin, S., Corma,A., Iglesias, M., and Sanchez, F. (2005) Stabilization of Au(III) on heterogeneous catalysts and their catalytic similarities with homogeneous Au(III) metal organic complexes. Applied Catalysis A: General, 291, 247–252.

Chang, F.–W., Yu, H.–Y., Roselin, L.S., Yang, H.–C., and Ou, T.–C. (2006) Hydrogen production by partial oxidation of methanol over gold catalysts supported on TiO2-MOx (M = Fe, Co, Zn) composite oxides. Applied Catalysis A: General, 302, 157–167.

Chang, F.-W., Lai, S.–C., and Roselin, L.S. (2008) Hydrogen production by partial oxidation of methanol over ZnO-promoted Au/Al_2O_3 catalysts. Journal of Molecular Catalysis A: Chemical, 282, 129–135.

Chang, F.W., Roselin, L.S., and Ou, T.–C. (2008) Hydrogen production by partial oxidation of methanol over bimetallic $Au–Ru/Fe_2O_3$ catalysts. Applied Catalysis A: General, 334, 147–155.

Chen, W.–H., and Lin, B.–J. (2010) Effect of microwave double absorption on hydrogen generation from methanol steam reforming. International Journal of Hydrogen Energy, 35, 1987–1997.

Cormos, C.–C. (2011) Hydrogen production from fossil fuels with carbon capture and storage based on chemical looping systems. International Journal of Hydrogen Energy, 36, 5960–5971.

Costello, C.K., Yang, J.H., Law, H.Y., Wang, Y., Lin, J.N., Marks, L.D., Kung, M.C., and Kung, H.H. (2003) On the potential role of hydroxyl groups in CO oxidation over Au/Al_2O_3. Applied Catalysis A: General, 243, 15–24.

Diagne, C., Idriss, H., and Kiennemann, A. (2002) Hydrogen production by ethanol reforming over $Rh/CeO_2–ZrO_2$ catalysts. Catalysis Communications, 3, 565–571.

Dinh, L.N., Pascaline, L., and Cuong, P.H. (2009) Influence of the oxygen pretreatment on the CO_2 reforming of methane on Ni/β-SiC catalyst. Catalysis Today, 141, 393–396.

El-Moemen, A., Karpenko, A., Denkwitz, Y., and Behm, R.J. (2009) Acticity, stability and deactivation behavior of Au/CeO_2 catalysts in the water gas shift reaction at increased reaction temperature (300°C). Journal of Power Sources, 190, 64–75.

Faungnawakij, K., Tanaka, Y., Shimoda, N., Fukunaga, T., Kikuchi, R., and Eguchi, E. (2007) Hydrogen production from dimethyl ether steam reforming over composite catalysts of copper ferrite spinel and alumina. Applied Catalysis B: Environmental, 74, 144–151.

Freyschlag, C.G., and Madix, R.J. (2011) Precious metal magic: catalytic wizardry. Materials Today, 14, 134–142.

Grau–Crespo, R., Cruz Hernandez, N., and H. de Leeuw, N. (2007) Theoretical Investigation of the Deposition of Cu, Ag, and Au Atoms on the $ZrO_2(111)$ Surface. Journal of Physical Chemistry C, 111, 10448–10454.

Gomez, I., Kocemba, I., and Rynkowski, J. (2008) $Au/Ce_{1-x}Zr_xO_2$ as effective catalysts for low–temperature CO oxidation. Applied Catalysis B: Environmental, 83, 240–255.

Gottfried, M., and Erlangen-Nurnberg, U. (2003) Catalysis by gold and further catalysis-related research. Journal of Physical Chemistry C, 112, 1–11.

Gu, W., Shen, J.–P., and Song, C. (2003) Hydrogen production from integrated methanol reforming over $Cu-ZnO/Al_2O_3$ AND Pt/Al_2O_3 catalysts for PEM fuel cells. Preprints of Symposia–American Chemical Society, Division of Fuel Chemistry, 48, 804–807.

Haruta, M. (1997) Novel catalysis of gold deposited on metal oxides. Catalysis Surveys of Japan, 1, 61–73.

Haruta, M. and Date, M. (2001) Advances in the catalysis of Au nanoparticles. Applied Catalysis A: General, 222, 427–437.

Hong, X., and Ren, S. (2008) Selective hydrogen production from methanol oxidative steam reforming over Zn-Cr catalysts with or without Cu loading. Journal of Molecular Catalysis A: Chemical, 33, 700–708.

Horny, C., Kiwi–Minsker, L., and Renken, A. (2004) Micro-structured string-reactor for autothermal production of hydrogen. Chemical Engineering Journal, 101, 3-9.

Houteit, A., Mahzoul, H., Ehrburger, P., Bernhardt, P., Legare, P., and Garin, F. (2006) Production of hydrogen by steam reforming of methanol over copper-based catalysts: The effect of cesium doping. Applied Catalysis A: General, 306, 22–28.

Huang, G., Liaw, B.–J., Jhang, C.J., and Chen, Y.–Z. (2009) Steam reforming of methanol over $CuO/ZnO/CeO_2/ZrO_2/Al_2O_3$ catalysts. Applied Catalysis A: General, 358, 7–12.

Idakiev, V., Tabakova, T., Naydenov, A., Yuan, Z.–Y., and Su, B.-L. (2006) Gold catalysts supported on mesoporous zirconia for low-temperature water–gas shift reaction. Applied Catalysis B: Environmental, 63, 178-186.

Jacob, G., Graham, U.M., Chenu, E., Patterson, P.M., Dozier, A., and Davis, B.H. (2005) Low-temperature water–gas shift: impact of Pt promoter loading on the partial reduction of ceria and consequences for catalyst design. Journal of Catalysis, 229, 499–512.

Kambolis, A., Matralis, H., Trovarelli, A., and Papadopoulou, Ch. (2010) $Ni/CeO_2–ZrO_2$ catalysts for the dry reforming of methane. Applied Catalysis A: General, 377, 16–26.

Kunming, J., Huili, Z., and Wencui, L. (2008) Effect of morphology of the ceria support on the activity of Au/CeO_2 catalysts fot CO oxidation. Chinese Journal of Catalysis, 29, 2089–1092.

Lenarda, M., Storaro, L., Frattini, R., Casagrande, M., Marchiori, M., Capannelli, G., Uliana, C., Ferrari, F., and Ganzerla, R. (2007) Oxidative methanol steam reforming (OSRM) on a PdZnAl hydrotalcite derived catalyst. Catalysis Communications, 8, 467–470.

Liu , S.Y., and Yang, S.M. (2008) Complete oxidation of 2–propanol over gold–based catalysts supported on metal oxides. Applied Catalysis A: General, 334, 92–99.

Luengnaruemitchai, A., and Kaengsilalai, A. (2008) Activity of different zeolite–supported Ni catalysts for methane reforming with carbon dioxide. Chemical Engineering Journal, 144, 96–102.

Ma, Z., and Dai, S. (2010) Development of Novel Supported Gold Catalysts: A Materials Perspective. Nano Research, 4(1), 3–32.

Mastalir, A., Frank, B., Szizybalski, A., Soerijanto, H., Deshpande, A., Niederberger, M., Schomäcker, R., Schlögl, R., and Ressler, T. (2005) Steam reforming of methanol over $Cu/ZrO_2/CeO_2$ catalysts: a kinetic study. Journal of Catalysis, 230, 464–475.

Matter, P.H., Braden, D.J., and Ozkan, U.S. (2004) Steam reforming of methanol to H_2 over nonreduced Zr-containing CuO/ZnO catalysts. Journal of Catalysis, 223, 340–351.

Matter, P.H., and Ozkan, U.S. (2005) Effect of pretreatment conditions on Cu/Zn/Zr-based catalysts for the steam reforming of methanol to H_2. Journal of Catalysis, 234, 463–475.

Niu, K., Zhang, X., Song Tan, W., and Long Zhu, M. (2010) Characteristics of fermentative hydrogen production with Klebsiella pneumoniae ECU-15 isolated from anaerobic sewage sludge. International Journal of Hydrogen Energy, 35, 71–80.

Oguchi, H., Nishiguchi, T., Matsumoto, T., Kanai, H., Utani, K., Matsumura, Y., Imamura, S. (2005) Steam reforming of methanol over $Cu/CeO_2/ZrO_2$. Applied Catalysis A: General, 281, 69–73.

Park, S., Yoo, K., Park, H.J., Lee, J.C., and Lee, J.H. (2006) Rapid gold ion recovery from wastewater by photocatalytic ZnO nanopowders. Journal of Electroceramics, 17, 831–834.

Patel, S., and Panta, K.K. (2007a) Selective production of hydrogen via oxidative steam reforming of methanol using Cu–Zn–Ce–Al oxide catalysts. Chemical Engineering Science, 62, 5436–5443.

Patel, S., and Pant, K. (2007b) Hydrogen production by oxidative steam reforming of methanol using ceria promoted copper–alumina catalysts. Fuel Processing Technology, 88, 825–832.

Perez-Hernandez, R., Gutierrez–Martinez, A., and Gutierrez–Wing, C.E. (2007) Effect of Cu loading on CeO_2 for hydrogen production by oxidative steam reforming of methanol. International Journal of Hydrogen Energy, 32, 2888–2894.

Perez–Hernandez, R., Galicia, G.M., Anaya. D.M., Palacios. J., Angeles-Chavez, C., and Arenas-Alatorre, J. (2008) Synthesis and characterization of bimetallic Cu–Ni/ZrO_2 nanocatalysts: H_2 production by oxidative steam reforming of methanol. International Journal of Hydrogen Energy, 33, 4569–4576.

Perez–Hernandez, R., Gutierrez-Martinez, A., . Palacios, J., Vega–Hernandez, M., and Rodriguez-Lugo, V. (2011) Hydrogen production by oxidative steam reforming of methanol over Ni/CeO_2-ZrO_2 catalysts. International Journal of Hydrogen Energy, 36, 6601–6608.

Pinzari, F., Patrono, P., and Costantino, U. (2006) Methanol reforming reactions over Zn/TiO_2 catalysts. Catalysis Communications, 7, 696–700.

Pojanavaraphan, C., Luengnaruemitchai, A., and Gulari, E. (2012) Hydrogen production by oxidative steam reforming of methanol over Au/CeO_2 catalysts. Chemical Engineering Journal, 192, 105–113.

Rao, G., and Sahu, H. (2001) XRD and UV–Vis diffuse reflectance analysis of CeO_2–ZrO_2 solid solutions synthesized by combustion. Journal of Chemical Sciences, 113, 651–658.

Roh, H.–S., Eum, I.–H., Jeong, D.–W. (2012) Low temperature steam reforming of methane over $Ni/Ce_{(1-x)}Zr_{(x)}O_2$ catalysts under severe conditions. Renewable Energy, 42, 212–216.

Rui–hui, L., Cun–man, Z., and Jian–xin, M. (2010) Gold catalysts supported on crystalline Fe_2O_3 for low-temperature CO oxidation. Chemical Research Chinese University, 26, 98–104.

Rynkowski, J.M., and Dobrosz–Gomez, I. (2009) Ceria–zirconia supported gold catalysts, Annales Universitatis Mariae Curie – Sklodowska Lublin – Polonia, Chemistry, 64, 197–217.

Scire, S., Minico, S., Crisafulli, C., Santriano, C., and Pistone, A. (2003) Catalytic combustion of volatile organic compounds on gold/cerium oxide catalysts Applied Catalysis B: Environmental, 40, 43–49.

Shen, P., and Lee, W. H. (2001) (111)–Specific Coalescence Twinning and Martensitic Transformation of Tetragonal ZrO_2 Condensates. Nano Letters, 1, 707–711.

Shishido, T., Yamamoto, Y., Morioka, H., and Takehira, K. (2007) Production of hydrogen from methanol over Cu/ZnO and Cu/ZnO/Al_2O_3 catalysts prepared by homogeneous precipitation: Steam reforming and oxidative steam reforming. Journal of Molecular Catalysis A: Chemical, 268, 185–194.

Tabakova, T., Boccuzzi, F., Manzoli, M., and Andreeva, D. (2003) FTIR study of low–temperature water–gas shift reaction on gold/ceria catalyst. Applied Catalysis A: General, 252, 385–397.

Tabakova, T., Avgouropoulos, G., Papavasiliou, J., Manzoli, M., Boccuzzi, F., Tenchev, K., Vindigni, F., and Ioannides T. (2011) CO–free hydrogen production over Au/CeO_2–Fe_2O_3 catalysts: Part 1. Impact of the support composition on the performance for the preferential CO oxidation reaction. Applied Catalysis B: Environmental, 101, 256–265.

Velu, S., Suzuki, K., Okazaki, M., Kapoor, M.P., Osaki, T., and Ohashi, F. (2000) Oxidative Steam Reforming of Methanol over CuZnAl(Zr)–Oxide Catalysts for the Selective Production of Hydrogen for Fuel Cells: Catalyst Characterization and Performance Evaluation. Journal of Catalysis, 194, 373–384.

Velu, S., Suzuki, K., Kapoor, M.P., Ohashi, F., and Osaki, T. (2001) Selective production of hydrogen for fuel cells via oxidative steam reforming of methanol over CuZnAl(Zr)-oxide catalysts. Applied Catalysis A: General, 213, 47–63.

Wang, Z., Wang, W., and Lu, G. (2003) Studies on the active species and on dispersion of Cu in Cu/SiO_2 and $Cu/Zn/SiO_2$ for hydrogen production via methanol partial oxidation. International Journal of Hydrogen Energy, 28, 151–158.

Wei, Y., Liu, J., Zhao, Z., Duan, A., and Jiang, G. (2012) The catalysts of three–dimensionally ordered macroporous $Ce_{1-x}Zr_xO_2$–supported gold nanoparticles for soot combustion: The metal–support interaction. Journal of Catalysis, 287, 13–29.

Yang, H.–C., Chang, F.–W., and Roselin, L.S. (2007) Hydrogen production by partial oxidation of methanol over Au/CuO/ZnO catalysts. Journal of Molecular Catalysis A: Chemical, 276, 184–190.

Yaseneva, P., Pavlova, S., Sadykov, V., Moroz, E., Burgina, E., Dovlitova, L., Rogov, V., Badmaev, S., Belochapkin, S., and Ross, S. (2008) Hydrogen production by steam reforming of methanol over Cu–CeZrYO_x-based catalysts. Catalysis Today, 138, 175–182.

Ying, L.–A., Liu, J., Mo, L., Lou, H., and Zheng, X. (2012) Hydrogen production by oxidative steam reforming of methanol over $Ce_{1-x}Zn_xO_y$ catalysts prepared by combustion method. International Journal of Hydrogen Energy, 37, 1002–1006.

Yuan, Z.–Y., Idakiev, V., Vantomme, A., Tabakova, T., Ren, T.–Z., and Su, B.–L. (2008) Mesoporous and nanostructured CeO_2 as supports of nano-sized gold catalysts for low-temperature water-gas shift reaction. Catalysis Today, 131, 203–210.

Zanella, R., Giorgio, S., Shin, C.–H., Henry, C.R., and Louis, C. (2004) Characterization and reactivity in CO oxidation of gold nanoparticles supported on TiO_2 prepared by deposition-precipitation with NaOH and urea. Journal of Catalysis, 222, 357–367.

Zhang, X., and Shi, P. (2003) Production of hydrogen by steam reforming of methanol on CeO_2 promoted Cu/Al_2O_3 catalysts. Journal of Molecular Catalysis A: Chemical, 194, 99–105.

Zhang, C., Yuan, Z., Liu, N., Wang, S., and Wang, S. (2006) Study of Catalysts for Hydrogen Production by the High Temperature Steam Reforming of Methanol. Fuel Cells, 6, 466–471.

Zhang, R.–R., Ren, L.–H., Lu, A.–H., and Li, W.–C. (2011) Influence of pretreatment atmospheres on the activity of Au/CeO_2 catalyst for low–temperature CO oxidation. Catalysis Communications, 13, 18–21.

APPENDICES

Appendix A The methanol conversion and hydrogen yield of catalysts

The methanol conversion and hydrogen yield are calculated by Equation A1–A2.

$$X = \frac{CO + CO_2 + CH_4}{MeOH_{(in)}} \times 100(\%) \quad \text{(A1)}$$

where:

X = methanol conversion (%)

$MeOH_{(in)}$ = mole of methanol inlet

$$Y_{H_2} = X \times S_{H_2} \quad \text{(A2)}$$

where:

Y_{H_2} = hydrogen yield (%)

H_2 = mole of hydrogen in the product stream

CO = mole of carbon monoxide in the product stream

CO_2 = mole of carbon dioxide in the product stream

CH_4 = mole of carbon methane in the product stream

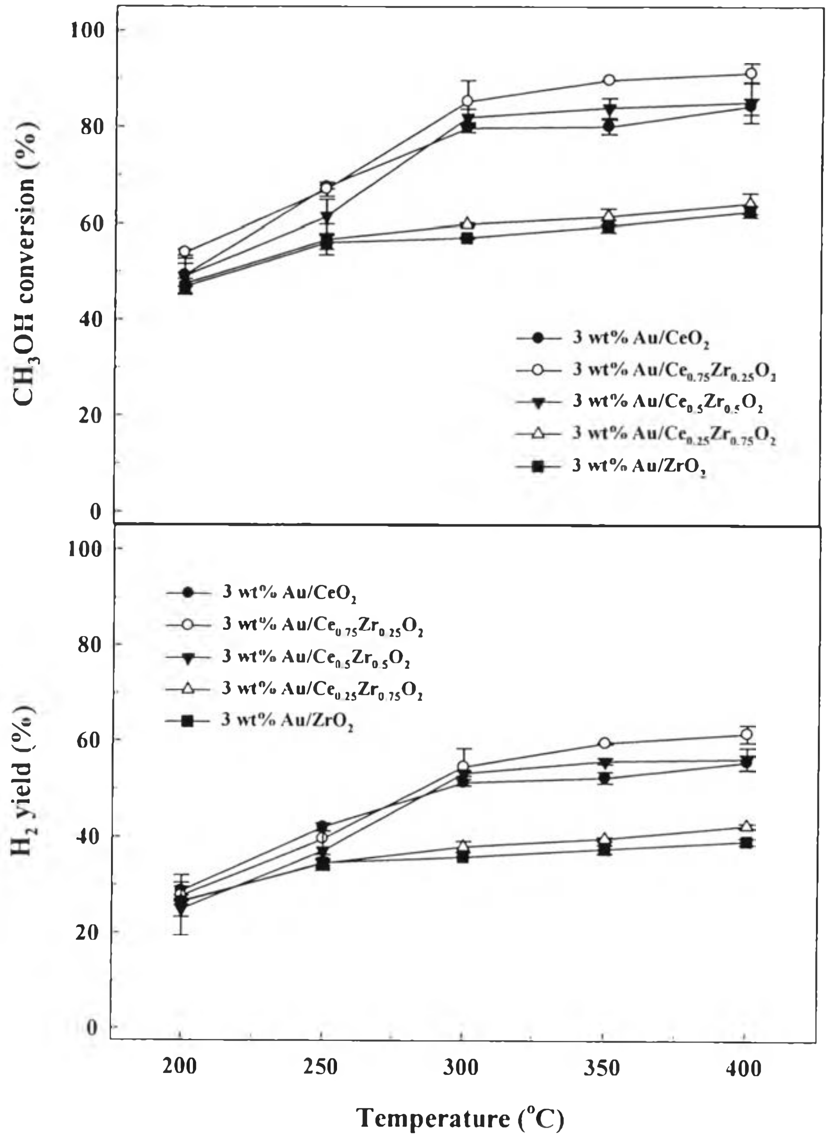

Figure A1 Effect of Ce/(Ce+Zr) atomic ratio on the methanol conversion and hydrogen yield over 3 wt% of Au/CeO_2–ZrO_2 catalysts calcined at 400 °C. (Reaction conditions: O_2/H_2O/CH_3OH molar ratio = 0.6:2:1).

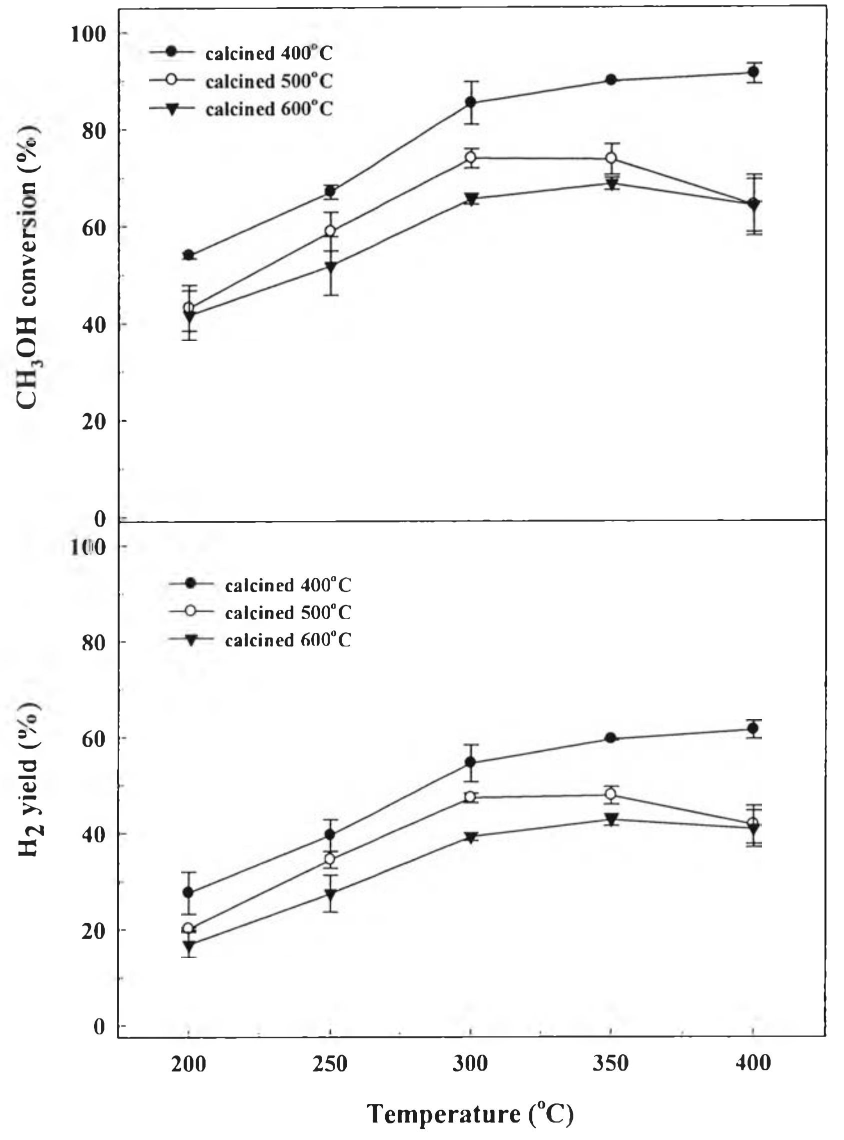

Figure A2 Effect of calcination temperature on the methanol conversion and hydrogen yield over 3 wt% of $Au/Ce_{0.75}Zr_{0.25}O_2$ catalysts. (Reaction conditions: $O_2/H_2O/CH_3OH$ molar ratio = 0.6:2:1).

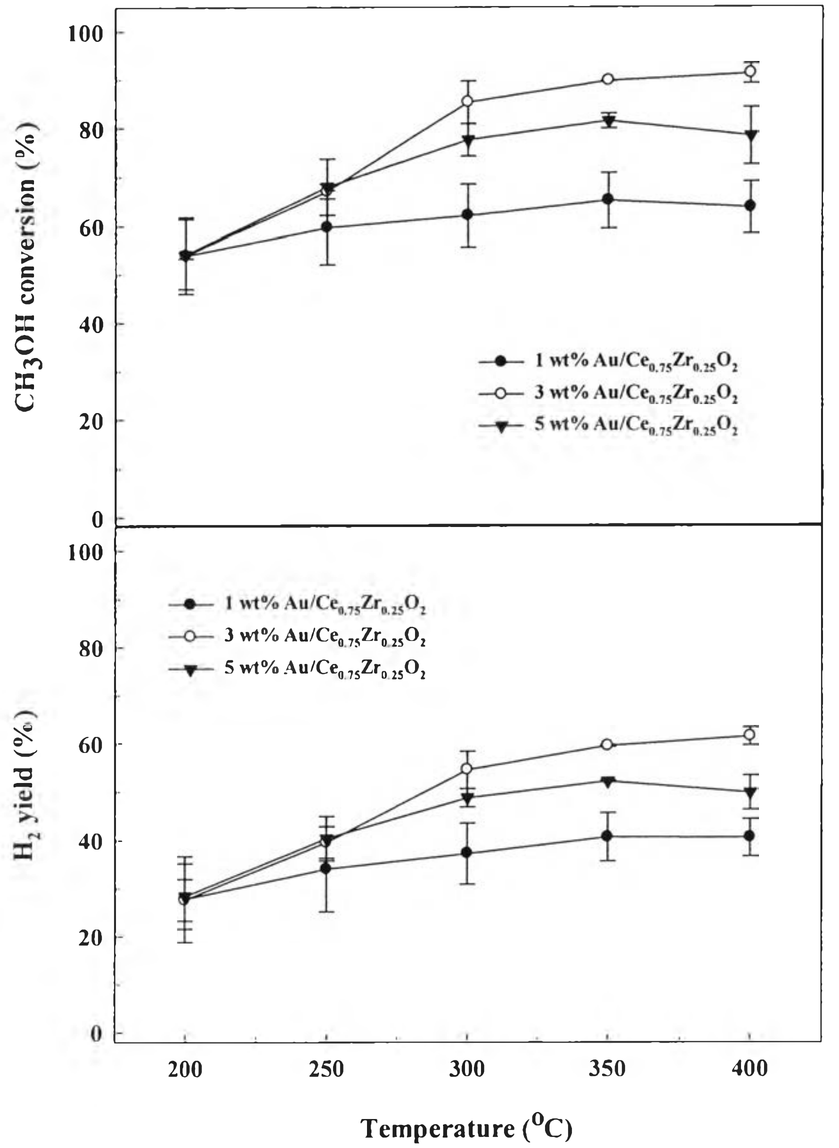

Figure A3 Effect of Au content on the methanol conversion and hydrogen yield over $Au/Ce_{0.75}Zr_{0.25}O_2$ catalysts. (Reaction conditions: $O_2/H_2O/CH_3OH$ molar ratio = 0.6:2:1).

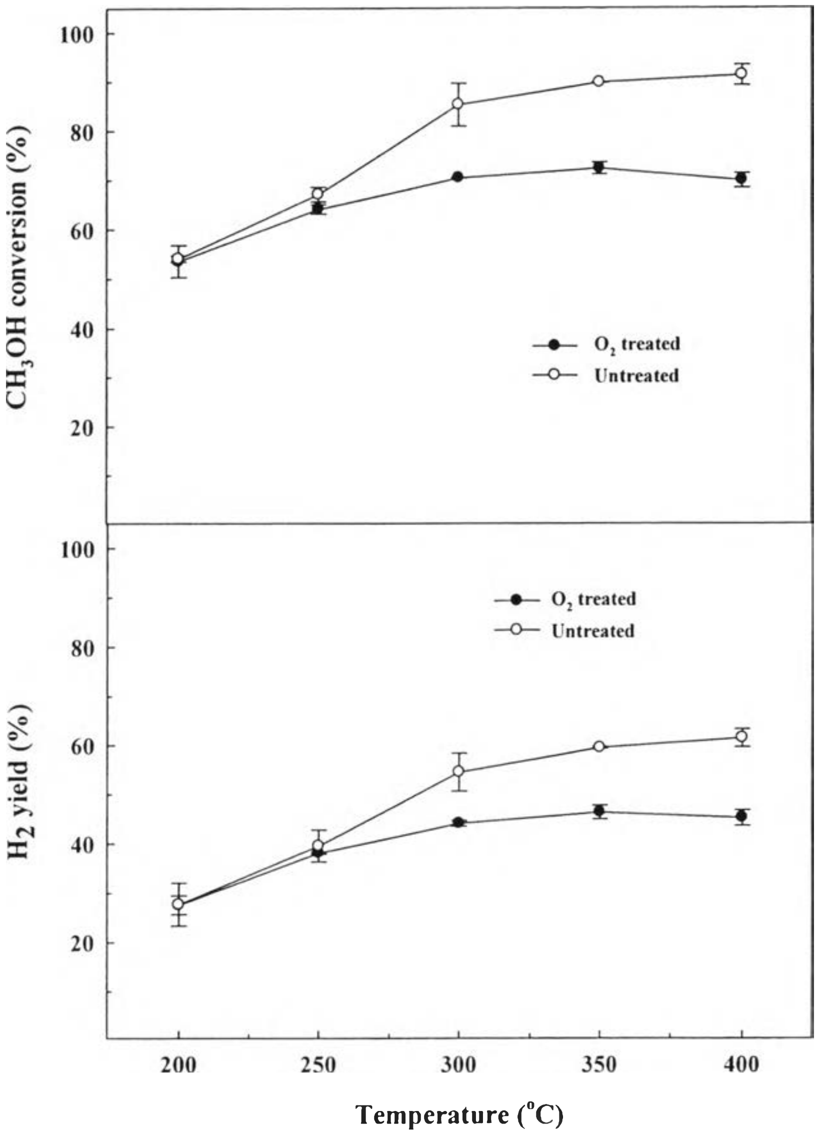

Figure A4 Effect of O_2 pretreatment on the methanol conversion and hydrogen yield over 3 wt%Au/$Ce_{0.75}Zr_{0.25}O_2$ catalysts. (Reaction conditions: $O_2/H_2O/CH_3OH$ molar ratio = 0.6:2:1).

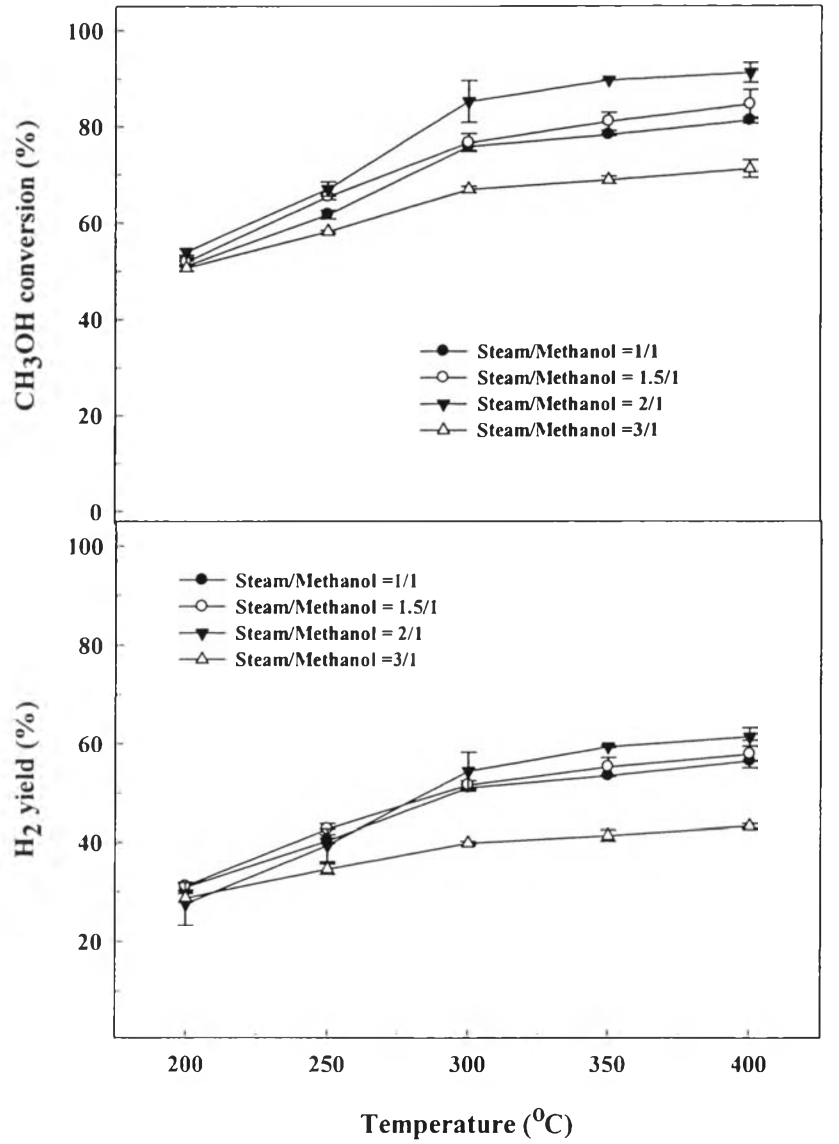

Figure A5 Effect of H_2O/CH_3OH molar ratio on the methanol conversion and hydrogen yield over 3 wt%Au/$Ce_{0.75}Zr_{0.25}O_2$ catalysts calcined at 400 °C.

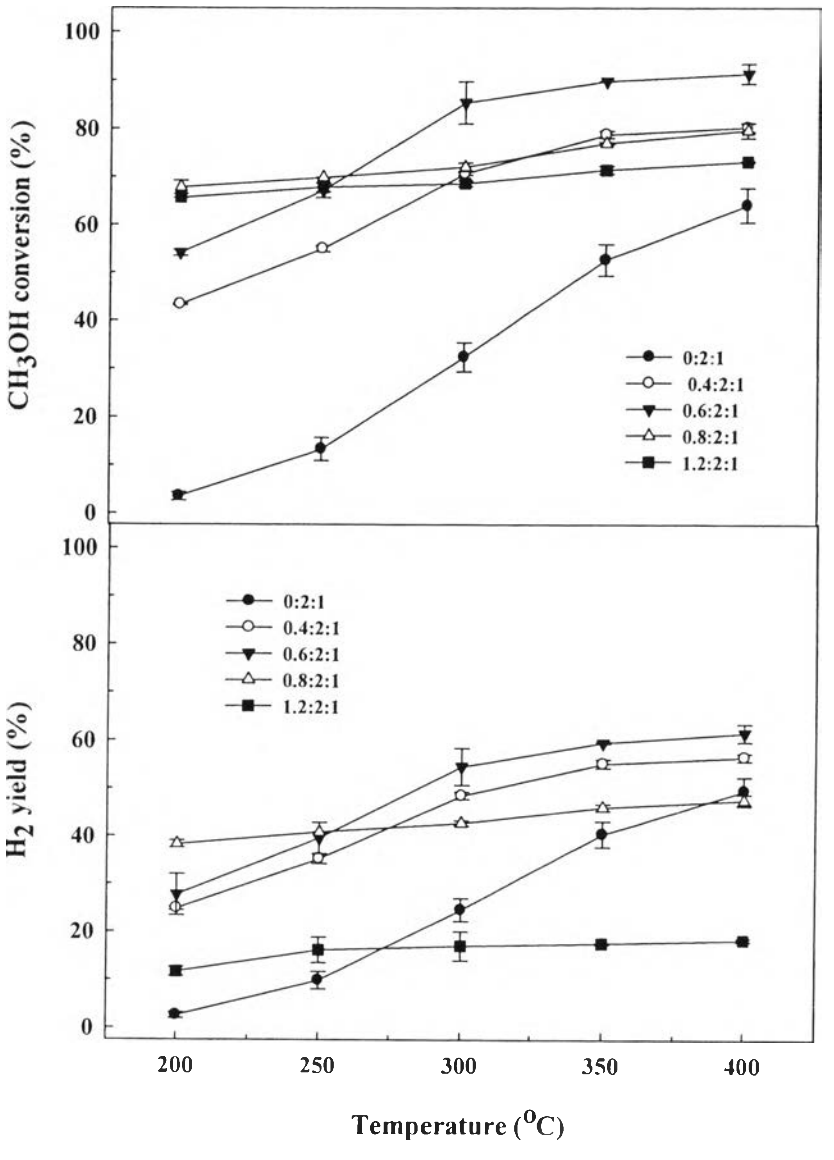

Figure A6 Effect of $O_2/H_2O/CH_3OH$ molar ratio on the methanol conversion and hydrogen yield over 3 wt%Au/$Ce_{0.75}Zr_{0.25}O_2$ catalysts calcined at 400 °C.

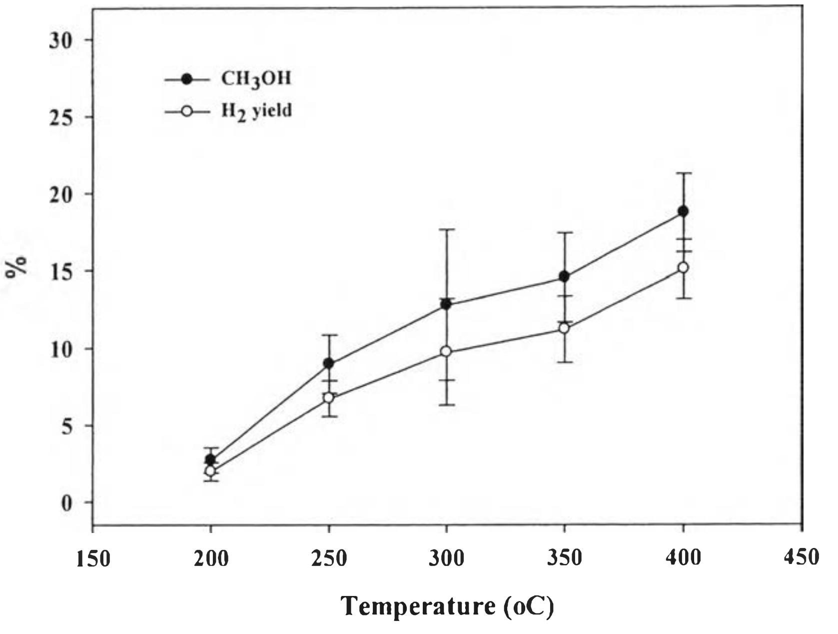

Figure A7 The methanol conversion and hydrogen yield over 3 wt%Au/$Ce_{0.75}Zr_{0.25}O_2$ catalyst in the methanol decomposition reaction.

Appendix B Calibration Curve of Gas Products

The relationship between the peak area from GC analysis and the gas concentration was conducted for the possible gas products such as hydrogen, carbon dioxide, carbon monoxide, oxygen and methane.

Hydrogen (H_2)

Peak Area	Amount (%mole, %vol.)
0	0
35241.5	21.35
60376	27.26
76992.5	33.57

Carbon monoxide (CO)

Peak Area	Amount (%mole, %vol.)
0	0
2728591	4.50
3809977.5	5.76
5123331	7.51

Carbon dioxide (CO_2)

Peak Area	Amount (%mole, %vol.)
0	0
168757	1.33
243160.7	2.24
423115.5	3.41

Methane (CH_4)

Peak Area	Amount (%mole, %vol.)
0	0
676791	12.03
1294423	18.88
2028339.5	24.46
2714826.5	29.71

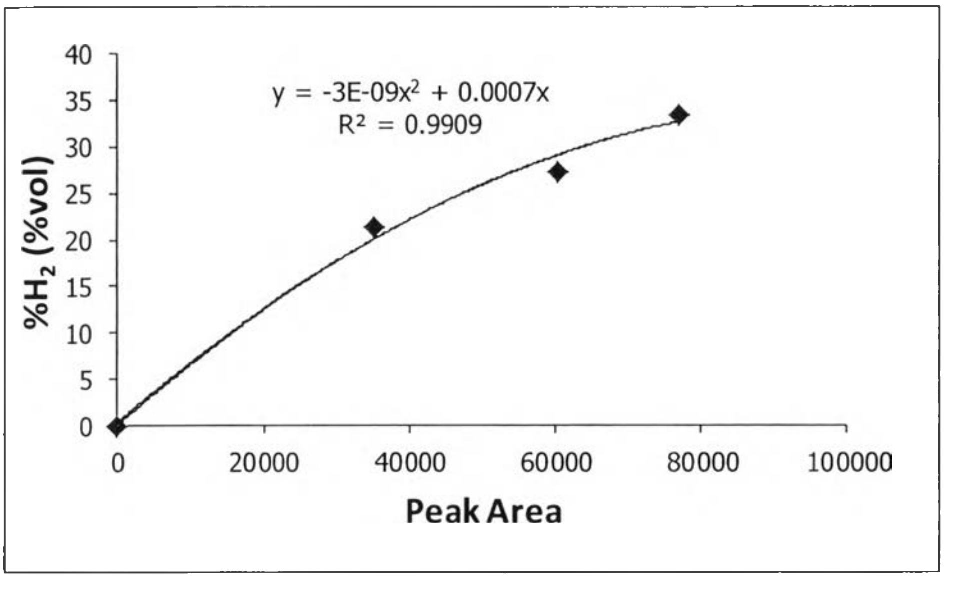

Figure B1 Calibration curve of hydrogen gas.

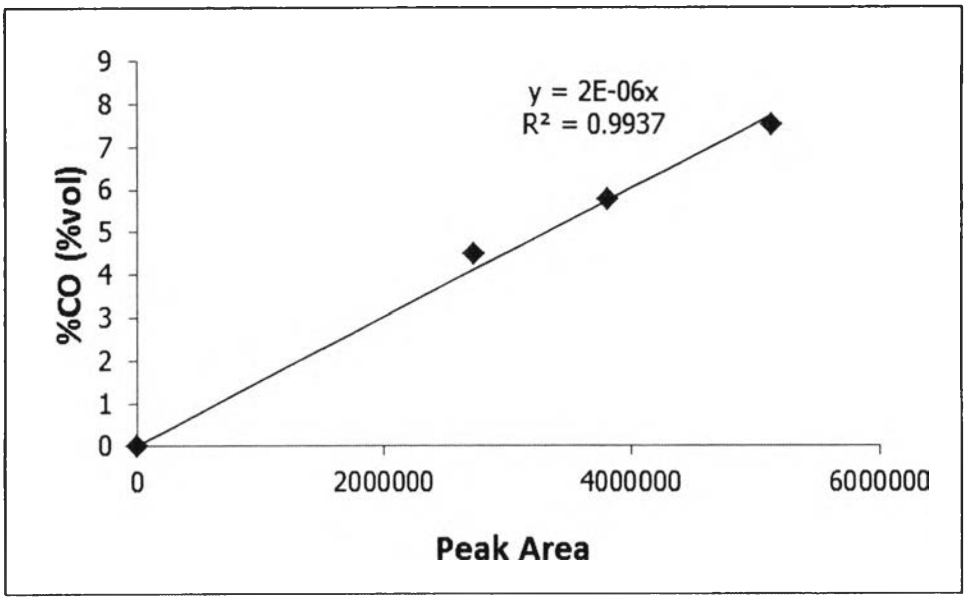

Figure B2 Calibration curve of carbon monoxide gas.

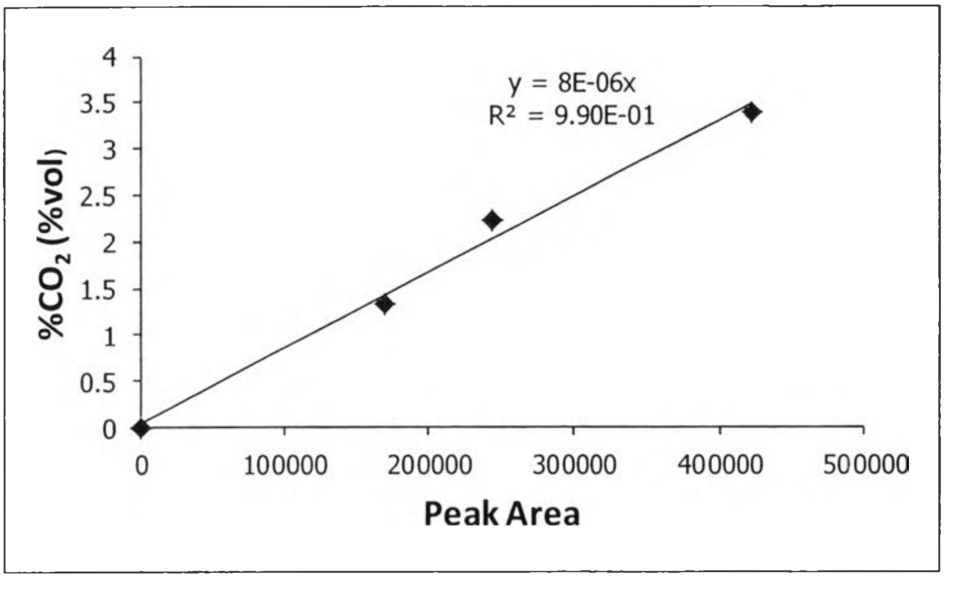

Figure B3 Calibration curve of carbon dioxide gas.

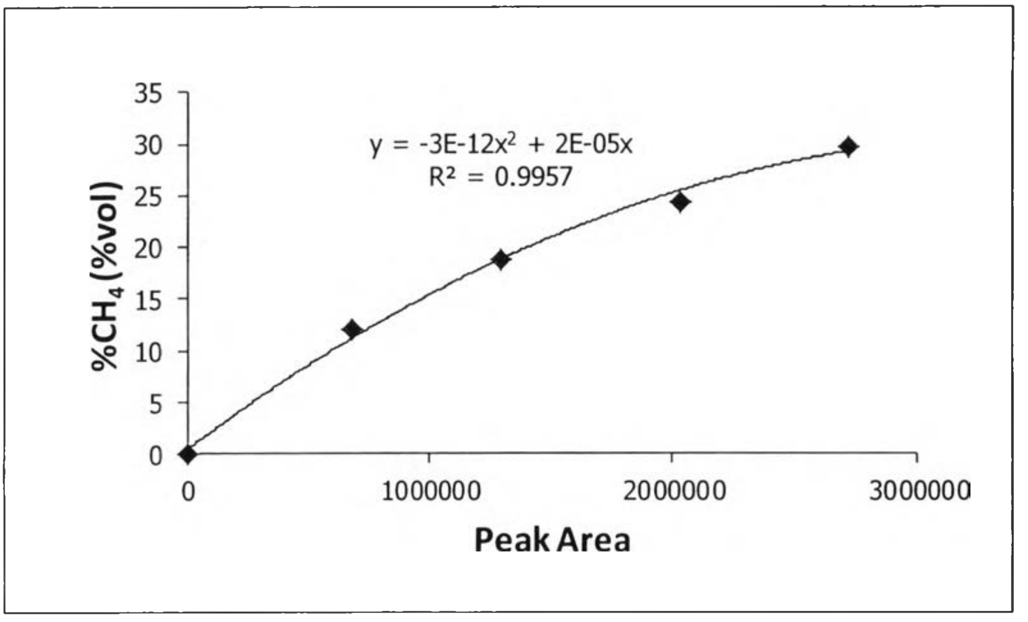

Figure B4 Calibration curve of methane gas.

Where x is peak area from GC analysis

y is concentration (%)

CURRICULUM VITAE

Name: Ms. Warapun Nakaranuwattana

Date of Birth: September 21, 1988

Nationality: Thai

University Education:

2010–2012 Master of Science in Petroleum Technology, The Petroleum and Petrochemical College (PPC), Chulalongkorn University, Bangkok, Thailand.

2006–2010 Bachelor of Engineering Program in Petrochemicals and Polymeric Materials, Silpakorn University, Nakhon Pathom, Thailand.

Working Experience:

2008-2009 Position: Internship

Company name: IRPC POLYOL CO., LTD.

Presentations:

1. Nakaranuwattana,W., Luengnaruemitchai, A., and Gulari, E. (2013, April 10-11) Effect of Au Loading on The Catalytic Performance of Supported Au Catalysts. Poster present at Symposium on catalysis for fine chemicals, Palermo, Italy.
2. Nakaranuwattana,W., Luengnaruemitchai, A., and Gulari, E. (2013, April 23) Hydrogen Production from Oxidative Steam Reforming of Methanol over Au/CeO_2–ZrO_2 Catalysts. Poster present at The 4th Research Symposium on Petrochemical and Materials Technology and The 19th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.