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出國報告（出國類別：其他）

2016 第四屆化學迴圈國際研討會赴大陸南京出國報告

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派赴國家：大陸
出國期間：105 年 9 月 25 日~105 年 9 月 29 日
報告日期：105 年 10 月 28 日

摘 要

本次公差行程為參加 2016 年第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)，與發表研究成果論文。本屆化學迴圈國際研討會於大陸南京舉行，期程：105 年 9 月 26 日至 9 月 28 日，研討會由大陸東南大學主辦，總報名人數超過兩百人，不乏來自各國化學迴圈相關研究團體或機構之專家學者。會議以化學迴圈技術為主軸，提供各專家學者分享最新研究與創新思想，衍生相關化學迴圈領域五大技術進行專題討論，包括先導工廠測試、氫氣產物與氣化反應、載氧體分析與改質、化學迴圈模型建構，以及鈣迴圈技術討論。此次參與第四屆化學迴圈國際研討會以口頭報告方式發表論文「Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process」，該論文被安排於載氧體分析與改質會議中討論，藉此機會讓外界了解核研所(以下稱本所)對於化學迴圈研究的投入。會後彙整各分項議題之心得與建議簡述如下：化學迴圈為一頗具潛能之前瞻能源技術，本所若能充分掌握研究方向，將有助於國內提升能源技術之水平，除建立國內自主能源技術外，亦能與國際合作擴展能源技術之海外市場。

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一、目　的

近年來，全球氣候議題持續升溫，各方研究顯示人為溫室氣體排放對於全球溫室效應有關鍵性的影響。目前對於二氧化碳的處理技術，包括：二氧化碳之捕獲技術、轉化及再利用技術、與儲存及固定技術等，皆已成為各國積極研究與發展的方向。為推動國家減碳政策，政府近年積極建構低碳能源發展藍圖。本所目前亦積極進行能源國家型科技計畫之「淨碳技術領域」相關研究發展計畫，期望從永續發展觀點推動自主潔淨能源技術之建立。本次出國公差為執行「碳基能源永續潔淨利用技術發展」分支計畫，赴大陸南京參加 2016 年第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)，此國際研討會今年由大陸東南大學主辦，議程為 9 月 26 日至 9 月 28 日，本屆會議實際參與人數超過兩百人，不乏來自各國化學迴圈相關研究團體或機構之專家學者。本所淨碳技術團隊在大會以口頭報告方式發表研究成果論文“Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process”，藉此機會與國際學者專家討論、分享本所近年來在化學迴圈燃燒程序應用在淨碳技術的研究成果，並藉以掌握國際間化學迴圈燃燒程序發展之現況與趨勢，拓展與國際學者專家之關係及國際合作。

二、過　程

(一) 公差行程

本次公差前往大陸南京參加第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)，行程自民國 105 年 9 月 25 日至 9 月 29 日止，總計共 5 日，行程規劃大致如下表所示。

表 1. 公差行程表

日期	地點	工作內容概述
105/09/25 星期日	台北松山機場 → 上海虹橋機場 高鐵上海虹橋站 → 高鐵南京南站 高鐵南京南站 → 南京國際會議大酒店	去程、辦理會議註冊與報到
105/09/26 星期一	南京國際會議大酒店	出席第四屆化學迴圈國際研討會 4th International Conference on Chemical Looping，發表論文
105/09/27 星期二	南京國際會議大酒店、大陸東南大學	出席第四屆化學迴圈國際研討會 4th International Conference on Chemical Looping，參訪大陸東南大學實驗室
105/09/28 星期三	南京國際會議大酒店	出席第四屆化學迴圈國際研討會 4th International Conference on Chemical Looping
105/09/29 星期四	高鐵南京站 → 高鐵上海站 高鐵上海站 → 上海浦東機場	回程

(二) 第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)

本屆 ICCL 由大陸東南大學主辦，大會於民國 105 年 9 月 25 日至 9 月 28 日在大陸南京國際會議大酒店舉行(圖 1、圖 2)，為化學迴圈技術領域的年度國際盛會之一；會議主題以化學迴圈技術為主軸，提供各專家學者分享最新研究與創新思想，衍生相關化學迴圈領域五大技術進行專題討論，包括先導工廠測試、氫氣產物與氣化反應、載氧體分析與改質、化學迴圈模型建構，以及鈣迴圈技術討論。

ICCL 2016 之議程與詳細口頭報告安排時程如表 2 所示，會議自 9 月 25 日(星期日)開始註冊與報到，於 9 月 26 日星期一早上舉行開幕典禮，隨後進行 2 場 Keynote 演講；在短暫休息後，即開始平行場次口頭論文發表。壁報論文自 9 月 26 日星期一起開始展示至 9 月 28 日下午，壁報論文展示於會場中庭與提供咖啡茶敘之休息場地，由作者進行現場解說。9 月 27 日下午，大會安排參訪大陸南京東南大學沈來宏教授實驗室，由實驗室負責人講解說明氣化與化學迴圈實驗技術概況。大會共安排 4 場 Keynote 演講，3 場全體會議(Plenary Sessioin)，其餘時段皆為平行場次口頭論文發表場次共計 94 場，五大技術議題列舉如下：

1. Pilot Plants
2. Hydrogen Production &Gasification
3. Oxygen Carrier
4. Modelling
5. Calcium Looping

此次參與第四屆化學迴圈國際研討會以口頭報告方式發表論文 "Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process"，該論文被安排於 9 月 26 日中午的平行場次「載氧體分析與改質會議(C-1 Oxygen Carrier)」中討論，藉此機會讓外界了解核研所對於化學迴圈研究的投入，同時在報告結束後也與多名研究人員進行流體化床及化學迴圈技術之討論，實為難得的經驗。

筆者在大陸的公差行程於 9 月 28 日告一段落，次日(9 月 29 日星期四)即自大陸上海浦東國際機場搭機，由於梅姬颱風影響，班機延誤兩個半小時，返回台灣桃園國際機場已為 9 月 30 日凌晨 12 點 38 分，結束本次公差行程。

表 2. 4th International Conference on Chemical Looping 之議程

Summary

Sept.25

Time	
14:00 - 22:00	Registration

Sept.26

Time	Friendship Hall	Magnolia Hall	Violet Hall	Tulip Hall
9:00-9:10	Welcome			
9:10-9:50	Keynote 1 Liang-Shih Fan			
9:50-10:30	Keynote 2 Laihong Shen			
10:30-10:50	Parallel Sessions			
10:50-12:30	A-1 Pilot Plants	B-1 Hydrogen Production Gasifiction		C-1 Oxygen Carrier
12:30-14:00	Lunch			
14:00-16:00		B-2 Hydrogen Production Gasifiction	D-1 Modelling	C-2 Oxygen Carrier
16:00-16:20	Break			
16:20-18:00		B-3 Hydrogen Production Gasifiction	D-2 Modelling	C-3 Oxygen Carrier
18::30	Banquet at Zijin Building Conference Hall			

Sept.27

Time	Friendship Hall	Violet Hall	Tulip Hall
8:40-9:20	Keynote 3 Anders Lyngfelt		
9:20-9:30	Parallel Sessions		
9:30-10:30	A-2 Pilot Plants	D-3 Modelling	C-4 Oxygen Carrier
10:30-10:50	BREAK		
10:50-12:30	A-2 Pilot Plants	D-3 Modelling	C-4 Oxygen Carrier
12:30-14:00	Lunch		
14:00-18:00	Poster Session Lab Visit Tour		
18::30	Conference Dinner at Mandarin Garden Nanjing		

Sept.28

Time	Friendship Hall	Magnolia Hall	Tulip Hall
8:40-9:20	Keynote 4 Juan Adánez		
9:20-9:30	Parallel Sessions		
9:30-10:30	A-3 Pilot Plants	B-4 Hydrogen Production Gasifiction	E-1 Calcium Looping
10:30-10:50	BREAK		
10:50-12:30	A-3 Pilot Plants	B-4 Hydrogen Production Gasifiction	E-1 Calcium Looping
12:30-14:00	Lunch		
14:00-15:40	A-4 Pilot Plants		
15:40-16:00	Break		
16:00-17:00	Panel Discussion		

Oral Presentations are presented in five sessions (A: Pilot Plants; B: Hydrogen Production & Gasification; C: Oxygen Carrier; D: Modelling; E: Calcium Looping) and held in four halls (Friendship Hall, Magnolia Hall, Violet Hall and Tulip Hall).

Detailed Scientific Program

Oral Presentations

The keynote and plenary lecture invited speakers have 35 min + 5 min dedicated for discussion at their disposal.
The presenters of the topical oral presentations have 15 min + 5 min discussion at their disposal.
Presenters are kindly asked to upload their presentations in the designated session room before their presentation is scheduled. Also, please make sure your presentation is compatible with the AV system provided.

Sept.26	Friendship Hall 友谊厅
9:00-9:10	Welcome Chair: Laihong Shen, Young Ku
9:10-9:50	Keynote 1 Chemical Looping Partial Oxidation *Liang-Shih Fan* *Ohio State University, USA*
9:50-10:30	Keynote 2 Reactor for Chemical-Looping Combustion of Solid Fuels *Laihong Shen* *Southeast University, China*

Time	Friendship Hall 友谊厅	Magnolia Hall 白玉兰厅	Tulip Hall 郁金香厅
10:30-10:50	Parallel Sessions		
	Session A - 1 Pilot Plants Chair: Juan Adánez, Ranjani Siriwardane	Session B - 1 Hydrogen Production & Gasification Chair: Junichiro Otomo, Tobias PRÖLL	Session C - 1 Oxygen Carrier Chair: Francisco García Labiano, Yao-Hsuan Tseng
10:50-11:10	Characterization of Oxygen Carriers during Combustion and CLC Conditions in a 12 MWth Circulating Fluidized Bed Biomass Boiler *Malin HANNING, Angelica CORCORAN, Dongmei ZHAO #, Fredrik LIND, Magnus RYDÈN* *Chalmers University of Technology, Sweden*	Evolution of a Composite Redox-active Oxygen Carrier for Hydrogen Production *Danny Mak, E.I. Papaioannou, B. Ray* *Newcastle University, UK*	Reactivity of Oxygen Carriers after Recycling in Chemical Looping Combustion of Coal *Tomonao SAITO #, Shi-Ying LIN* *Japan Coal Energy Center, Japan*
11:10-11:30	Design and Operation of a 50 kWth Chemical Looping Combustion (CLC) Reactor Using Coal as Fuel *Jinchen MA #, Haibo ZHAO, Pengjie NIU, Xin CHEN, Xin TIAN, Chuguang ZHENG* *Huazhong University of Science and Technology, China*	Water Splitting for Hydrogen Production: From Chemical Looping Concept to Membrane Reactor *Xing ZHU, Lingyue SUN, Kongzhai LI* *Kunming University of Science and Technology, China*	A Facile Synthesis of Na-modified Fe2O3/Al2O3 Oxygen Carrier for Improved Reduction Performance in Chemical Looping Combustion Process *Wei-Chen Huang #, Jia-Siang Huang, Yu-Lin Kuo, Fan Hsu* *National Taiwan University of Science and Technology, Taiwan, China*
11:30-11:50	On the Distribution of Residence Times of Solids in a Circulating Fluidised Bed Reactor for Chemical Looping Combustion *Felix DONAT #, Wenting HU, Stuart A. SCOTT, John S. DENNIS* *University of Cambridge, UK*	Development of a 2 kWh Chemical-Looping Reforming Reactor with Integrated Selective Metallic-Supported Pd Membranes for Highly Efficient In-Situ Pure H_2 Production and CO_2 Capture *Jose Antonio MEDRANO #, Vincenzo SPALLINA, Alessandro BATTISTELLA* *Eindhoven University of Technology, Netherlands*	Selective Oxidations via Chemical Looping: Selective Combustion of Hydrogen in Hydrocarbon Mixtures *M.S.C. CHAN #, J.S. DENNIS* *University of Cambridge, UK*
11:50-12:10	Development of Three-Tower (reactors) Technology for Chemical Looping Coal Combustion *Shi-Ying LIN #, Tomonao SAITO* *Japan Coal Energy Center, Japan*	Using Synthetic Cu-Fe Metal Oxides as Oxygen Carriers in Biomass Chemical-Looping Gasification *Yuexin Ma, Haibo Zhao, Pengjie Niu #* *Huazhong University of Science and Technology, China*	The Kinetics of Redox Reactions for Prospective Oxygen Carrier Material Made from Iron Ore *Ewelina KSEPKO, Piotr BABINSKI, Lori NALBANDIAN* *Institute for Chemical Processing of Coal, Poland*
12:10-12:30	Coal Based Pressurized Chemical Looping Combustion Combined Cycle Process Development and Analysis *Zhen Fan, Liangyong Chen, Fang Liu, Jinhua Bao, Heather Nikolic, Kunlei Liu* *University of Kentucky, USA*	Increasing the Carbon Capture Efficiency of the Ca/Cu Looping Process with Advanced Process Schemes *Michela MARTINI #, Isabel MARTINEZ, Fausto GALLUCCI* *Eindhoven University of Technology, Netherlands*	Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process *You-Pin Chyou #, Der-Ming Chang, Ching-Ying Huang, Hsuan-Hua Chang #* *Institute of Nuclear Energy Research, Taiwan, China*
12:30-14:00	LUNCH		

Sept.26	Magnolia Hall 白玉兰厅	Violet Hall 紫罗兰厅	Tulip Hall 郁金香厅
	Session B - 2 Hydrogen Production & Gasification Chair: Henrik Thunman, Dongmei Zhao	Session D - 1 Modelling Chair: Øyvind Langørgen, Jing Liu	Session C - 2 Oxygen Carrier Chair: Arnold Lambert, Antonio Coppola
14:00-14:20	Plenary 1 Chemical Looping Coal Gasification with Calcium Ferrite and Barium Ferrite via Solid-Solid Reactions *Hanjing Tian [#], Ranjani Siriwardane, Jarrett Riley* *USDOE-National Energy Technology Laboratory, USA*	Integration of Solid Oxide Fuel Cells and Chemical Looping Combustion for Efficient Power Production with CO_2 Capture *Vincenzo Spallina [#], Pasquale Nocerino, Matteo C. Romano, Martin van Sint Annaland, Stefano Campanari, Fausto Gallucci* *Eindhoven University of Technology, Netherlands*	Plenary 2 Heat Management Strategies in Chemical-Looping Combustion of Methane using a Thermal Storage Functional Oxygen Carrier *Kongzhai Li, Hua Wang, Yonggang Wei, Xing Zhu, Ningning Li* *Kunming University of Science and Technology, China*
14:20-14:40		Copper-Based Oxygen Carriers Supported with Alumina/Lime for Conversion of Gaseous Fuels *Syed K HAIDER, María ERANS [#], Felix DONAT, Lunbo DUAN, Stuart A SCOTT, Vasilije MANOVIC, Edward J ANTHONY* *Cranfield University, UK*	
14:40-15:00	Interaction Effect between Coal Ash and Oxygen Carrier for the Chemical Looping Gasification *Qishun Wan,Yong zhuo Liu [#], Qingjie Guo* *Qingdao University of Science and Technology, China*	The Effect of Different Particle Residence Time Distributions on the Chemical Looping Combustion Process *Matthias A. SCHNELLMANN [#], Felix DONAT, Stuart A. SCOTT, Gareth WILLIAMS, John S. DENNIS* *University of Cambridge, UK*	Thermochemical Energy Storage Based on the Reversible Reaction of Manganese Iron Oxide *Michael WOKON, Dr. phil. Thomas BAUER, Dr.-Ing. Marc LINDER* *German Aerospace Center, Germany*
15:00-15:20	Analysis of Char Gasification Enhancement during Chemical Looping Combustion *Ewa MAREK, Yaoyao ZHENG, Ewelina KSEPKO* *University of Cambridge, UK*	Molecular Dynamics Simulation of CuO Sintering Process in Cu-based Oxygen Carrier Particle *Jinfa Gui, Haibo Zhao* *Huazhong University of Science and Technology, China*	Ultra-Low NOx emission of pulverized coal staged combustion coupling with chemical looping combustion *Zhi Zhang [#], Denggao Chen, Zhenshan Li, Ningsheng Cai* *Tsinghua University, China*
15:40-15:40	Numerical Study of the Scale-Up of Chemical Looping Reforming *Xavier SCHEUER, Juray DE WILDE* *Université Catholique De Louvain, Belgium*	Cu-Mn Mixed Oxide as Oxygen Carrier for CLOU Process *Iñaki ADÁNEZ-RUBIO, Alberto ABAD, Pilar GAYÁN, Francisco GARCÍA-LABIANO, Luis F. de DIEGO, Juan ADÁNEZ [#]* *Instituto De Carboquímica (ICB-CSIC), Spain*	Reaction Kinetics and Morphological Variation of Fe-based Oxygen Carriers in Redox Cycles of Chemical Looping Systems *Junichiro OTOMO, Yuya SAITO, Kazuyuki MIYA, Noriaki KIKUCHI, Fumihiko KOSAKA* *The University of Tokyo, Japan*
15:40-16:00	Characterization of Combined Fe-Cu Oxides as Oxygen Carrier in Biomass Gasification using Chemical Looping *Huijun GE [#], Laihong SHEN, Tao SONG* *Southeast University, China*	Heat Management of Pre-Combustion Chemical Looping Technology using Packed Bed Reactors *Vincenzo Spallina [#], Michel P.C. van Etten, Fausto Gallucci, Martin van Sint Annaland* *Eindhoven University of Technology, Netherlands*	Manganese Containing Mixed-Oxides as Versatile Oxygen Carrying Agents for Chemical Looping Applications *Seif Yusuf, Luke Neal, Nathan Galinsky, Fanxing Li* *North Carolina State University, USA*
16:00-16:20	BREAK		
	Session B - 3 Hydrogen Production & Gasification Chair: Hanjing Tian, Fang He	Session D - 2 Modelling Chair: Mahdi Yazdanpanah, Fanxing Li	Session C - 3 Oxygen Carrier Chair: Stuart Ashely Scott, Kongzhai Li
16:20-16:40	Processing and Characterization of Fe-based Oxygen Carriers for Chemical Looping for Hydrogen Production *Yoran DE VOS [#], Marijke JACOBS, Isabel VAN DRIESSCHE* *Flemish Institute for Technological Research (VITO), Belgium*	Evaluation of a Promising Cu-based Oxygen Carrier for its Use at Industrial Scale in CLC of CH_4 *Arturo CABELLO, Pilar GAYÁN [#], Alberto ABAD, Luis F. de DIEGO, Francisco GARCÍA-LABIANO, María T. IZQUIERDO, Andrew SCULLARD, Gareth WILLIAMS, Juan ADÁNEZ* *Instituto De Carboquímica (ICB-CSIC), Spain*	Evolution of Chemical Structure of Coal during Its Chemical Looping Combustion with Fe2O3 Oxygen Carrier *Baowen Wang, Aijun Wang, Weishu Wang, Haibo Zhao, Chuguang Zheng* *North China University of Water Resources and Electric Power, China*

Sept.26	Magnolia Hall 白玉兰厅	Violet Hall 紫罗兰厅	Tulip Hall 郁金香厅
16:40-17:00	Coal Chemical Looping Gasification for Synthetic Natural Gas Production *Yongzhuo LIU, Tao LIU, Yongqiang YUE* *Qingdao University of Science and Technology, China*	Periodic Density Functional Study of the Interaction Mechanism of CO with Spinel-Type $MnFe_2O_4$ Surface in Chemical-Looping Combustion *Feng Liu [#], Jing Liu, Jinxin Dai, Yingju Yang, Zhen Zhang, Minjun Wang* *Huazhong University of Science and Technology, China*	Autothermal Operation of a Pressurized Gas Switching Combustion Reactor with a Mn based Oxygen Carrier *Abdelghafour ZAABOUT, Schalk CLOETE, Shahriar Amini [#]* *SINTEF Materials and Chemistry, Norway*
17:00-17:20	Hydrogen Production by Integration of Steam Reformation with Chemical-Looping Combustion *Viktor STENBERG [#], Magnus RYDÉN, Tobias MATTISSON* *Chalmers University of Technology, Sweden*	Flowsheet Simulation of Chemical Looping Combustion *Johannes HAUS [#], Ernst-Ulrich HARTGE, Stefan HEINRICH, Joachim WERTHER* *Hamburg University of Technology, Germany*	Biomass Ash as Oxygen Carrier in Fluidized Bed Processes Daniel Schweitzer, Fabian Nagel, Max Schmid [#], *Reinhold Spörl, Günter Scheffknecht* *University of Stuttgart, Germany*
17:20-17:40	Various Support Iron-based Oxygen Carriers for Chemical Looping Hydrogen Generation in a Moving Bed Reactor *Hsuan-Chih Wu , Young Ku, Yin-Zhe Wang [#]* *National Taiwan University of Science and Technology, Taiwan, China*	1D Model of Solid Fuel Conversion in the Bottom Bed of a Chemical Looping Combustion Unit *Jesper ARONSSON, David PALLARÈS, Anders LYNGFELT* *Chalmers University of Technology, Sweden*	Cement Bonded Fine Hematite and Copper Ore Particles as Oxygen Carrier in Chemical Looping Combustion *Xin Tian [#], Haibo Zhao [#], Jinchen Ma* *Huazhong University of Science and Technology, China*
17:40-18:00	Coal Direct Chemical Looping Hydrogen Production with K-Fe-Al Composite Oxygen Carrier *Zhongliang Yu, Yanyan Yang, Chunyu Li* *Chinese Academy of Sciences, China*	Characterization of Scaling Laws in Computational Fluid Dynamics Simulations of Chemical Looping Combustion *AGARWAL, Ramesh K. and BANERJEE, Subhodeep* *Washington University in St. Louis, USA*	Performance and Degradation Mechanisms of CLC Particles Produced by Industrial Methods *Arnold Lambert [#], Airy Tilland, William Pelletant, Stéphane Bertholin, Florent Moreau, Isabelle Clemençon, Mahdi Yazdanpanah* *IFP Energies nouvelles, France*
18:30	Banquet at Zijin Building Conference Hall		

Sept.27	Friendship Hall 友谊厅		
8:40-9:20	Keynote 3 Chair: Joachim Werther Chemical-Looping Combustion of Solid Fuels – What Is Needed To Reach Full-Scale ? *Anders Lyngfelt* *Chalmers University of Technology, Sweden*		
9:20-9:30	Parallel Sessions		
	Friendship Hall 友谊厅	Violet Hall 紫罗兰厅	Tulip Hall 郁金香厅
	Session A - 2 Pilot Plants Chair: Ho-Jung Ryu, Francisco R García–García	Session D - 3 Modelling Chair: Stéphane Bertholin, Jørild Svalestuen	Session C - 4 Oxygen Carrier Chair: Ernst-Ulrich Hartge, Fabio MONTAGNARO
9:30-9:50	Experience of more than 1000h of Operation with Oxygen Carriers and Solid Biomass at Large Scale *Teresa BERDUGO VILCHES [#], Fredrik LIND, Magnus RYDEN, Henrik THUNMAN* *Chalmers University of Technology, Sweden*	Comparison of Three Different Methods for the Determination of Solids Circulation Rates in Solid Looping Systems *José A. MEDRANO, Maria NORDIO, Martin van SINT ANNALAND, Fausto GALLUCCI* *Eindhoven University of Technology, Netherlands*	Manganese Ore Screening and Solid Fuel Testing *Sebastian Sundqvist, Tobias Mattisson* *Chalmers University of Technology, Sweden*

9:50-10:10	Chemical Looping Combustion of Four Different Solid Fuels Using a Manganese-Silicon-Titanium Oxygen Carrier *Matthias SCHMITZ, Carl Johan LINDERHOLM[#], Anders LYNGFELT* *Chalmers University of Technology, Sweden*	Two-fluid CFD-based Model for 1 MW_{th} Chemical Looping Pilot Plant: Modelling and Validation of Air and Fuel Reactors *Jan MAY, Peter OHLEMÜLLER, Falah Alobaid, Jochen STRÖHLE[#], Bernd EPPLE* *TU Darmstadt, Germany*	Assessment of Natural Ilmenite and Synthetic Oxygen Carrier for Chemical Looping Combustion of Victorian Brown Coal *David STOKIE, Srikanth CHAKRAVARTULA SRIVATSA, Sankar BHATTACHARYA, Frans SIKERNIS, Corinne BEAL, Seng LIM* *Monash University, Australia*
10:10-10:30	Biomass with CO2 Capture Using CLC: Results in a 500 Wth unit *Teresa MENDIARA, María Teresa IZQUIERDO, Antón PÉREZ-ASTRAY, Alberto ABAD, Luis F. de DIEGO, F. GARCÍA-LABIANO[#], Pilar GAYÁN, Juan ADÁNEZ* *Instituto de Carboquímica (ICB-CSIC), Spain*	Application of Chemical Looping Air Separation in Oxy-Fuel Combustion for Power Production with CO_2 Sequestration *Shiyi CHEN[#], Wenguo XIANG, Min ZHU, Shiwei MA, Zhao SUN* *Southeast University, China*	Development of Iron-based Particles Enriched with Copper Oxide as Low Cost Oxygen Carriers for Solid Fuels Combustion with CO2 Capture by Chemical Looping Technology *Anita SKULIMOWSKA, Asunción ARANDA, Luca DI FELICE[#], Agnieszka CELIŃSKA* *Institutt for energiteknikk(IFE), Norway*
10:30-10:50	BREAK		
10:50-11:10	Development and Scale-Up of Copper-Based Chemical Looping with Oxygen Uncoupling *Kevin J. WHITTY[#], JoAnn S. LIGHTY, Andrew FRY* *University of Utah, USA*	CFD Simulation of a 10 kW Chemical Looping with Oxygen Uncoupling System: Effects of Process and Fuel Parameters *Matthew A. Hamilton[#], Kevin J. Whitty, JoAnn S. Lighty* *University of Utah, USA*	Chemical Looping with Air Separation (CLAS) in a moving bed reactor with CuO/ZrO2 Oxygen Carriers *Young Ku, Hsuan-Chih Wu[#], Chia-Wei Chang, Shr-Han Shiu, Yao-Hsuan Tseng, Hao-Yeh Lee, Yu-Lin Kuo* *Taiwan University of Science & Technology, Taiwan, China*
11:10-11:30	Use of Manganese Ores as Oxygen Carriers in Chemical-Looping Combustors for Solid Fuels *Carl LINDERHOLM[#], Anders LYNGFELT* *Chalmers University of Technology, Sweden*	Numerical Simulation of In-Situ Gasification Chemical Looping Combustion-Effect of Operating Conditions *Xiaojia Wang, Baosheng Jin, Yali Shao and Yong Zhang* *Southeast University, China*	Reactivity and Stability of Various Supported Fe-Cu Composite Oxygen Carriers for CLHG *Young Ku, Yu-Cheng Liu, Jing-An Chen, Yu-Lin Shen[#], Hsuan-Chih Wu, YaoHsuan Tseng, Hao-Yeh Lee, Yu-Lin Kuo* *National Taiwan University of Science and Technologyy, Taiwan, China*
11:30-11:50	Annular Carbon Stripper for Chemical-looping Combustion of Coal *Mao Cheng, Hongming Sun, Ye Lia, Zhenshan Lia, Ningsheng Cai* *Tsinghua University,China*	Development and Validation of 1D Process Model with Autothermal Operation of a 1 MW_{th} Chemical Looping Pilot Plant *Peter OHLEMÜLLER[#], Falah ALOBAID, Alberto ABAD, Juan ADANEZ, Jochen STRÖHLE, Bernd EPPLE* *TU Darmstadt, Germany*	Theoretical Calculation and Experimental Evaluation of Interactions Between Ash and Oxygen Carriers in Chemical-Looping Combustion - K, Ca, Si and Fe2O3, Mn3O4 and Synthesized Ilmenite *Dongmei Zhao, Robin Deniz[#], Henrik Leion* *Chalmers University of Technology, Sweden*
11:50-12:10	4000 Hours of Operation with Oxygen-Carriers in Industrial Relevant Scale (75 MWth) *Bengt-Åke ANDERSSON, Fredrik LIND, Angelica CORCORAN, Henrik THUNMAN[#]* *Chalmers University of Technology, Sweden*	System-Level Analysis of CO_2 Mitigation Efficiency in Chemical-Looping Combustion Combined Cycle Power Plants *Chen CHEN, Lu HAN, George M. BOLLAS[#]* *University of Connecticut, USA*	Development of Mechanically Strong Manganese-based Oxygen Carriers by Spray Drying Method *Marijke JACOBS[#], Pieter WELTENS, Yoran DE VOS, Dazheng JING, Tobias MATTISSON, Frans SNIJKERS* *Flemish Institute for Technological Research (VITO), Belgium*
12:10-12:30	Implementation of Design Improvements into a 50 kWth CLC Pilot Plant with Coal *Alberto ABAD[#], José A. BUENO, Raúl PÉREZ-VEGA, Francisco GARCÍA-LABIANO, Pilar GAYÁN, Luis F. de DIEGO, Juan ADÁNEZ* *Instituto De Carboquímica (ICB-CSIC), Spain*	Evolution and Reaction Mechanism of Iron-Based Oxide Microparticles in Chemical Looping *Lang Qin, Zhuo Cheng, Mengqing Guo, Jonathan Fan, Liang-Shih Fan* *The Ohio State University, USA*	Chemical Cycling Testing of Fe2O3-Al2O3 Oxygen Carrier for Chemical Looping Combustion *Juha Lagerbom, Toni Pikkarainen[#]* *VTT Technical Research Centre of Finland Ltd, Finland*
12:30-14:00	LUNCH		
14:00-18:00	Poster Session	Lab Visit	Tour
18:30	Conference Dinner at Mandarin Garden Nanjing		

Sept.28	Friendship Hall 友谊厅		
8:40-9:20	**Keynote 4** Chair: Carl Johan LINDERHOLM Overview of Operational Experience for Solid Fuels CLC *Juan Adánez* *Instituto de Carboquimica (CSIC), Zaragoza, Spain*		
9:20-9:30	Parallel Sessions		
	Friendship Hall 友谊厅	Magnolia Hall 白玉兰厅	Tulip Hall 郁金香厅
	Session A - 3 Pilot Plants Chair: Anders Lyngfelt, Pilar Gayan Sanz	Session B - 4 Hydrogen Production & Gasification Chair: Alberto Abad, Baowen Wang	Session E - 1 Calcium Looping Chair: Haibo Zhao, Tomonao Saito
9:30-9:50	Chemical Looping Combustion Development in Korea *Jeom-In BAEK[#], Uisik KIM, Hyungeun JO, Tae Hyoung EOM, Joong Beom LEE,Ho-Jung RYU* *Korea Electric Power Corporation Research Institute, Korea*	Experimental Investigation on Chemical Looping Gasification of Biomass Char using Fe-Ni Bimetallic Oxygen Carrier *Zhen Huang, Fang He, Dezhen Chen* *Chinese Academy of Sciences, China*	Characterization of the Calcium Looping Performance of a Limestone in a Novel Twin-Bed Test Reactor *Antonio COPPOLA[#], Liberato GARGIULO, Fabrizio SCALA, Piero SALATINO* *Consiglio Nazionale delle Ricerche, Italy*
9:50-10:10	Performance of a 150 kW Chemical Looping Combustion Reactor System for Qaseous Fuels Using a Copper-based Oxygen Carrier *Øyvind LANGØRGEN[#], Inge SAANUM, Nils Erland L. HAUGEN* *SINTEF Energy Research, Norway*	Chemical Looping Dry Reforming of Methane using Mixied Oxides of Iron and Cerium *F.R. García–García, J.S. Dennis, I.S. Metcalfe* *University of Cambridge, UK*	Comparison of Energy Penalty in Post-Combustion and Pre-Combustion Calcium Looping Systems using Aspen Plus DAI, Wei, BANERJEE, Subhodeep, AGARWAL, Ramesh K. Washington University in St. Louis, USA
10:10-10:30	Piloting of Bio-CLC for BECCS *Toni Pikkarainen[#], Ilkka Hiltunen, Sebastian Teir* *VTT Technical Research Centre of Finland Ltd, Finland*	Effects of Support on the Performance of Chemical Looping Hydrogen Generation using Iron Oxides *Ma Shiwei[#], Xiang Wenguo, Chen Shiyi* *Southeast University, China*	CO2 Capture Behaviour of Carbide Slag under High Concentration of Steam as Calcination Atmosphere during Calcium Looping Cycles *Wan Zhang[#], Yingjie Li, Zirui He, Chunmei Lu* *Shandong University, China*
10:30-10:50	BREAK		
10:50-11:10	**Plenary 3** Zero Emissions Pressurized Chemical Looping Combustion for Heavy Oil Extraction *Dennis Lu* *Canmet ENERGY, Canada*	Mixed Oxide Based Redox Catalysts for Hydrogen and Liquid Fuel Co-Production via a Hybrid Solar-Redox Scheme *Vasudev Haribal, Feng He, Fanxing Li[#]* *North Carolina State University, USA*	Experiments on the Processes of biomass Chemical Looping Gasification based on CaO Sorbent *Yi Feng, Qinhui Wang, Hongtao Fan, Zhongyang Luo* *Zhejiang University, China*
11:10-11:30		Low Dioxin Emission from Chemical Looping Combustion of Digested Sludge *Xiuning HUA[#], Lidan YIN, Yidi WANG* *Tsinghua University, China*	Calcium Looping Process integrated with a Concentrated Solar Power System: Assessment of Limestone Performance *Claudio TREGAMBI, Fabio MONTAGNARO[#], Piero SALATINO, Roberto SOLIMENE* *Università degli Studi di Napoli Federico II, Italy*
11:30-11:50	Fluid Dynamic Evaluation of a Next Scale Reactor Design for Chemical Looping Combustion of Gaseous Fuels *Michael STOLLHOF[#], Stefan PENTHOR, Karl MAYER, Hermann HOFBAUER* *Vienna University of Technology, Austria*	Chemical Looping Combustion and Gasification Technologies: Pilot Plant Process Development and Operation *Dikai XU, Tien-Lin HSIEH, Andrew TONG[#]* *Ohio State University, USA*	Experiments on in-situ Gasification Chemical Looping Combustion (iG-CLC) of Plastic Waste with CaO-Decorated Iron Ore for Inhibiting Chlorobenzene *Jinxing Wang, Haibo Zhao, Jinchen Ma* *Huazhong University of Science and Technology, China*

11:50-12:10	Effect of Solid Residence Time on CO2 Selectivity in a Semi-Continuous Chemical Looping Combustor *Ho-Jung RYU #, Dong-Ho LEE, Dowon SHUN, Jong-Ho MOON, Jeom-In BAEK* *Korea Institute of Energy Research, Korea*	Carbon Deposition and Sintering Characteristics on Iron-Based Oxygen Carriers in Catalytic Cracking Process of Coal Tar *Xu JIANG, Yongpeng LI, Fei HUANG, Yongzhuo LIU, Cuiping WANG #* *Qingdao University, China*	HCl Capture Performance of Cycled Mg-stabilized Carbide Slag from Calcium Looping Cycles for CO2 Capture *Changyun Chi #, Yingjie Li, Lei Shi, Xiaotong Ma* *Shandong University, China*
12:10-12:30	The Roles of Iron-Based Oxygen Carriers in Pressurized Chemical Looping Combustion of Solid Fuel *Liangyong Chen, Zhen Fan, Fang Liu, Jinhua Bao, Heather Nikolic, Kunlei Liu* *University of Kentucky, USA*		Effect of dilute CH4 and CO2 concentration on the stability of limestone in Calcium Looping Processes *Savankumar Patel, Priscilla Tremain, Behdad Moghtaderi, James Sandford, Kalpit Shah #* *The University of Newcastle, Australia*
12:30-14:00	LUNCH		
Sept.28	Friendship Hall 友谊厅		
	Session A - 4 Pilot Plants Chair: Shi-ying Lin, Andrew Tong		
14:00-14:20	Commercial Scale Preparations of CuO-Fe2O3-Alumina Oxygen Carrier with various techniques: Bench Scale Fluidized Bed Tests with Coal/Air and Methane/air and Pilot Scale (51 Kwth) Chemical Looping Combustion Tests With Methane/Air *Ranjani Siriwardane #, Hanjing Tian, Jarrett Riley, William Benincosa, Douglas Straub, Justin Weber, George Richards* *National Energy Technology Center (NETL), USA*		
14:20-14:40	Fate of Sulfur in Chemical Looping Combustion of Qaseous Fuels Using a Copper Based Oxygen Carrier *Robert F. PACHLER #, Mario KOLLERITS, Karl MAYER, Stefan PENTHOR, Hermann HOFBAUER* *Vienna University of Technology, Austria*		
14:40-15:00	Chemical Looping Combustion of High Sodium Lignite in the Fluidized Bed: Combustion Performance and Sodium Transfer *Tao Song, Ernst-Ulrich Hartge, Stefan Heinrich, Laihong Shen, Joachim Werther* *Hamburg University of Technology, Germany*		
15:00-15:20	Practical Potential and Technological Limitations of Power Generation via Chemical Looping Combustion of Gaseous Fuels *Florian ZEROBIN, Tobias PRÖLL* *University of Natural Resources and Life Sciences, Austria*		
15:20-15:40	Reactivity of Ilmenite in Pressurized Chemical-looping Combustion with CO *Xuao Lu #, Dennis Y. Lu, Firas N.Ridha, Robin W. Hughes* *North China Electric Power University, China*		
15:40-16:00	BREAK		
16:00-17:00	Panel Discussion Chair: Kevin Whitty		

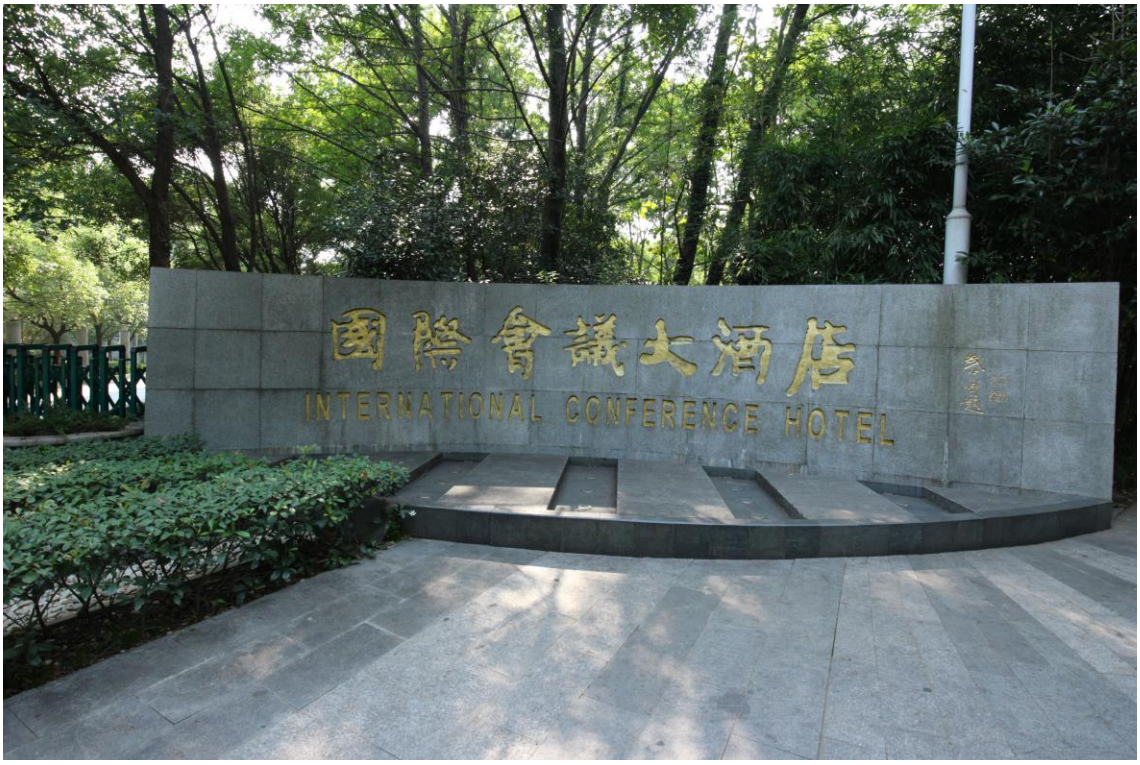

圖 1. 4th International Conference on Chemical Looping 舉辦地點酒店

圖 2. 4th International Conference on Chemical Looping 會場

三、心　得

目前本所積極進行能源國家型科技計畫之「淨碳技術領域」相關研究發展計畫，並配合能源局能專計畫項下之「潔淨低碳多元應用暨氣體處理技術發展」計畫，期望從永續發展觀點推動自主潔淨能源技術之建立。本次出國公差為執行「碳基能源永續潔淨利用技術發展」分支計畫，筆者代表本所化學組淨碳分組出席 2016 年第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)，並以口頭報告方式發表研究成果論文“Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process”，期望藉由本次會議，了解與掌握國際間化學迴圈燃燒程序發展之現況與趨勢，拓展與國際學者專家之關係及國際合作。本報告將依序分別選擇重點摘要於下文中。

(一) 4th International Conference on Chemical Looping 大會議程

第四屆化學迴圈國際研討會於 105 年 9 月 25 日至 9 月 28 日在大陸南京國際會議大酒店舉行，由大陸東南大學主辦，此會議提供國際間化學迴圈技術相關研究機構之工程師、研究人員、教授等專家學者一個開放平台，分享與展示他們的最新研究成果與創新思想。大會議題以化學迴圈技術為主軸，包含該技術目前的發展趨勢和未來規劃與需求，衍生相關五大技術議題進行專題討論，包括先導工廠測試、氫氣產物與氣化反應、載氧體分析與改質、化學迴圈模型建構，以及鈣迴圈技術討論。

ICCL 2016 會議於 9 月 25 日(星期日)開始註冊與報到(圖 3~圖 4)；大會的開幕典禮於 9 月 26 日(星期一)早上舉行(圖 5~圖 6)，本屆大會由大陸東南大學的沈來宏教授擔任主席，典禮流程包括貴賓致詞、開幕等，在大會主席沈教授致詞歡迎各國與會嘉賓後，即開始大會的會議議程，分為主題演講(Keynote Speech)、全體會議(Plenary Session)、論文口頭發表、及壁報論文展示四部分，將分章節依序描述於本報告中。

圖 3. ICCL 2016 會場內之報到櫃檯

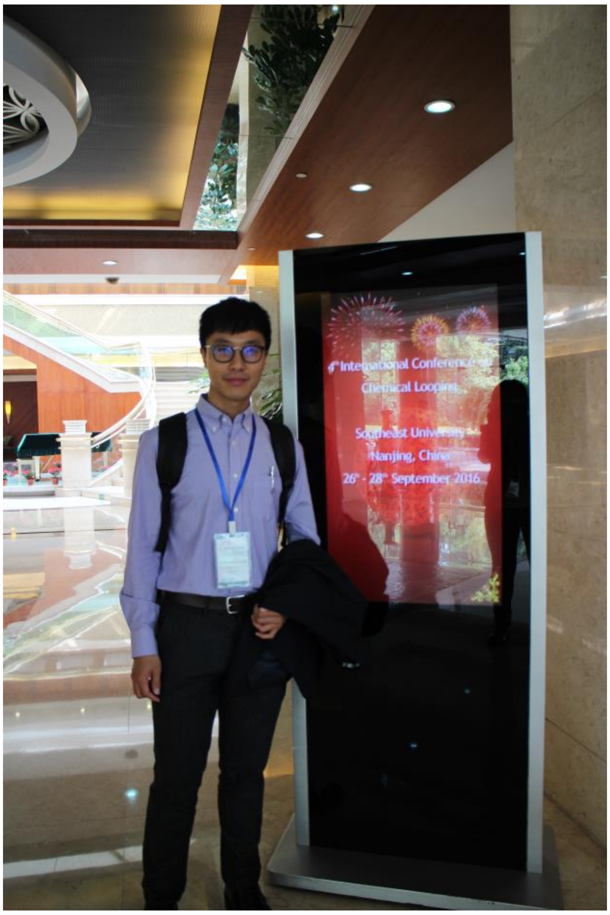

圖 4. 筆者攝於 ICCL 2016 大會場館

圖 5. 開幕典禮會場內景象

圖 6. 開幕典禮大會主席致詞

1. Keynote Speech

大會於星期一早上安排兩場 Keynote Speech，星期二與星期三早上各安排一場 Keynote Speech；相關各應邀講員之資料與講題列舉如下：

Keynote 1- Chemical Looping Partial Oxidation
Prof. Liang-Shih Fan
Ohio State University, USA

Keynote 2- Reactor for Chemical-Looping Combustion of Solid Fuels
Prof. Lai-Hong Shen
Southeast University, China

Keynote 3- Chemical-Looping Combustion of Solid Fuels – What Is Needed To Reach Full-scale
Prof. Anders Lyngfelt
Chalmers University of Technology, Sweden

Keynote 4- Overview of Operational Experience for Solid Fuels CLC
Dr. Juan Adanez
Instituto de Carboquimica (CSIC), Zaragoza, Spain

由於篇幅考量，本報告選擇與本單位研究較相關之演講分別摘要重點於下文中。

(1) Chemical Looping Partial Oxidation

本篇 Keynote Speech 排定於 9 月 26 日早上，演講者為 Prof. Liang-Shih Fan 來自 Ohio State University, USA。該演講之重要資料如圖 7~圖 21 所示。該演講討論混和金屬氧化物作為化學迴圈載氧體時，其離子擴散、奈米結構、粒子表面的變化，以及其氧化還原機制。講者於演講中也提到研究團隊對於重製技術(reforming process)例如甲烷的氧耦合作用(oxygen coupling of methane)以及直接氣化技術如何達成高純度合成氣目標的相關研究，同時講者也將該研究的模擬方法與技術經濟分析與商業化潛力一起進行闡述。

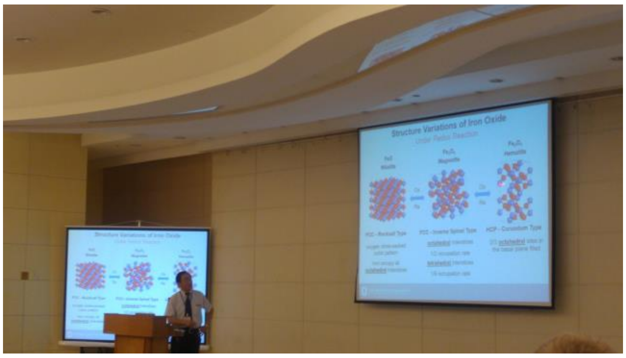

圖 7. Keynote Speech 1-1

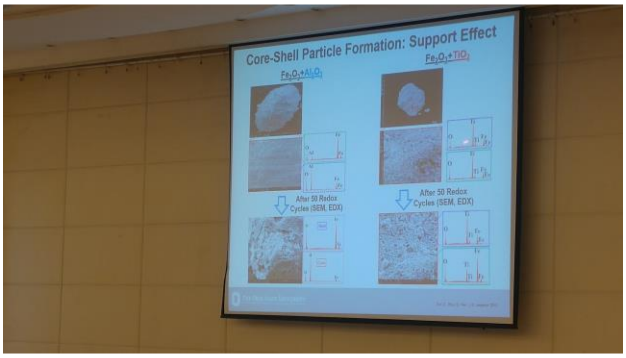

圖 8. Keynote Speech 1-2

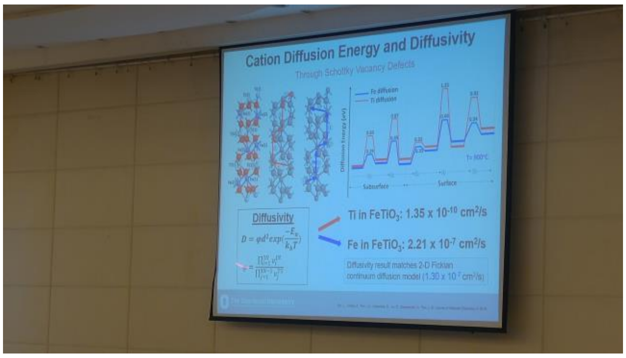

圖 9. Keynote Speech 1-3

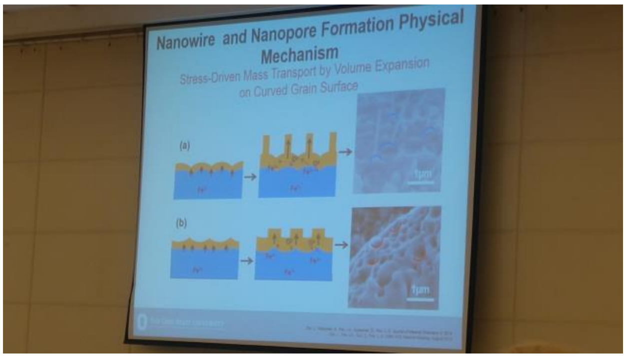

圖 10. Keynote Speech 1-4

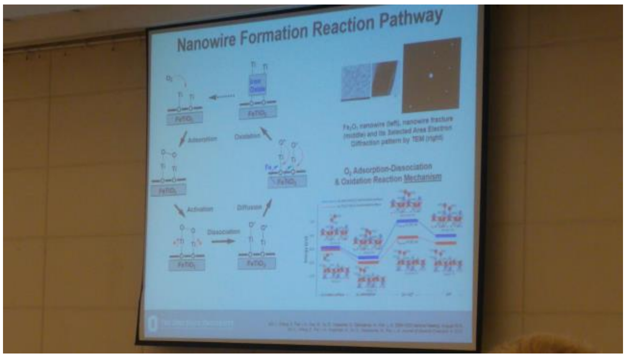

圖 11. Keynote Speech 1-5

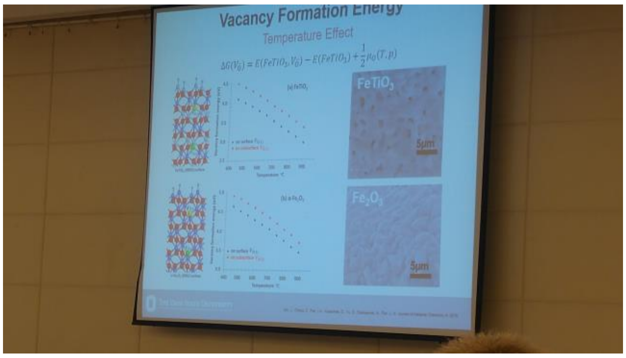

圖 12. Keynote Speech 1-6

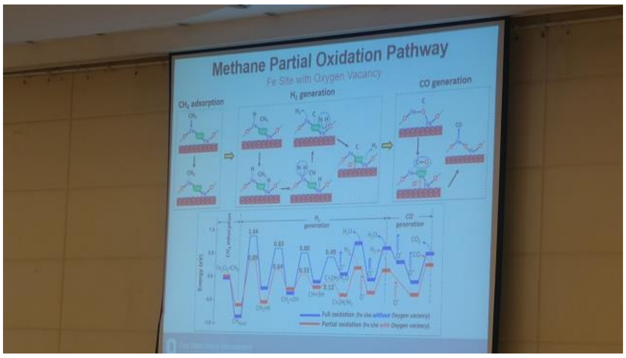

圖 13. Keynote Speech 1-7

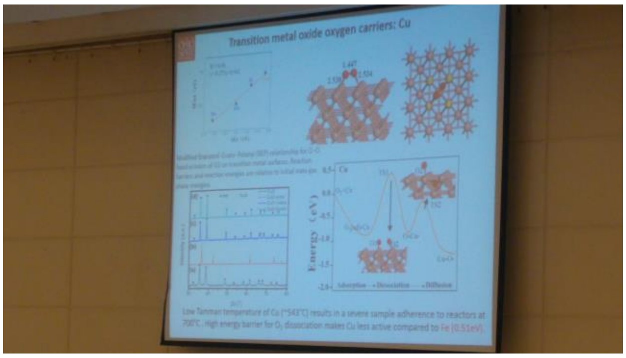

圖 14. Keynote Speech 1-8

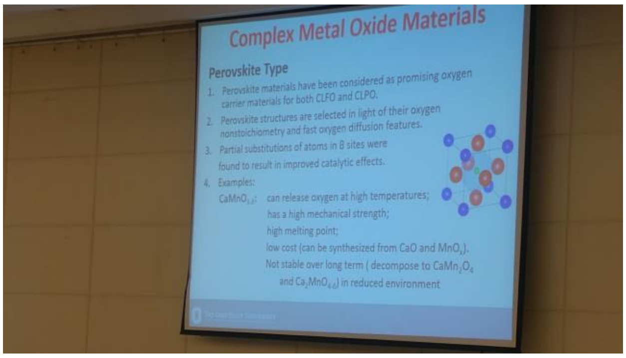

圖 15. Keynote Speech 1-9

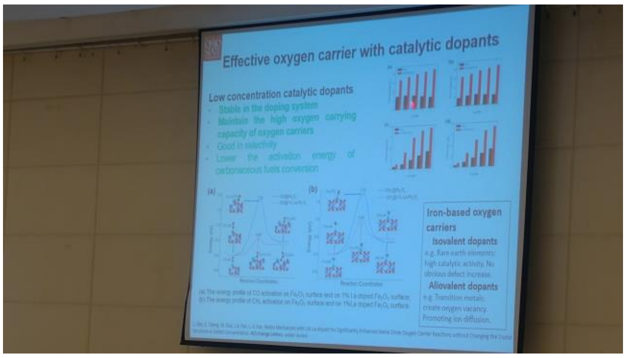

圖 16. Keynote Speech 1-10

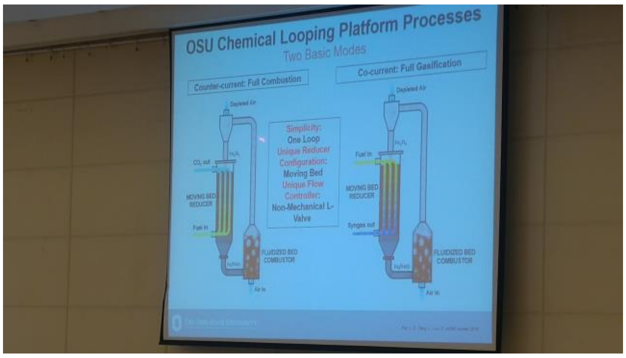

圖 17. Keynote Speech 1-11

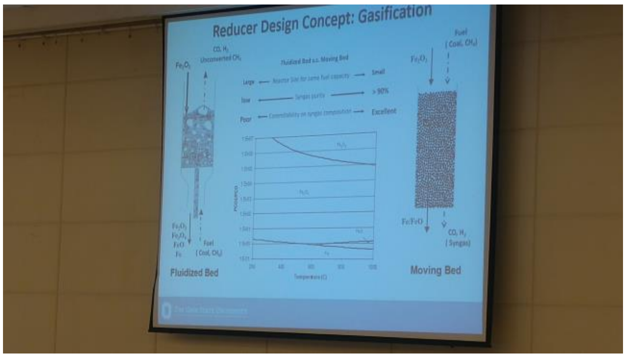

圖 18. Keynote Speech 1-12

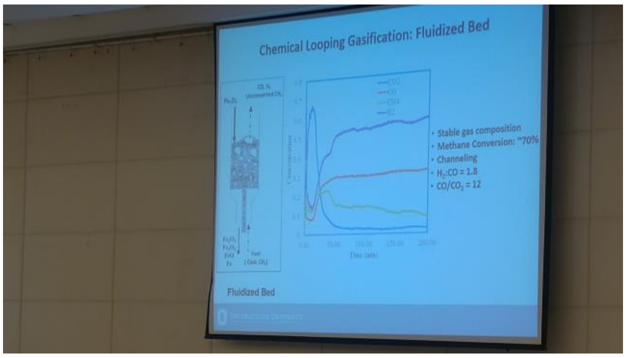

圖 19. Keynote Speech 1-13

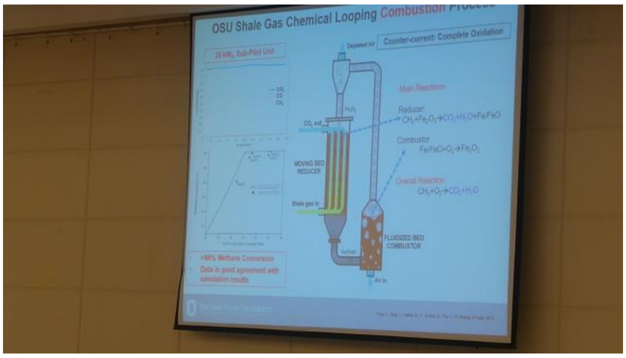

圖 20. Keynote Speech 1-14

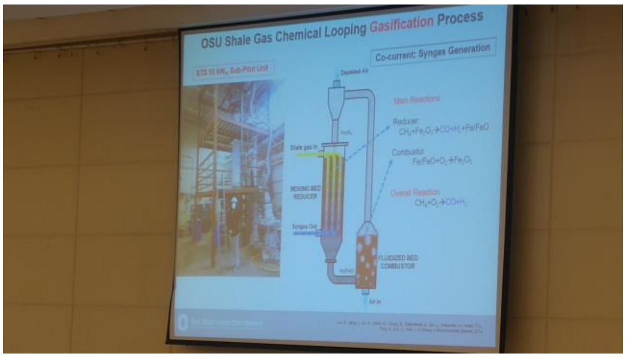

圖 21. Keynote Speech 1-15

(2) Reactor for Chemical-Looping Combustion of Solid Fuels

演講者為 Prof. Lai-Hong Shen，沈教授為大陸東南大學教授，同時為本次大會主席，演講中提到時至今日固態燃料用於化學迴圈技術已有不少研究，主要實驗研究主題為載氧體、空氣反應器、燃料反應器、以及燃料餵料方法等等。沈教授提到了一種將固態燃料用於具有氣泡式塔的燃料反應器，並且展示了研究團隊目前用於觀察流場的化學迴圈冷流模型，用以研究顆粒循環與流化現象，也提到塔式燃料反應器對壓降的影響。塔式燃料反應器的想法是在下方床體中引入固態燃料，其中固態燃料被氣化後大部分轉化為氣態燃料。在上方床體中，由下方床體夾帶的可燃氣體和固體將與載氧體接觸，如此將可提高轉化率，該演講之重要資料如圖 22~圖 43 所示。

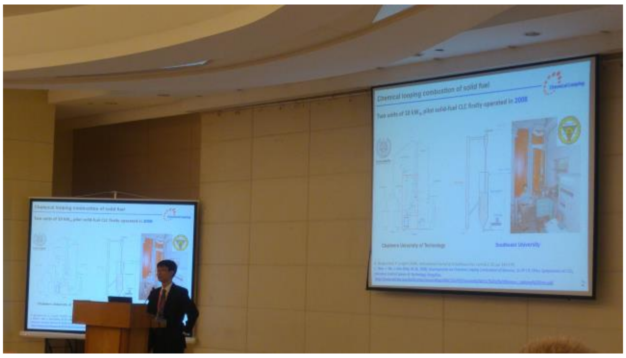

圖 22. Keynote Speech 2-1

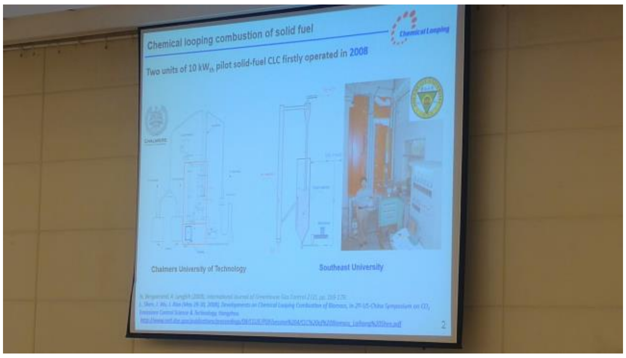

圖 23. Keynote Speech 2-2

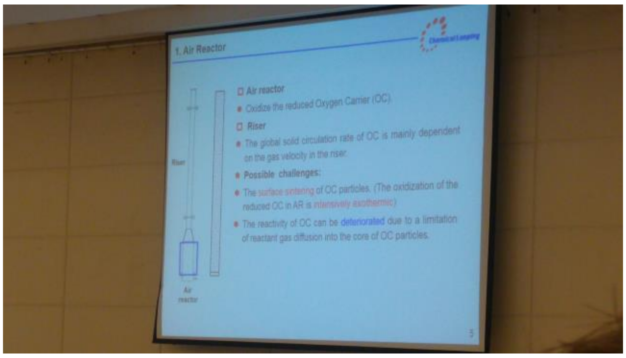

圖 24. Keynote Speech 2-3

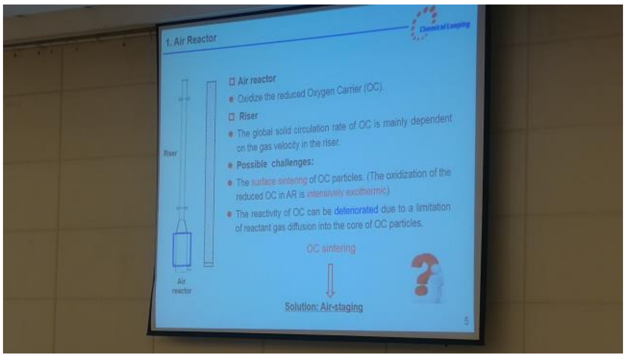

圖 25. Keynote Speech 2-4

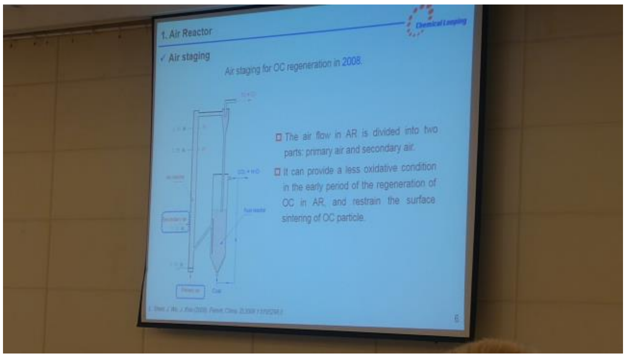

圖 26. Keynote Speech 2-5

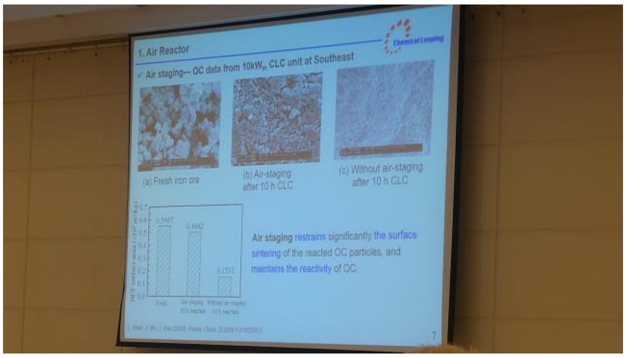

圖 27. Keynote Speech 2-6

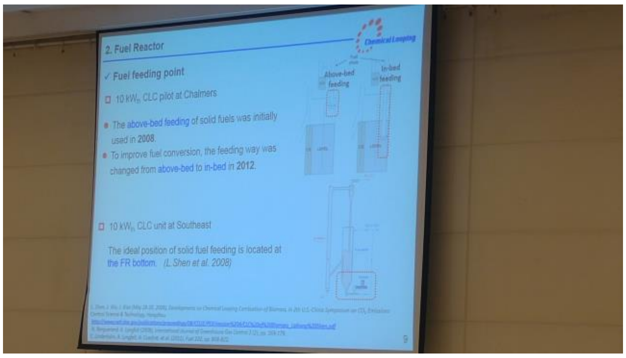

圖 28. Keynote Speech 2-7

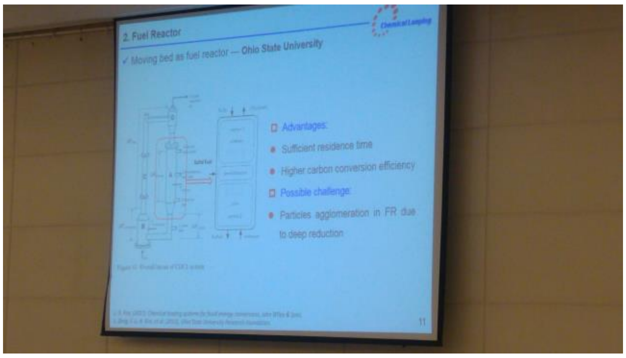

圖 29. Keynote Speech 2-8

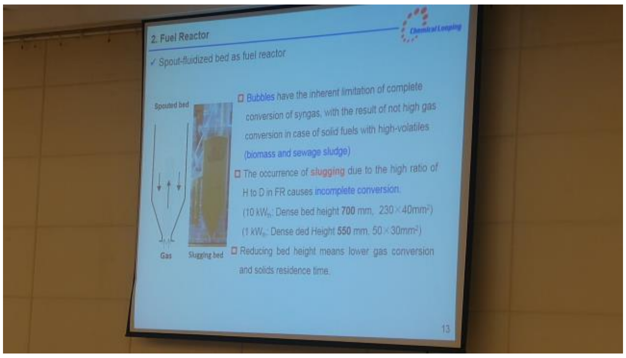

圖 30. Keynote Speech 2-9

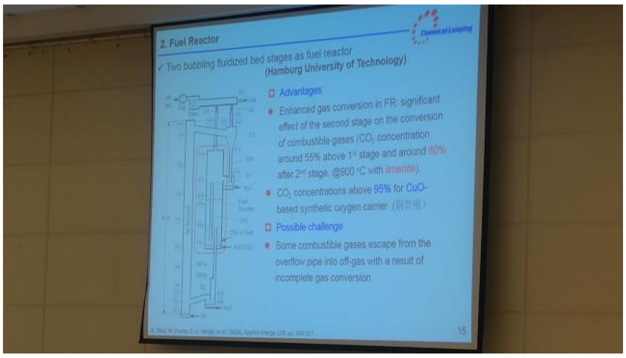

圖 31. Keynote Speech 2-10

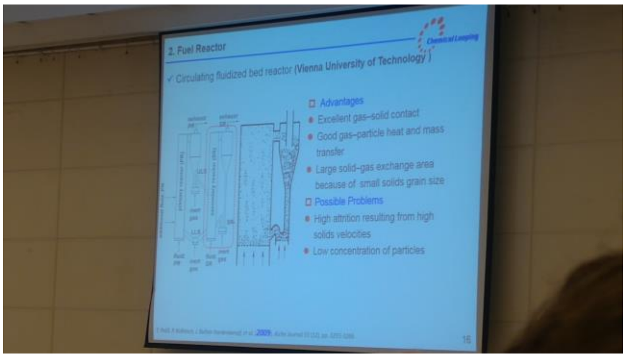

圖 32. Keynote Speech 2-11

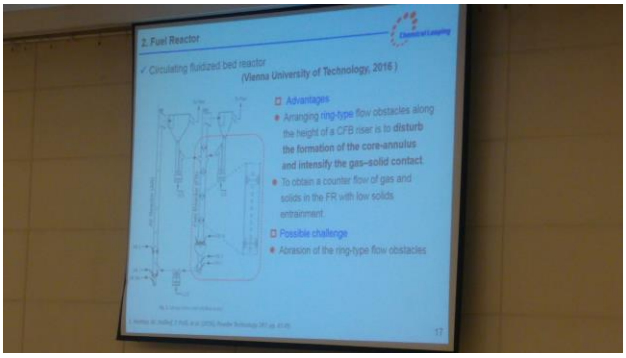

圖 33. Keynote Speech 2-12

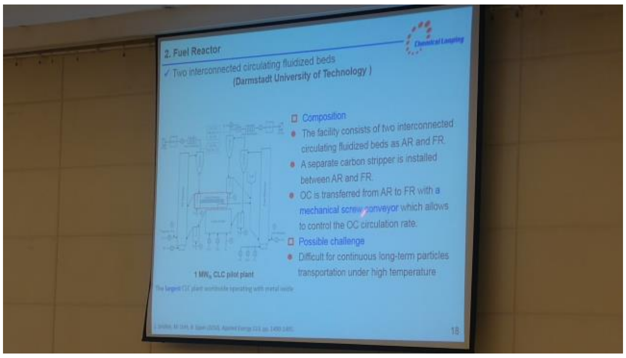

圖 34. Keynote Speech 2-13

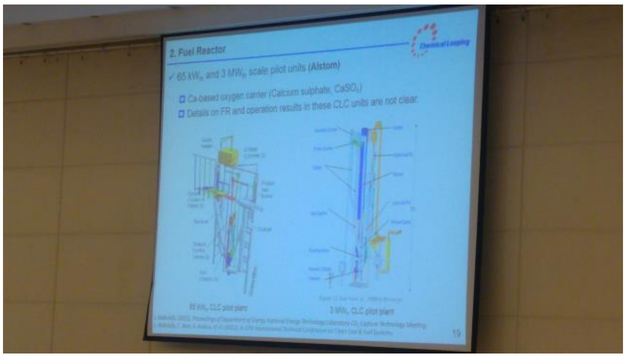

圖 35. Keynote Speech 2-14

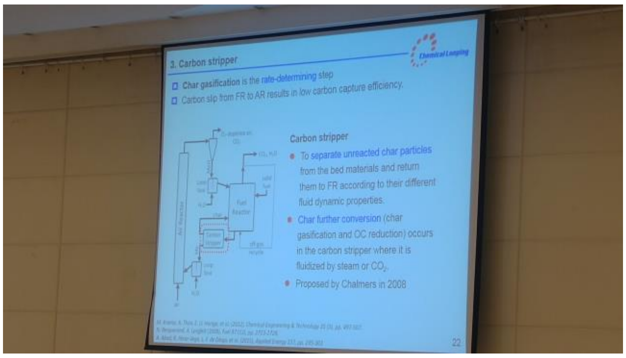

圖 36. Keynote Speech 2-15

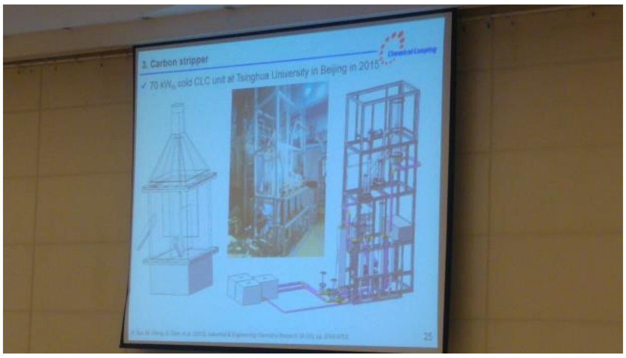

圖 37. Keynote Speech 2-16

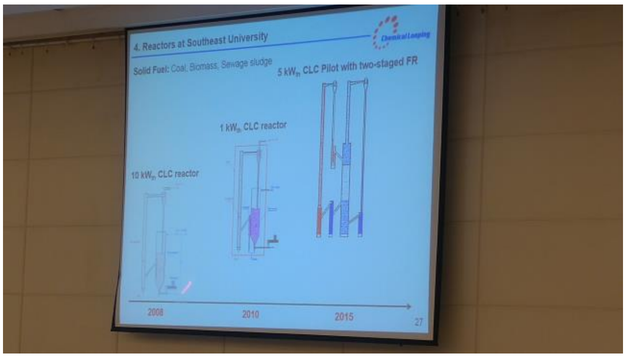

圖 38. Keynote Speech 2-17

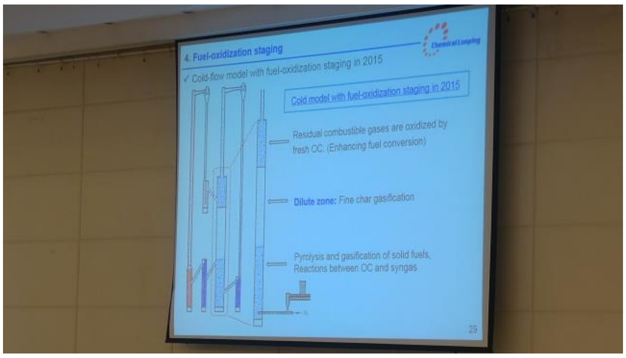

圖 39. Keynote Speech 2-18

圖 40. Keynote Speech 2-19

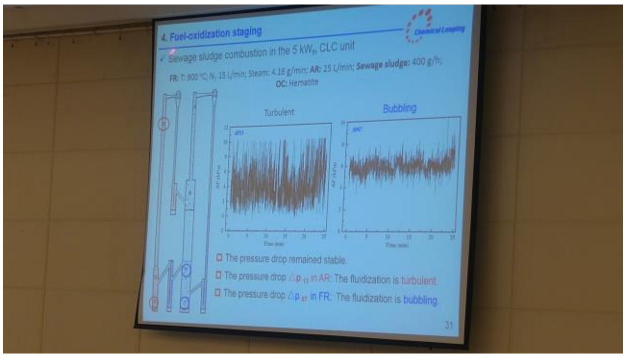

圖 41. Keynote Speech 2-20

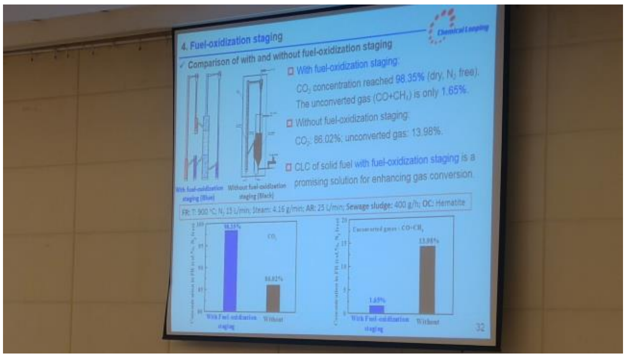

圖 42. Keynote Speech 2-21

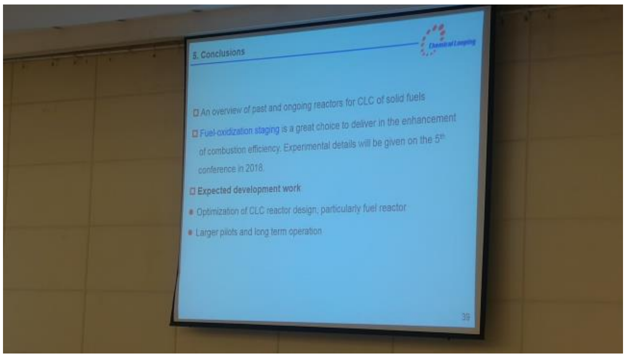

圖 43. Keynote Speech 2-22

2. Plenary Session

本次大會共安排三場次全體會議(Plenary Session)，本報告中摘錄第三場全體會議演講陳述，本篇大會演講排定於 9 月 28 日早上，演講主題為 “Zero Emissions Pressurized Chemical Looping Combustion for Heavy Oil Extraction”，演講者 Dennis Lu 來自加拿大的 CanmetENERGY。該演講之重要資料如圖 44~圖 67。

其內容以模擬與實驗方式於化學迴圈燃燒程序中增加壓力(Pressurized Chemical Looping Combustion, PCLC)，認為增加壓力將能夠增加系統效率，整個程序只需極少的額外電力，且能在燃料反應器的出口採集到高壓二氧化碳，如此二氧化碳捕獲率將提高，減少二氧化碳排放量。該研究也以實驗方法確認加拿大鈦鐵礦為 PCLC 的良好載氧體，且其成本低廉且對環境衝擊極小。另外，CanmetENERGY 計畫發展 PCLC 技術達成 200kW$_{th}$ 目標，以產生氫氣、蒸汽、以及電力。

圖 44.　Plenary Session 1-1

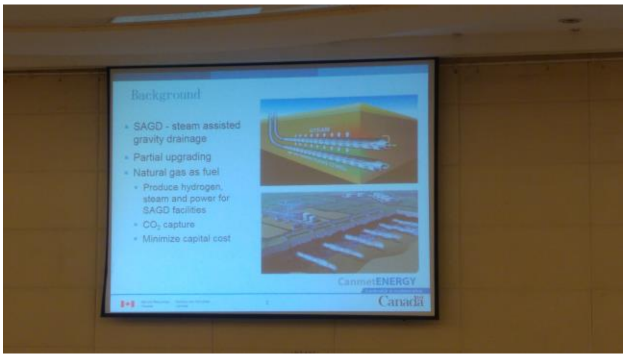

圖 45. Plenary Session 1-2

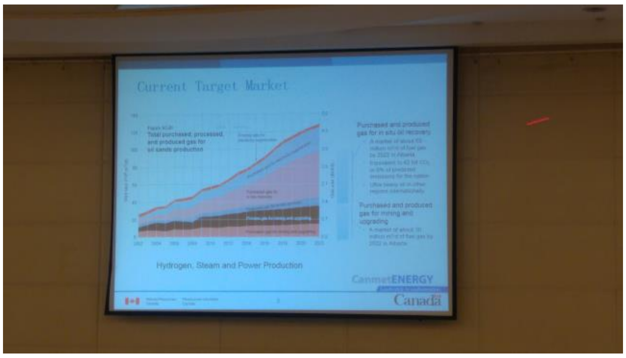

圖 46.　Plenary Session 1-3

圖 47. Plenary Session 1-4

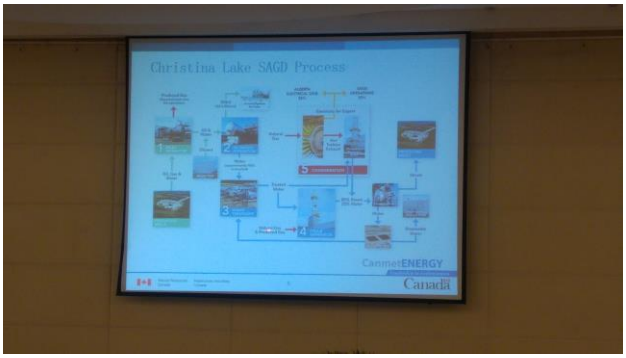

圖 48.　Plenary Session 1-5

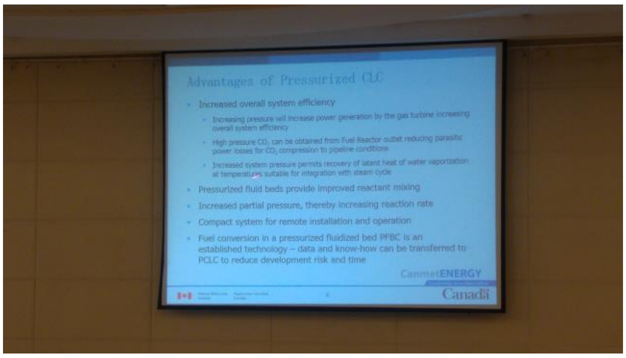

圖 49. Plenary Session 1-6

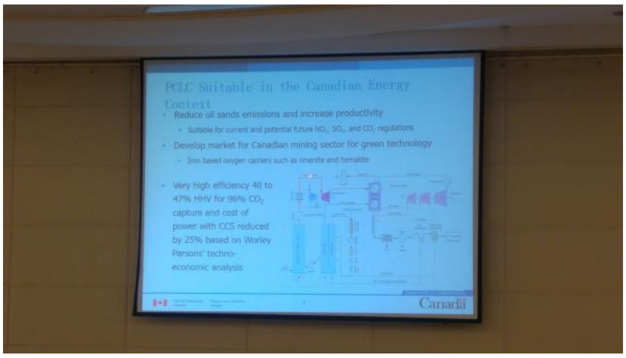

圖 50.　Plenary Session 1-7

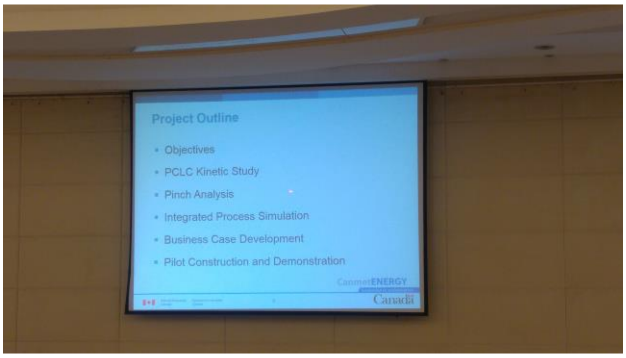

圖 51. Plenary Session 1-8

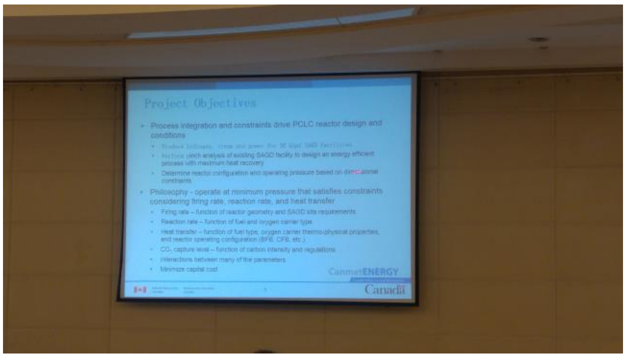

圖 52.　Plenary Session 1-9

圖 53. Plenary Session 1-10

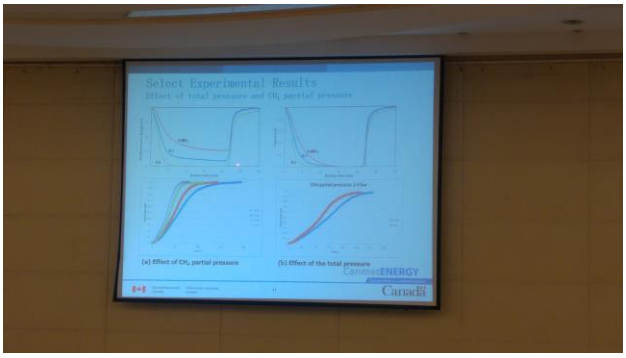

圖 54.　Plenary Session 1-11

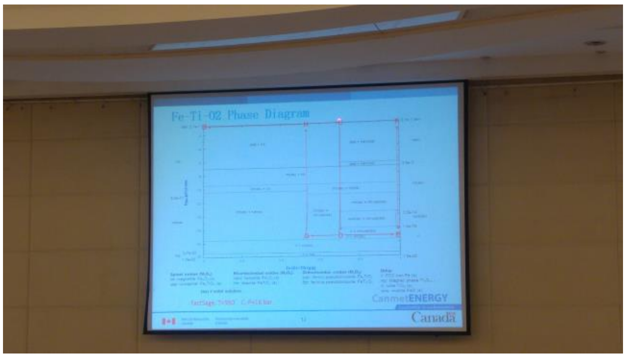

圖 55. Plenary Session 1-12

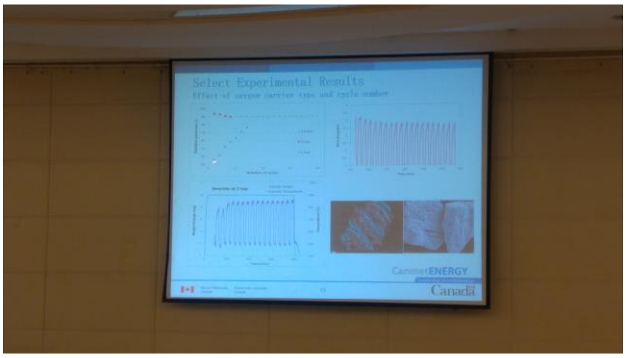

圖 56.　Plenary Session 1-13

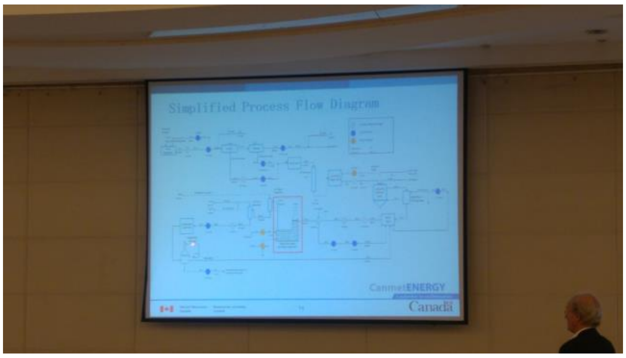

圖 57. Plenary Session 1-14

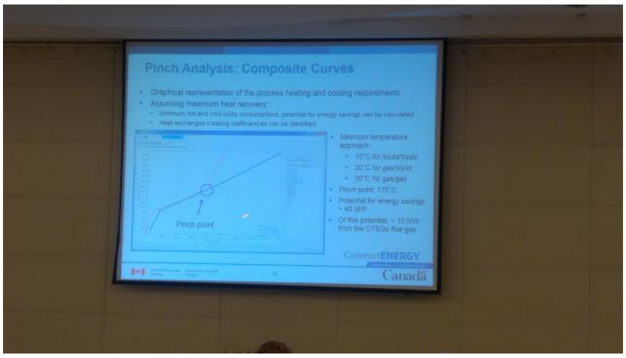

圖 58.　Plenary Session 1-15

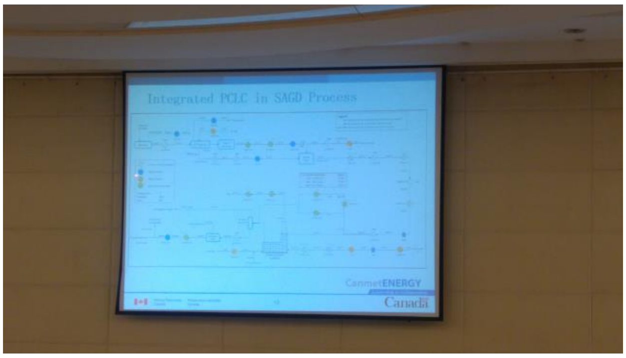

圖 59. Plenary Session 1-16

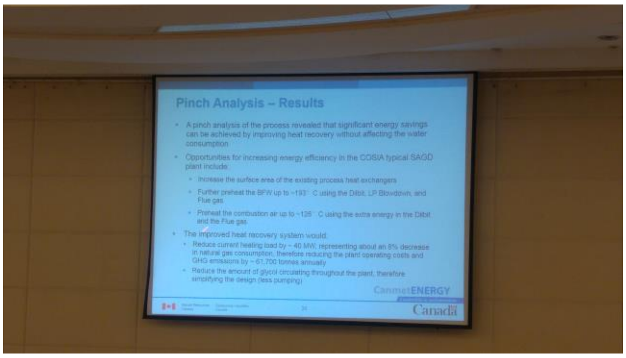

圖 60.　Plenary Session 1-17

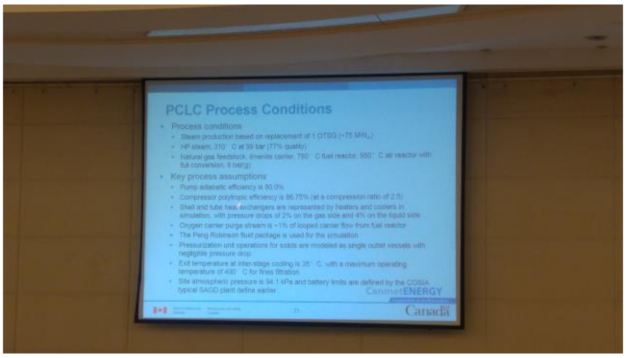

圖 61. Plenary Session 1-18

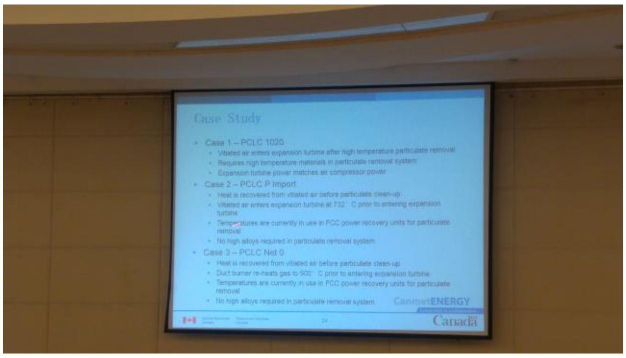

圖 62.　Plenary Session 1-19

圖 63. Plenary Session 1-20

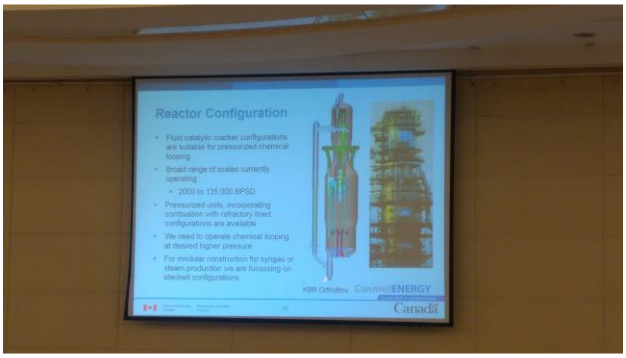

圖 64.　Plenary Session 1-21

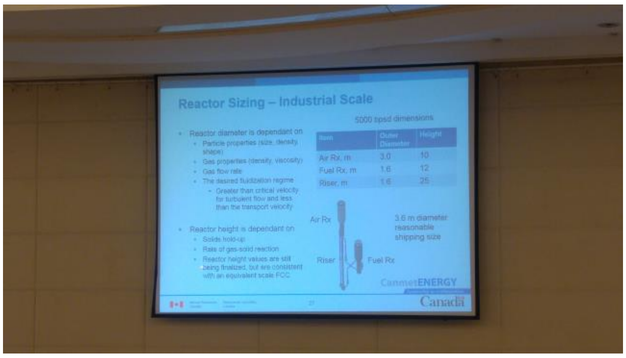

圖 65. Plenary Session 1-22

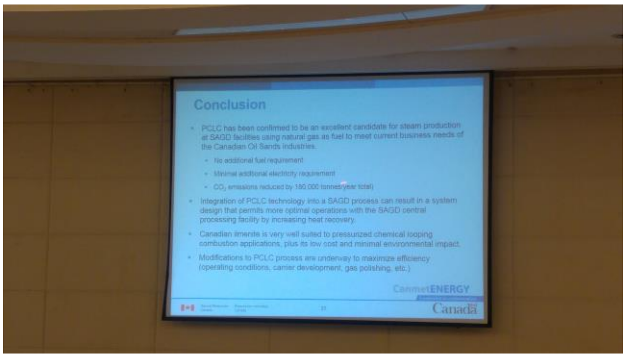

圖 66.　Plenary Session 1-23

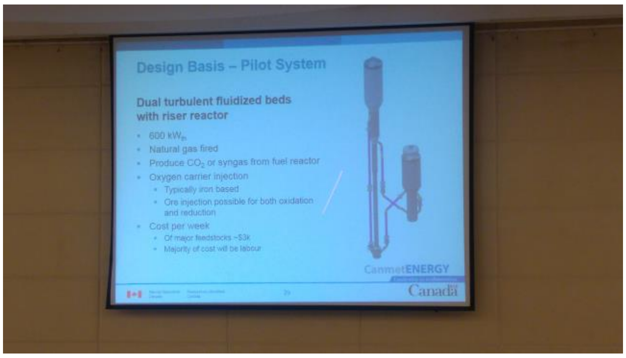

圖 67. Plenary Session 1-24

3. Oral Paper Sessions

ICCL 口頭論文發表議程每天大致分為四個時段，同時各有三個平行場次之口頭論文發表，每個時段至多安排五場專題演講，其間則有中場休息為區隔。技術議題涵蓋先導工廠測試、氫氣產物與氣化反應、載氧體分析與改質、化學迴圈模型建構，以及鈣迴圈技術討論，本次大會口頭論文篇數多達 94 篇。

(1) 本團隊在這次 ICCL 大會中發表之研究成果論文

筆者參與 2016 年第四屆化學迴圈國際研討會(4th International Conference on Chemical Looping)，發表研究成果論文"Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process"，口頭演講時間安排於 9 月 26 日中午 12:10 ~ 12:30，但原本安排於筆者前一場的講者並未出席，所以論文發表演講提前開始，本場次會議主持人為台科大曾堯宣教授以及來自西班牙國家研究會的 Dr. Francisco Garcia Labiano。筆者演講內容之簡報如附錄所示。

筆者之簡報獲得在場與會者與會議主持人之熱烈回應討論(圖 68~圖 69)，原本安排問題時間為 5 分鐘，因該時段在筆者後並無安排其他演講，所以共討論了 10 分鐘，能與國際學者專家討論、分享本所近年來在化學迴圈燃燒程序應用在淨碳技術的研究成果，實為難得經驗。

圖 68. 筆者報告情形由會議工作人員所拍攝

圖 69. 報告後問題討論情形

(2) ICCL 大會中相關代表性口頭發表論文

基於篇幅及研究相關性考量，本報告摘錄前述主題「載氧體分析與改質」之代表性論文。

A. Reactivity of Oxygen Carriers after Recycling in Chemical Looping Combustion of Coal

此論文由 Japan Coal Energy Center, Japan 的研究人員所發表，內容呈現了鈦鐵礦以及 Fe_2O_3/Al_2O_3 作為載氧體時，在經過 CO 和 CO/CO_2 還原氣氛下的化學迴圈燃燒，其反應性及形態的變化。演講內容摘錄如圖 70~圖 73 所示。

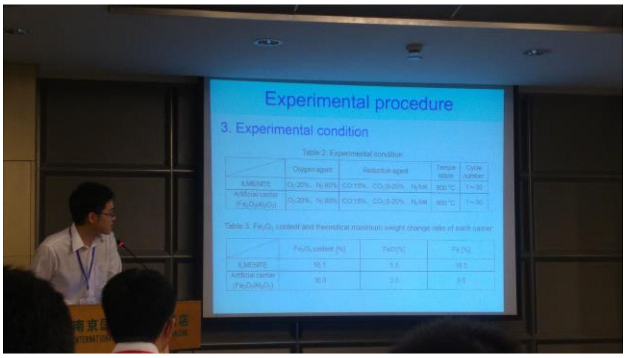

圖 70. Oral Paper 1-1

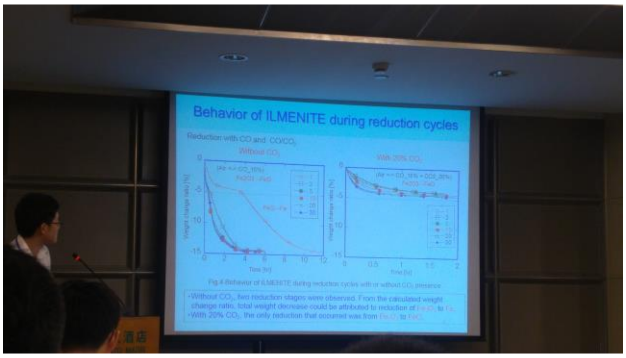

圖 71. Oral Paper 1-2

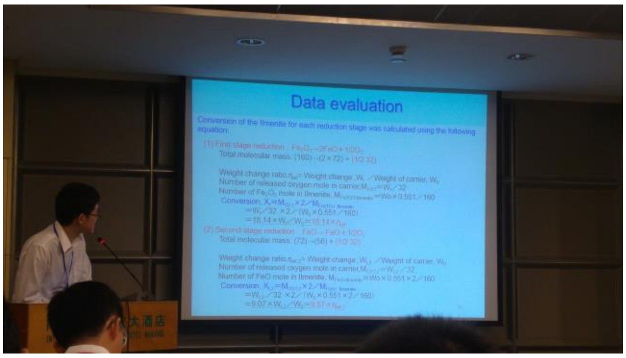

圖 72. Oral Paper 1-3

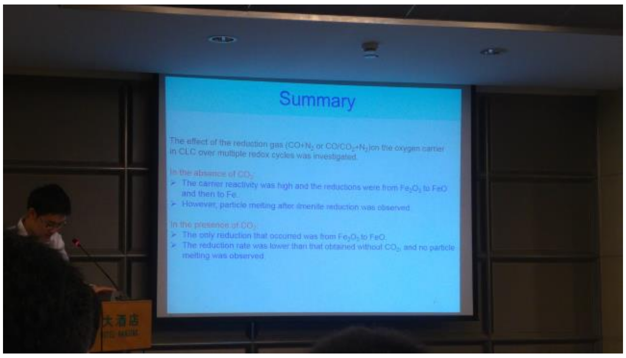

圖 73. Oral Paper 1-4

B. Selective Oxidations via Chemical Looping: Selective Combustion of Hydrogen in Hydrocarbon Mixtures

此論文由 University of Cambridge, UK 的研究團隊所發表，他們將顆粒狀載氧體改質，並研究它們在 C_2H_4 存在下選擇性燃燒 H_2 的活性、選擇性和儲氧能力。研究發現載氧體在 H_2 存在下對 C_2H_4 較具惰性，但在缺少 H_2 的條件下，載氧體對 C_2H_4 更具反應性。演講內容摘錄如圖 74~圖 80 所示。

圖 74. Oral Paper 2-1

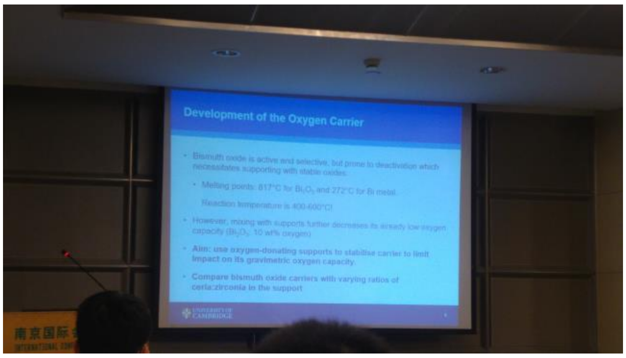

圖 75. Oral Paper 2-2

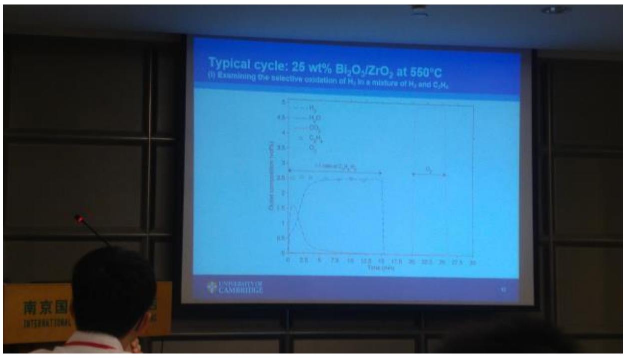

圖 76. Oral Paper 2-3

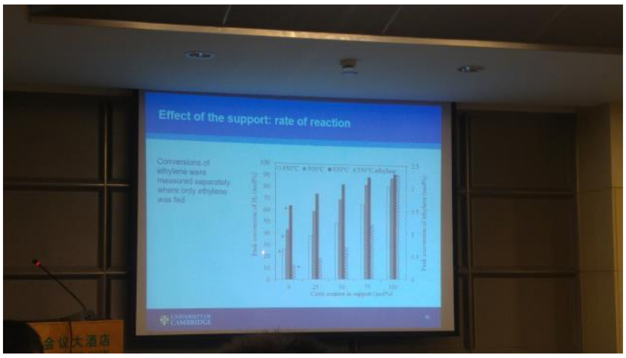

圖 77. Oral Paper 2-4

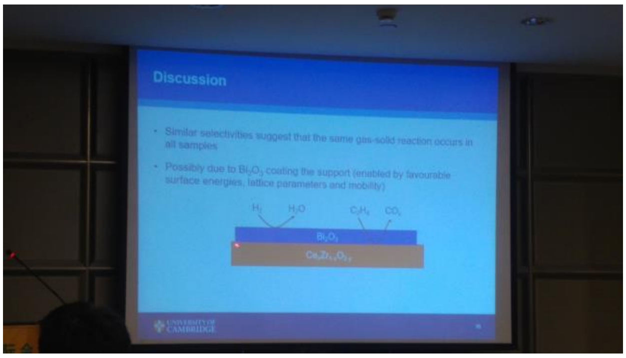

圖 78. Oral Paper 2-5

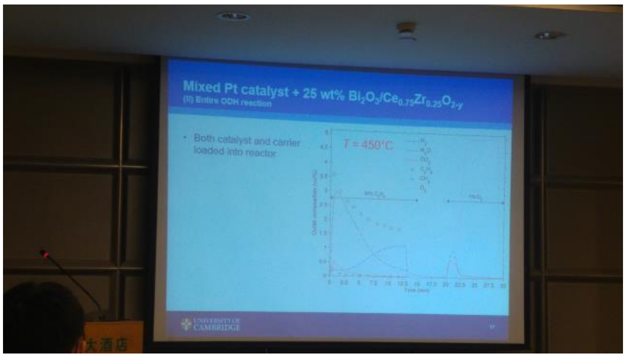

圖 79. Oral Paper 2-6

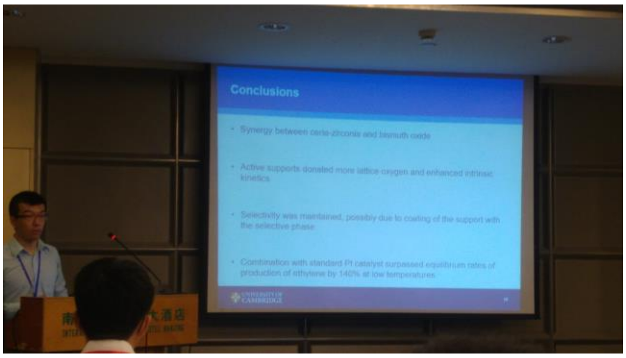

圖 80. Oral Paper 2-7

4. Poster Session

大會在壁報論文區備有咖啡、茶水及點心，供與會者於中場休息時可在此區聚集，參觀壁報論文展示，並互相討論(圖 81~圖 83)。

依大會議程安排，壁報論文自第一天起開始張貼，即從早上 8:30 開始到傍晚 18:00，持續展示至會議結束。筆者亦抽空參閱了解壁報論文發表，以了解各研究機關團體之研究成果與現況。本次會議壁報論文共有 49 篇，本報告摘錄數篇具相關性之論文展示於後，概分為下列五大領域(圖 84~圖 90)。

(1) Pilot Plants

A. “Enhanced Fuel Conversion by Staging Oxidization in a Continuous Chemical Looping Reactor based on iron ore oxygen carrier”(圖 84), Nanjing Institute of Technology & Southeast University, China

(2) Hydrogen Production & Gasification

A. “Process Simulation of a Hydrogen Production Chemical Looping Process with Various Coal Sources”(圖 85), National Taiwan University of Science & Technology, Taiwan

(3) Oxygen Carrier

A. “Chemical Looping Combustion of Coal by Using Limestone with In-Situ Desulfurization”(圖 86), Instituto de Carboquimica, Spain

B. “Characterization and Evaluation of Prepared TiO_2 and Al_2O_3 Supported Fe_2O_3 Oxygen Carriers for CLC”(圖 87), National Taiwan University of Science & Technology, Taiwan

(4) Modelling

A. "Numerical Simulation for Chemical Looping Combustion of Circulating Fluidized Bed Reactor"(圖 88), National Taiwan University of Science & Technology, Taiwan

B. "Computational Fluid Dynamics Simulation of a Cold Model of an Interconnected Fluidized Bed for Chemical Looping Combustion"(圖 89), CSIRO, Australia

(5) Calcium Looping

A. "Characteristic of $CoTiO_3$ as Oxygen Carrier"(圖 90), Chonbuk National University, Korea

圖 81. 大會中場休息於壁報發表場所景象-1

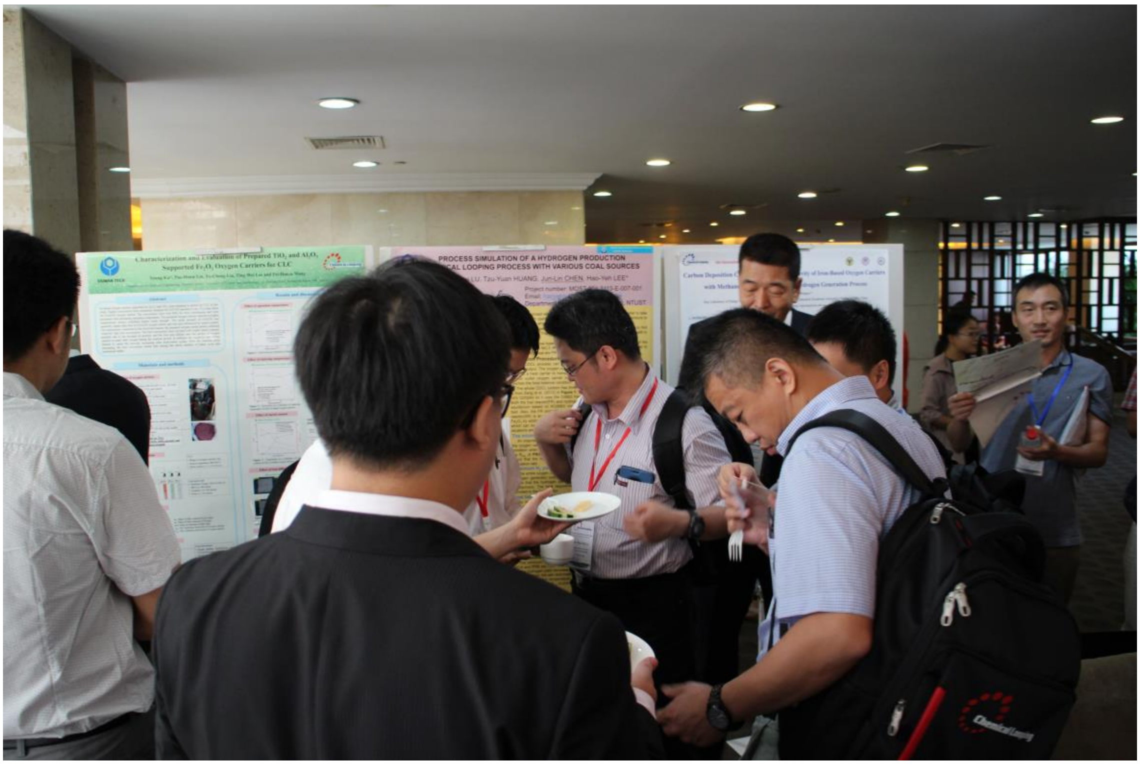

圖 82. 大會中場休息於壁報發表場所景象-2

圖 83. 大會中場休息於壁報發表場所景象-3

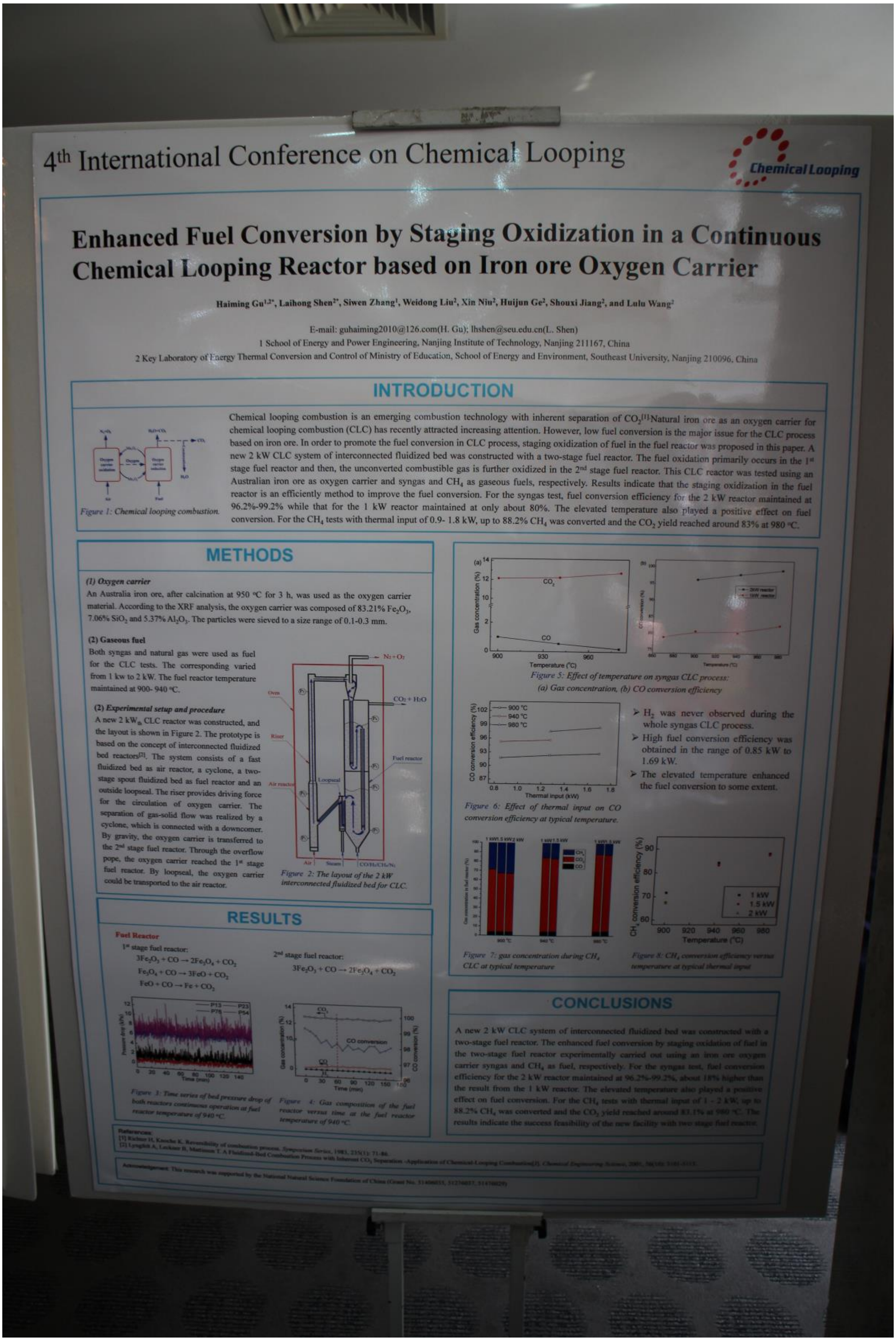

圖 84. 海報論文展示- Pilot Plants

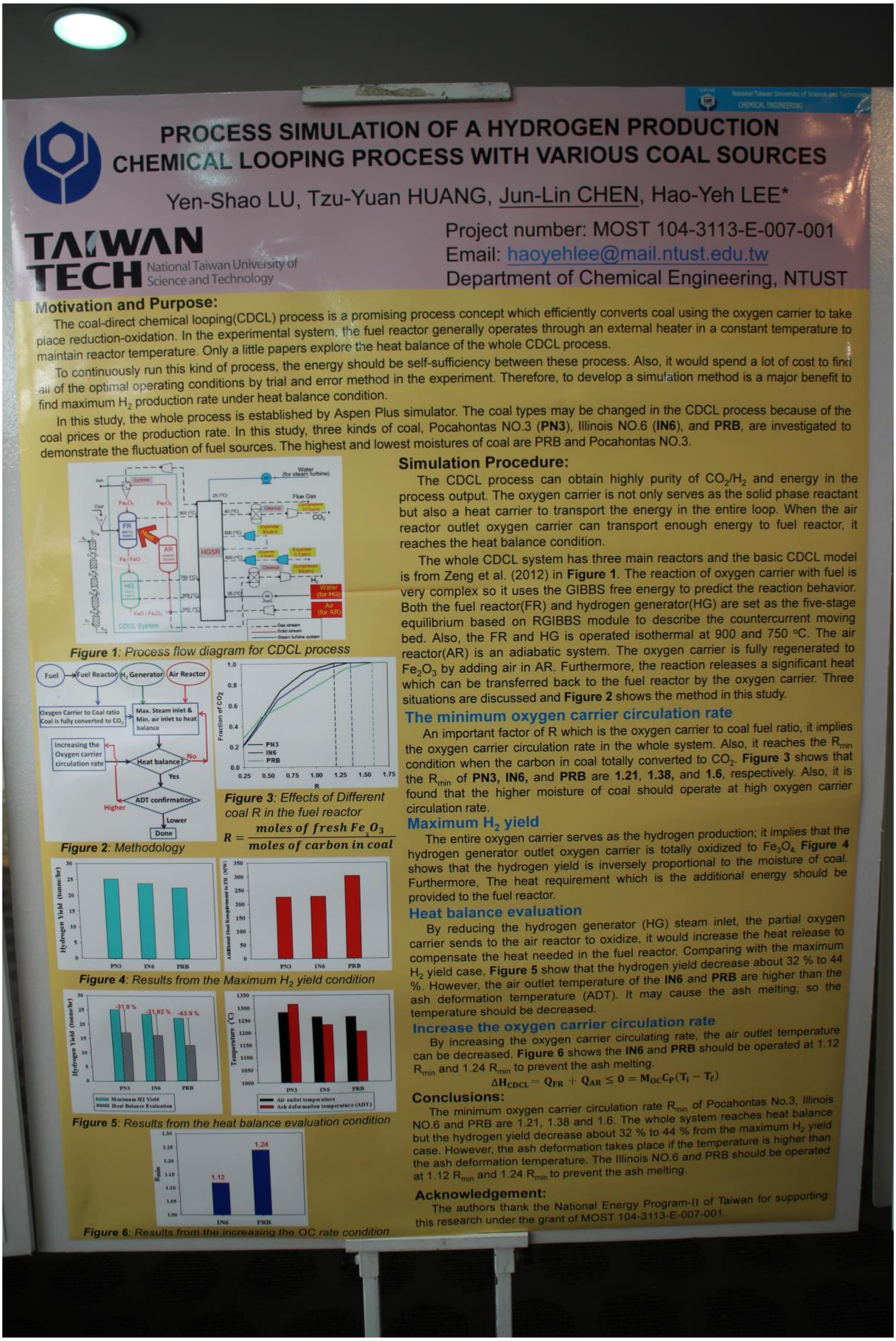

圖 85. 海報論文展示- Hydrogen Production & Gasification

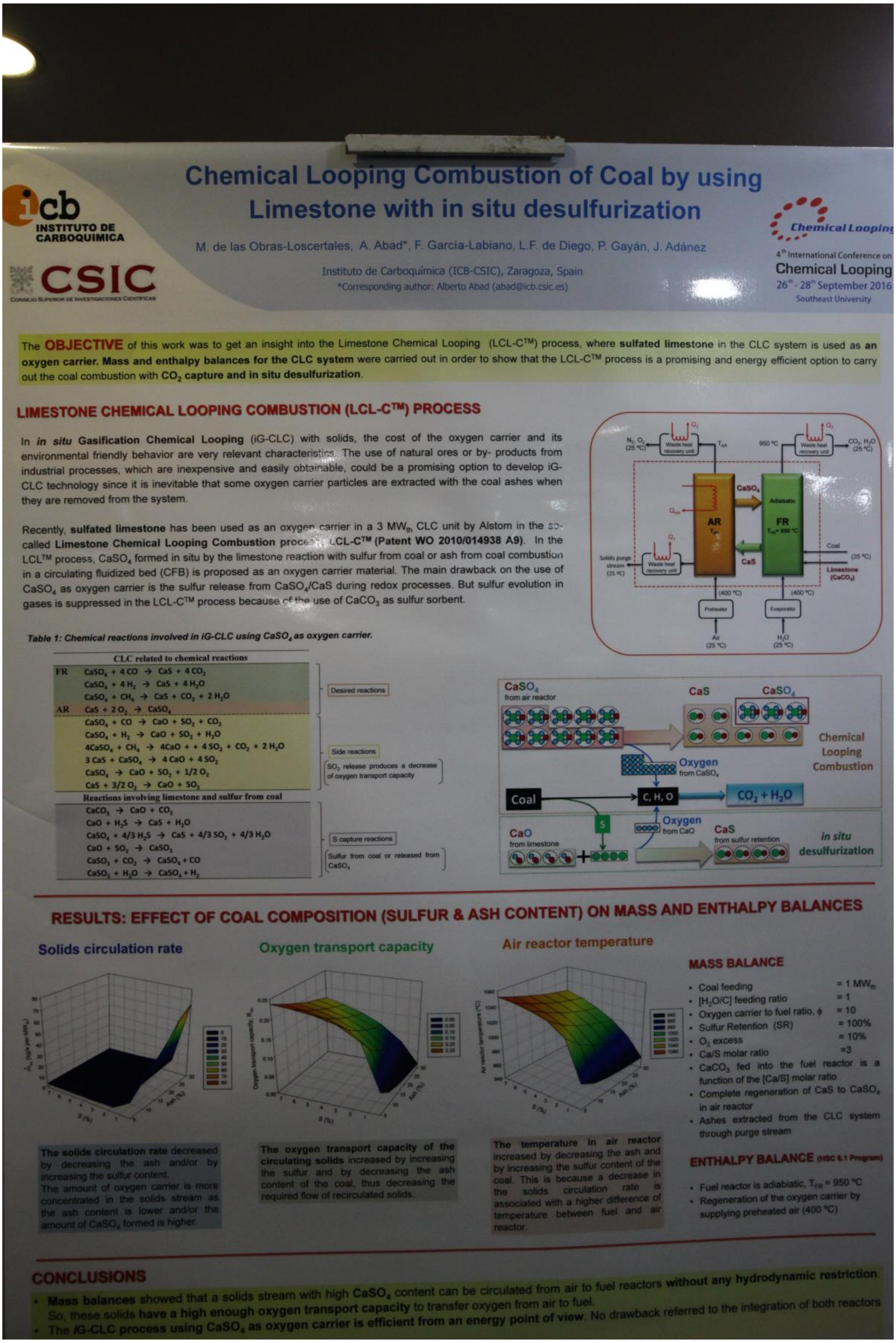

圖 86. 海報論文展示- Oxygen Carrier – A

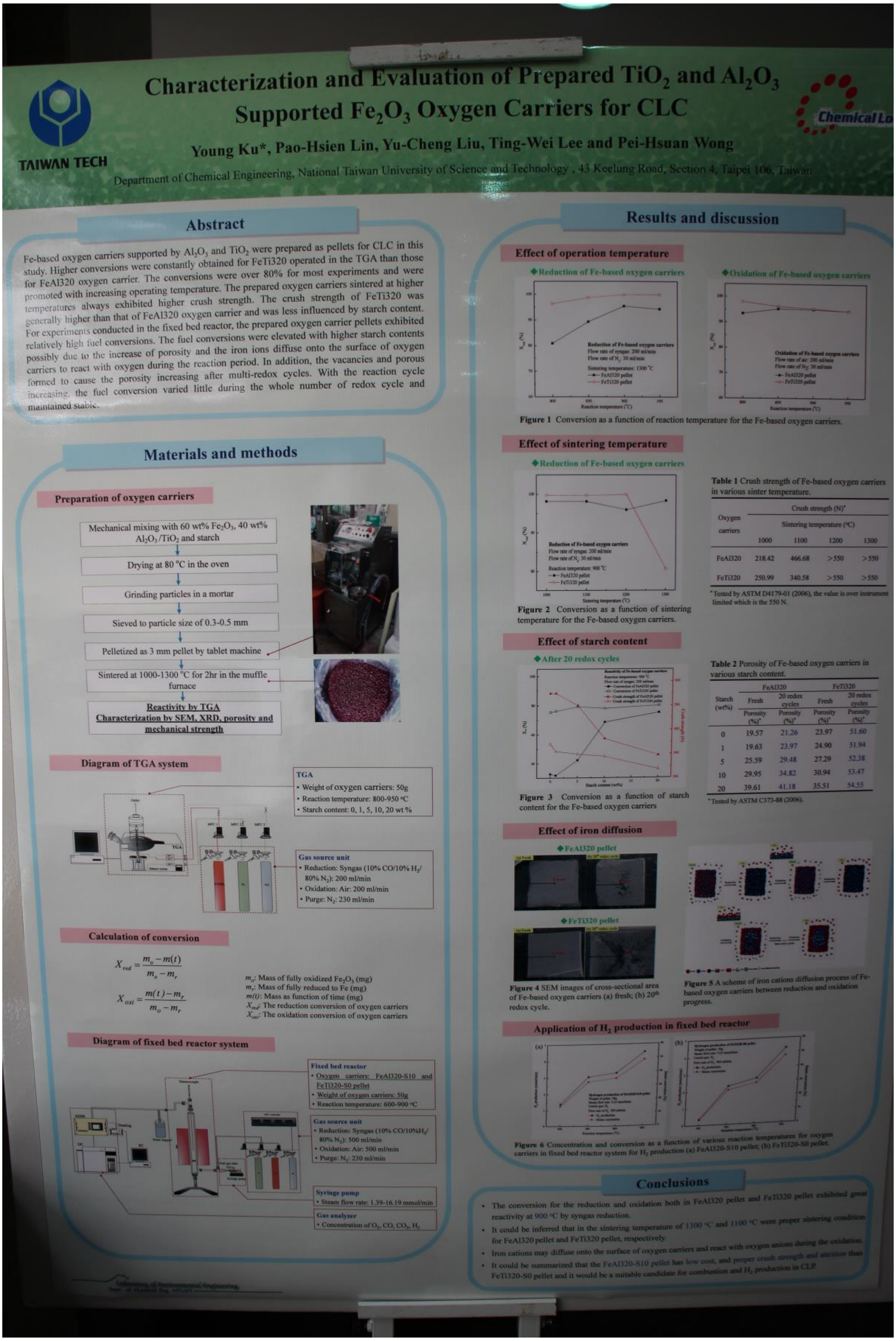

圖 87. 海報論文展示- Oxygen Carrier - B

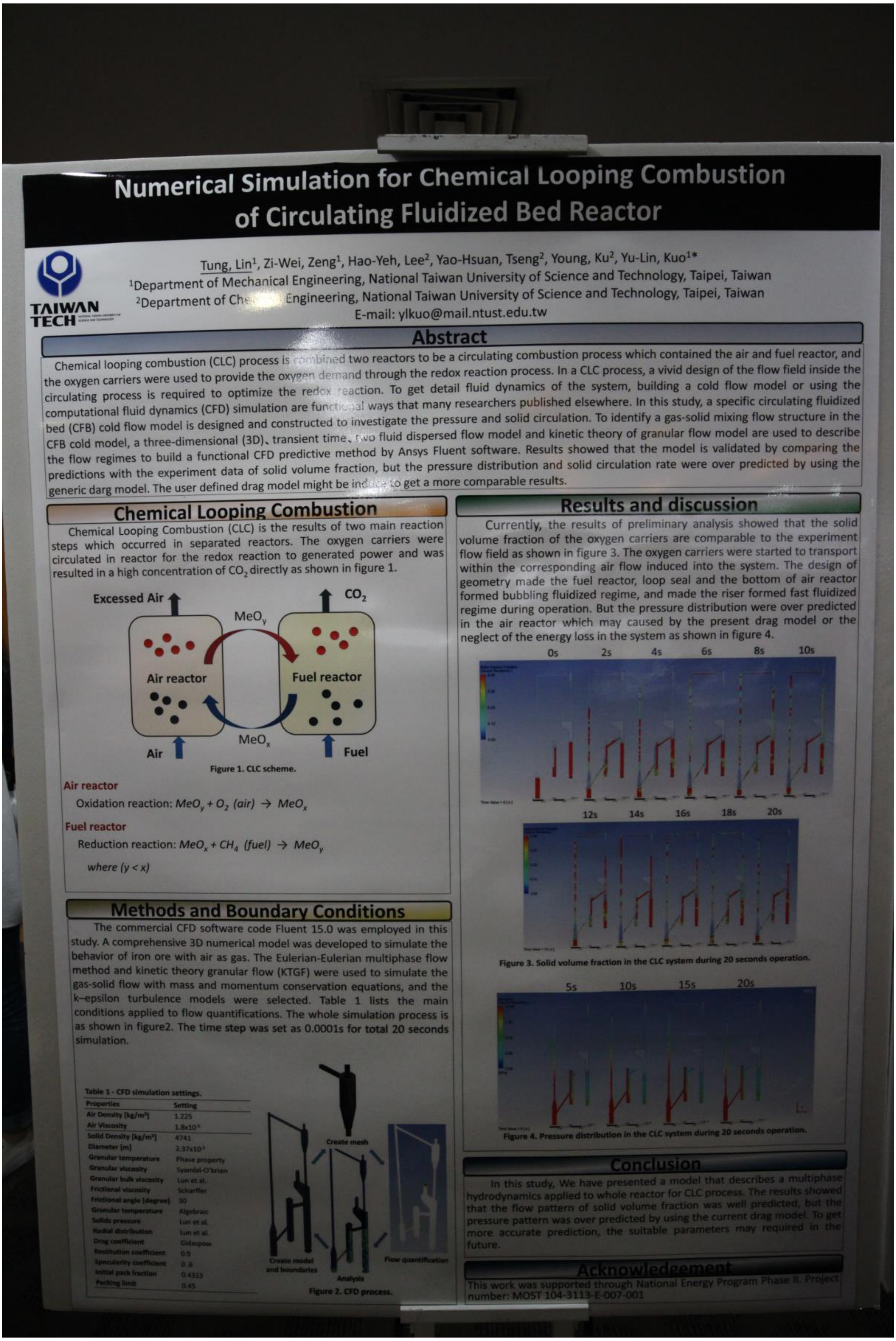

圖 88. 海報論文展示- Modelling - A

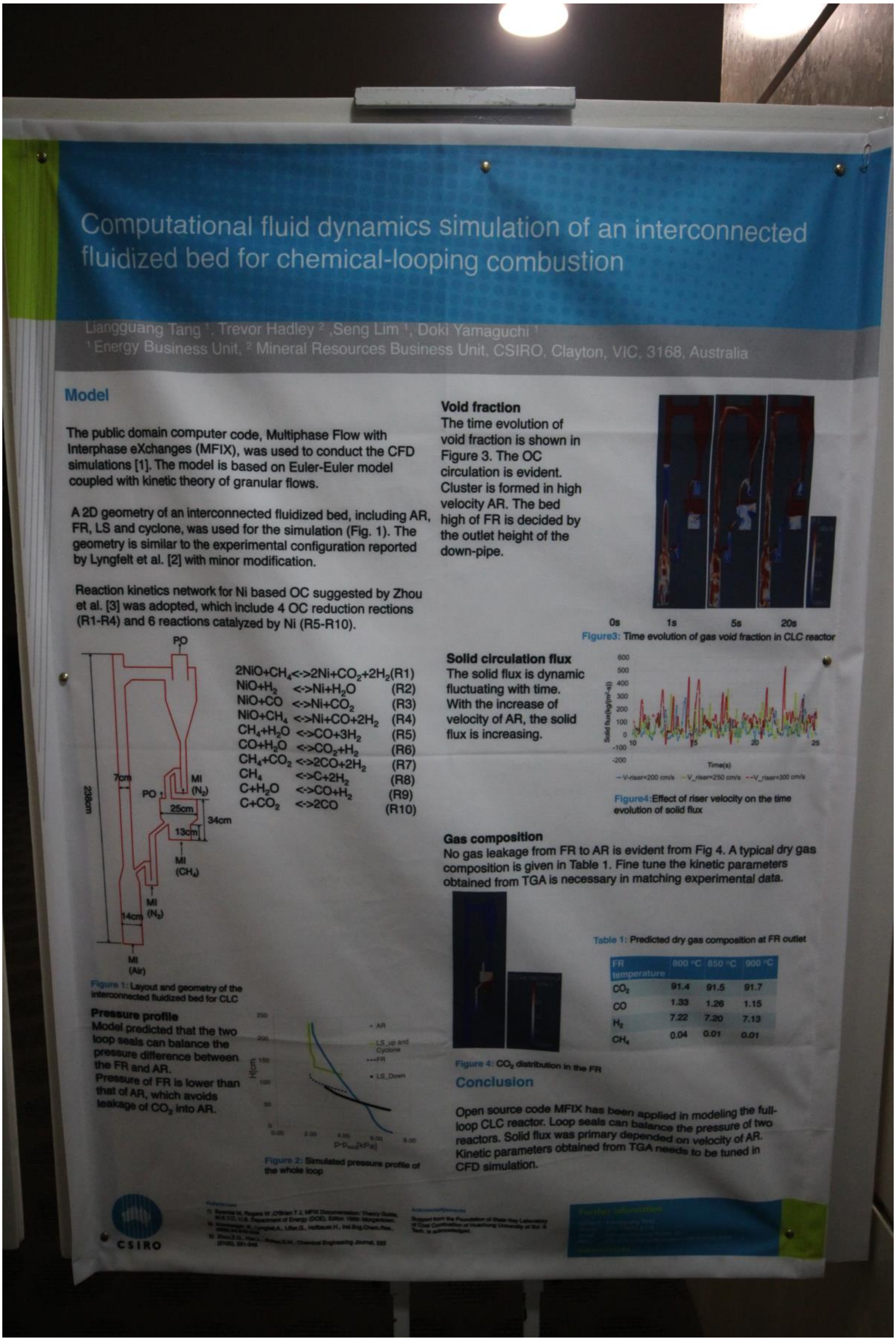

圖 89. 海報論文展示- Modelling - B

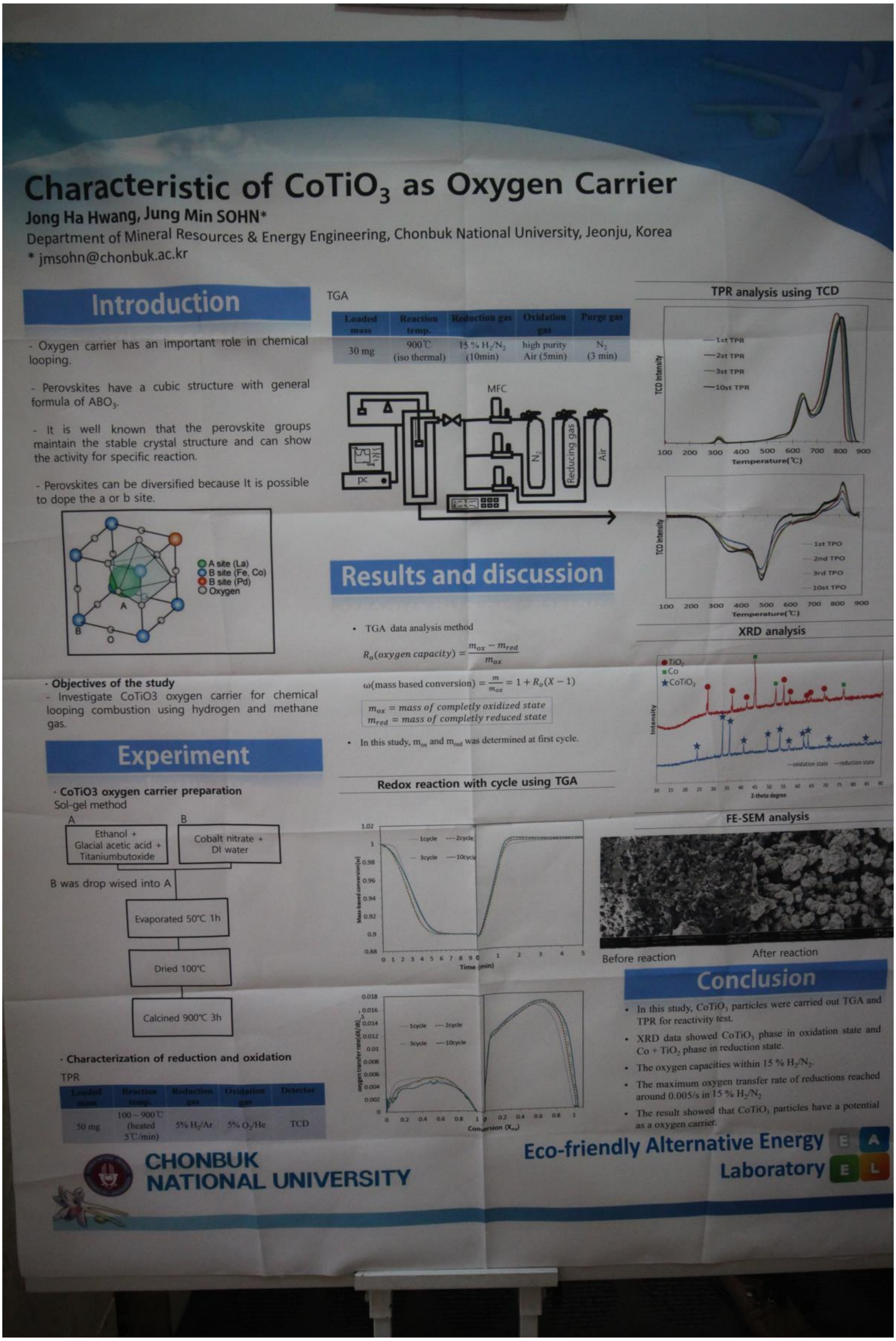

圖 90. 海報論文展示- Calcium Looping

(二) Lab Visit：參訪大陸東南大學沈來宏教授實驗室

大會於 9 月 27 日下午安排參訪大陸南京東南大學沈來宏教授實驗室，東南大學位於南京市玄武區，距離會議場館南京國際會議大酒店大約 7 公里，車程約 30 分鐘。東南大學參訪過程如圖 91~圖 99 所示。

沈來宏教授團隊已有多年氣化燃燒技術與化學迴圈技術相關研究經驗，本次參訪主要看到沈教授研究團隊的大型流體化床氣化爐以及化學迴圈冷模實驗設備，各實驗相關設備皆有實驗室負責人講解，說明該團隊對於氣化與化學迴圈實驗技術概況，根據講解人員說法：此次看到的氣化爐為該團隊於 2011 年建立之 $50kW_{th}$ 流體化床氣化爐反應器，實驗燃料轉化率可接近 100%，二氧化碳捕獲率可達 94%，該團隊也規劃在未來四年內於東南大學新校區建立更大的反應器系統。由於本所尚未建置大型化學迴圈與氣化爐結合之設備，講解過程令筆者印象深刻，未來本所若持續化學迴圈相關技術研究，或可參考大陸東南大學相關研究成果，甚至可進一步洽談相關合作之方向。

圖 91. 東南大學流體化床氣化爐-1

圖 92. 東南大學流體化床氣化爐-2

圖 93. 東南大學流體化床氣化爐-3

圖 94. 東南大學流體化床氣化爐現場講解

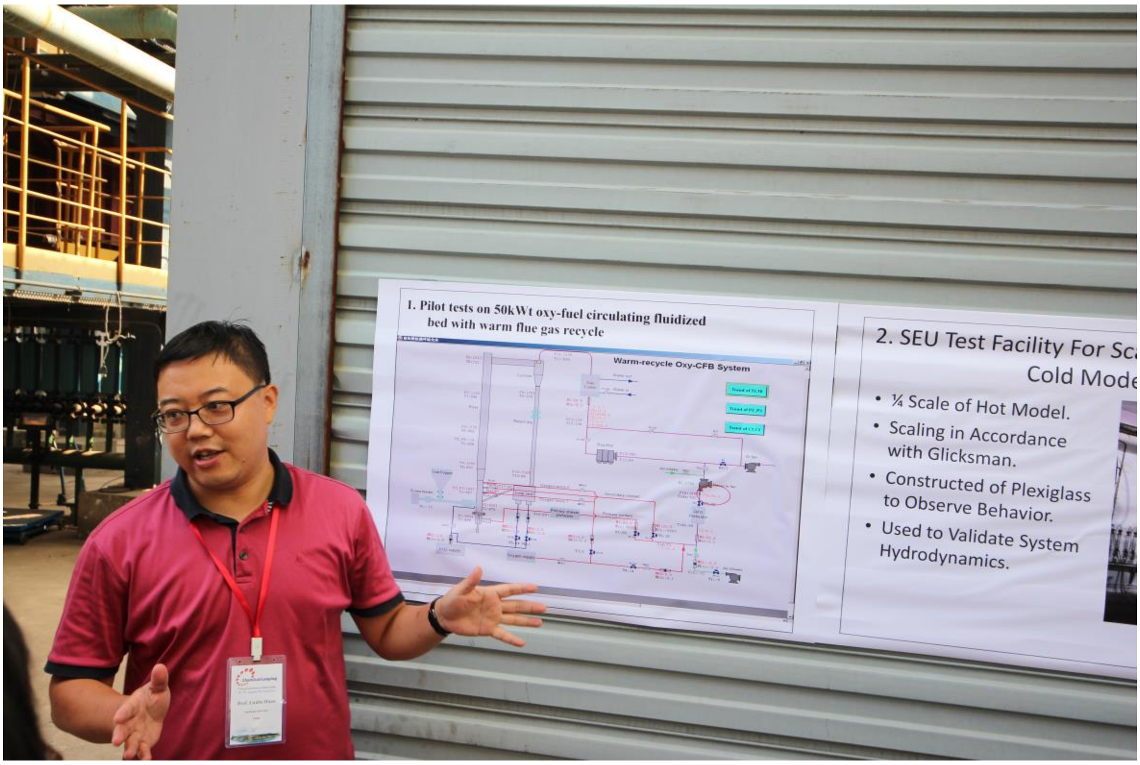

圖 95. 東南大學流體化床氣化爐概念海報解說-1

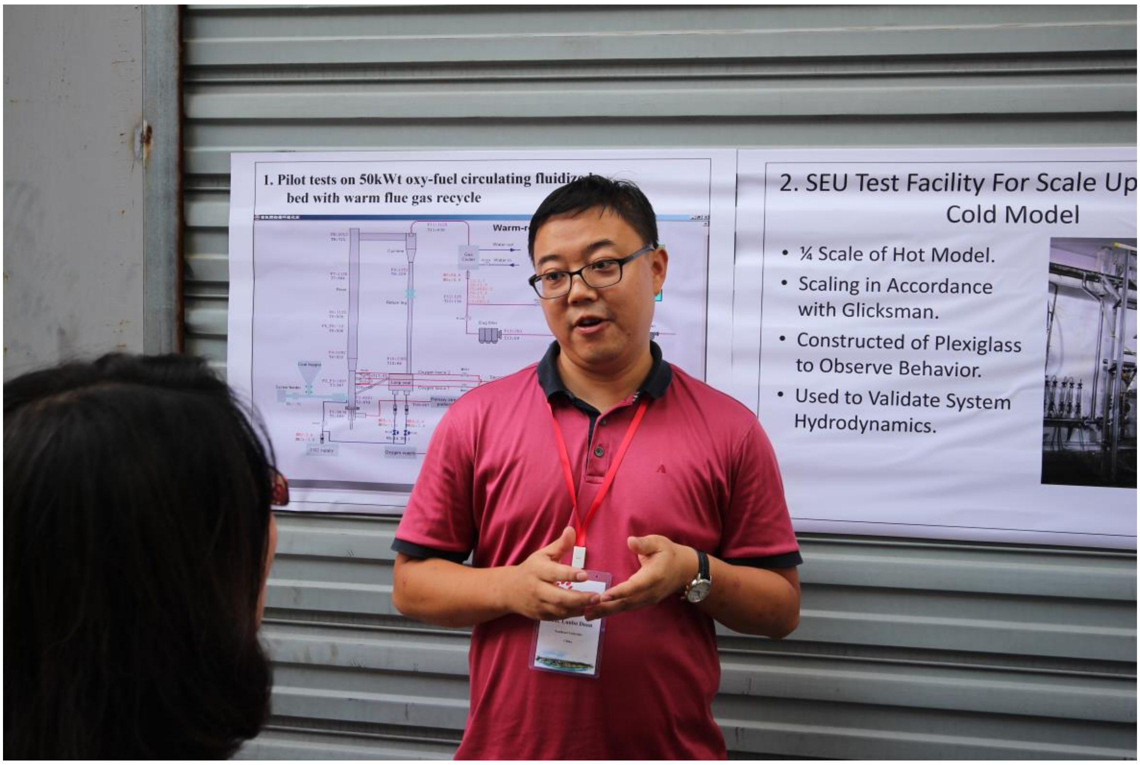

圖 96. 東南大學流體化床氣化爐概念海報解說-2

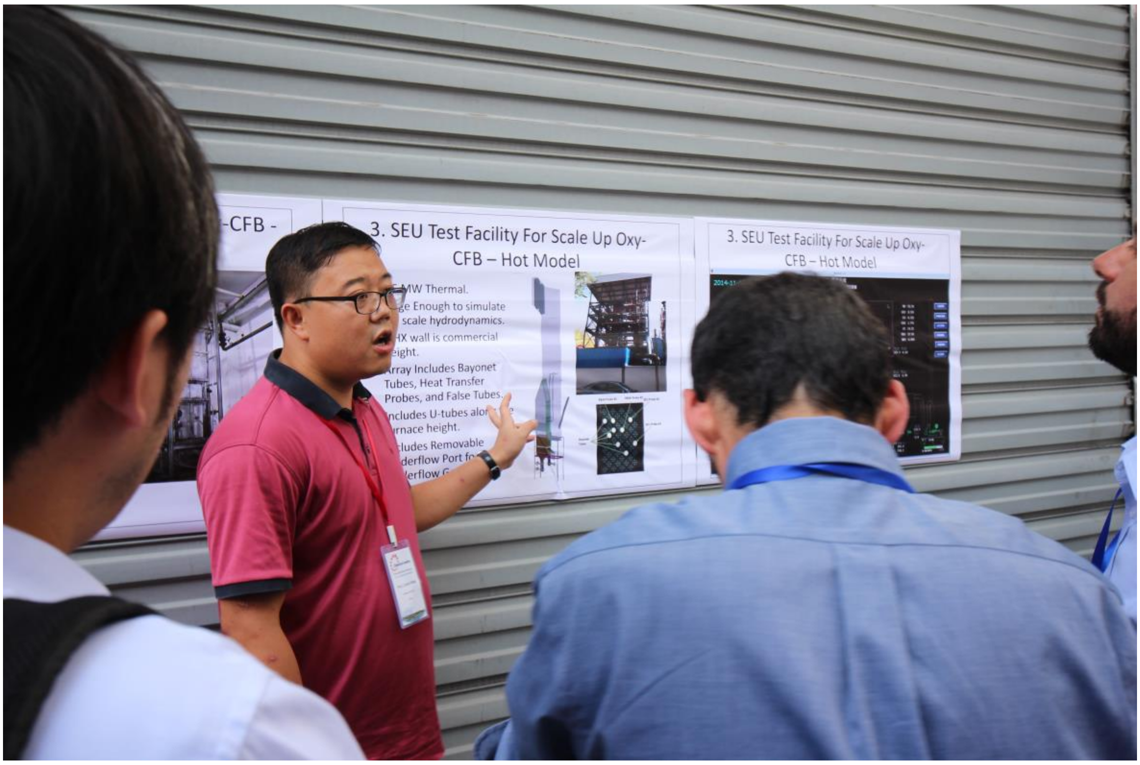

圖 97. 東南大學流體化床氣化爐概念海報解說-3


圖 98. 東南大學化學迴圈冷模系統

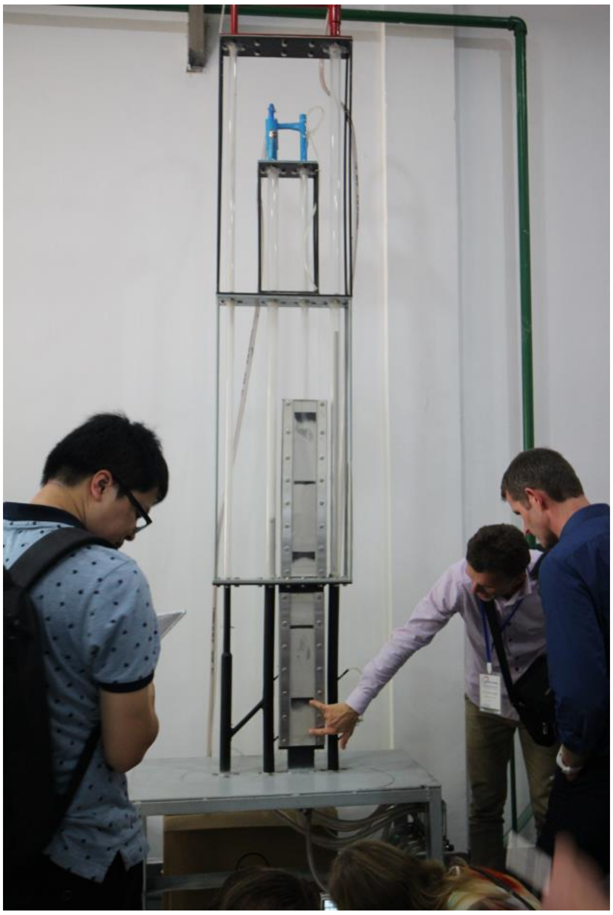
圖 99. 東南大學化學迴圈冷模系統現場講解

四、建　議　事　項

近年來，全球氣候議題持續升溫，各方研究顯示人為溫室氣體排放對於全球溫室效應有關鍵性的影響。根據國際能源總署（IEA）報告，能夠直接減少工業碳排放的最有效技術即為碳捕獲技術。化學迴圈燃燒(chemical looping combustion, CLC)是一項新穎的富氧燃燒技術，化學迴圈燃燒程序幾無 NOx、SOx 等污染物排放，具有能源效率高與二氧化碳分離之特性，成為有效降低 CO2 排放的甚佳途徑，因此，吸引國際研究機構投入開發，例如奧地利 Vienna 科技大學、瑞典 Chalmers 大學、美國 OHIO 州立大學、猶他大學等，另外，本屆化學迴圈國際研討會的主辦單位：大陸東南大學，近年也具有相當豐碩的相關研究成果。

在本屆國際研討會的各項會議中，除了可以看到研究機構與專家近期的研究現況，也看到不少廠商在朝技術的實際應用發展，諸如此類大型國際研討會所交流訊息及獲取經驗必定對國家產業發展及落實推廣計畫有一定影響力，建議如下：

- 實際參與此國際性研討會議後，看到世界各國研究單位對於化學迴圈燃燒技術的投入，本所若能充分掌握相關研究方向，將有助於國內提升能源技術之水平，除建立國內自主能源技術外，亦能與國際合作擴展能源技術之海外市場。
- 化學迴圈燃燒技術是 ICCL 大會的討論主軸,被歐盟與美國能源部評估為最具前瞻性的二氧化碳捕獲技術，亦顯示本所淨碳技術開發計畫之推動符合國際主流趨勢，值得繼續推動。
- 藉由多參與大型研討會及利用投稿方式，一方面提高核研所的曝光度，一方面更能達到宣導本所研究的效果，有助拓展與國際學者專家之關係及國際合作，並提升本所化學迴圈研究人員的視野與強化本職的學識與技能。

五、附　錄

附錄一、本次會議研究論文發表摘要

Study on Combustion-supporting Behavior of Ilmenite in Chemical Looping Combustion Process

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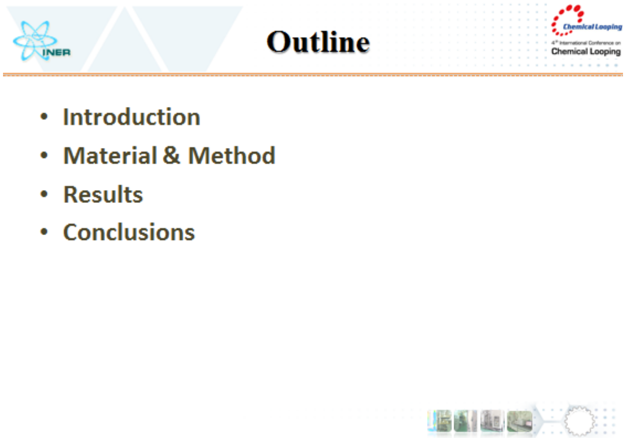
**Yau-Pin Chyou, ypchyou@iner.gov.tw*

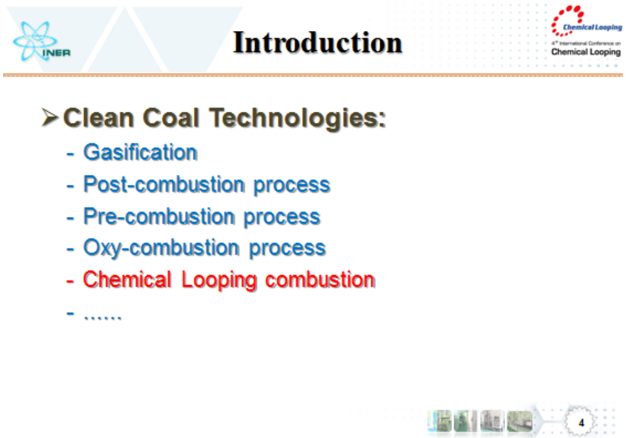
Abstract – Chemical looping combustion (CLC) which divides the combustion process into an air reactor and a fuel reactor has been regarded as an effective method to facilitate carbon dioxide sequestration. Between the two reactors, specific metal-oxide particles, called Oxygen Carrier (OC), are used for oxygen transport. Because OC is the main additional cost of the whole process, it is proposed that low-cost minerals such as ilmenite can be a candidate with great potential to work.

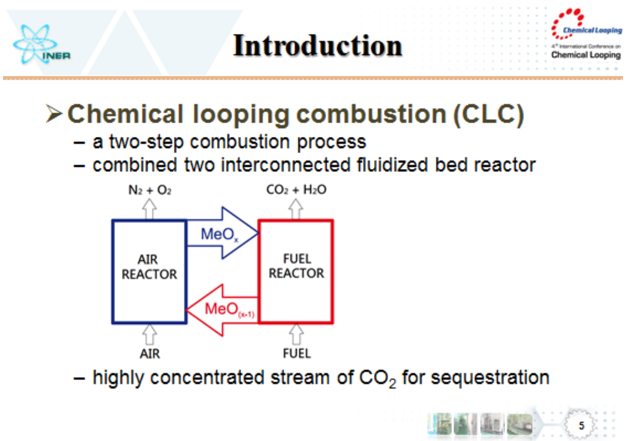
The first part of this study is to characterize the properties of the selected material. Consecutive reduction-oxidation cycles of ilmenite were carried out in a thermogravimetric analyzer (TGA) with the main gases from coal gasification, i.e., H_2, CO, and CH_4. The TGA analysis results show that the ilmenite have the best oxygen transfer capacity with hydrogen as fuel gas, followed by simulated syngas (10 vol% H_2 and 10 vol% CO) and methane. The oxygen transfer capacities of ilmenite with H_2 and syngas as fuel gas were close to the theoretical oxygen transfer capacity (12.67%). When using CH_4 as fuel gas, carbon deposition occurred on the surface of ilmeite and decreased the oxygen transfer capacity. During the 10 redox cycling tests, the reactivity of ilmenite increased with increasing the number of redox cycles under the syngas environment.

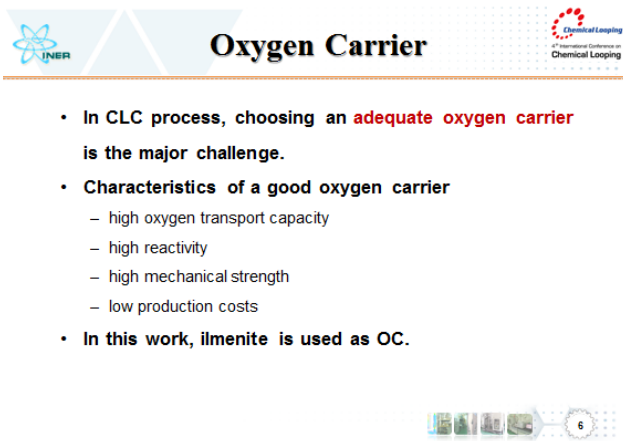
The Ilmenite was further examined in a bubbling fluidized-bed column with methane as fuel. The trend of conversion ratio of fuel shows that a low flow rate of 6 lpm (liter per minute) outperforms for most of the time the counterpart of the case with higher flow rate (10 lpm). Also, for the low flow rate with preheating to 400^{o}C, the conversion ratio does not rise significantly, or rather is very close to that for the case of 10 lpm without preheat process. Finally, under different concentration, the results show that the reduction of concentration can improve the conversion ratio of methane.

附錄二、本次會議研究論文演講簡報









Oxygen Carrier: Ilmenite

- a natural iron-containing mineral
- cyclic stability during repeated cycles of oxidation and reduction
- reactivity increase with the number of cycles
- ilmenite is a good candidate of oxygen carrier in terms of the economical and environmental issues

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Test system

- **Fluidized bed reactor:**
  - 2 inches Ø X 4 feet height
  - the flow rates of the feed gases were controlled by three mass flow meters
- **On-line gas analyzer:**
  - *Molecular analysis 6000* for CH_4, O_2, CO_2 and CO
- **TGA system:**
  - *Weight of oxygen carrier:~20mg*
  - *Reaction temperature:900 ˚C*

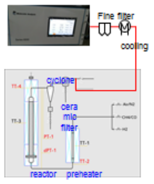

Fig. Fluidized bed reactor

Fig. TGA system

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Material

- **Oxygen carrier: ilmenite mineral**
  - **Apparent density**: ~3.9 g/cm³
  - **Composition:**
    - 42.2% Fe_2O_3、54.86%TiO_2、2.94% others
  - **Particle size:** 170 μm
  - u_{mf}: 1.75 cm/s @900°C
- **Fuel: methane**
  - 20 vol% CH_4、80 vol% N_2

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Methods Data Analysis

- **Fuel reaction**
  - the oxygen release rate from OC

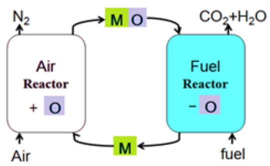
$$\dot{r}_{O_2} = \dot{n}_{in} M_{O_2} \left(y_{CO_2} + 1.5 y_{CO} \right)_{out}$$

  - the weight change of OC

$$\Delta W_{CO} = \frac{-\int \dot{r}_{O_2} dt}{W_{CO,0}}$$

  - the factional conversion of fuel

$$X_{CH_4} = \left(\frac{\dot{n}_{CO} + \dot{n}_{CO_2}}{\dot{n}_{Total\ C}} \right)_{out} = \left(\frac{y_{CO} + y_{CO_2}}{y_{CO} + y_{CO_2} + y_{CH_4}} \right)_{out}$$



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Methods Data Analysis

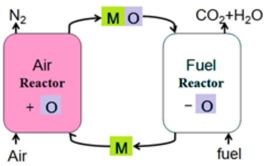
- **Air reaction**
  - the oxygen recovered rate on OC

$$\dot{r}_{O_2} = \dot{n}_{in} M_{O_2} \left(y_{O_2,in} - \frac{\dot{n}_{out}}{\dot{n}_{in}} \left(0.5 y_{CO} + y_{CO_2} + y_{O_2} \right)_{out} \right)$$

where $\frac{\dot{n}_{in}}{\dot{n}_{out}} = \frac{y_{N_2,out}}{y_{N_2,in}} = \frac{1-\left(y_{CO}+y_{CO_2}+y_{O_2}\right)_{out}}{y_{N_2,in}}$

  - the weight change of OC

$$\Delta W_{CO} = \frac{\int \dot{r}_{O_2} dt}{W_{CO,0}}$$



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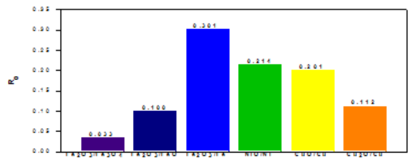
Methods Data Evaluation

- **Oxygen ratio (R_o):**

It describes the maximum oxygen of the oxygen carrier could be transferred during between the air and the reducing (fuel) reaction.

R_o(oxygen ratio)= $\frac{m_{ox} - m_{red}}{m_{ox}}$

m_{ox}: mass of metal-oxide;
m_{red}: mass of reduced metal-



Theoretical oxygen ratio, Ro, for the different pairs of metals/metal oxides

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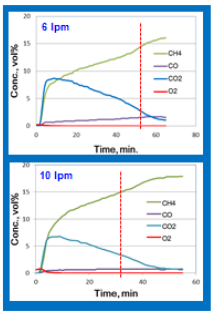
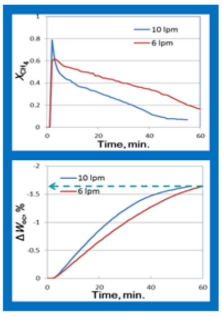
Results
Fuel Reaction: Influence of flow rate (1)



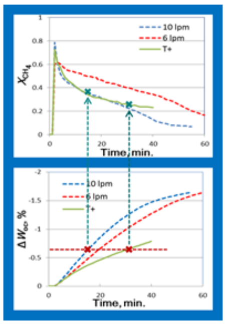
- **Test Conditions：**
  flow rate are set to 6 and 10 lpm respectively, at 900°C with 4kg ilmenite
- higher flow rate case, *the combustion* of methane is less complete
- the time for outlet concentration of remaining methane to reach 80% of inlet concentration is shorter.

Results
Fuel Reaction: Influence of flow rate (2)



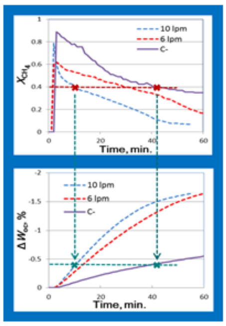
- 10 lpm case：
  - the fractional conversion is close to 80% at initial stage
  - drop dramatically later with gradually decreasing slope.
- 6 lpm case：
  - the ratio went more smoothly
  - outperform the 10 lpm most of the time
- Weight change of the OC：
  - the rate to release the oxygen is higher in 10 lpm case, but not in direct proportion
  - the final reduction weight of the carrier for the both cases is close to 1.6%

Results
Fuel Reaction: Influence of temperature



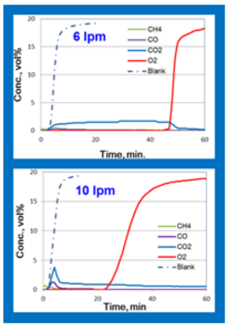
- **Test Conditions：**
  fuel is preheated to 400°C at a flow rate of 6 lpm
- Fractional conversion：
  - does not rise significantly with the increasing temperature, but close to the 10 lpm case
- Weight change of the OC：
  - the higher temperature demonstrates worse result as the counterpart at normal temperature

Results
Fuel Reaction: Influence of concentration



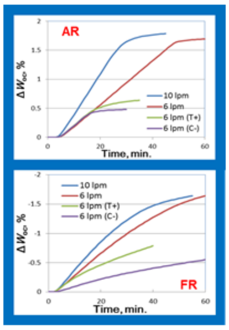
- **Test Conditions：**
  mix the fuel with nitrogen to reduce the concentration to 1/5 of the original level (@ 6 lpm, non-preheated)
- The reduction of concentration can improve the fractional conversion.
- The tendency of weight reduction of the OC is slower.

Results
Air Reaction (1)



- **Test Conditions：**
  flow rates of 6 and 10 lpm respectively, at 900°C without preheat process with 4kg ilmenite
- oxygen will be consumed completely after initiation
- A portion of oxygen is used for the oxidation of carbon residue.
- The low flow rate case required a longer time to oxidize the used OC with air.

Results
Air Reaction (2)



- Weight change of the OC：
  - the rising slope with 10 lpm is steeper than that with 6 lpm
  - For all 6 lpm cases, the weight change rates are all the same in the beginning.
  - In case that the time is sufficient, oxygen carrier for reduction can be recovered by oxidation, and usually take a shorter time.

Conclusions

1. The flow rate, temperature, and concentration are all important parameters when designing a reactor.
2. Based on the results of temperature and concentration, it is conjectured that the speed of the mass transfer is the dominating factor to control the reaction.
3. The reduction of fractional conversion of methane occurs when increasing reaction temperature, due to shorter residence time.
4. The oxidation reaction rate of ilmenite is much faster than its reduction reaction rate.

Any question?