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出國報告（出國類別：其他）

赴義大利參加 CCT2017 研討會出國報告

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摘　要

本次公差主要係赴義大利參加由 IEA 主辦之 CCT2017 會議，發表研究論文，並與同儕技術交流。CCT 大會**強調跨領域整合低碳潔淨能源研究，契合核研所淨碳計畫內容，具備未來性與競爭力**，建議**應持續參與**。生質物與煤**共氣化技術應用**、高效低排 (HELE) 電廠等重點項目**為未來潔淨能源轉換的重要平台**，有助於實現永續發展，本所**應積極持續推動**。**減碳程序技術**，包含化學迴路等，**代表**未來提供能源、環境與經濟的**整合解決方案**的可能途徑，**值得持續關注**。本所淨碳團隊於會議中**發表論文**，推動技術交流，有助於未來**國際合作及跨領域之整合**。由美國 DOE 與 IEA 等國外機構之**技術展望藍圖**，可**了解國際技術發展之趨勢**；故此次公差拓展國際人脈，為掌握低碳能源發展最新研發現況之重要場合。

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摘　要

一、目　的

為推動國家減碳政策，政府積極建構低碳能源發展藍圖；同時，透過國際共同研發，引進淨煤技術及發展碳捕捉與封存，降低國內能源系統的碳排放。核能研究所（以下稱本所）目前亦積極進行能源國家型科技計畫領域之「淨碳技術發展」研究計畫，冀望從永續發展觀點推動自主性潔淨能源技術之建立。有鑑於為有效掌握國際潔淨能源議題，本次公差主要係赴義大利參加 The Eighth International Conference on Clean Coal Technologies (CCT2017)，發表會議論文，並與國際同儕進行技術交流。

CCT 是由國際能源總署 (International Energy Agency, IEA) 主辦，兩年一度之淨煤技術領域國際盛會，第八屆大會於 2017 年 5 月 8 日至 12 日於義大利卡哥利亞 (Cagliari) 舉行；會議主題涵蓋高效低排 (HELE) 電廠、氣化、燃燒、生質物、碳管理、污染與控制、煤料處理與級配、國際趨勢等，為掌握低碳能源發展最新研發現況之重要場合。依據大會資料，參與今年 CCT2017 大會者共計有來自全世界 30 餘國在低碳潔淨能源、淨煤技術等重點研究領域之學者、專家超過 200 人；其中不乏來自亞洲，包含大陸、日本、韓國、印度、馬來西亞、台灣等地，顯見會議之國際參與性。

本所目前正積極進行淨碳技術研發工作，並執行本所施政計畫「碳基能源永續潔淨利用技術發展」分支計畫。本年度本所淨碳技術團隊在 CCT2017 大會發表一篇計畫成果論文 “**On the evaluation of ilmenite as an oxygen carrier for natural/synthesis gases in chemical-looping combustion**”。故派員參與會議，發表論文，並與國際學者專家討論、分享核研所近年來在淨碳技術的研究成果；藉以掌握國際間氣化、氣體淨化、二氧化碳管理以及潔淨低碳技術之發展與趨勢，拓展本所與國際學者專家之交流以及合作可行性。

二、過　程

（一）公差行程

本次公差自民國 106 年 5 月 7 日至 12 日止，共計 6 天 (圖 II-0)。

05 月 07 日(星期日)　自台灣桃園 (TPE) 國際機場出發，經曼谷 (BKK) 抵達倫敦希斯洛 (LHR) 國際機場

05 月 08 日(星期一)　自倫敦 蓋威克機場 **(LGW)** 出發，抵達卡哥利亞 **(CAG)** 卡利亞里機場，

05 月 08 日(星期一) ～ 05 月 11 日(星期四)　停留卡哥利亞
辦理會議註冊，出席第 8 屆 CCT 國際會議 (International Conference on Clean Coal Technologies)，發表論文

05 月 11 日(星期四)　卡哥利亞 **(CAG)** 搭機，抵達倫敦蓋威克 **(LGW)** 機場；搭大巴轉往倫敦希斯洛 (LHR) 國際機場，轉機返回台灣

05 月 12 日(星期五)　經曼谷 (BKK) 短暫停留，返抵台北

（二）第 8 屆淨煤技術國際研討會議 (The 8th International Conference on Clean Coal Technologies, CCT2017)

CCT 是由國際能源總署 (International Energy Agency, IEA) 主辦，為兩年一度之淨煤技術領域國際盛會，第八屆大會於 2017 年 5 月 08 日至 12 日於義大利卡哥利亞 (Cagliari) 舉行 (圖 II-1 ~ II-3)；會議主題涵蓋氣化、燃燒、碳捕捉與封存、污染與控制、煤料處理與級配、國際趨勢等，另亦概括生質能、sCO_2 循環、電廠運轉實務、社環困境議題。今年 CCT2017 大會者共計有來自全世界 30 餘國在低碳潔淨能源、淨煤技術等重點研究領域之學者、專家超過 200 人參與，其中超過三分之一來自產業界；另外，不少來自亞洲，包含大陸、日本、韓國、印度、馬來西亞、台灣等地，顯見會議之國際參與特性。

CCT2017 之議程如表 II-1 所示，會議活動自 5 月 8 日（星期一）開始，並於當天晚上舉行歡迎茶會。在星期二早上舉行開幕典禮，隨後進行全體會議 (Plenary Session) 之開幕致詞與兩場 Keynote 演講。另外，在星期三早上安排兩場 Keynote 演講；而在星

期四下午則為閉幕典禮，並安排兩場 Plenary 演講。其他時段則為口頭論文發表場次，分為三個時段，同時各有三個平行場次之口頭論文發表。壁報論文則自星期二起開始展示，從早上 09:00 開始到傍晚 - 17:00。

大會口頭論文發表場次共計 30 場，個別的領域列舉如下：

1. high efficiency, low emissions plant
2. developments in carbon capture
3. SOx, NOx, mercury, and particulate controls
4. low rank coal utilisation
5. policy and financing
6. social acceptance
7. gasification, IGCC and IGFC
8. underground coal gasification and coal-bed methane
9. high-temperature materials
10. advanced power cycles such as supercritical CO2 turbines
11. coal to chemicals
12. efficiency upgrading technologies
13. fluidised bed combustion
14. biomass cofiring and co-gasification
15. coal characterisation and blending

筆者在歐洲的公差行程於 5 月 11 日告一段落，當日（星期四）即自卡哥利亞 **(CAG)** 搭機，抵達倫敦蓋威克 **(LGW)** 機場；再前往倫敦希斯洛 (LHR) 國際機場，轉機返回台灣。回程途經曼谷 (BKK) 短暫停留，最後於 5 月 12 日（星期五）深夜返抵台北，結束本次公差行程。

§II　有關 2017 EU 公差行程之圖表

表 II-1：CCT2017 之議程

The 8th International Conference on Clean Coal Technologies (CCT2017) Programme

IEA CLEAN COAL CENTRE

The eighth international conference on

Clean Coal Technologies

Cagliari, Italy
8–12 May 2017

Monday, 8th May 2017　　**Registration** & Welcome reception

Tuesday, 9th May 2017

	Hall T1	Hall T3	Hall T4
09:00 - 09:30	**Welcome**		
09:30 - 10:30	**Keynote session I**		
10:30 - 10:50	**Coffee break**		
10:50 - 12:30	**High-efficiency plant**	**Biomass I**	**Chemical looping I**
12:30 - 13:30	**Lunch**		
13:30 - 15:10	**Power plant operation**	**Biomass and industrial CCS**	**Combustion studies**
15:10 - 15:40	**Coffee break**		
15:40 - 17:20	**NOx controls**	**Biomass II**	**Gasification**
17:20 - 18:30	**Poster session**		

Wednesday, 10th May 2017

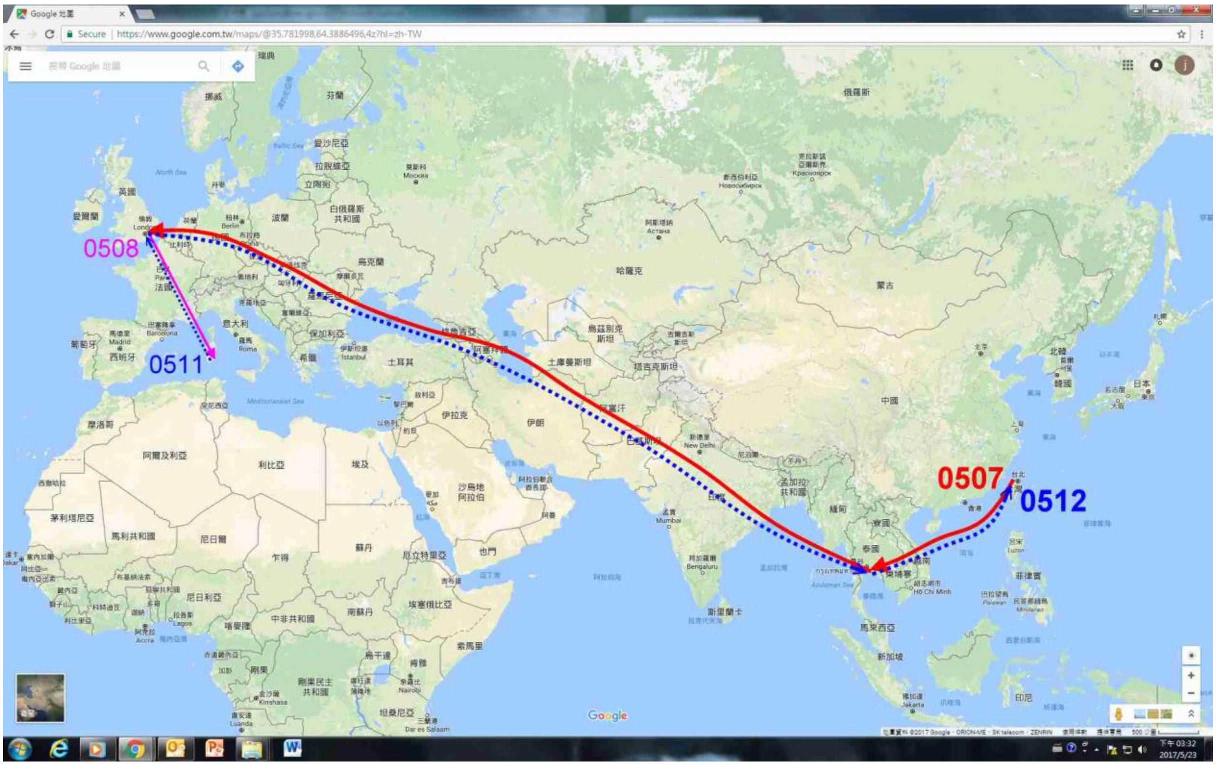
	Hall T1	Hall T3	Hall T4
08:30 - 09:20	**Keynote session II**		
09:25 - 10:45	**IGCC**	**Fluidised bed combustion**	**Particulate controls**
10:45 - 11:20	**Coffee break**		
11:20 - 13:00	**Coal in a low carbon world**	**Mercury controls**	**Chemical looping II**
13:00 - 14:00	**Lunch**		
14:00 - 15:20	**Supercritical CO2 power cycles**	**CCS: Sorbents and membranes**	**Social and environmental issues**
15:20 - 15:40	**Coffee break**		
15:40 - 17:30	**Panel session: The energy trilemma**		

Thursday, 11th May 2017

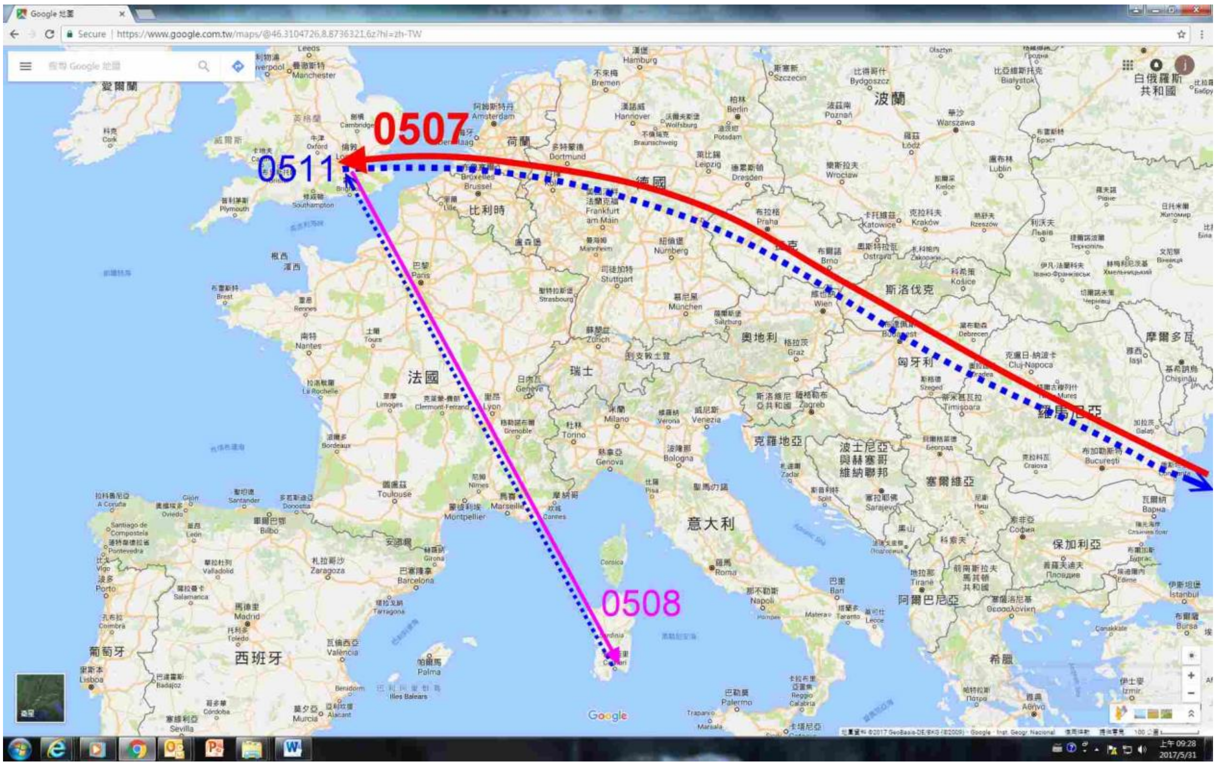
	Hall T1	Hall T3	Hall T4
09:00 - 10:40	**Carbon capture and storage**	**Materials and corrosion**	**Lignite and low rank coal**
10:40 - 11:10	**Coffee break**		
11:10 - 12:50	**CCS: amines** **CCS panel session**	**Pollutant controls**	**Underground coal gasification and coal bed methane**
12:50 - 14:00	**Lunch**		
14:00 - 15:20	**Coal conversion**	**Oxyfuel combustion**	**Coal beneficiation**
15:20 - 15:40	**Coffee break**		
15:40 - 17:00	**Closing plenary session**		

Friday, 12th May 2017

09:00 - 17:00 Technical tour



A. 亞、歐跨洲全程（TPE ↔ LHR, 2017. 05. 07. ~ 12.）



B. 歐陸轉機 **(LGW ↔ CAG)**

圖 II-0： 公差行程示意圖

圖 II-1： CCT 2017 大會網頁的看板景象之一

圖 II-2： CCT 2017 大會網頁的看板景象之二

圖 II-3：　CCT 2017 會場地點景象：T 旅館

三、心　得

本次公差主要係出席 The 8th International Conference on Clean Coal Technologies CCT2017，並發表會議論文，就淨煤領域之氣化、化學迴路技術與國際合作可能性進行交流。本報告將依序分別選擇重點摘要於下文中。

（一）CCT 2017 大會

第 8 屆 CCT 於 2017 年 5 月 8 - 12 日在義大利卡哥利亞 (Cagliari) 舉行，由 IEA 淨煤中心 (Clean Coal Centre) 主辦，並聯合當地學術機構 SOTACARBO (Sustainable Energy Research Centre) 協助舉辦；另接受 SANDVIK, Kawasaki, AkzoNobel, VGB/POWERTECH 等機構之贊助。這個聯合活動的目的是提供工程師、科學家、研究人員、技術人員、學生和其他人的平台，展示他們的最新成果、交換想法、建立新的聯繫、建立新的合作關係等。大會議題涵蓋淨煤領域的技術和工程實務，包括目前的發展趨勢和未來的規畫與需求。

CCT2017 會議排程自 5 月 8 日（星期一）揭開序幕，多數與會者於當天抵達，晚上並進行歡迎茶會。開幕典禮在 5 月 9 日（星期二）早上舉行，本屆大會典禮流程包括開幕、貴賓致詞等 (圖 III-1 ~ III-2)，隨後進行開幕 Keynote 演講。CCT2017 的議程分為全體會議 (Plenary Session)、論文口頭發表、及壁報論文展示三部分，每天上、下午各有一段中場休息以為區隔 (圖 III-3 ~ III-4)。相關議程將分章節依序描述於本報告中。

1. Plenary Sessions

大會共安排四場 Keynote 演講，包括開幕典禮安排兩場，在星期三早上的全體會議 (Plenary Session) 中，另安排兩場 Keynote 演講；各應邀講員之資料與講題列舉如下：

Plenary Keynote Presentations

K-I.1: *Clean coal in a post-COP21 era*

Jean-Francois Gagné - Head of Energy Technology Policy, IEA
International Energy Agency
France

K-I.2: ***Smarter. Cleaner. Steam Power***
Ashok Ganesan - General Manager of Steam Plant Solutions,
GE Power Services
Switzerland

K-II.1: ***Thermal power sector: Challenges and opportunities for the Indian power sector***
Partha Mazumder - General Manager
NTPC Ltd.
India

K-II.2: ***Opportunities, challenges, and priorities for clean fossil energy***
Mr. Scott Smouse
National Energy Technology Laboratory
USA

本報告將選擇較屬策略性、概觀性之演講依序分別摘要重點於下文中。

(1) ***Clean coal in a post-COP21 era*** (圖 III.1.1-1 ~ III.1.1-2；圖 III.1.1-3 ~ III.1.1-24)

五月九日早上開幕典禮大會演講 (Plenary lecture) 的首位演講者 Mr. Jean-Francois Gagné 來自法國，為 IEA 機構的 Head of Energy Technology Policy (圖 III.1.1-1)，其講題為"***Clean coal in a post-COP21 era***" (圖 III.1.1-2)。該演講之重點資料摘要與主要涵蓋下列議題如圖 III.1.1-3 ~ III.1.1-24 所示。

該演講之內容主要係闡述**後 *COP21* 年代的淨煤議題前景**，包含相關報告如 Renewable Energy 2016、World Energy Outlook 2016、Energy Technology Perspectives 2016、Tacking Clean Energy Progress 2016、Tacking Clean Energy Progress 2017 等，其內容摘要如下：

- Key points of orientation
  - The energy sector is key to sustainable economic growth
  - The global energy transition gained momentum in 2016
  - There is no single story about the future of global energy
- 風能與光伏價格持續下降
- 低碳能源佔比逐年提升，煤面臨艱難的定位
- 近三年全球 CO_2 排放成長趨緩

– 能源創新可擴張當前動能氣勢：

  - 2DS 的挑戰非常嚴峻，需要各類技術組合。
  - 重新佈局電力供應組合。
  - 燃煤未來趨勢：提升效率、再佈署 CCS、降低成本。
  - 增加生質物與煤**共燒應用**，以抵銷 CO_2 排放。
  - 重整輸碳與儲碳之基礎架構、改變電廠角色、需要以彈性換取效率。

– **國際合作為加速創新之關鍵！**

(2) ***Smarter. Cleaner. Steam Power*** (圖 III.1.1-25 ~ III.1.1-26；圖 III.1.1-27 ~ III.1.1-36)

五月九日早上的次場演講者 Mr. Ashok Ganesan 來自瑞士，為 GE Power Services 的 General Manager of Steam Plant Solutions (圖 III.1.1-25)，其演講議題為 "***Smarter. Cleaner. Steam Power***" (圖 III.1.1-26)。該演講之重點資料摘要與主要涵蓋下列議題如圖 III.1.1-27 ~ III.1.1-36 所示。

該演講之內容主要係闡述**更智慧、潔淨的蒸汽發電**，其內容摘要如下：

– 全球電力資源分配嚴重不均！

– 全球電力產業之轉型與機會

  - 燃煤市場未來需求仍可觀，主要來自印度、中國、亞洲、……
  - GE 在蒸汽發電產業之領導地位
  - 客戶需求？
  - GE's Steam Center of Excellence

– The winning equation: **leading Efficiency, lower Emissions, better Economics!**

(3) ***Thermal power sector: Challenges and opportunities for the Indian power sector*** (圖 III.1.1-37, III.1.1-38；圖 III.1.1-39 ~ III.1.1-60)

五月十日早上的次場演講者 Mr. Partha Mazumder 來自印度，為 *NTPC Ltd.*的 General Manager (圖 III.1.1-37)，其演講議題為 "***Thermal power sector: Challenges and opportunities for the Indian power sector***" (圖 III.1.1-38)。該演講之重點資料摘要與主要涵蓋下列議題如圖 III.1.1-39 ~ III.1.1-60 所示。

該演講之內容主要係闡述**印度火力發電的挑戰與機會**，其內容摘要如下：

- 印度電力部門的概觀 — 處於一條成長路徑
- 印度電力轉移至再生能源之驅動力
- 近期印度政府之主要倡議 (initiatives)
- 邁向將來之路徑

(4) ***Opportunities, challenges, and priorities for clean fossil energy*** (圖 III.1.1-61, III.1.1-62; III.1.1-63 ~ III.1.1-84)

五月十日早上的次場演講者 Mr. Scott Smouse 現任 USA Department of Energy, Office of Clean Coal & Carbon Management 之 Senior Advisor (圖 III.1.1-61)，其演講議題為 "***Opportunities, challenges, and priorities for clean fossil energy***" (圖 III.1.1-62)。該演講之內容其重點資料摘要如圖 III.1.1-63 ~ III.1.1-84 所示。

該演講之內容主要係闡述**美國潔淨化石能源的機會、挑戰、與優先度**，其內容摘要如下：

- 美國化石能源產業之概觀
- 天然氣價格為影響預測未來電力與燃料組合之關鍵因素
- 美國能源相關之 CO_2 排放已較 2005 降低 12%
- 美國 DOE 的化石能源重點領域：
    - **Advanced energy systems**
    - Large-scale carbon management projects
    - CCS
    - Tech. transfer
    - Strategic petroleum reserves
    - Oil and gas R&D
- Transformative R&D: sCO_2
- 開發先進材料
- 水資源管理
- 系統整合

2. Technical Paper Sessions

CCT 口頭論文發表議程每天各分為三個時段，同時各有三個平行場次之口頭論文發表。各場次排定四至五場專題演講 (Lecture)，每天上、中午各有一段中場休息

以為區隔。技術議題涵蓋前述十五大領域，其論文篇數計逾百篇。基於篇幅考量，本報告中摘錄了數場相關的代表性論文加以陳述之。

- ✓ Gasification;
- ✓ Chemical Looping;
- ✓ IGCC;
- ✓ Supercritical CO_2 power cycles.

(1) INER 在 CCT2017 大會中口頭發表之論文

在此次 CCT 大會中，本所淨碳團隊係以口頭宣讀方式發表一篇論文“**On the evaluation of ilmenite as an oxygen carrier for natural/synthesis gases in chemical-looping combustion**”，被安排在 5 月 10 日（星期三）的場次，屬於化學迴路領域，主題聚焦於鈦鐵礦在流體化床內之燃燒反應研究，為先進能源系統之重點。演講內容摘要如圖 III.1.2-1 ~ III.1.2-12 所示。筆者透過簡報發表本所之研發成果，可讓在場與會者獲得深刻印象並提供不錯之回應交流；未來或可藉以推動國際合作項目，在國際合作及跨領域之整合扮演關鍵性支持角色。該篇論文亦獲大會推薦，擴充內容後轉投稿國際知名 SCI 期刊。

論文摘要亦陳述如下以供參考：

Climate change is a real global problem and is caused by multiple factors, one of which is greenhouse gas (CO_2 predominant) emissions from the combustion of fossil fuels. Chemical looping combustion (CLC) is a combustion technique where the CO_2 produced is inherently separated from the rest of the flue gases with a considerably low energy penalty. For this reason, CLC has emerged as one of the attractive options to capture CO_2 from fossil fuel combustion. The combustion process via CLC is divided into an air reactor and a fuel reactor. Between the two reactors, specific metal-oxide particles, called Oxygen Carrier (OC), are used for oxygen transport. Because OC is the main additional operating cost of the whole process, it is proposed that low-cost minerals such as ilmenite can be a candidate with great potential to work.

In this study, ilmenite was tested with methane in a bubbling fluidized-bed column as the reference case for gaseous 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 a 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. Under different concentration of methane, the results show that the reduction of concentration can improve the conversion ratio of methane.

Furthermore, a simulated syngas as fuel was tested with the ilmenite oxygen carrier by similar method for parametric studies. Comparing the trend of conversion ratio of fuel in different flow rate, the low flow rate outperforms the case with a higher flow rate. Simultaneously, the conversion ratio of syngas is also better than the result of methane. Finally, a 10-redox-cycle test in a bubbling fluidized-bed reactor was examined that shows the natural ilmenite exhibits high reactivity for the syngas.

(2) 此次 CCT 大會中發表之相關的代表性論文

A. **Chemical Looping Sessions:** (圖 III.1.1-13 ~ III.1.1-36)

(A) 論文 (D1-T4-S1-P2)：本論文由 Instituto de Carboquimica (CSIC), Spain 的研究人員發表，演講主題為 **“Performance of Mn-Fe-based Oxygen Carriers in Coal Combustion by iG-CLC and CLaOU processes”**。演講內容摘要如圖 III.1.1-13 ~ III.1.1-18 所示。

近年來，淨煤技術(Clean coal technologies) 的需求益形增加，尤其是在降低溫室氣體排放上限。因此，燃燒煤的二氧化碳捕獲和儲存是穩定大氣中的二氧化碳濃度一個中期的解決方案。化學迴路燃燒（CLC）技術降低在煤燃燒過程中的捕獲固有 CO_2 產出的捕集成本。所需煤氧化的氧氣是由一種金屬氧化物作為載氧體所提供。這個金屬氧化物在兩個相互連接的流體化床反應器之間循環。在燃料反應器中，煤被氧化成 CO_2 和 H_2O，而載氧體被還原。當水被冷凝時，在產品流中的 CO_2 可以很容易地被捕捉。然後，將還原的載氧體輸送到空氣反應器中，並在空氣中再氧化。

CLC 技術的是原位氣化（in-situ gasification, IG-CLC），並隨後燃燒產物氣體。在此方案中，煤和載氧體是在燃料反應器中物理性混合，而 H_2O 和/或 CO_2 被用作流體化氣和氣化劑。現今最常用的載氧體是鐵礦砂(Fe-ores)或工業廢棄產物（例如 redmud）。然而，便宜金屬的合成材料由於反應性較佳被建議為替代載體。如雙金屬錳鐵顆粒之類的替代材料，由於其具有從結構釋放一小部分氣態氧的氧解偶聯 (oxygen uncoupling) 行為，被研究作為 CLC 技術中載氧體的效能。氧解偶聯輔助的化學迴路（Chemical Looping assisted by Oxygen Uncoupling, CLaOU）製程比傳統的 IG-CLC 製程，具有轉換燃料更快、需要載氧體材料較少的優點，從

而可降低反應器的尺寸和相關成本。

本研究評估兩種不同的 Mn-Fe 載氧體在 500 W_{th} 超過 140 小時內連續運轉的煤燃燒的行為。於 CLaOU 製程中使用噴霧乾燥的材料： $(Mn_{0,66}Fe_{0,34})_2Ti_{0,15}O_{3,3}$ 和 $(Mn_{0,77}Fe_{0,23})_3O_4$，並與傳統的 IG-CLC 製程相比較。探討各種操作條件對燃燒效率和需氧量的影響：如燃料反應器溫度、固體循環速率、空氣反應器的溫度、以及在空氣反應器中的過量空氣。結果發現，CLC 可以通過使用具有氧解偶聯性質的載氧體和優化操作條件，且這些機制普及並被執行之下，將可大幅改善製程效能。

(B) 論文 (D1-T4-S1-P3)：本論文由 Universidad del Valle, Columbia 的研究人員發表，演講主題為 **"Selecting a Low-cost Oxygen Carrier in Southwestern Colombia, and its use in the Insitu Gasification Chemical Looping Combustion Technology"**。演講內容摘要如圖 III.1.1-19 ~ III.1.1-24 所示。

在化學迴路燃燒（CLC）中，載氧體（OC）是該過程的主要組成部分。大多數 OC 為人工合成開發，使用活性金屬氧化物與惰性材料結合。當使用固體燃料時，OC 的損失與 CLC 過程中灰分的產生導致成本增高。因此，對使用 Mn 和 Fe 的低成本 OC 的興趣大增。由於廣泛使用煤來生產能源，因此應用 CLC 於固體燃料有增加的趨勢。

在這項研究中，研究了一種源自錳礦石淨化的副產物，其具有高矽含量。該副產品是從哥倫比亞西南部的礦山採集的 8 種礦物中選出的。這些礦物質中含有錳和鐵。以粉碎強度，X 射線螢光和使用 CH_4 的熱重分析進行篩選過程和材料選擇，發現來自 Nariño 部門的 Mn 礦物呈現出最佳的行為，具有足夠的破碎強度，3.2%的氧氣輸送能力，80 秒內高反應性達到 80%的降低轉化率。為了提高材料的機械性能，在 1050°C 下經歷了 4 小時的煅燒過程(calcination process)，使用 AJI ASTM 標準方法將磨耗率 (attrition velocity)從 7.6 降低到 5.3。

此研究還發現該物質在 H_2 和 CO 中比在 CH_4 中更具反應性。在使用缩核模型(shrinking core model)的動力學研究中證明了這一點。在 950°C 下，在 50 次循環中，使用 CH_4，CO 和 H_2 針對篩選出的材料進行分批流體化床反應器的測試。結果顯示，用 CO 和 H_2 觀察到良好的反應，中度摩擦，材料壽命為 2,960 小時。該材料呈現出與 CH_4 低附聚的趨勢，並且不會與 CO 和 H_2 結合。此研究同時也

評估 CLC 解偶聯（CLOU）效應，但是在 950°C，1000°C 和 1040°C，使用 N_2 作為還原氣體，與在 10% O_2 作為氧化氣體條件下未發現 CLOU 效應的發生。

由於其與 CO 和 H_2 的良好性能，在原位氣化化學迴路燃燒（iG-CLC）技術中，使用智利反應性煤作為燃料在 900°C，950°C 和 1000°C 的溫度下評估該材料。結論顯示，矽的存在提高了材料的機械性能和 Mn 反應性。此外，它與 H_2 和 CO 的良好行為使其成為 iG-CLC 技術的有希望的 OC。

(C) 論文 (D2-T4-S2-P1)：本論文由 Technische Universität Darmstadt, Germany 的研究人員發表，演講主題為 **"Long-term pilot testing of the carbonate looping process in 1 MWth scale"**。演講內容摘要如圖 III.1.1-25 ~ III.1.1-30 所示。

碳酸鈣迴路 (calcium carbonate looping, CaL) 過程是一種高效的後燃燒技術，用於利用石灰石成分的吸附劑捕獲石化燃料電廠和工廠的二氧化碳排放。CaL 程序的特點是低能量損失，僅降低約 6%的效率，其他特點尚包括壓縮二氧化碳，去除二氧化碳成本低及對環境衝擊低。由兩個相互連接的 CFB 反應器組成的半工業規模的 CaL 先導測試設施，其中裝有典型工業 CFB 系統的所有常規組件，以及規模為 1 百萬瓦 (1 MW_{th}) 熱容量的碳酸化器(carbonator) 提供碳源煙道氣 (flue gas) 的爐子，這些皆位於達姆施塔特技術大學。藉由富含 O_2 的再循環煙道氣可使具有高二氧化碳濃度的富氧燃燒 (oxy-fuel) 條件，可獲取關於吸附劑失去活性的可靠資料。該先導測試設施在 CFB 模式下運行了 3000h 以上，其中 CaL 的二氧化碳捕獲超過 1200 h。這項工作提出了在這個 1 百萬瓦試點工廠進行的四個長期測試作業的實驗結果，這些試驗工廠用硬煤和褐煤，旨在將作業規模擴大到工業規模。研究了燃料類型、吸附劑、煙道氣組成、反應器設計和操作條件對長期運轉的影響。通過使用各種粒度的硬煤和褐煤作為燃料，在高達 60 小時的時間內維持參數來實現穩態條件。特別關注的是不同操作參數下吸附劑反應性的長期表現，例如反應器溫度、補充流 (make-up flow)、固體循環率。從各個取樣點定期取出的固體樣品，以研究由燒結和雜質累積造成的的劣化現象。碳酸化器中 CO_2 吸收率高達 94%，總體二氧化碳 (包含在穩態運行中，煅燒爐中的燃料燃燒釋放的二氧化碳) 捕獲率超過 96%，由此可驗證 CaL 程序的可行性。

(D)　論文 (D2-T4-S2-P5)：本論文由 SINTEF, Norway 的研究人員發表，演講主題為 **“COMPOSITE Process: Highly efficient IGCC power generation with CO2 capture by integration of CLAS and CLC”**。演講內容摘要如圖 III.1.1-31 ~ III.1.1-36 所示。

新型複合程序將化學迴路燃燒（chemical looping combustion, CLC）和化學迴路空氣分離（chemical looping air separation, CLAS）的概念高效率地結合到整合式氣化複循環（integrated gasification combined cycle, IGCC）發電廠中。CLAS 單元用於將氧氣與空氣分離，並隨後將該氧氣供應給氣化單元。然後將來自 CLAS 單元的廢氣用於 CLC 裝置的氧化和除熱階段。 這樣的配置可省掉 CLC-IGCC 配置中的空氣分離單元（和相關的能量損失）。

能源損失是二氧化碳捕集技術面臨的主要經濟挑戰。該研究工作通過一個新穎的發電廠配置來應對挑戰，能夠實現燃煤的 45.4%的發電效率和 95%的 CO_2 捕集效率。這是通過將化學迴路空氣分離（CLAS）反應器和填充床化學迴路燃燒（packed bed chemical looping combustion, PBCLC）反應器結合到整合式氣化複循環（IGCC）發電廠中來實現。實施熱氣淨化技術以提高工廠效率。當使用商業化的冷氣淨化技術時，工廠效率降低了 2%，但比類似的 PBCLC-IGCC 發電廠高出了 2.3 個百分點，比使用燃燒前二氧化碳捕獲的 IGCC 發電廠高出了 5.7 個百分點。此外，COMPOSITE 發電廠的性能對 CLAS 反應器性能的變化不敏感，這意味著與該新型程序組件相關的不確定性不會降低此複合概念發電廠的潛力。

COMPOSITE 概念提出的主要過程挑戰是在到達氣化器的 CLAS 單元的出口流中氧濃度可相對較低（～15mol％）。這導致合成氣流熱值降低，和空氣流氣化產生的結果類似。因此，由於需要處理的大量合成氣，因此使用成熟的低溫合成氣清洗變得更具挑戰性。

本研究提出了使用成熟的氣化和氣體清潔技術將 CLC 和 CLAS 裝置的填充床反應器組合的複合工藝的初步熱力學評估。並將先前評估的使用空氣分離單元而不是 CLAS 反應器的 CLC-IGCC 方法以及先進的燃燒前二氧化碳捕集技術（Selexol 與高溫燃氣渦輪機組合）進行比較。還討論了諸如熱氣體清潔等其他程序改進對效率提升的潛在性。為 CLC 和 CLAS 單元進行詳細的 1D 反應器模擬，以確保準確地呈現出這些發展中的技術。然後將反應器出口流數值送入過程流程

表和發電廠模擬，以計算所得到的設備效率。

B. **Gasification Session:** (圖 III.1.1-37 ~ III.1.1-48)

(A) 論文 (D1-T4-S3-P1)：本論文由 TU Freiberg, Germany 的研究人員發表，演講主題為 **“Towards high-fidelity simulations of coal gasification”**。演講內容摘要如圖 III.1.1-37 ~ III.1.1-42 所示。

淨煤技術(Clean coal technologies)的發展需要先進和綜合的計算工具，能夠準確預測這些系統的性能和排放。大尺度的渦流模擬（LES）在模擬反應流中尤其受歡迎，因其允許準確描述反應混合物的流體動力學。

其次，製圖表策略廣泛應用於建模氣體反應流中的紊流反應流。然而，延伸這些方法至煤燃燒和氣化的應用並不簡單，需要特別處理來考慮煤顆粒與氣相之間存在的複雜質量交換，包括去揮發化(devolatilization) 和焦炭轉化。使用製圖表化學方法較諸其他用於模擬煤氣化的方法可以明顯降低 CFD 模擬計算成本。因此，製表法的評估是邁向高真實性 LES 模擬煤氣化的基本步驟。

(B) 論文 (D1-T4-S3-P3)：本論文由 TU München, Germany 的研究人員發表，演講主題為 **“Reaction behaviour of fuels of different quality in entrained flow gasifiers”**。演講內容摘要如圖 III.1.1-43 ~ III.1.1-48 所示。

挾帶流氣化 (Entrained flow gasification) 就電力、燃料或化學品的原料和產物方面，是提高氣化廠靈活性的具潛力技術。為了瞭解氣化過程中的化學和物理過程，對氣化反應的實驗研究有很大的興趣。由於燃料的性質和氣化條件影響轉化行為，為了瞭解與工業氣化爐相似的條件下發生的現象，需要廣泛的原料的實驗數據。另外，由於燃料性質如反應性、灰分含量或灰分熔融行為，並不是每種原料都適用於挾帶流動氣化器中的使用。使這些可用於挾帶流動氣化的燃料的一種解決方案是使用不同燃料的混合物。因此，有必要對不同性質和等級的燃料進行分析，以得出燃料混合物氣化行為的結論。

該研究分析和比較了不同燃料（生質、褐煤和煙煤）的氣化行為。在慕尼黑技術大學能源系統研究所的實驗是在大氣壓和高壓高溫挾帶流反應器中進行的，該反應器運行溫度高達 1600°C。反應器中的氛圍(atmosphere)可以加以設置，以便進行在惰性氣氛中熱解實驗或用氧氣、二氧化碳或蒸汽進行氣化實驗。分析在

實驗期間收集的焦炭 (chars) 的結構特性 (例如表面積)。此外，在熱重分析儀中研究熱裂解焦炭以獲得固有的動力學數據 (intrinsic kinetic data)，例如活化能和反應次序，或者確定溫度和停留時間對不同焦炭的反應性的影響。熱重分析儀中的實驗在可以排除質傳限制的溫度下進行。

該研究結果提供了洞察氣化反應時不同面向影響燃料的挾帶流動反應行為。挾帶流動反應器中的實驗顯示了去揮發和氣化過程中溫度、氣氛和停留時間對燃料轉化的影響。該研究發現結果可用於動力學模型的開發及其驗證。此外，可以評估燃料及其混合物對工業挾帶氣流的適用性。

C. **IGCC Session:** (圖 III.1.1-49 ~ III.1.1-60)

(A) 論文 (D2-T1-S1-P1)：本論文由 New Energy and Industrial Technology Development Organization, Japan 的研究人員發表，演講主題為 **"NEDO's Clean Coal Technology Development for reduction of CO_2 emissions"**。演講內容摘要如圖 III.1.1-49 ~ III.1.1-54 所示。

新能源和工業技術開發組織（NEDO）自 1980 年成立以來，一直是日本最大的公共研發管理機構之一。NEDO 正在推動日本在"清潔煤炭技術（Clean Coal Technology, CCT）"等技術開發領域的研發項目，以實現技術創新。日本的 CCT 已經達到世界最高的技術優勢，日本燃煤電廠發電量的二氧化碳排放量也低於其他工業化國家的水準。

燃煤發電效率較高將可減少二氧化碳排放量。為了提高火力發電的效率，有必要在燃煤技術領域應用整合型煤氣化複循環（Integrated Coal Gasification Combined Cycle, IGCC）和整合型煤氣化燃料電池聯合循環（Integrated Coal Gasification Fuel Cell Combined Cycle, IGFC）等下一代技術，以及燃氣技術領域的超高溫燃氣輪機。在公共和私營部門的合作之下，加快發展和早日建立新一代火力發電技術。在這方面，CCT 將通過減少二氧化碳排放量和維持 GDP 增長來滿足經濟和環境要求。

為了進一步實現二氧化碳減排，不僅要有效率高，而且要控制二氧化碳排放。因此，正在進行許多研究和開發。在本次會議中，我們將提及高性能二氧化碳捕獲技術，EAGLE 計畫"封閉式 IGCC"（二氧化碳捕獲的下一代 IGCC）和化學迴路煤燃燒（chemical looping coal combustion, CLC）的發展。

(B) 論文 (D2-T1-S1-P4)：本論文由 TU München, Germany 的研究人員發表，演講主題為 **“Experimental Investigation of Alkali Sorption with Mineral Getter Materials for IGCC Power Plants”**。演講內容摘要如圖 III.1.1-55 ~ III.1.1-60 所示。

在煤氣化過程中，鹼性化合物會以微量物質釋放到氣相中。在具有整合型煤氣化複循環（IGCC）的發電廠中，這些鹼性化合物誘發的高溫腐蝕機制，對系統組件，特別是燃氣渦輪機造成嚴重的損害。在最先進的發電廠中，將合成氣冷卻至低溫以冷凝和分離這些鹼性化合物。矽鋁酸鹽材料作為所謂的吸收劑 (getters) 能夠通過吸附在高溫下從氣相中除去鹼金屬。該研究旨在將鹼濃度降低到非臨界水平，且不會由於合成氣的冷卻和再加熱而使效率損失。

在這項工作中，使用兩個試驗台研究了吸收劑材料的鹼吸附。使用高達 1800°C 的溫度和最大壓力為 50 bar 的高壓熱重分析儀（HPTGA）於吸附反應的動力學研究。修改 HPTGA 以使用第二個樣品置放器於加熱區中以稱重的吸收劑樣品吸附蒸發鹼性化合物。進一步在具有五個加熱區的活塞式流動反應器中進行用吸附劑顆粒固定床進行鹼吸附的研究。該反應器可以在高達 1300˚C 和 50 bar 的工業導向條件下進行實驗。鹼性化合物的蒸發和吸收劑吸附位於不同的加熱區。然後用原子吸收光譜法和 x 射線螢光分析評估吸收劑樣本的性能。

在 20 bar 的恆定壓力和 800°C 至 900°C 的溫度範圍內進行 HPTGA 和活塞流反應器中的實驗。氣化後的鹼濃度一般可調節至 50ppm 至 200ppm 的範圍內。使用 HPTGA，吾人可獲得動力學數據，如活化能和前指數因子 (pre-exponential factor)，而在活塞流反應器中的研究集中在量測負載和穿透曲線。

D. **Supercritical CO_2 power cycles Session:** (圖 III.1.1-61 ~ III.1.1-72)

(A) 論文 (D2-T1-S3-P2)：本論文由 National Energy Technology Laboratory, USA 的研究人員發表，演講主題為 **“Techno-economic Analysis of an Integrated Gasification Direct-Fired Supercritical CO_2 Power Cycle”**。演講內容摘要如圖 III.1.1-61 ~ III.1.1-66 所示。

美國能源部（The U.S. Department of Energy, DOE）化石能源辦公室致力於推動化石燃料的能源轉換技術，期能大幅度地提高系統效率和經濟績效，同時能解

決溫室氣體排放和其他排放的挑戰。美國能源部的國家能源技術實驗室（National Energy Technology Laboratory, NETL）一直在追求化石燃料超臨界 CO_2（supercritical CO_2, sCO_2）動力循環，作為實現這一使命的潛在途徑。

這項工作的重點是針對最新的用煤燃料，氧燃燒式的直接 sCO_2 動力循環的系統加以研究，該循環本質上適用於碳捕集和封存（CCS）過程。在該工廠中，煤首先在挾帶流動氣化器中氣化並淨化，以避免將硫和顆粒物質引入到 sCO_2 循環。清潔的合成氣被供應到 sCO_2 循環的氧氣燃燒器，其中在高度稀釋的 sCO_2 環境中用氧氣燃燒。隨後高溫和高壓的工作流體通過渦輪機膨脹並在廢氣中排放的熱能。水從工作流體冷凝後，一部分 CO_2 從 CCS 的循環中排出，平衡體在換熱器中被壓縮和加熱，以返回到燃燒器。

該研究探討了燃煤直接 sCO_2 發電廠的概念設計和 AspenPlus®模型，包括渦輪葉片冷卻的經驗模型，sCO_2 循環與氣化器之間的熱整合，以及用於優化整個設備配置和操作條件的參數分析。最後估算工廠的資本成本和經營費用，計算第一年電費（cost of electricity, COE）。研究結果顯示，相對於具有 CCS 的整合型氣化複循環（integrated gasification combined cycle, IGCC）參考廠，氣化 — 直接 sCO_2 設備的效率和 COE 顯著改善。直接 sCO_2 循環的性能也被證明可以與更先進的 IGCC 系統相媲美，包括配有 CCS 的間接 sCO_2 系統和其他具有 CCS 的燃煤系統。該研究提出了針對替代型氣化系統與氣化爐和直接 sCO_2 系統之間的熱整合修改之建議，相較於替代系統這將可進一步提高的設備性能。

(B) 論文 (D2-T1-S3-P3)：本論文由 EDF, China 的研究人員發表，演講主題為 **"Coal fired power plant efficiency boost through retrofitting with Supercritical CO_2 Brayton cycle"**。演講內容摘要如圖 III.1.1-67 ~ III.1.1-72 所示。

超臨界 CO_2 布雷頓循環預計能夠以現成的成本將當前的蒸汽發電循環效率提高 10%。如果能推廣應用於全球的化石燃料發電機組，應該能顯著減少二氧化碳排放。目前，啟動實施在產業上有重大挑戰：一方面，基於現有設計的 sCO_2 循環燃煤加熱器是使用昂貴的高品質材料而成本高昂的設備，另一方面則是所需的非常大容量（> 500 百萬瓦）sCO_2 渦輪機在短時間內無法普遍取得。對現有燃煤電廠進行改造，打造最高 sCO_2 循環週期可能可解決這兩個問題，並加速了該

技術的產業化。本研究旨在探討這樣的可行性。

本研究設計改進的主要特點是：1）保持爐殼水冷，從而產生蒸汽循環的大部分進氣量，並意味著在鍋爐設計（相同的燃燒器、分配器、水壁板、集管和鼓 header and drum）中幾乎不需改變；2) 去除蒸汽過熱和再熱器，並用奧氏體鋼製成的 sCO_2 加熱器更換（對於這些設備熱膨脹不是關鍵問題）；3) 在 sCO_2 渦輪機出口處添加高溫 sCO_2 /蒸汽熱交換器，以過熱和再加熱蒸汽保持蒸汽循環設計溫度；4) sCO_2 最高溫度為 700˚C 和最高壓力為 200 bar。並研究了不同的 sCO_2 循環設計：沒有回收 (recuperation)、有回收、重新壓縮、部分壓縮，以評估最佳候選者。蒸汽循環給水預熱連串系列中的 sCO_2 循環低溫整合也被考慮。對於每種情況，在設計參數中，蒸汽循環的負荷已經調整，以平衡 sCO_2 /蒸汽換熱器的使用負荷，並且已經評估了翻新廠的效率。

作為標竿案例，現有的具有詳細設計數據的 1000 百萬瓦超臨界蒸汽動力循環（250 bar / 600°C / 600°C）已經透過 sCO_2 頂級壓縮循環進行了翻新。蒸汽循環在約 60％負荷下降載，sCO_2 循環產生約 450MW，產生的設備總效率為 48.8％，相較之下蒸汽循環正常運行為 46.6％。這說明了在“最壞的情況下”這種翻新的潛力，實際上翻新應將舊亞臨界發電廠效率更大幅度提昇，且 sCO_2 渦輪機的容量應該保持在 100MW 範圍內。

下一步將重點評估亞臨界主機廠的最佳改造配置，並評估這種改裝案例的經濟盈利能力。

3. Poster Session

類似於一般國際研討會，壁報論文在 CCT 大會中主要係扮演輔助角色；其壁報論文總數並不多，佔大會論文的比例僅約兩成。大會議程安排自第一天起，即從早上 09:00 開始到傍晚 - 17:00，持續展示至會議結束。另外，本屆大會在第一天下午，特別安排 17:00 - 18:30 之時段，工作者及與會者齊聚一堂現場討論 (圖 III.1.3-1)。筆者抽空參閱了壁報論文發表，以瞭解彼等在未來之研發努力及現況成果。本報告中摘錄了數篇較具相關性的論文展示於後 (圖 III.1.3-2 ~ III.1.3-11)。

（二）國際學者專家人脈拓展

此次參加大會期間，筆者與多位國際學者專家深入討論專業技術議題，同時廣泛交流（表 III-1），推動進一步可能之更密切合作。值得於本報告中加以闡述者，筆者在會場分別巧遇兩位大會 Keynote 講員，並針對特定相關議題進行討論。其中一位為印度國營能源公司 **NTPC Ltd.** 之 **General Manager (Partha Mazumder)**，彼此相談甚歡。Mr. **Mazumder** 表示，**NTPC** 是印度最大之電力公司，目前正積極擴充該國能源系統領域，供應相關公用設施需求。另一位為美國 **DOE** 之 **Senior Advisor (Scott M. Smouse)**，可算是舊識。多年前，筆者曾陪同本所長官拜訪 NETL，Mr. **Smouse** 當年負責 APEC 業務，協助安排行程、安全查核等事宜，並與本所參訪團闢室討論台美合作之可能架構。筆者此次主要向他請教美國執政當局新行政措施之影響，瞭解政府長期政策之穩定性與短期調適彈性。

經由與相關同儕交流，可望拓展與能源學者專家之人脈，有助於未來推動國際合作及實務驗證專業工程技術之機會。

§III　有關 2017 EU 公差 CCT 之列表

表 III-1：CCT 2017 之國際學者專家

Name	Position	Affiliation	Remarks
Nick Butler	Visiting Professor	King's College London	Panelist
Scott M. Smouse	Senior Advisor	US DOE	Keynote Speaker
Partha Mazumder	General Manager	NTPC Ltd., India	Keynote Speaker
Markus E. Becker	Executive Director	GE Europe	Government Affairs & Policy
Ashutosh Shastri	Consultant	EnerStrat Consulting	Technology Transfer
Christian Neumeir	Underwriter	VHV Versicherungen	Machinery Insurance
Hermann Stelzer, Dr.-Ing.	Project Manager	Forschungszentrum Juelich	Energy system
Roh Pin Lee, Dr. rer. Pol.	Research Associate	TU Freiberg	Energy process and chemical engineering
Guangxi Yue	Professor	Tsinghua Univ., Beijing	Thermal engineering
Dunxi Yu	Professor & Dep. Director	Huazhong Univ. of Science & Tech., Wuhan	Coal combustion
Yili Xiong	R&D Engineer	EDF China	Power generation
Huiqi Wang	R&D Engineer	EDF China	Power generation

Ana-Maria Cormoş, Ph. D.	Assoc. Professor	Univ. Babeş-Bolyai, Romania	Chemical engineering
Tatyana Bogatova, Dr.-Ing.	Head of Dept.	Ural Federal Univ., Russia	Thermal Power
Florian Kerscher	Research Assist.	TU Munich	Energy system
Igor Kuštrin	Assist. Dr.	Univ. of Ljubljana, Slovenia	Mechanical engineering
Aimaro Sanna, Dr.	Research Fellow	Heriot-Watt Univ., UK	Mechanical, Process and Energy engineering
Thomas Greschik	Senior RD&I Engineer	AkzoNobel AB, Sweden	Pulp and Chemicals
Avijit Mallick	Senior Manager	Rellance, India	Power generation

§III.1　有關 2017 EU 公差 CCT 之圖像

CCT2017 Conference Opening

圖 III-1 開幕典禮會場內景象

圖 III-2 開幕典禮東道主致歡迎詞

中場休息

圖 III-3 筆者攝於 CCT 2017 大會會場

圖 III-4 大會中場休息景象

1. Plenary Keynote Sessions

K-I-1

圖 III.1.1-1

圖 III.1.1-2

圖 III.1.1-3

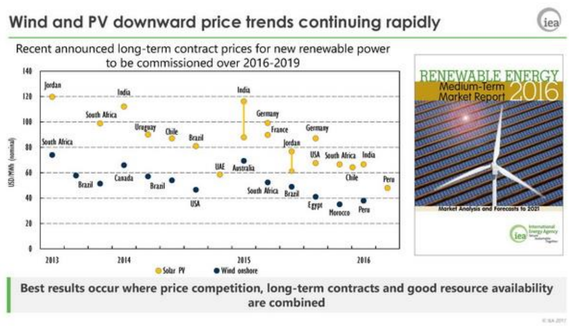
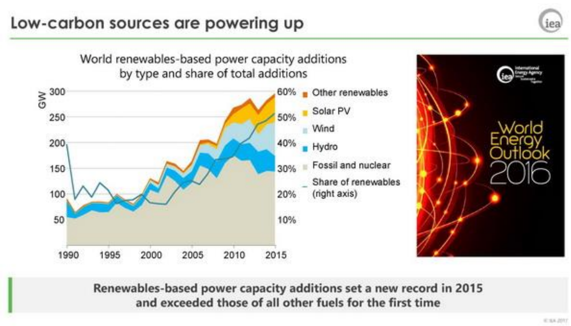


圖 III.1.1-4



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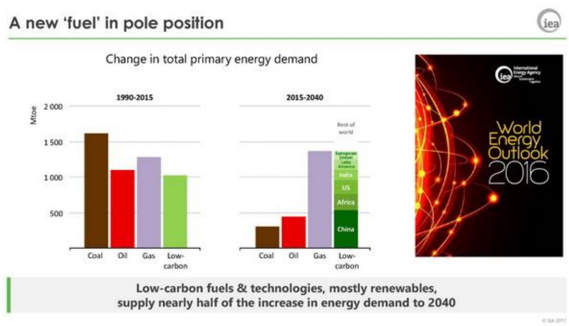

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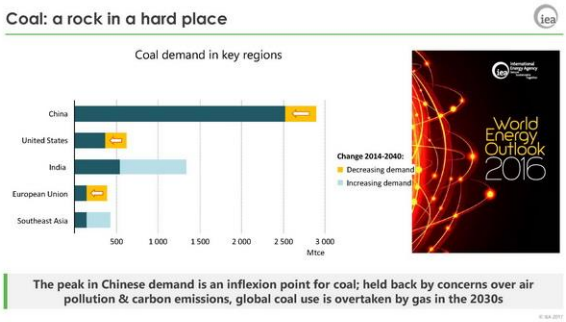

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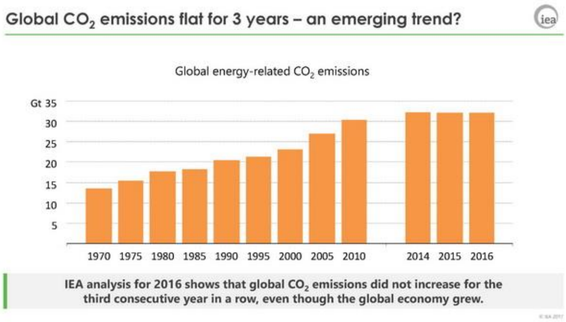

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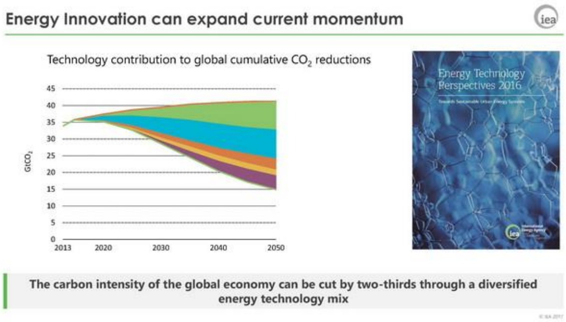

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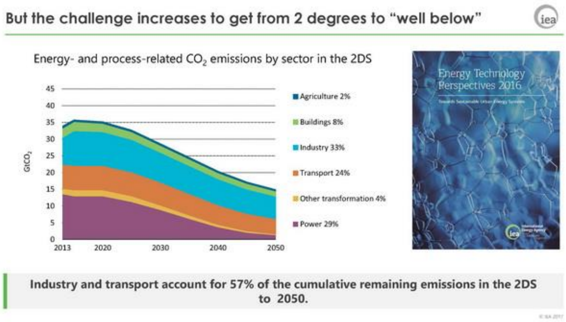

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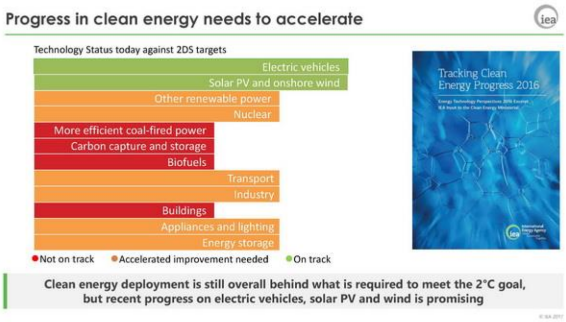

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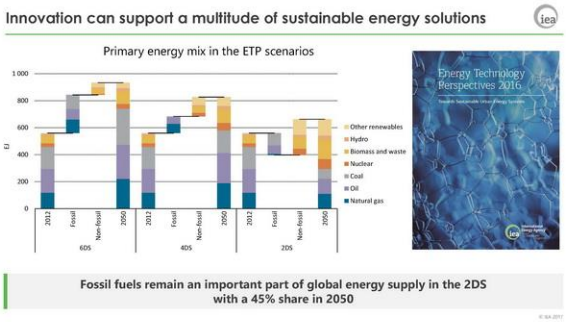

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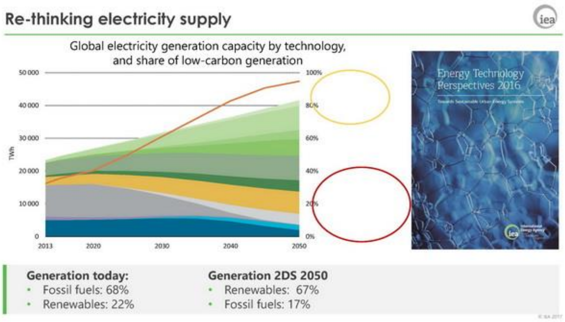

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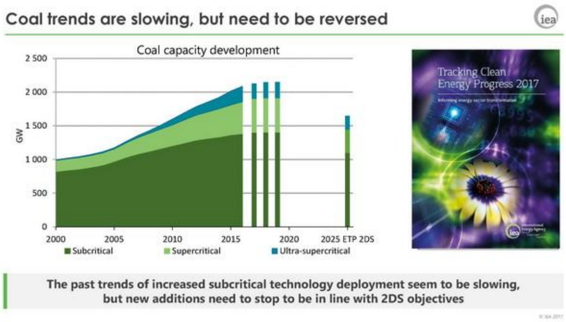

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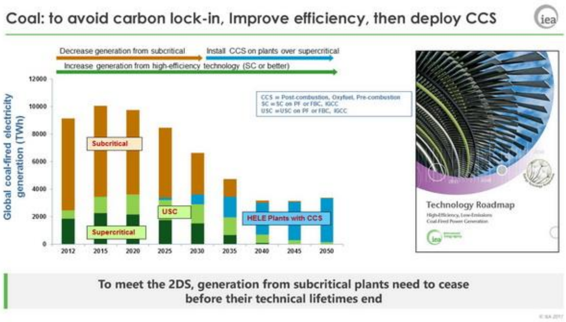

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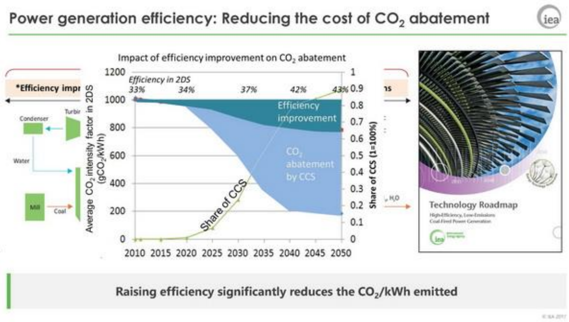

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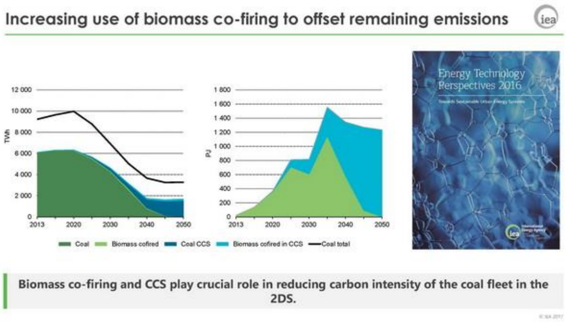

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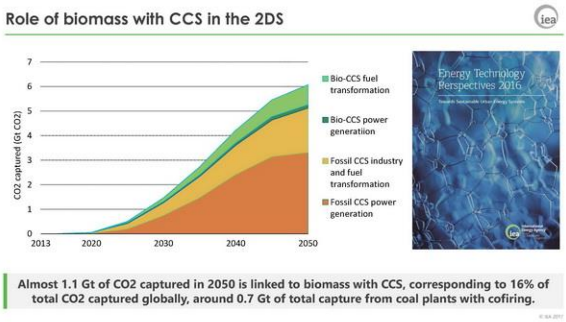

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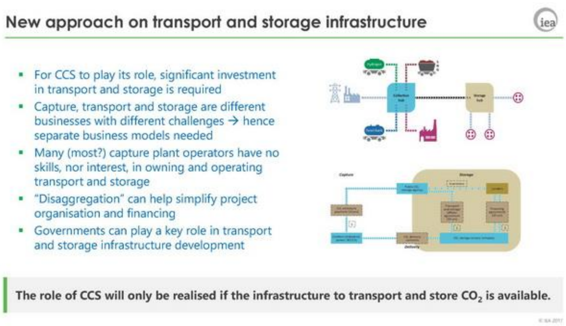

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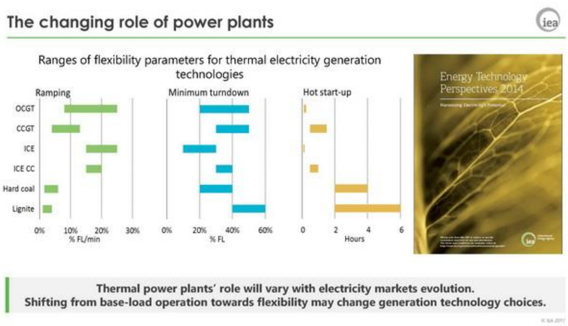

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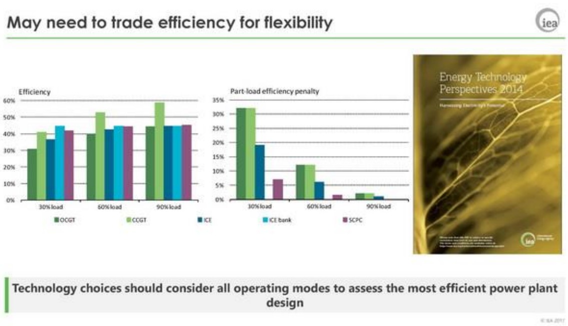

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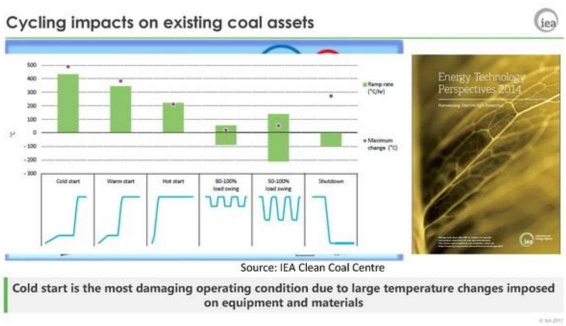

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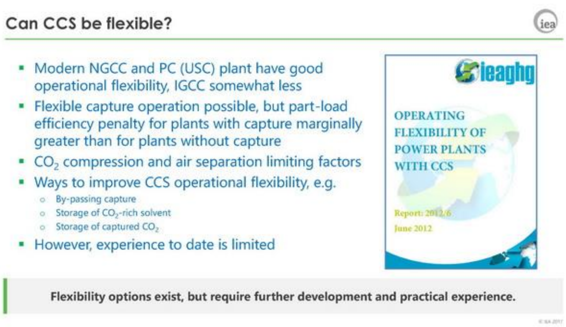

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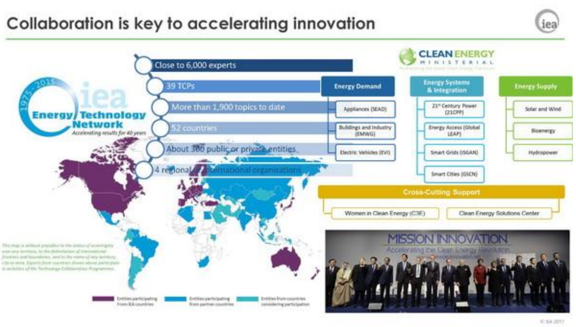


圖 III.1.1-24

K-I-2

圖 III.1.1-25

圖 III.1.1-26

圖 III.1.1-27

圖 III.1.1-28

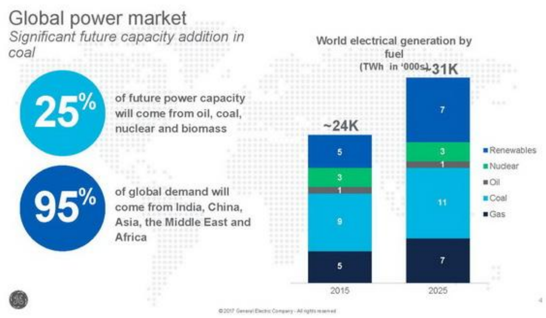


圖 III.1.1-29

圖 III.1.1-30

圖 III.1.1-31

圖 III.1.1-32

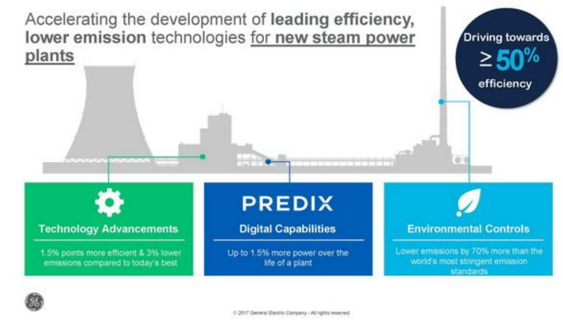


圖 III.1.1-33

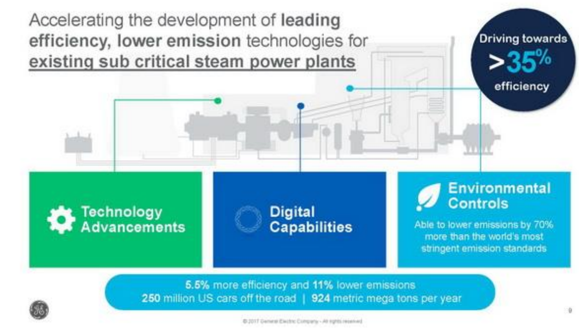


圖 III.1.1-34

圖 III.1.1-35

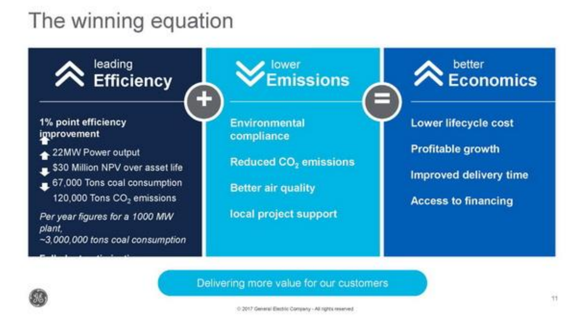
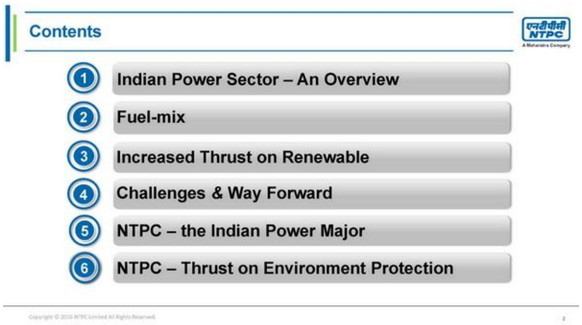


圖 III.1.1-36

K-II-1

圖 III.1.1-37

圖 III.1.1-38



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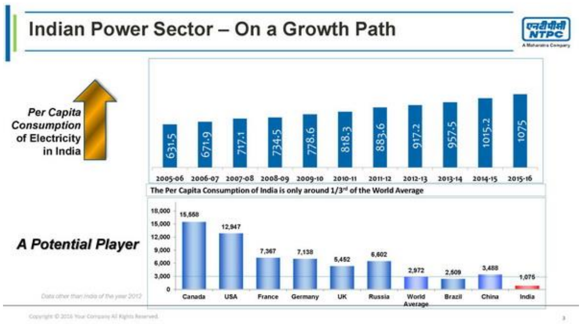


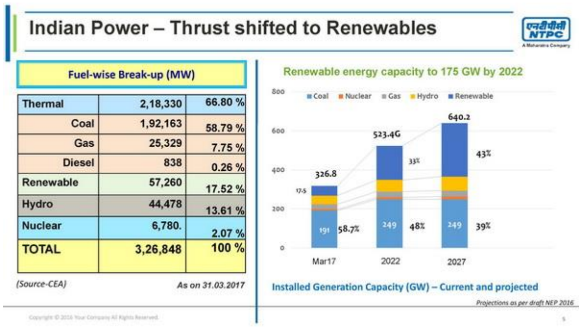
圖 III.1.1-40

Year	Energy Requirement (MU)	Peak Energy Availability (MU)	Surplus(+) / Deficit-) (MU)	Surplus(+) / Deficit-) (%)	Peak Demand (MW)	Peak Met (MW)	Surplus(+) / Deficit-) (MW)	Surplus(+) / Deficit-) (%)
2016-17 *	11,42,092	11,34,631	-7,461	-0.7	1,59,542	1,56,934	-2,608	-1.6
2015-16	11,14,408	10,90,850	-23,558	-2.1	1,53,366	1,48,463	-4,903	-3.2
2014-15	10,68,923	10,30,785	-38,138	-3.6	1,48,166	1,41,160	-7,006	-4.7
2013-14	10,02,257	9,59,829	-42,428	-4.2	1,35,918	1,29,815	-6,103	-4.5
2012-13	9,95,557	9,08,652	-86,905	-8.7	1,35,453	1,23,294	-12,159	-9

* Provisional

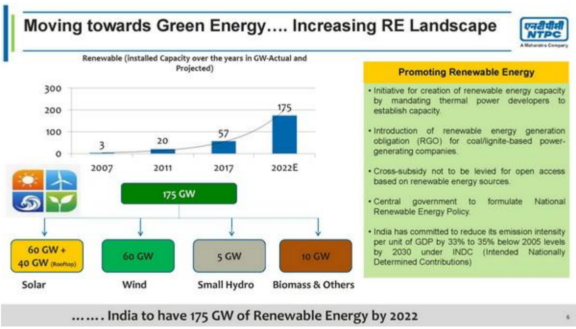
(Source-Ministry of Power)

圖 III.1.1-41



Thermal	2,18,330	66.80 %
Coal	1,92,163	58.79 %
Gas	25,329	7.75 %
Diesel	838	0.26 %
Renewable	57,260	17.52 %
Hydro	44,478	13.61 %
Nuclear	6,780.	2.07 %
TOTAL	3,26,848	100 %

圖 III.1.1-42



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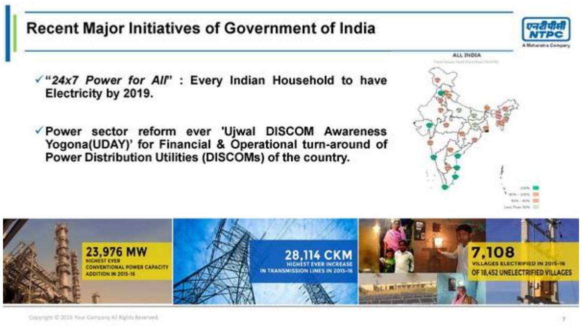

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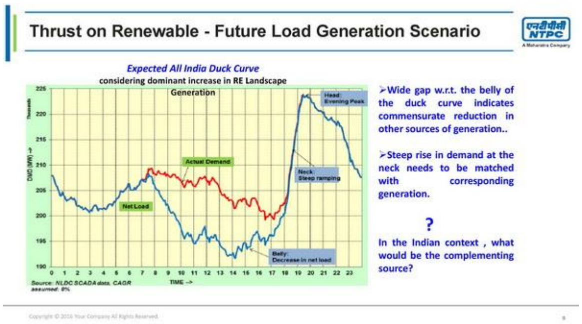
圖 III.1.1-45



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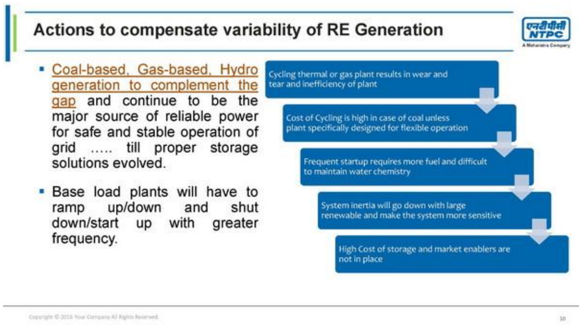

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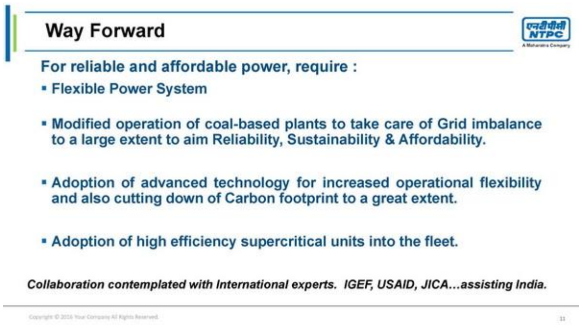

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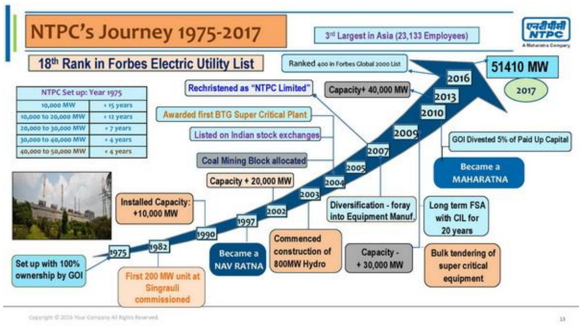
圖 III.1.1-49



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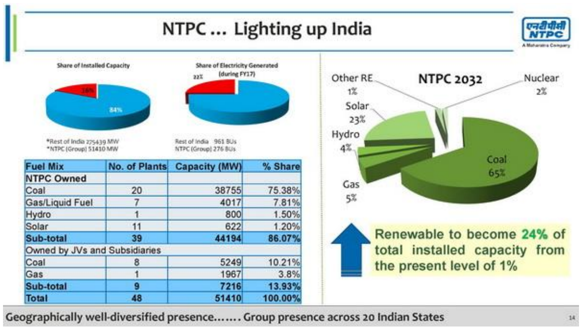

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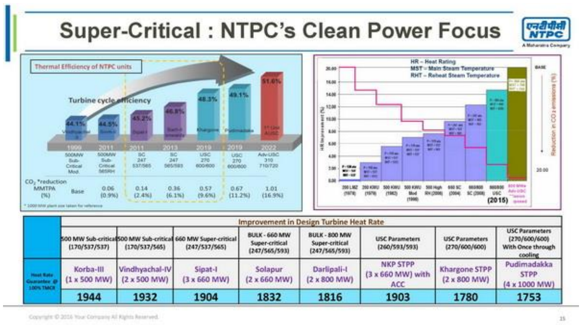

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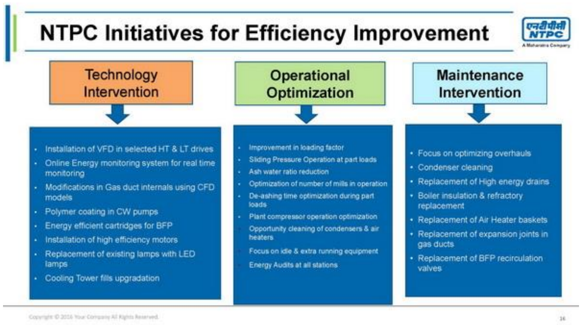

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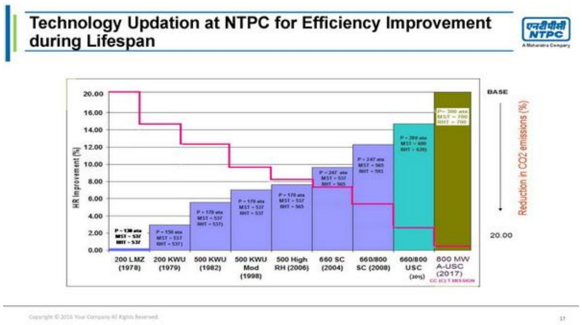

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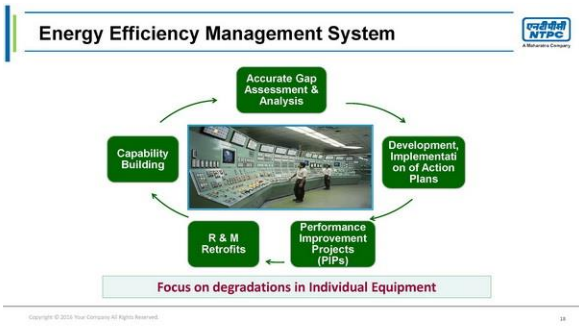

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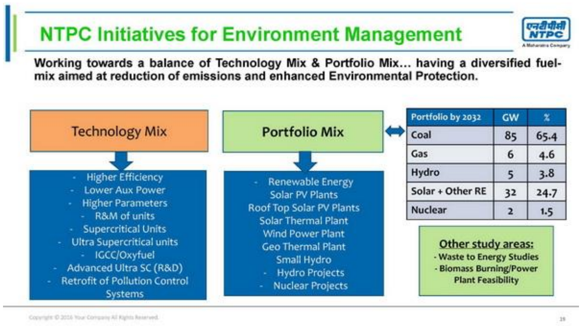

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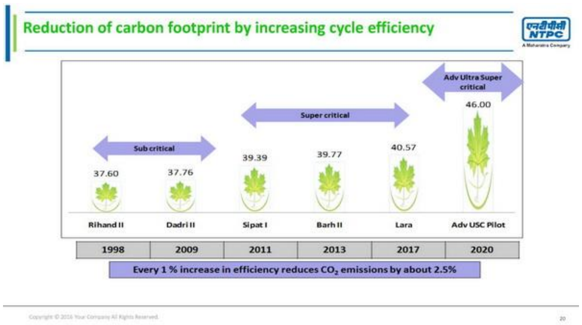

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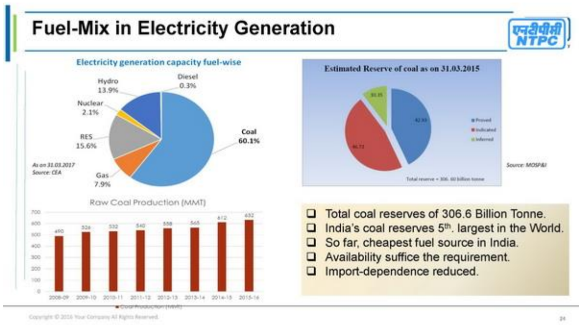
圖 III.1.1-58



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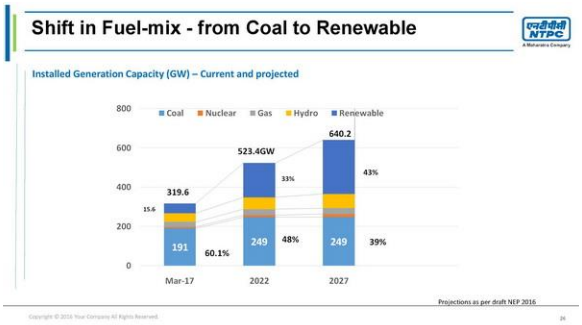


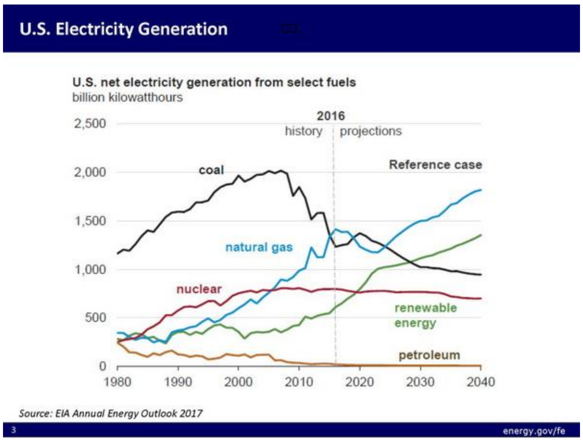
圖 III.1.1-60

K-II-2

圖 III.1.1-61

圖 III.1.1-62

圖 III.1.1-63



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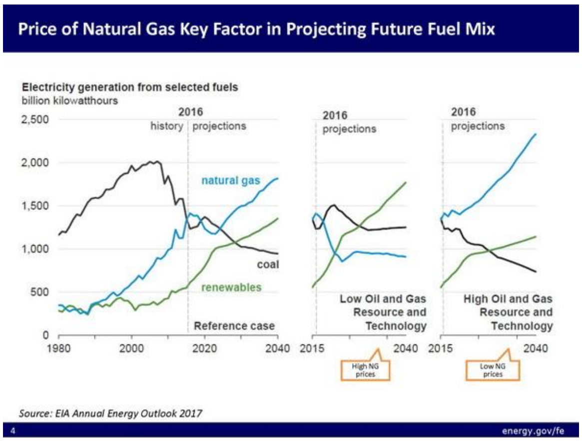

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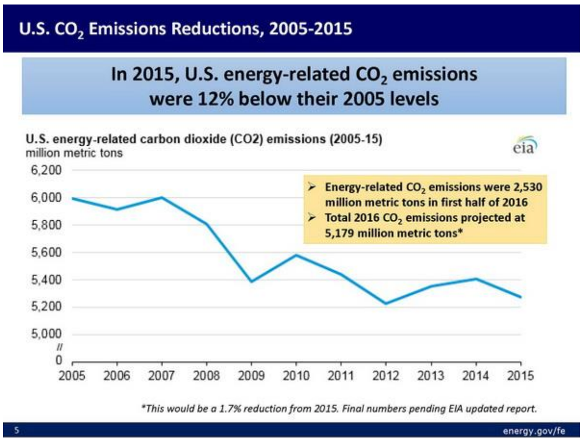

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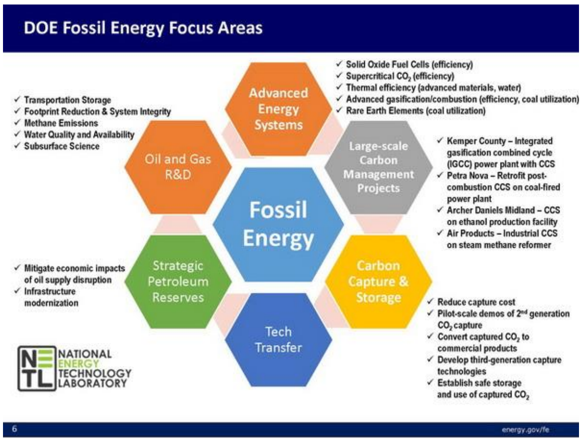

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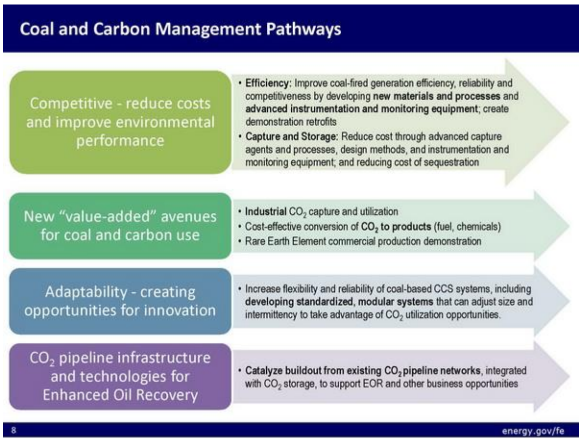
圖 III.1.1-68



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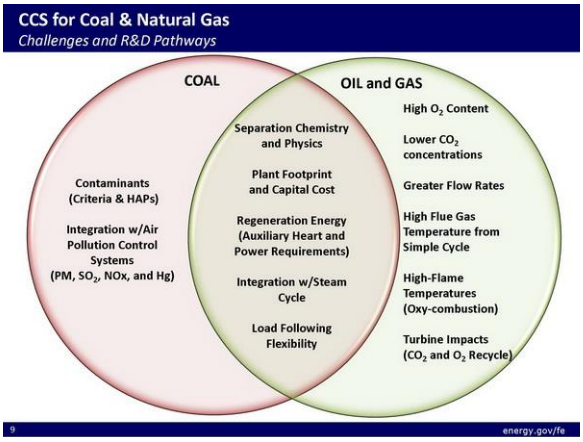

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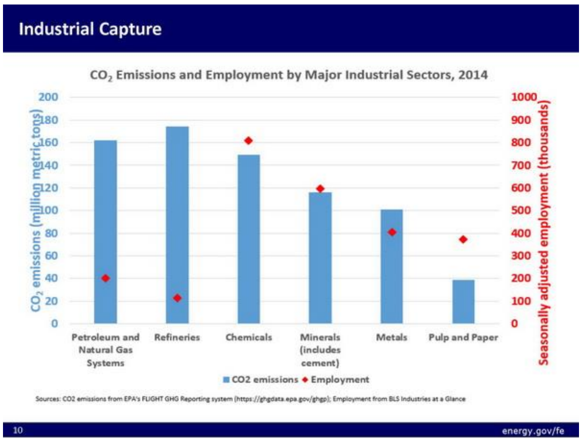

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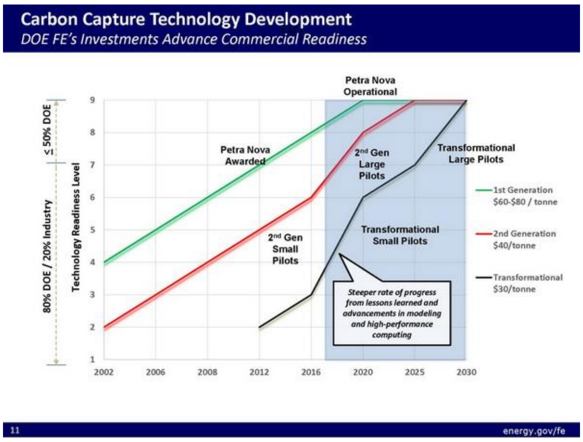

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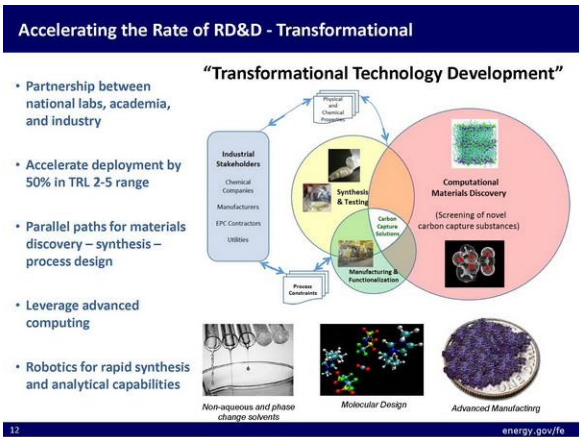

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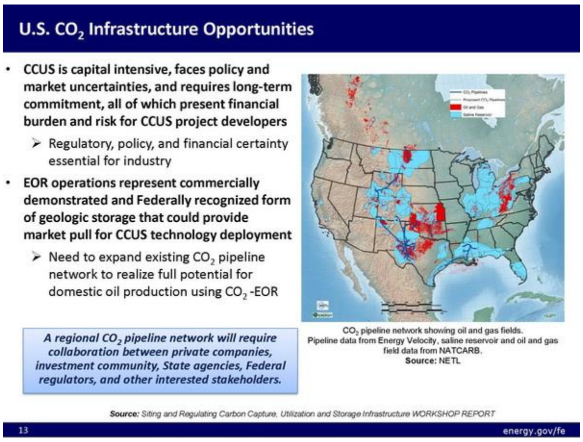

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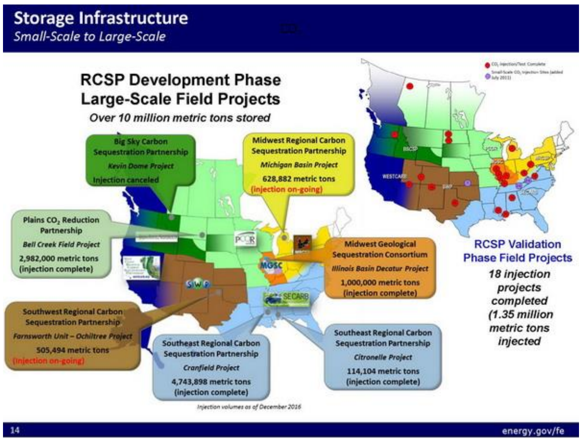

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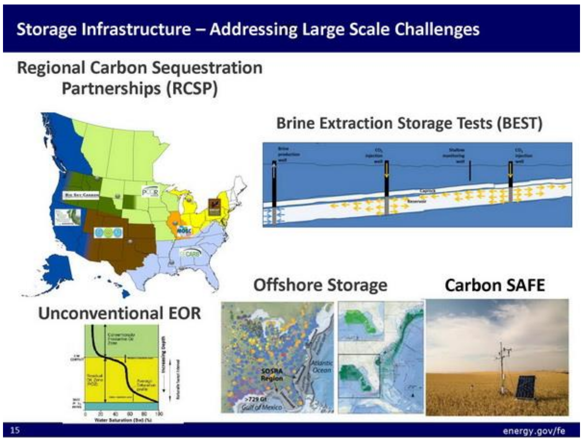

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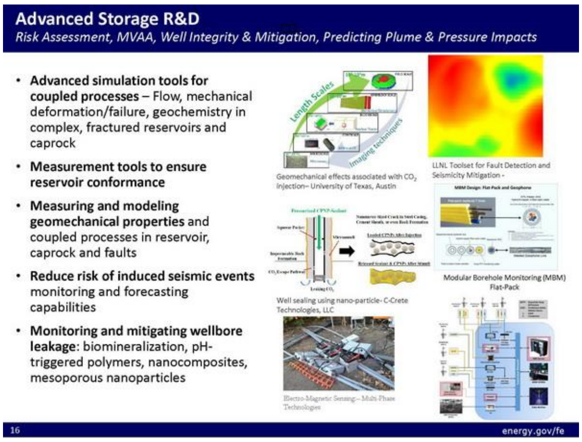

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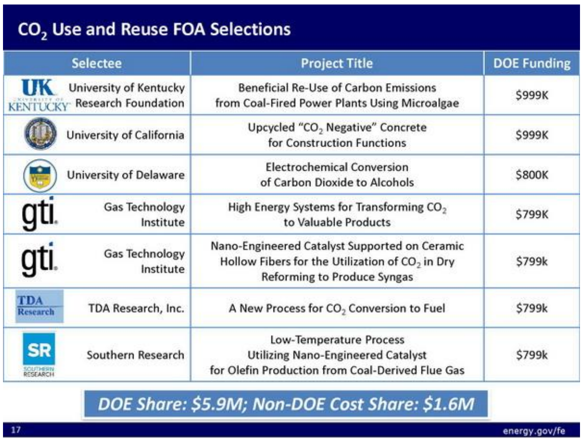

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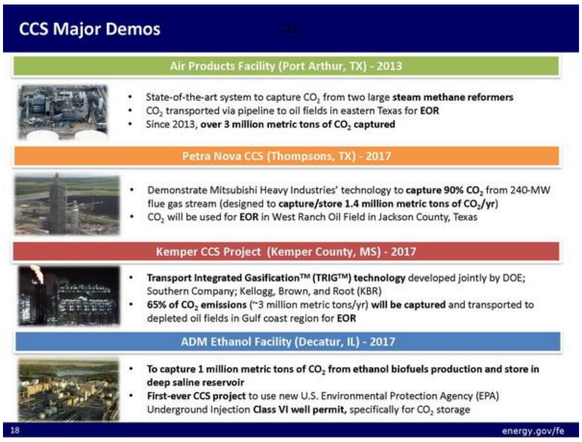

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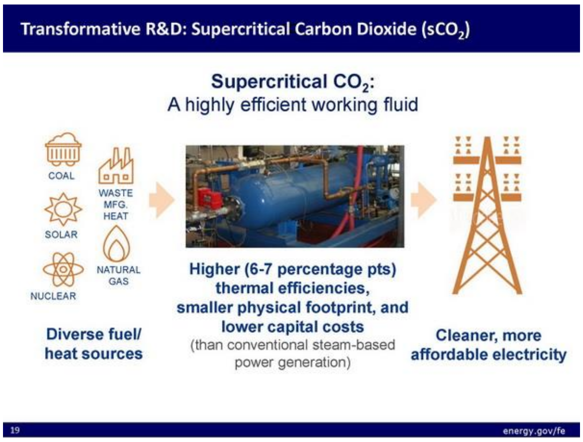

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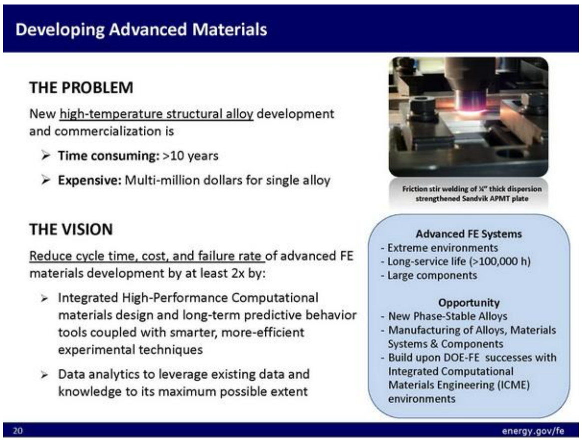

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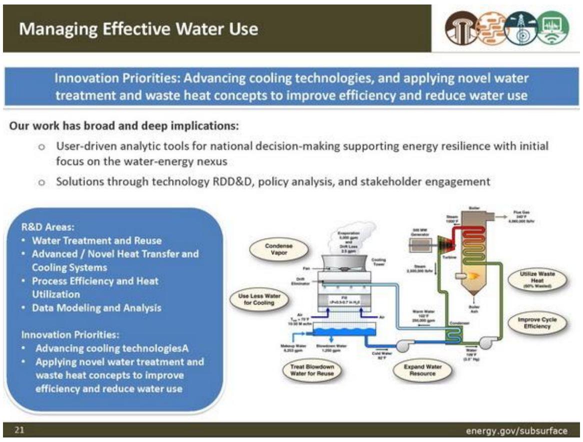

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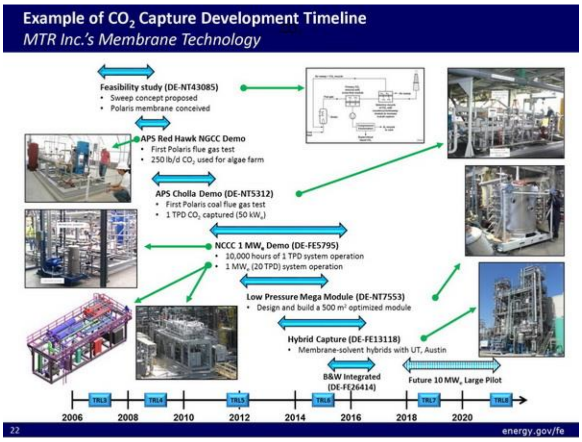

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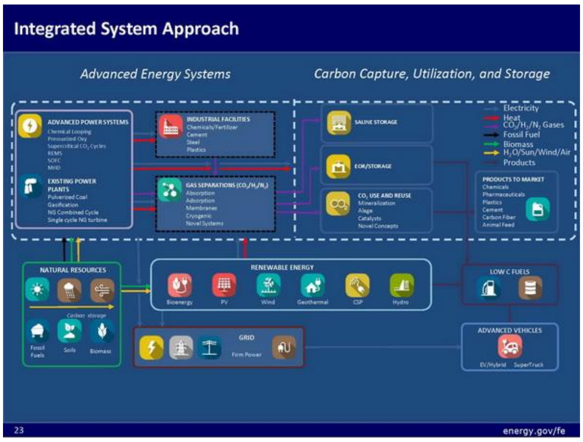
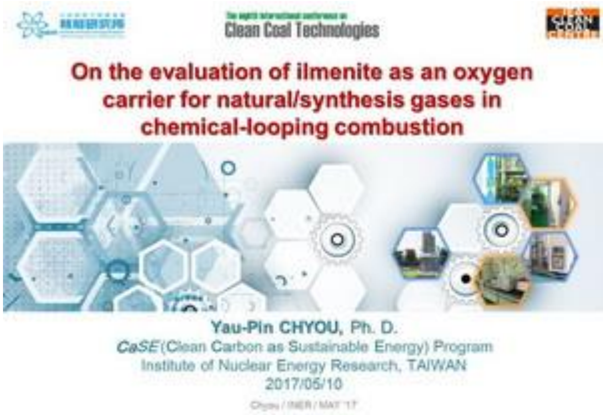


圖 III.1.1-84

2. Technical Paper Oral Sessions

(1) INER 發表論文之口頭簡報摘錄



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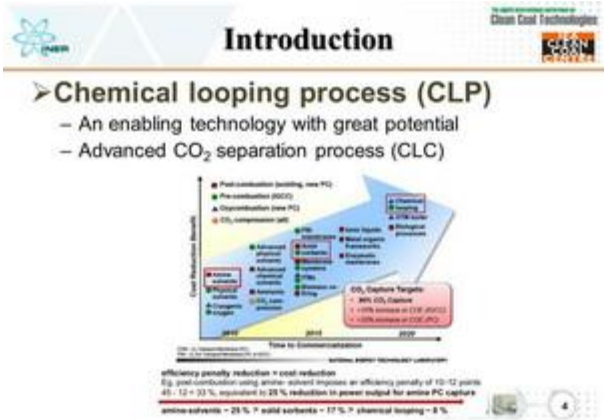

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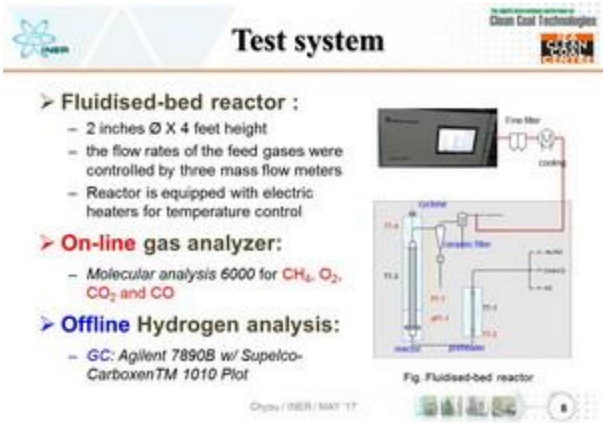
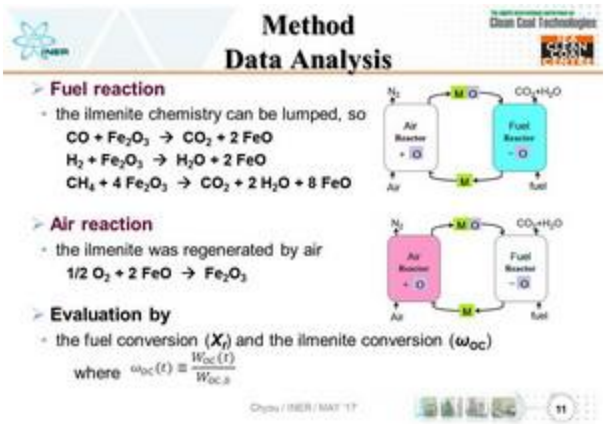


圖 III.1.2-3

圖 III.1.2-4



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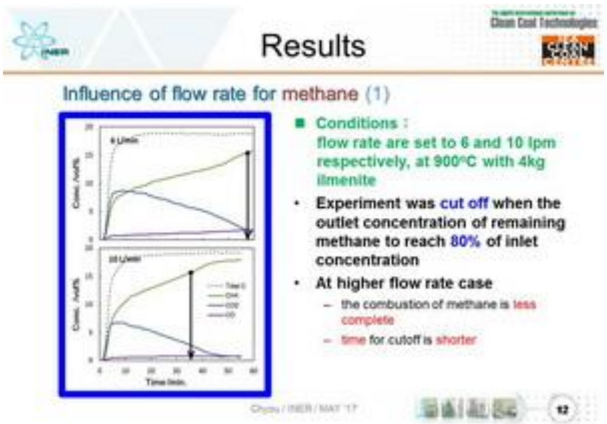

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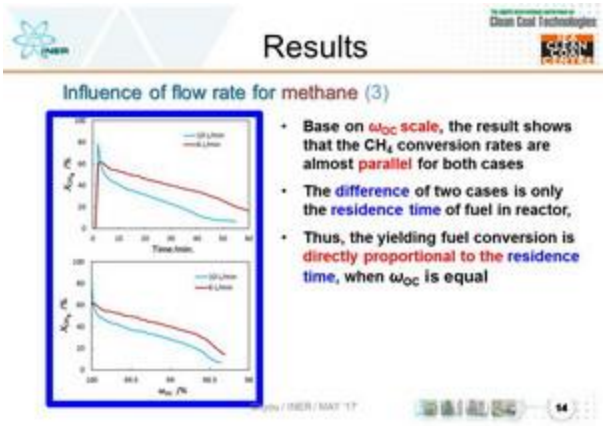

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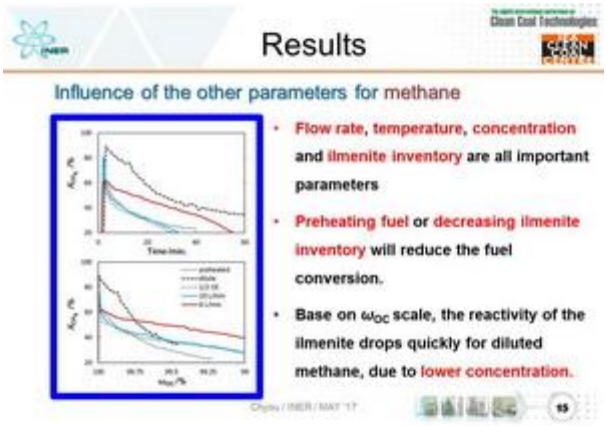

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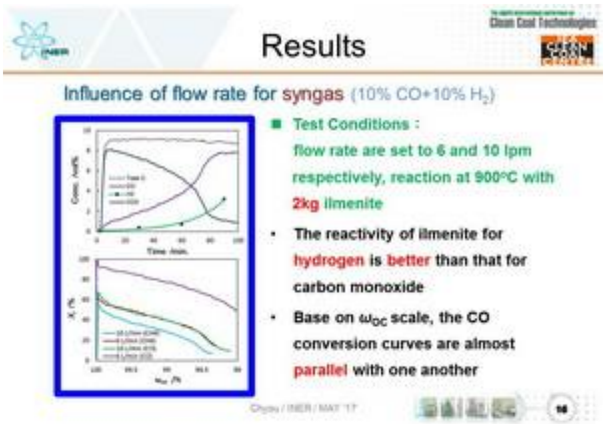

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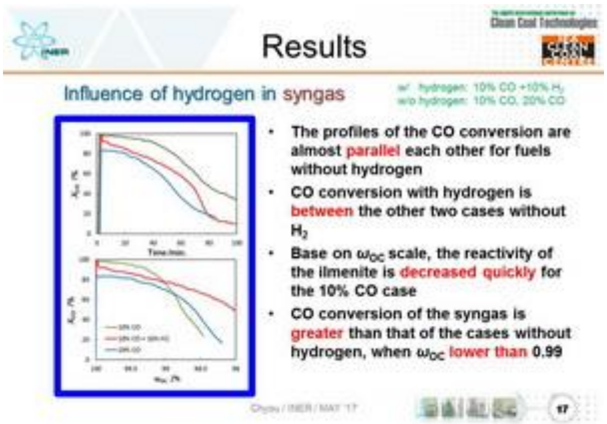

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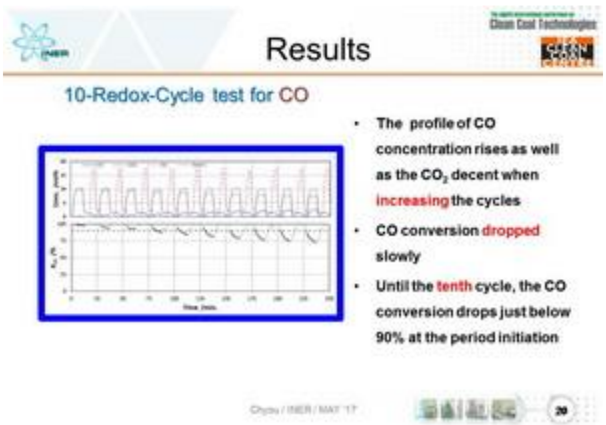

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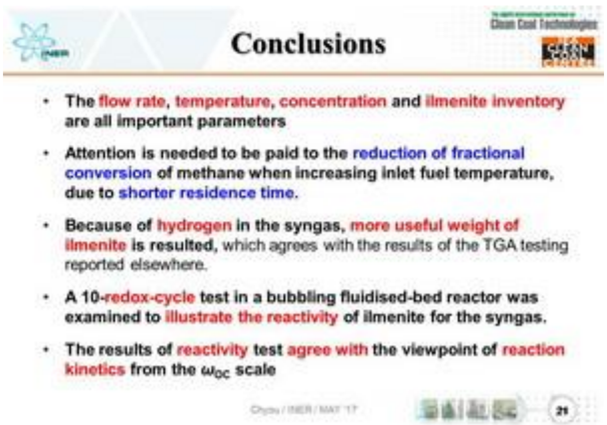
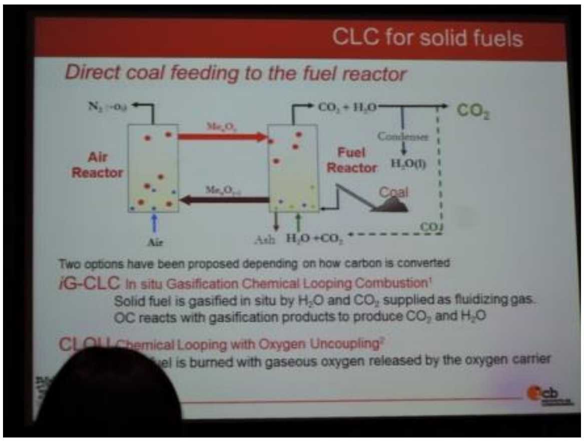


圖 III.1.2-12

(2) CCT 口頭發表論文之簡報摘錄

論文 (D1-T4-S1-P2)：



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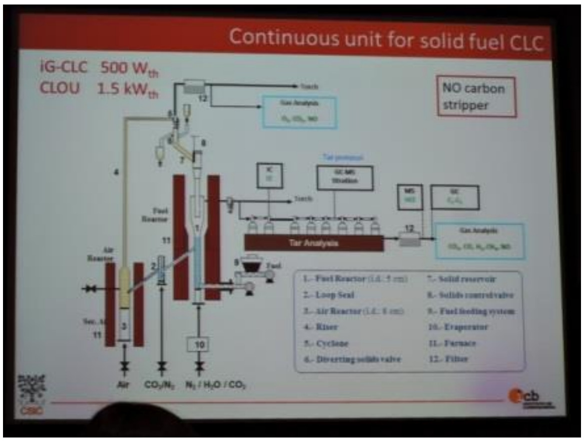

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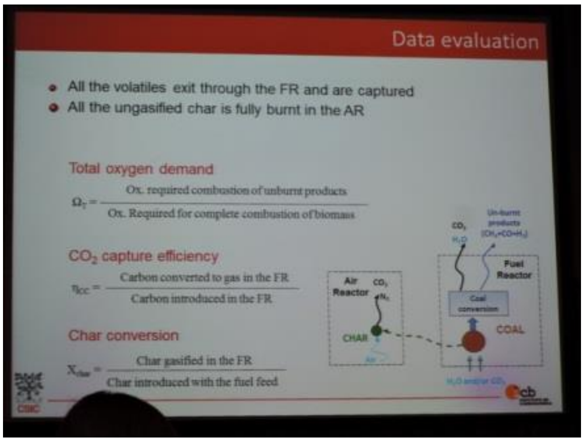

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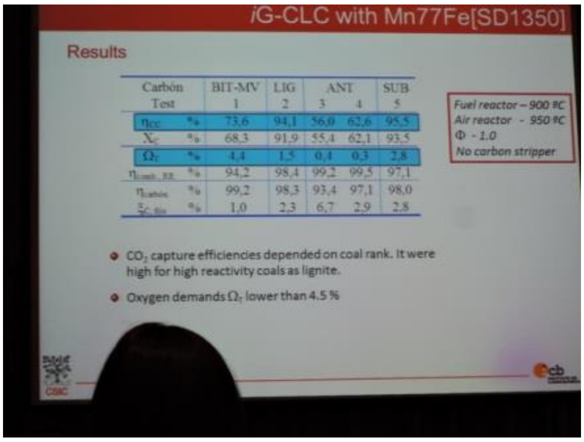

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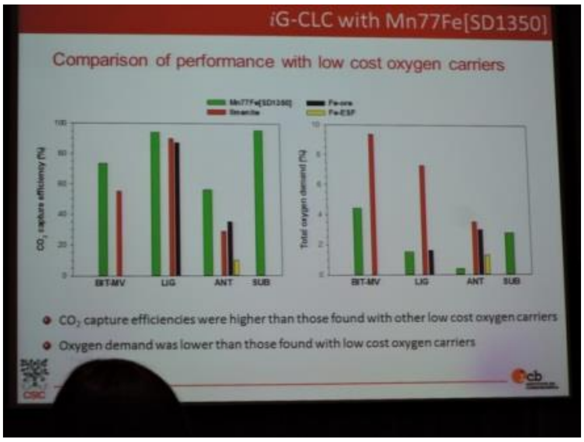

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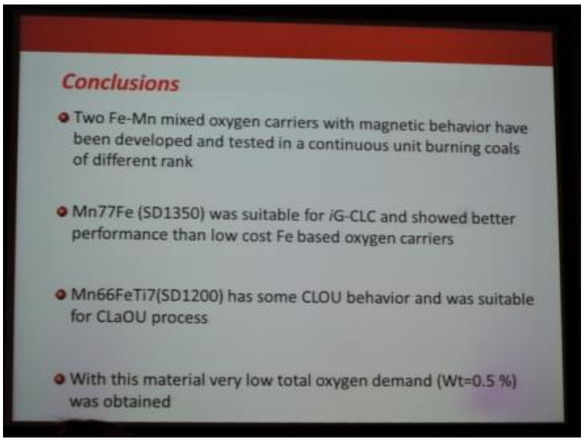
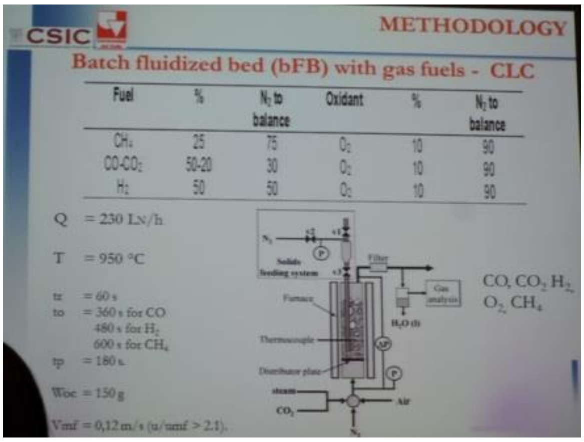


圖 III.1.2-18

論文 (D1-T4-S1-P3)：



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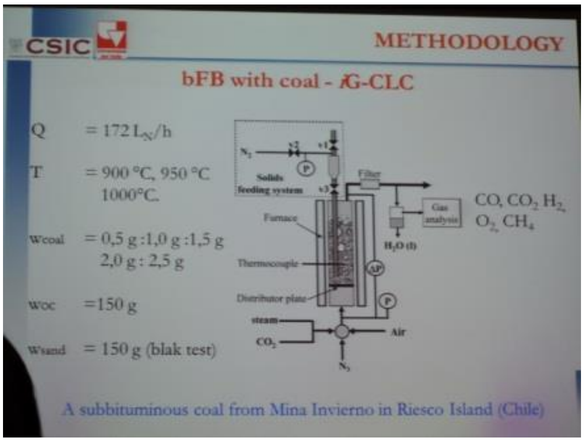

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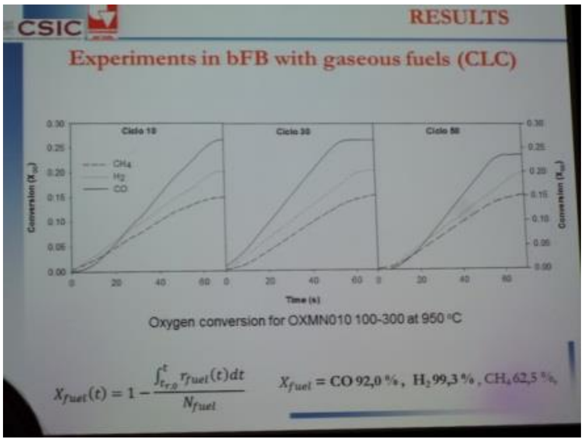

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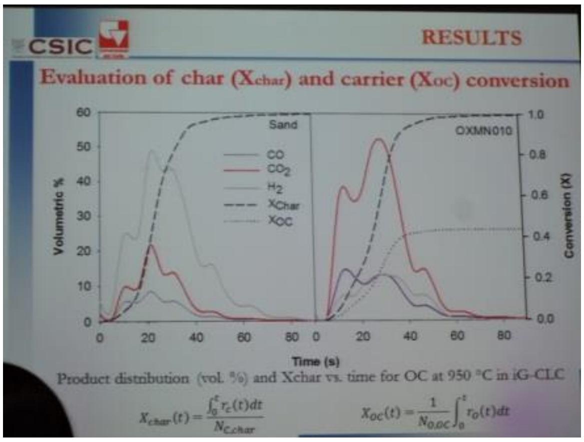

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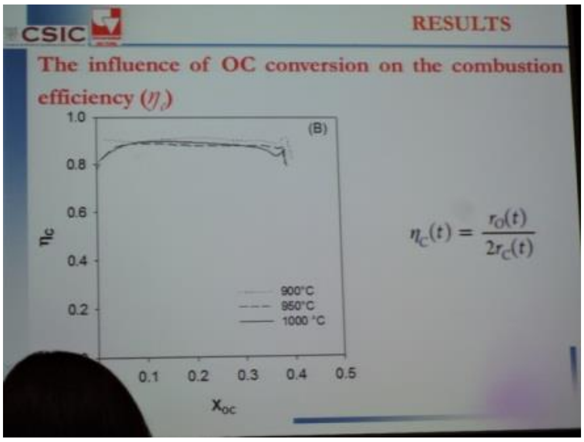

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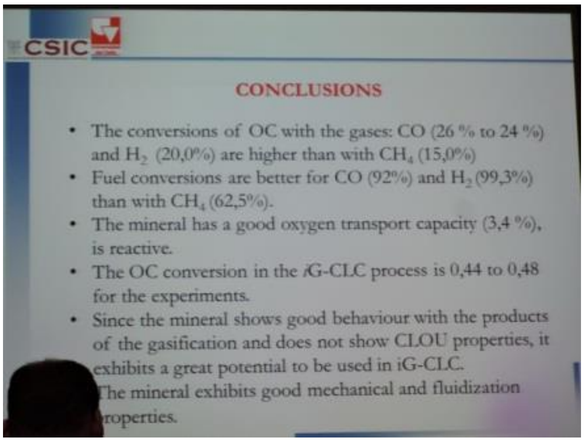

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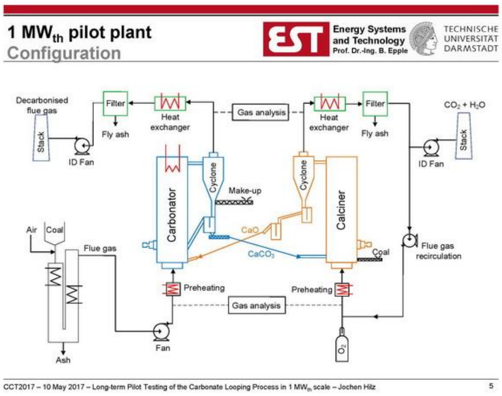
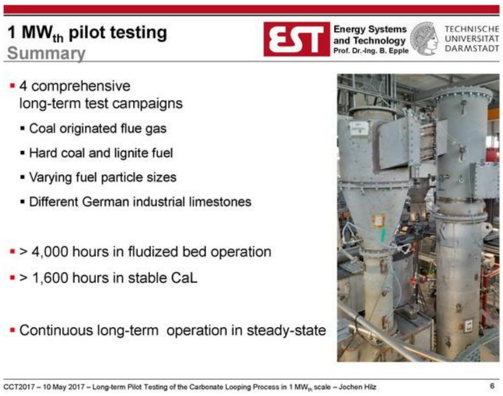


圖 III.1.2-25



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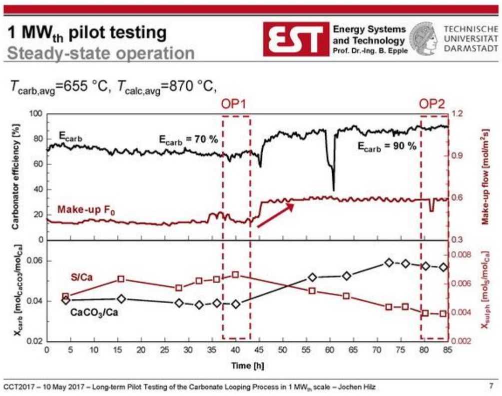

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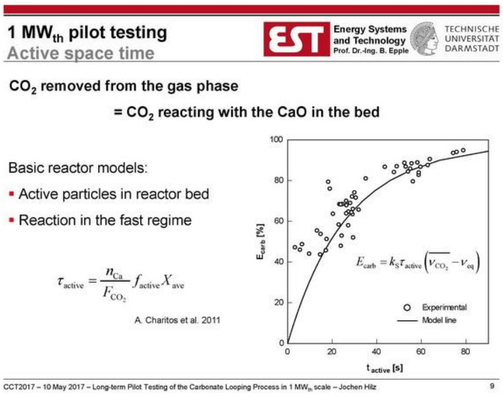

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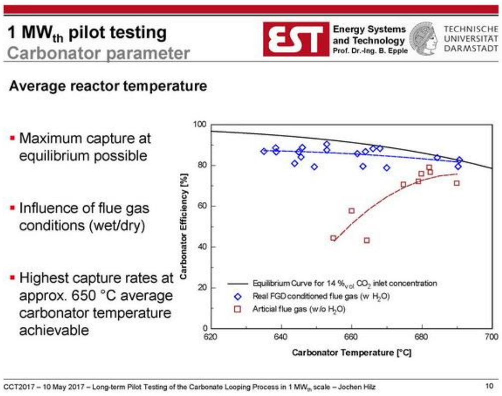

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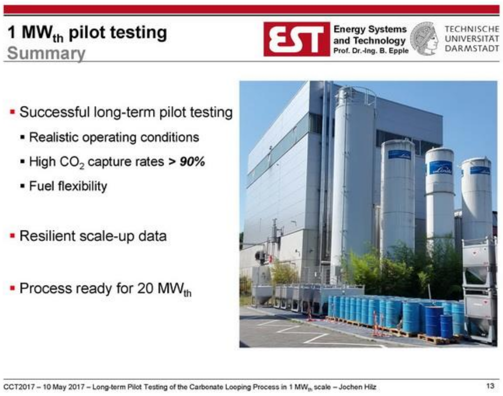
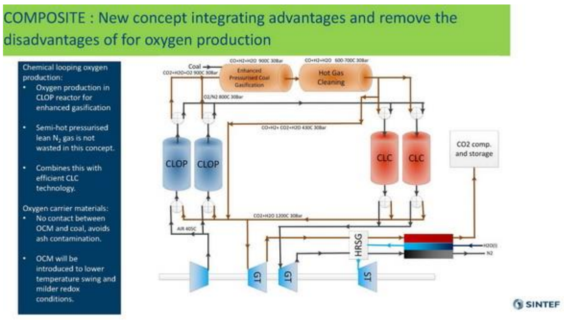


圖 III.1.2-30

論文 (D2-T4-S2-P5)：



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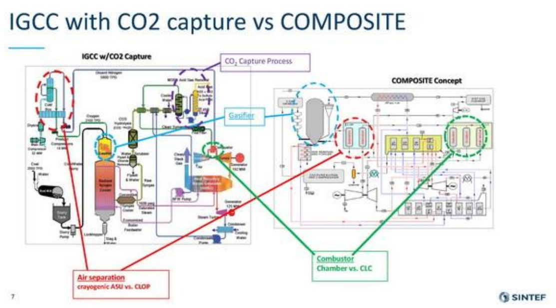
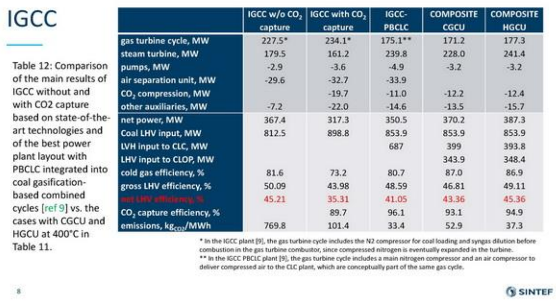


圖 III.1.2-32



	IGCC w/o CO_2 capture	IGCC with CO_2 capture	IGCC-PBCLC	COMPOSITE CGCU	COMPOSITE HGCU
gas turbine cycle, MW	227.5*	234.1*	175.1**	171.2	177.3
steam turbine, MW	179.5	161.2	239.8	228.0	241.4
pumps, MW	-2.9	-3.6	-4.9	-3.2	-3.2
air separation unit, MW	-29.6	-32.7	-33.9		
CO_2 compression, MW		-19.7	-11.0	-12.2	-12.4
other auxiliaries, MW	-7.2	-22.0	-14.6	-13.5	-15.7
net power, MW	367.4	317.3	350.5	370.2	387.3
Coal LHV input, MW	812.5	898.8	853.9	853.9	853.9
LVH input to CLC, MW			687	399	393.8
LHV input to CLOP, MW				343.9	348.4
cold gas efficiency, %	81.6	73.2	80.7	87.0	86.9
gross LHV efficiency, %	50.09	43.98	48.59	46.81	49.11
net LHV efficiency, %	45.21	35.31	41.05	43.36	45.36
CO_2 capture efficiency, %		89.7	96.1	93.1	94.9
emissions, kg_{CO2}/MWh	769.8	101.4	33.4	52.9	37.3

圖 III.1.2-33

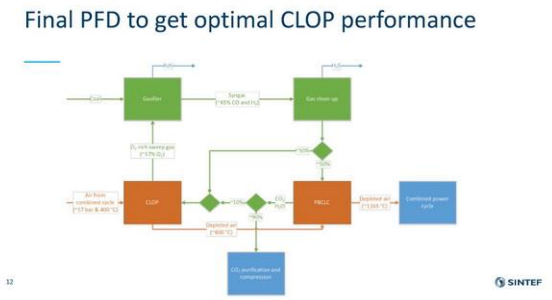
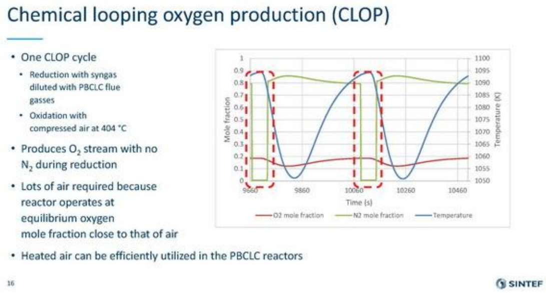


圖 III.1.2-34



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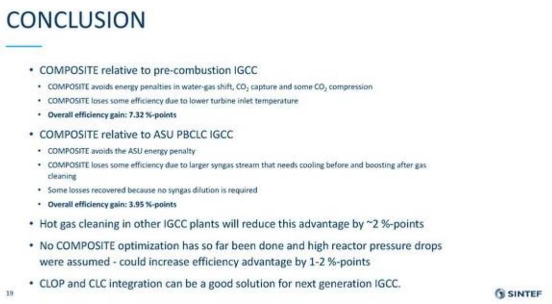
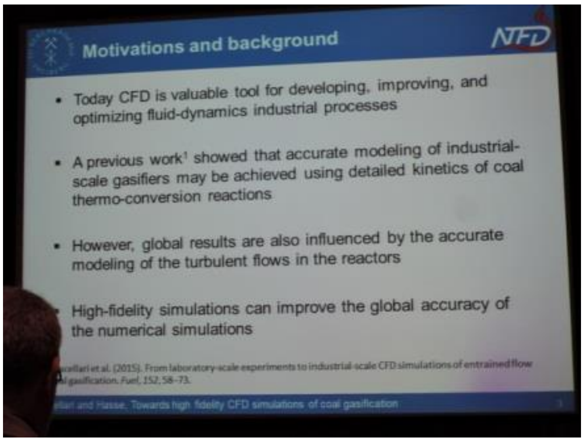


圖 III.1.2-36

論文 (D1-T4-S3-P1)：



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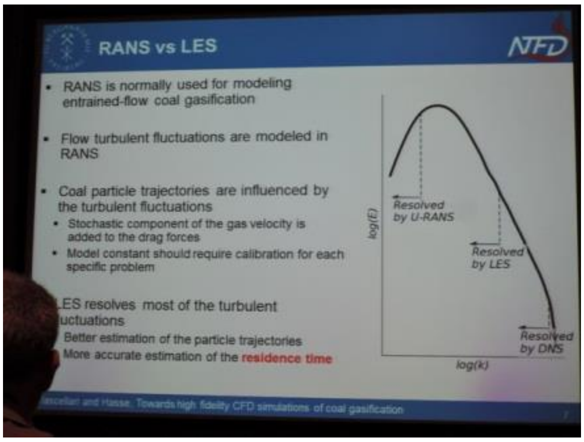
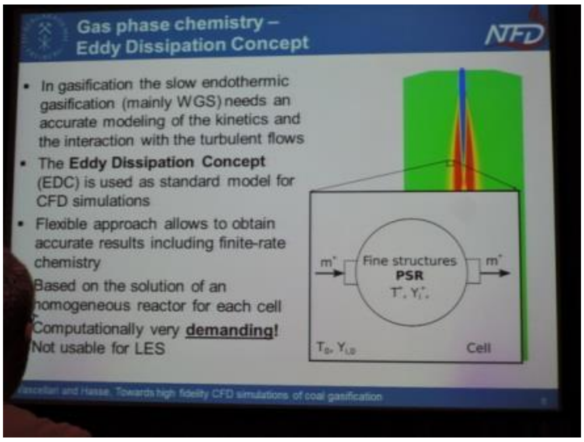


圖 III.1.2-38



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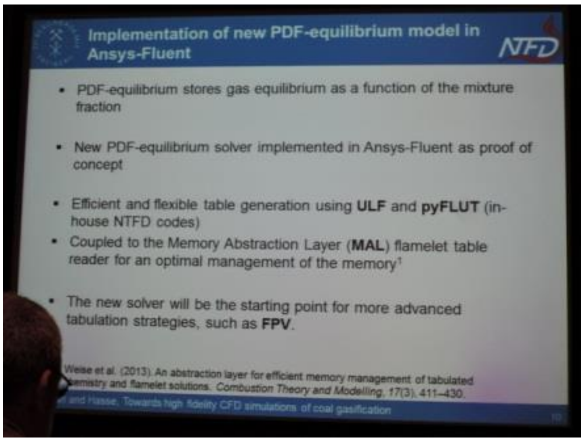


圖 III.1.2-40

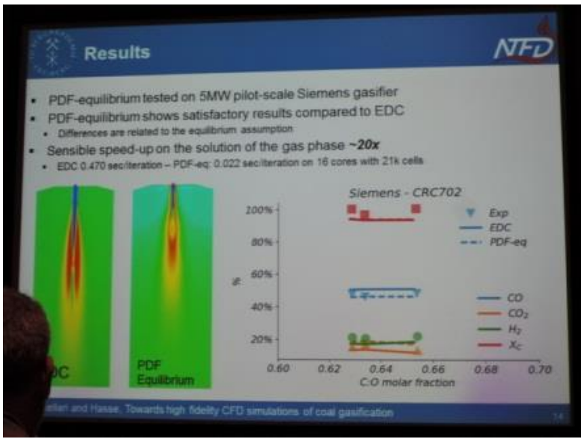


圖 III.1.2-41

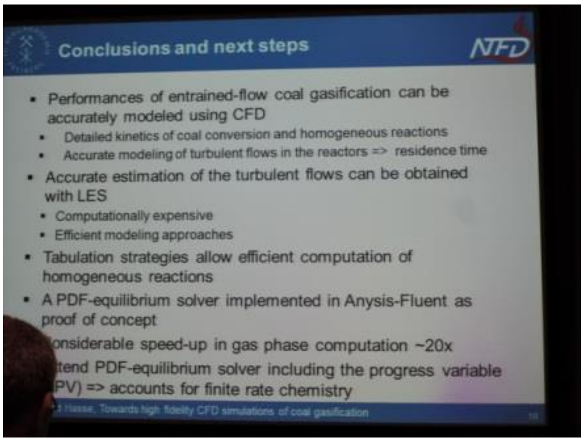
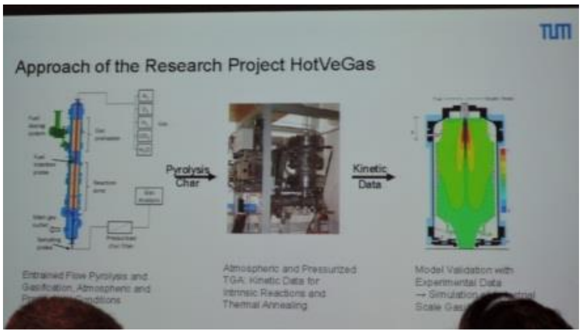


圖 III.1.2-42

論文 (D1-T4-S3-P3)：



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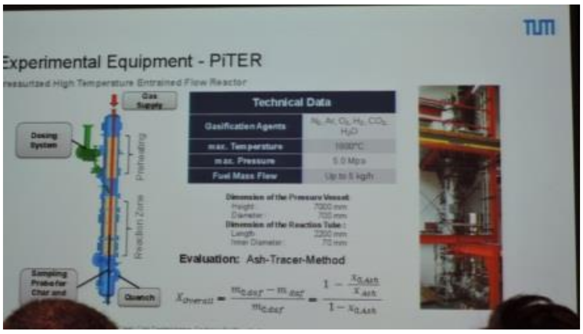

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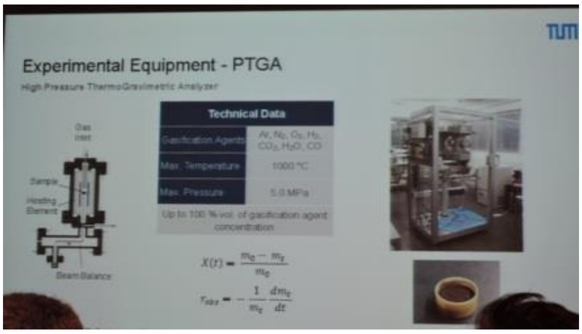

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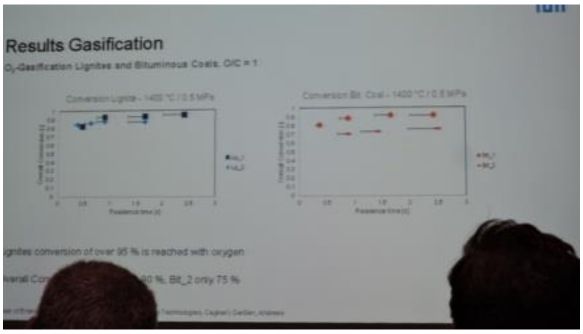

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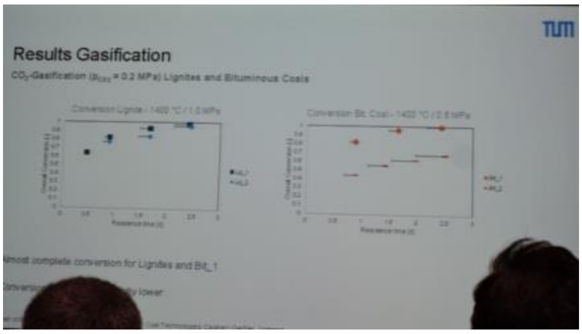

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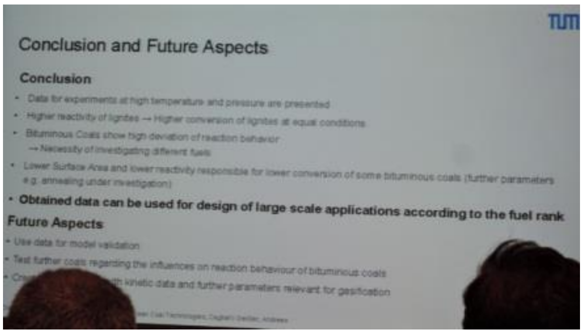


圖 III.1.2-48

論文 (D2-T1-S1-P1)：

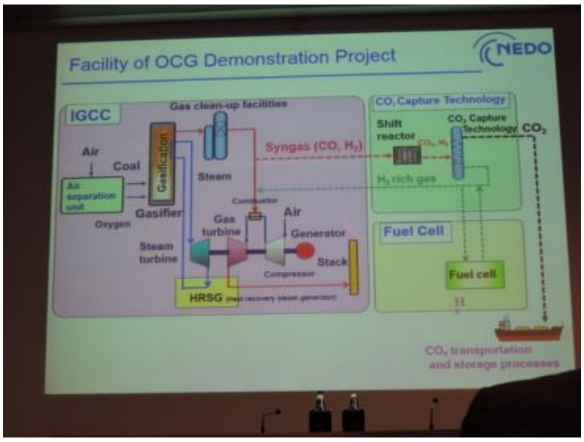
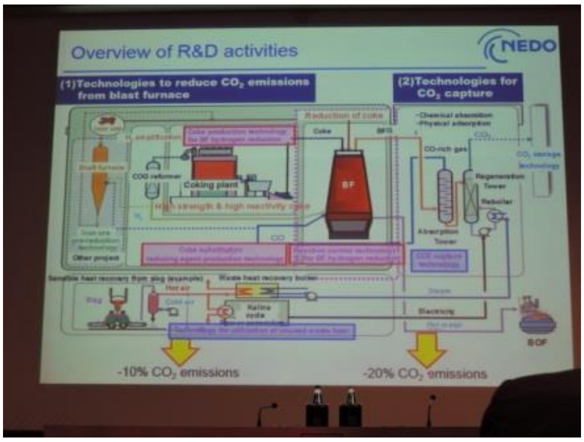


圖 III.1.2-49

圖 III.1.2-50



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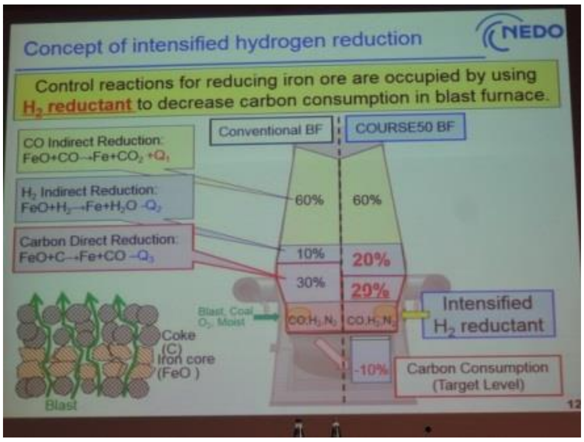

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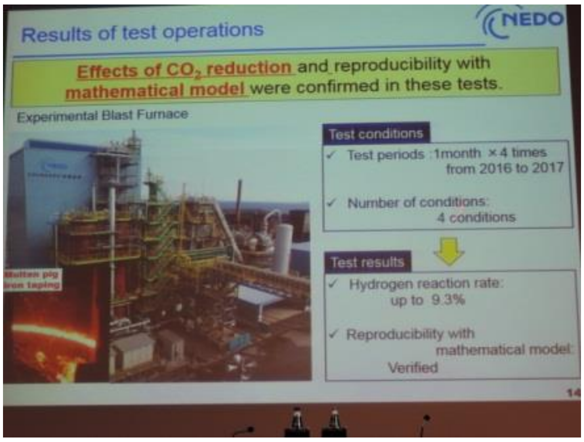

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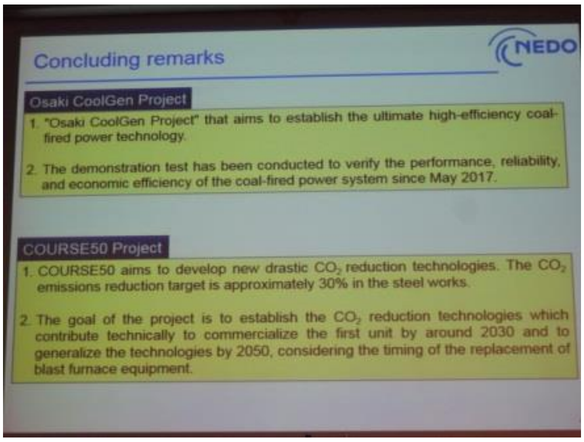

圖 III.1.2-54

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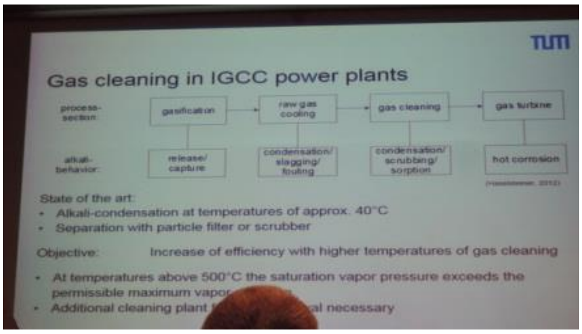

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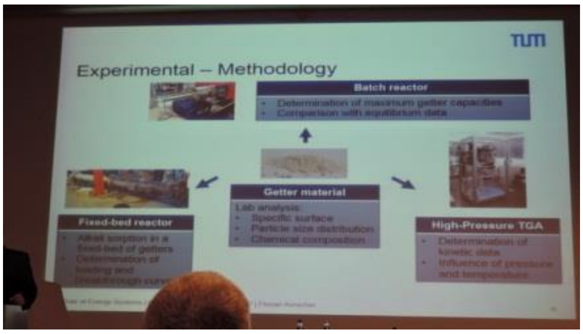

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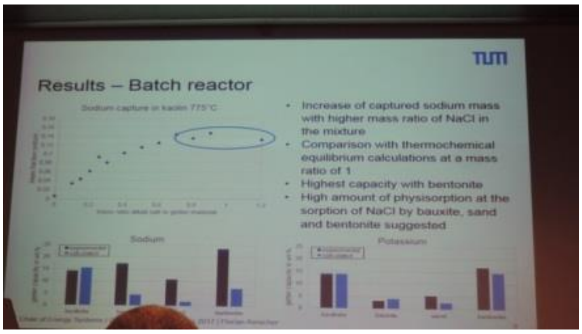

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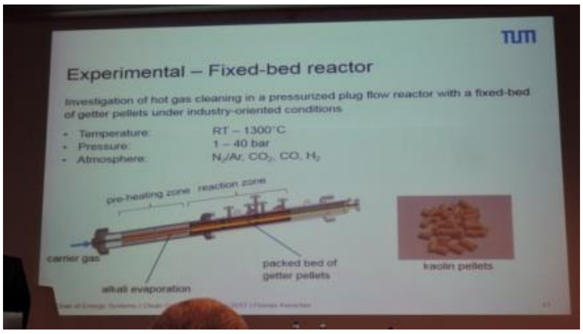

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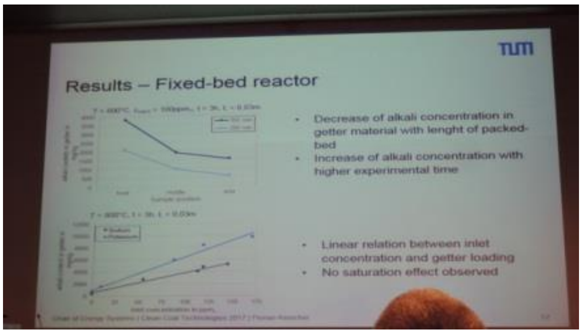


圖 III.1.2-59

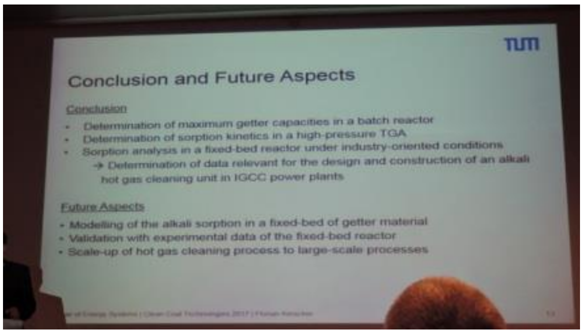
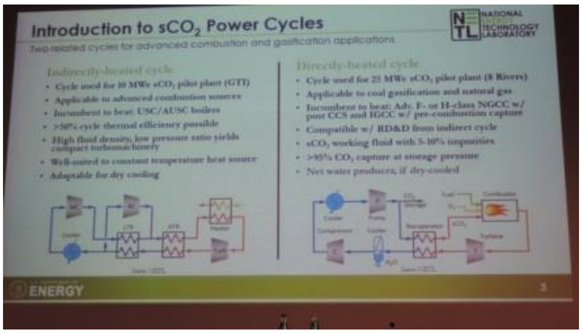


圖 III.1.2-60

論文 (D2-T1-S3-P2)：



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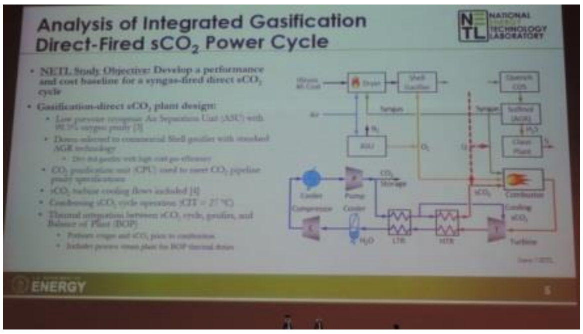

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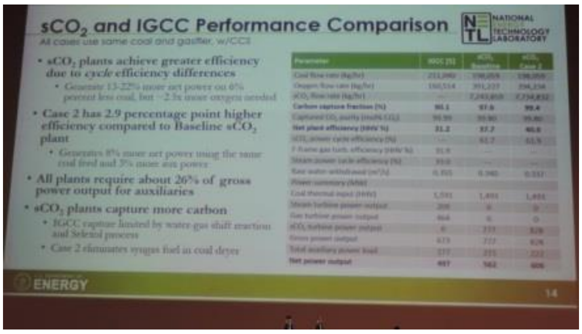

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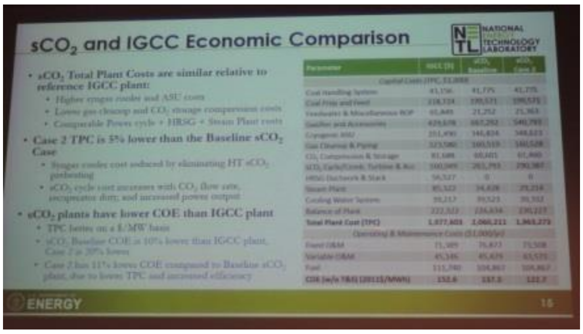

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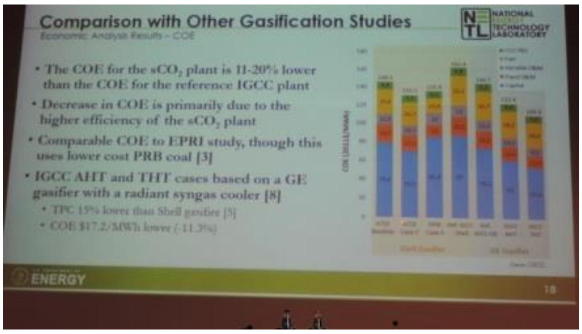

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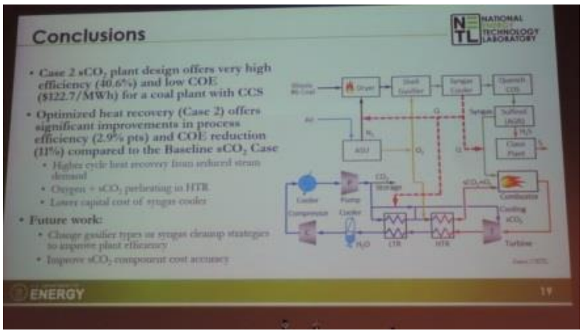
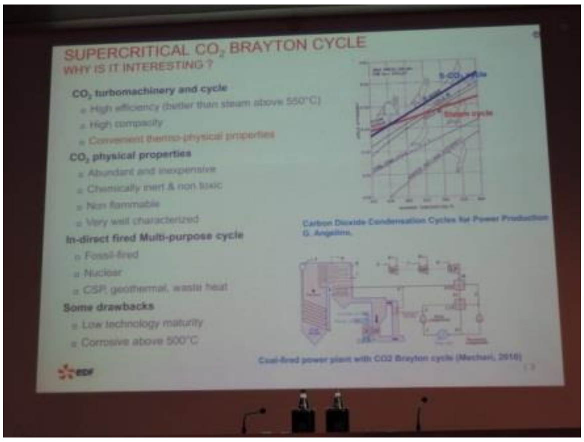


圖 III.1.2-66

論文 (D2-T1-S3-P3)：



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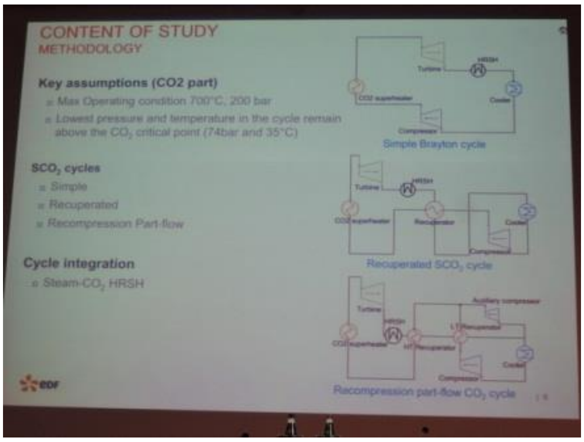


圖 III.1.2-68

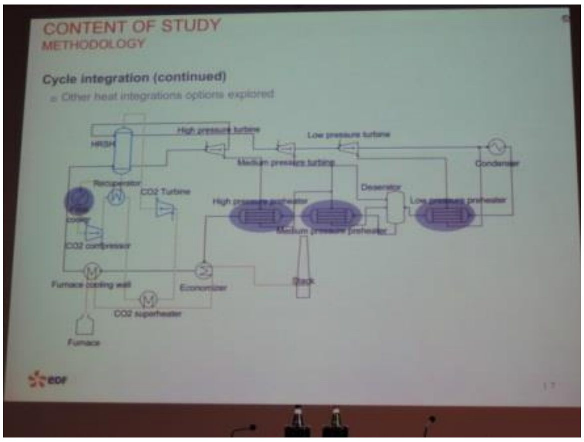


圖 III.1.2-69

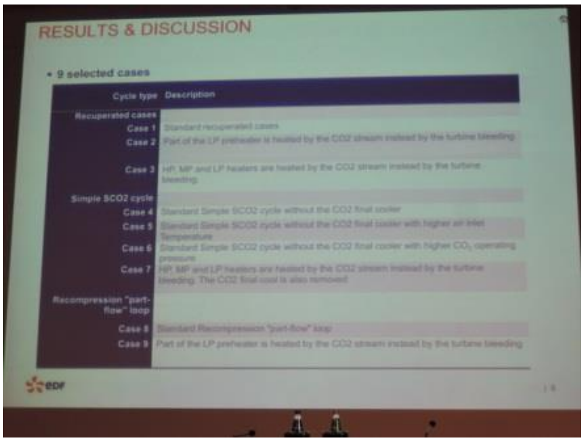


圖 III.1.2-70

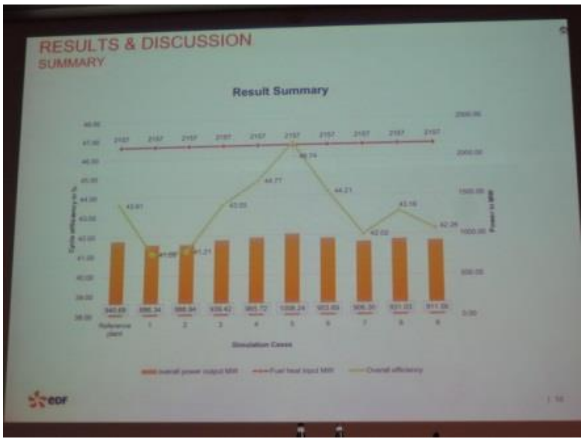


圖 III.1.2-71

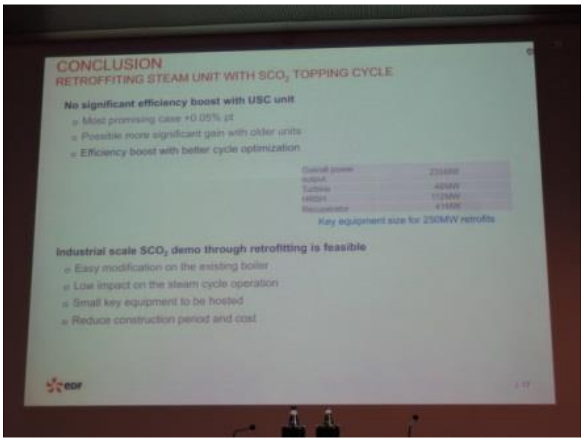


圖 III.1.2-72

3. Poster Session

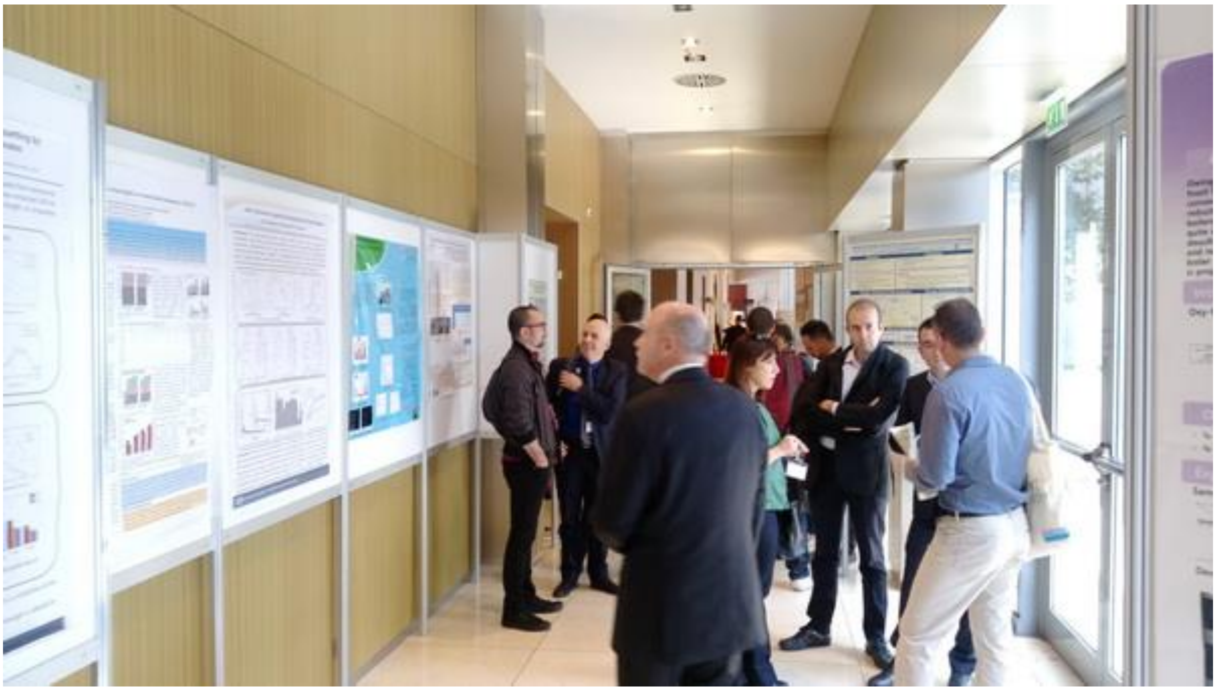
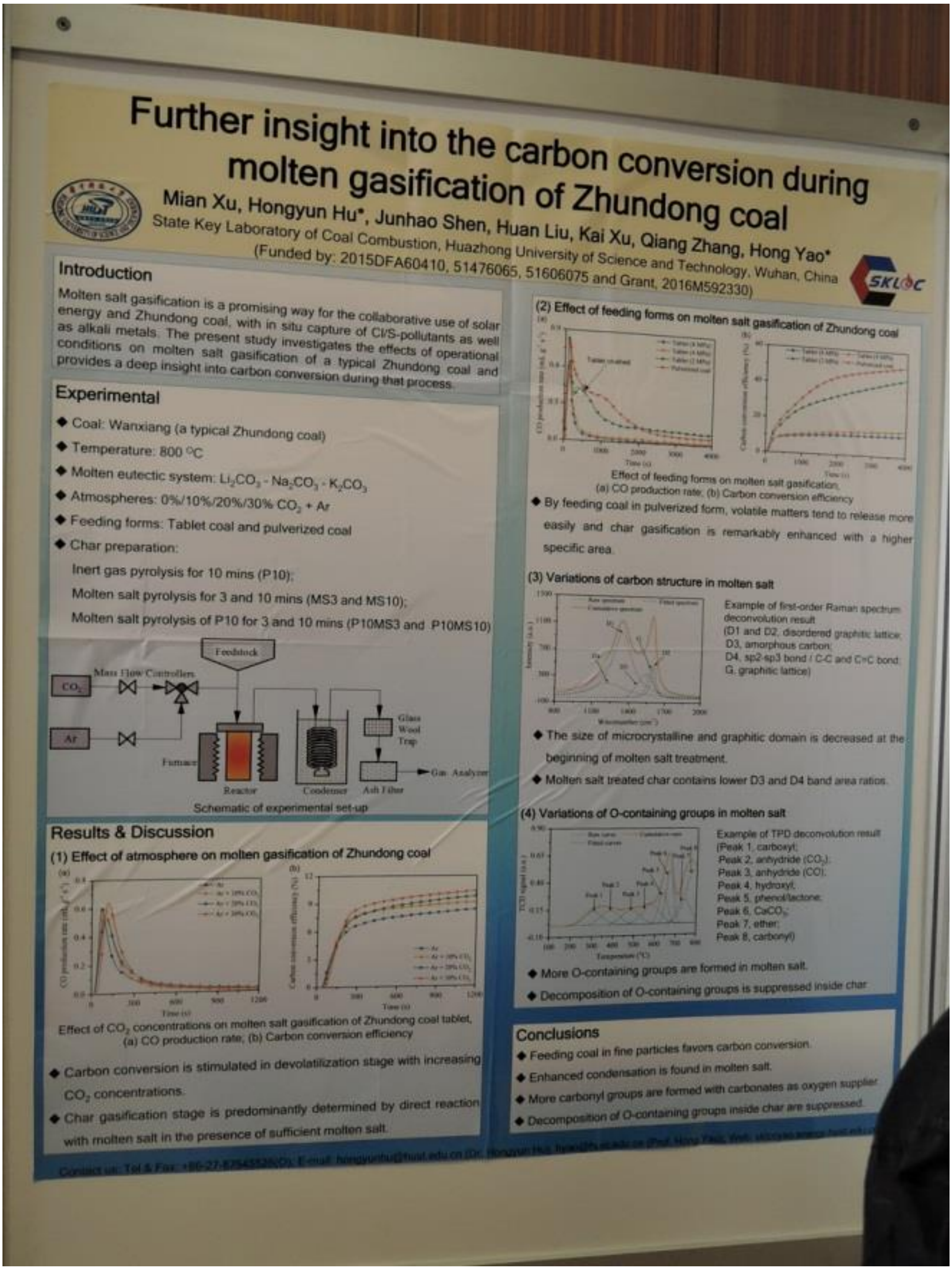


圖 III.1.3-1：


Further insight into the carbon conversion during molten gasification of Zhundong coal
Mian Xu, Hongyun Hu*, Junhao Shen, Huan Liu, Kai Xu, Qiang Zhang, Hong Yao*
State Key Laboratory of Coal Combustion, Huazhong University of Science and Technology, Wuhan, China
(Funded by: 2015DFA60410, 51476065, 51606075 and Grant, 2016M592330)
SKLCC
Introduction
Molten salt gasification is a promising way for the collaborative use of solar energy and Zhundong coal, with in situ capture of Cl/S-pollutants as well as alkali metals. The present study investigates the effects of operational conditions on molten salt gasification of a typical Zhundong coal and provides a deep insight into carbon conversion during that process.
Experimental
Coal: Wanxiang (a typical Zhundong coal)
Temperature: 800 °C
Molten eutectic system: Li2CO3 - Na2CO3 - K2CO3
Atmospheres: 0%/10%/20%/30% CO2 + Ar
Feeding forms: Tablet coal and pulverized coal
Char preparation:
Inert gas pyrolysis for 10 mins (P10);
Molten salt pyrolysis for 3 and 10 mins (MS3 and MS10);
Molten salt pyrolysis of P10 for 3 and 10 mins (P10MS3 and P10MS10)
Feedstock
Mass Flow Controllers
CO2
Ar
Furnace
Reactor
Condenser
Glass Wool Trap
Ash Filter
Gas Analyzer
Schematic of experimental set-up
Results & Discussion
(1) Effect of atmosphere on molten gasification of Zhundong coal
Effect of CO2 concentrations on molten salt gasification of Zhundong coal tablet, (a) CO production rate; (b) Carbon conversion efficiency
Carbon conversion is stimulated in devolatilization stage with increasing CO2 concentrations.
Char gasification stage is predominantly determined by direct reaction with molten salt in the presence of sufficient molten salt.
(2) Effect of feeding forms on molten salt gasification of Zhundong coal
Effect of feeding forms on molten salt gasification, (a) CO production rate; (b) Carbon conversion efficiency
By feeding coal in pulverized form, volatile matters tend to release more easily and char gasification is remarkably enhanced with a higher specific area.
(3) Variations of carbon structure in molten salt
Example of first-order Raman spectrum deconvolution result
(D1 and D2, disordered graphitic lattice;
D3, amorphous carbon;
D4, sp2-sp3 bond / C-C and C=C bond;
G, graphitic lattice)
The size of microcrystalline and graphitic domain is decreased at the beginning of molten salt treatment.
Molten salt treated char contains lower D3 and D4 band area ratios.
(4) Variations of O-containing groups in molten salt
Example of TPD deconvolution result
(Peak 1, carboxyl;
Peak 2, anhydride (CO2);
Peak 3, anhydride (CO);
Peak 4, hydroxyl;
Peak 5, phenol/lactone;
Peak 6, CaCO3;
Peak 7, ether;
Peak 8, carbonyl)
More O-containing groups are formed in molten salt.
Decomposition of O-containing groups is suppressed inside char
Conclusions
Feeding coal in fine particles favors carbon conversion.
Enhanced condensation is found in molten salt.
More carbonyl groups are formed with carbonates as oxygen supplier.
Decomposition of O-containing groups inside char are suppressed.
圖 III.1.3-2：

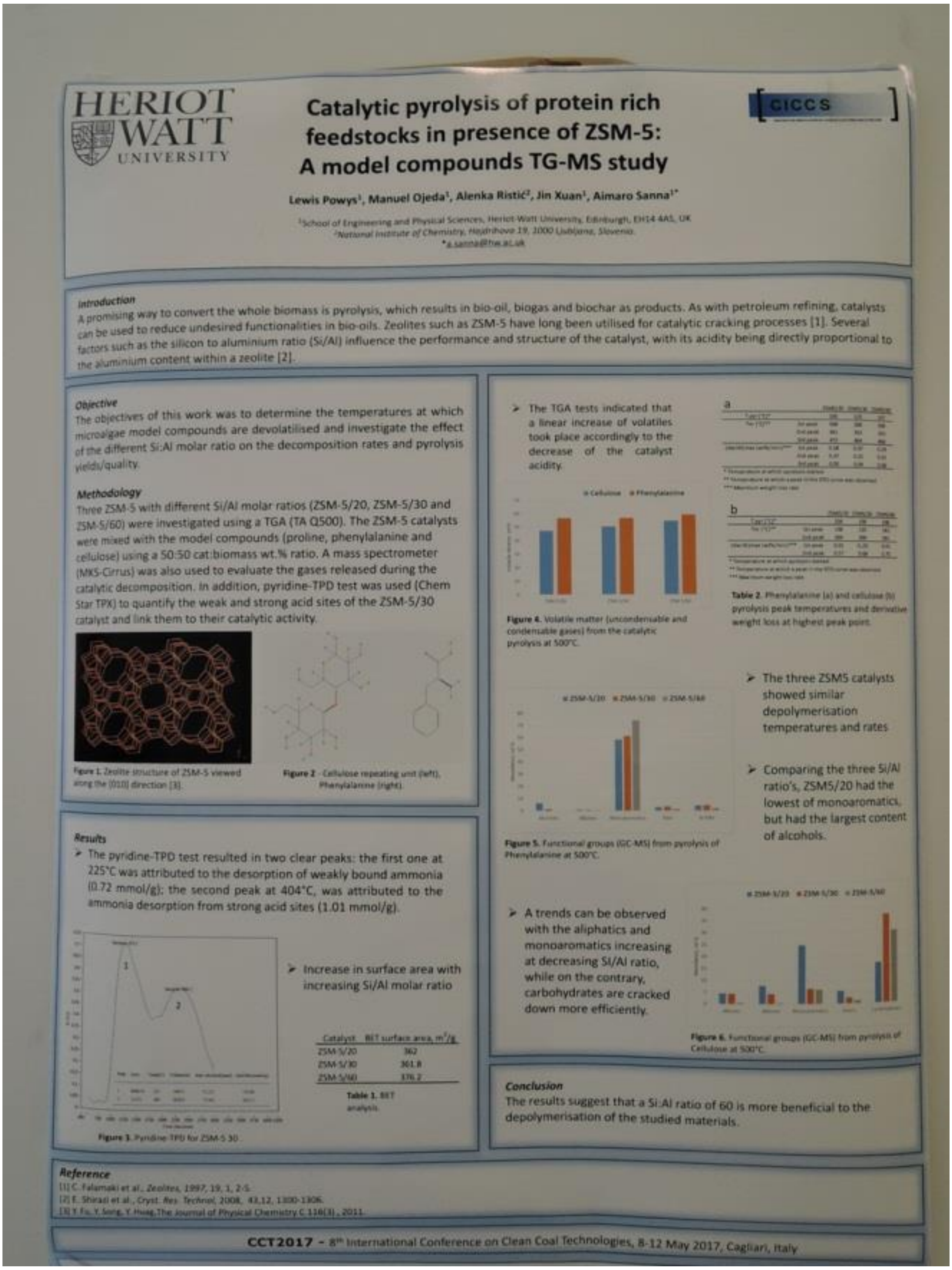

HERIOT WATT UNIVERSITY
Catalytic pyrolysis of protein rich feedstocks in presence of ZSM-5: A model compounds TG-MS study
Lewis Powys1, Manuel Ojeda1, Alenka Ristić2, Jin Xuan1, Aimaro Sanna1*
CICCS
Introduction
A promising way to convert the whole biomass is pyrolysis, which results in bio-oil, biogas and biochar as products. As with petroleum refining, catalysts can be used to reduce undesired functionalities in bio-oils. Zeolites such as ZSM-5 have long been utilised for catalytic cracking processes [1]. Several factors such as the silicon to aluminium ratio (Si/Al) influence the performance and structure of the catalyst, with its acidity being directly proportional to the aluminium content within a zeolite [2].
Objective
The objectives of this work was to determine the temperatures at which microalgae model compounds are devolatilised and investigate the effect of the different Si:Al molar ratio on the decomposition rates and pyrolysis yields/quality.
Methodology
Three ZSM-5 with different Si/Al molar ratios (ZSM-5/20, ZSM-5/30 and ZSM-5/60) were investigated using a TGA (TA Q500). The ZSM-5 catalysts were mixed with the model compounds (proline, phenylalanine and cellulose) using a 50:50 cat:biomass wt.% ratio. A mass spectrometer (MKS-Cirrus) was also used to evaluate the gases released during the catalytic decomposition. In addition, pyridine-TPD test was used (Chem Star TPX) to quantify the weak and strong acid sites of the ZSM-5/30 catalyst and link them to their catalytic activity.
Figure 1. Zeolite structure of ZSM-5 viewed along the [010] direction [3].
Figure 2 - Cellulose repeating unit (left), Phenylalanine (right).
Results
The pyridine-TPD test resulted in two clear peaks: the first one at 225°C was attributed to the desorption of weakly bound ammonia (0.72 mmol/g); the second peak at 404°C, was attributed to the ammonia desorption from strong acid sites (1.01 mmol/g).
Figure 3. Pyridine-TPD for ZSM-5 30
Increase in surface area with increasing Si/Al molar ratio
Catalyst BET surface area, m2/g
ZSM-5/20 362
ZSM-5/30 361.8
ZSM-5/60 376.2
Table 1. BET analysis
The TGA tests indicated that a linear increase of volatiles took place accordingly to the decrease of the catalyst acidity.
Cellulose Phenylalanine
Figure 4. Volatile matter (uncondensable and condensable gases) from the catalytic pyrolysis at 500°C.
Table 2. Phenylalanine (a) and cellulose (b) pyrolysis peak temperatures and derivative weight loss at highest peak point.
ZSM-5/20 ZSM-5/30 ZSM-5/60
Figure 5. Functional groups (GC-MS) from pyrolysis of Phenylalanine at 500°C.
The three ZSM5 catalysts showed similar depolymerisation temperatures and rates
Comparing the three Si/Al ratio's, ZSM5/20 had the lowest of monoaromatics, but had the largest content of alcohols.
A trends can be observed with the aliphatics and monoaromatics increasing at decreasing Si/Al ratio, while on the contrary, carbohydrates are cracked down more efficiently.
Figure 6. Functional groups (GC-MS) from pyrolysis of Cellulose at 500°C.
Conclusion
The results suggest that a Si:Al ratio of 60 is more beneficial to the depolymerisation of the studied materials.
Reference
CCT2017 - 8th International Conference on Clean Coal Technologies, 8-12 May 2017, Cagliari, Italy

圖 III.1.3-3：

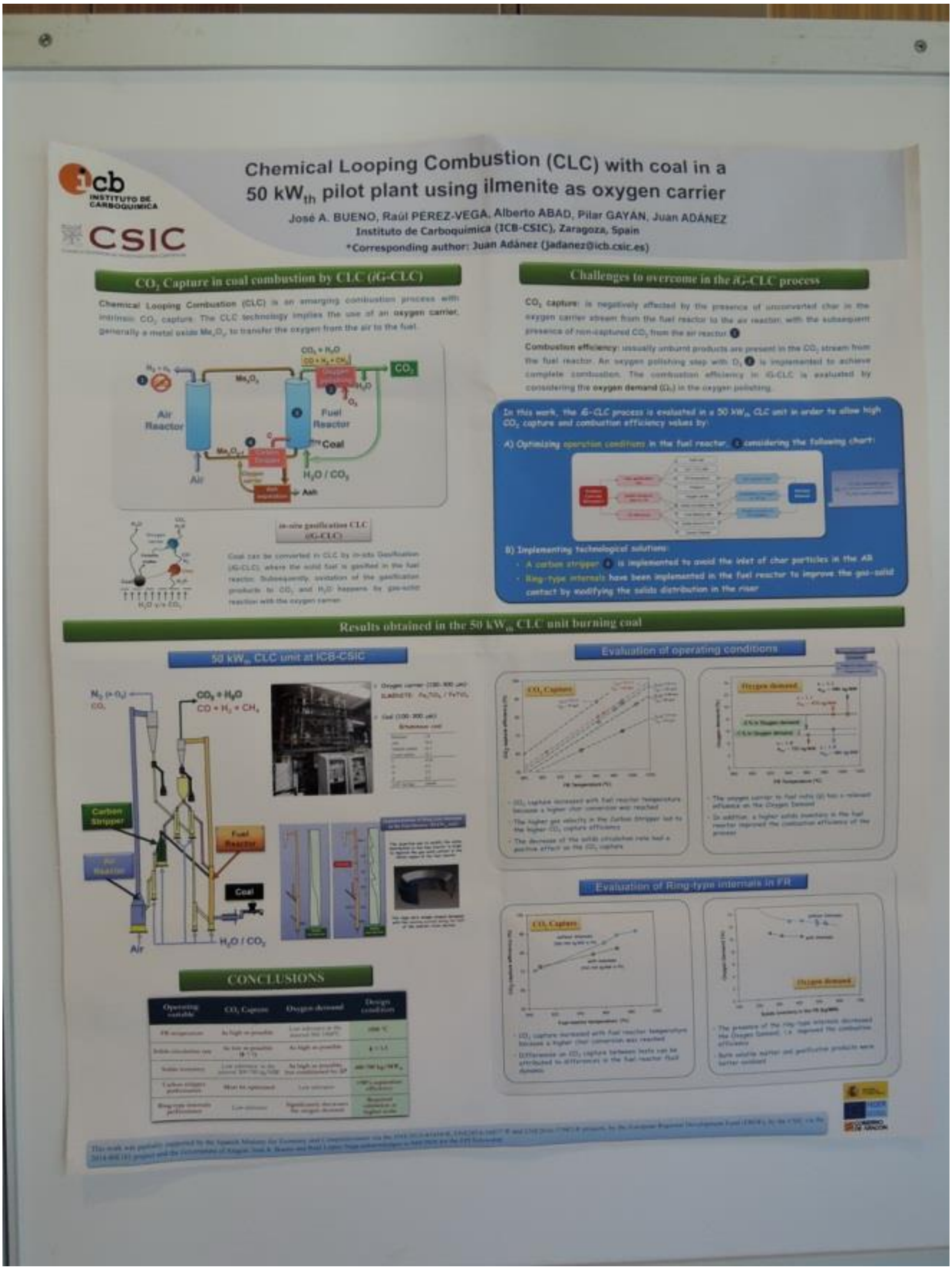

icb INSTITUTO DE CARBOQUIMICA
CSIC
Chemical Looping Combustion (CLC) with coal in a
50 kWth pilot plant using ilmenite as oxygen carrier
José A. BUENO, Raúl PEREZ-VEGA, Alberto ABAD, Pilar GAYAN, Juan ADÁNEZ
Instituto de Carboquímica (ICB-CSIC), Zaragoza, Spain
*Corresponding author: Juan Adánez (jadanez@icb.csic.es)
CO2 Capture in coal combustion by CLC (iG-CLC)
Chemical Looping Combustion (CLC) is an emerging combustion process with intrinsic CO2 capture. The CLC technology implies the use of an oxygen carrier, generally a metal oxide MexOy, to transfer the oxygen from the air to the fuel.
Air Reactor
Fuel Reactor
Coal
Air
H2O / CO2
Ash
CO2
Challenges to overcome in the iG-CLC process
Results obtained in the 50 kWth CLC unit burning coal
50 kWth CLC unit at ICB-CSIC
Carbon Stripper
Fuel Reactor
Air Reactor
Coal
Air
H2O / CO2
Evaluation of operating conditions
Evaluation of Ring-type internals in FR
CONCLUSIONS

圖 III.1.3-4：

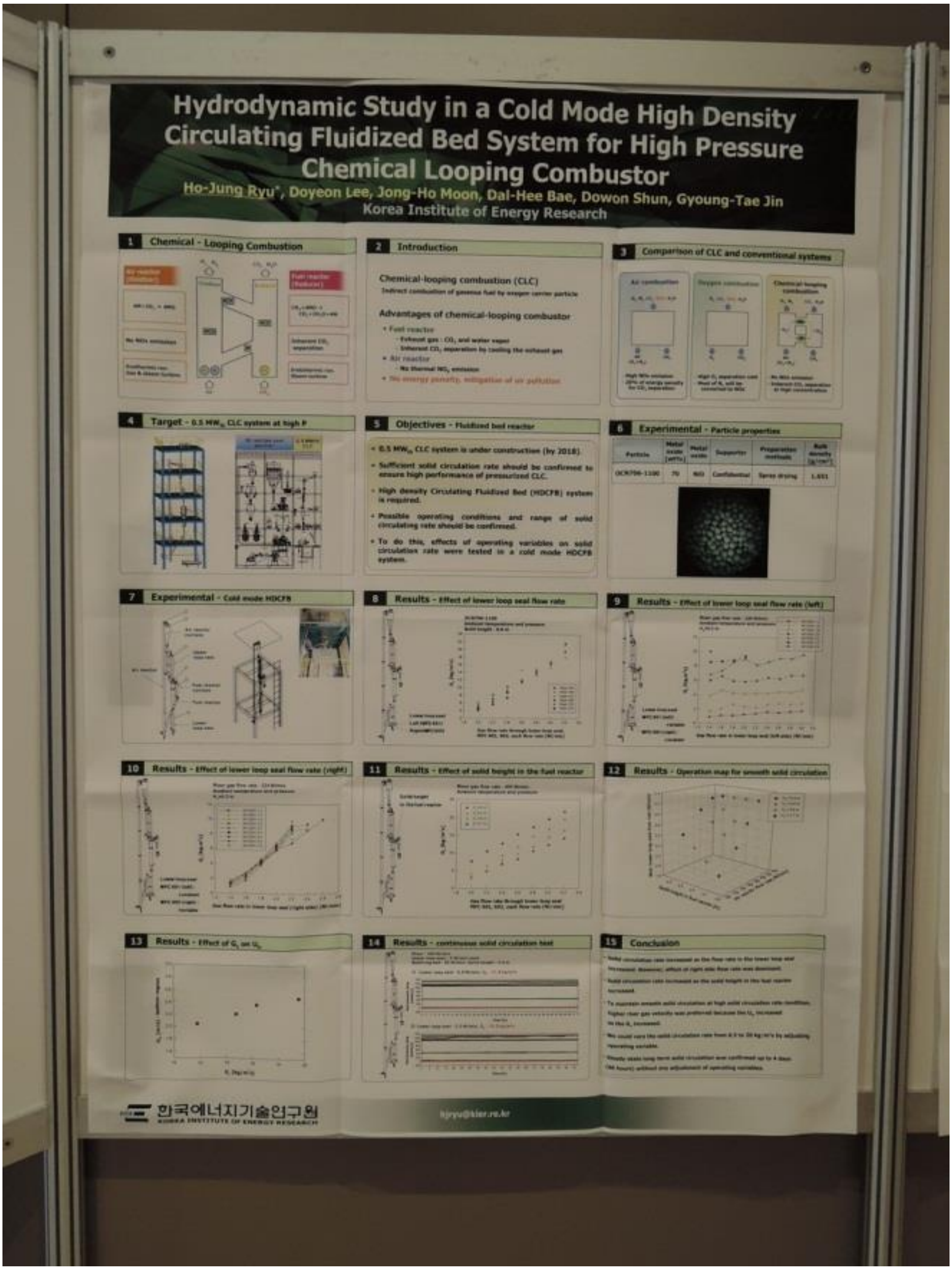

Hydrodynamic Study in a Cold Mode High Density Circulating Fluidized Bed System for High Pressure Chemical Looping Combustor
Ho-Jung Ryu*, Doyeon Lee, Jong-Ho Moon, Dal-Hee Bae, Dowon Shun, Gyoung-Tae Jin
Korea Institute of Energy Research
1 Chemical - Looping Combustion
2 Introduction
Chemical-looping combustion (CLC)
Advantages of chemical-looping combustor
3 Comparison of CLC and conventional systems
4 Target
5 Objectives - Fluidized bed reactor
6 Experimental - Particle properties
7 Experimental
8 Results
9 Results
10 Results
11 Results
12 Results
13 Results
14 Results
15 Conclusion
한국에너지기술연구원

圖 III.1.3-5：

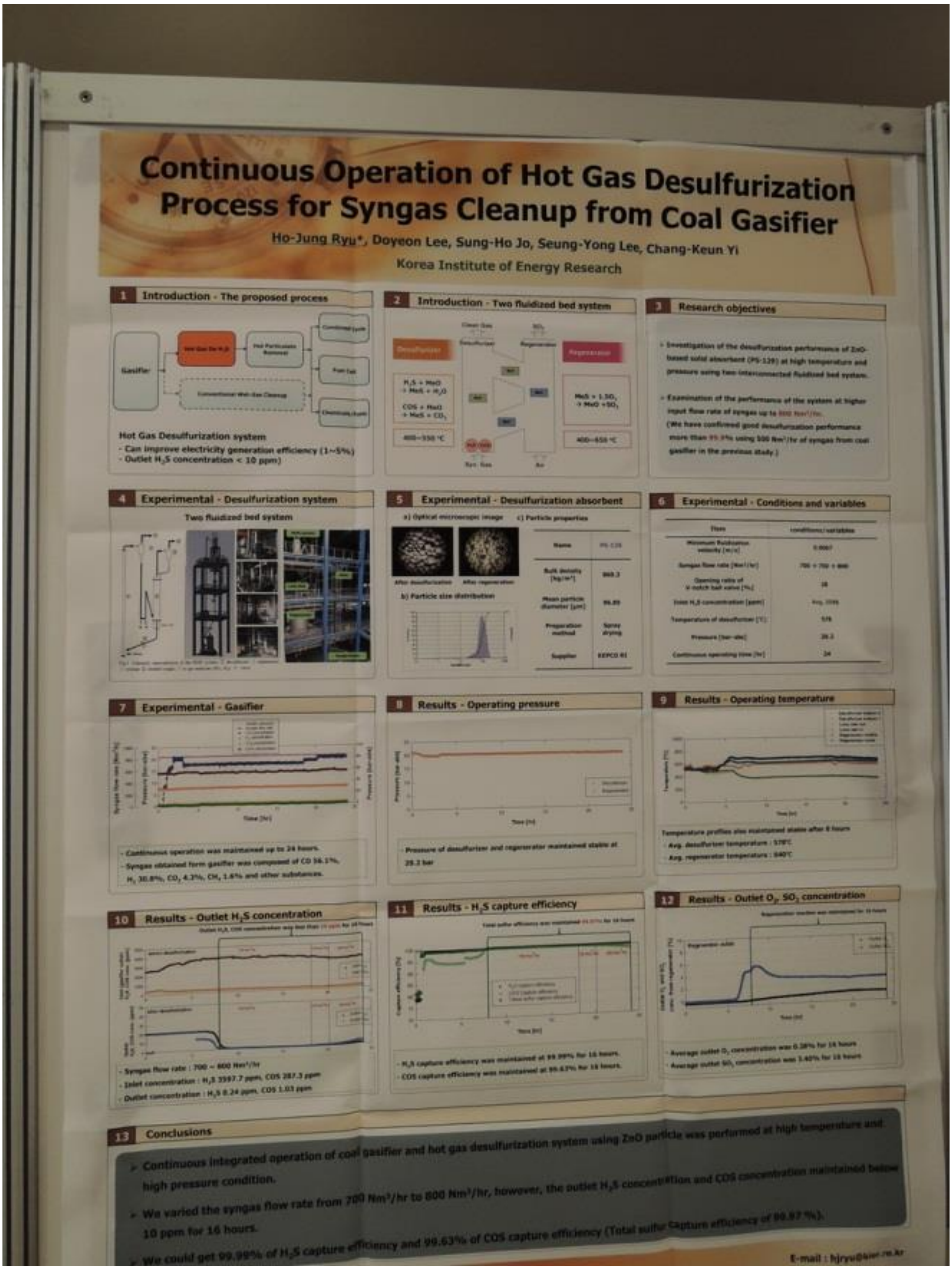

Continuous Operation of Hot Gas Desulfurization Process for Syngas Cleanup from Coal Gasifier
Ho-Jung Ryu*, Doyeon Lee, Sung-Ho Jo, Seung-Yong Lee, Chang-Keun Yi
Korea Institute of Energy Research
1 Introduction - The proposed process
Hot Gas Desulfurization system
- Can improve electricity generation efficiency (1~5%)
- Outlet H2S concentration < 10 ppm)
2 Introduction - Two fluidized bed system
3 Research objectives
4 Experimental - Desulfurization system
Two fluidized bed system
5 Experimental - Desulfurization absorbent
6 Experimental - Conditions and variables
7 Experimental - Gasifier
8 Results - Operating pressure
9 Results - Operating temperature
10 Results - Outlet H2S concentration
11 Results - H2S capture efficiency
12 Results - Outlet O2, SO2 concentration
13 Conclusions
Continuous integrated operation of coal gasifier and hot gas desulfurization system using ZnO particle was performed at high temperature and high pressure condition.
We varied the syngas flow rate from 700 Nm3/hr to 800 Nm3/hr, however, the outlet H2S concentration and COS concentration maintained below 10 ppm for 16 hours.
We could get 99.99% of H2S capture efficiency and 99.63% of COS capture efficiency (Total sulfur capture efficiency of 99.87 %).

圖 III.1.3-6：

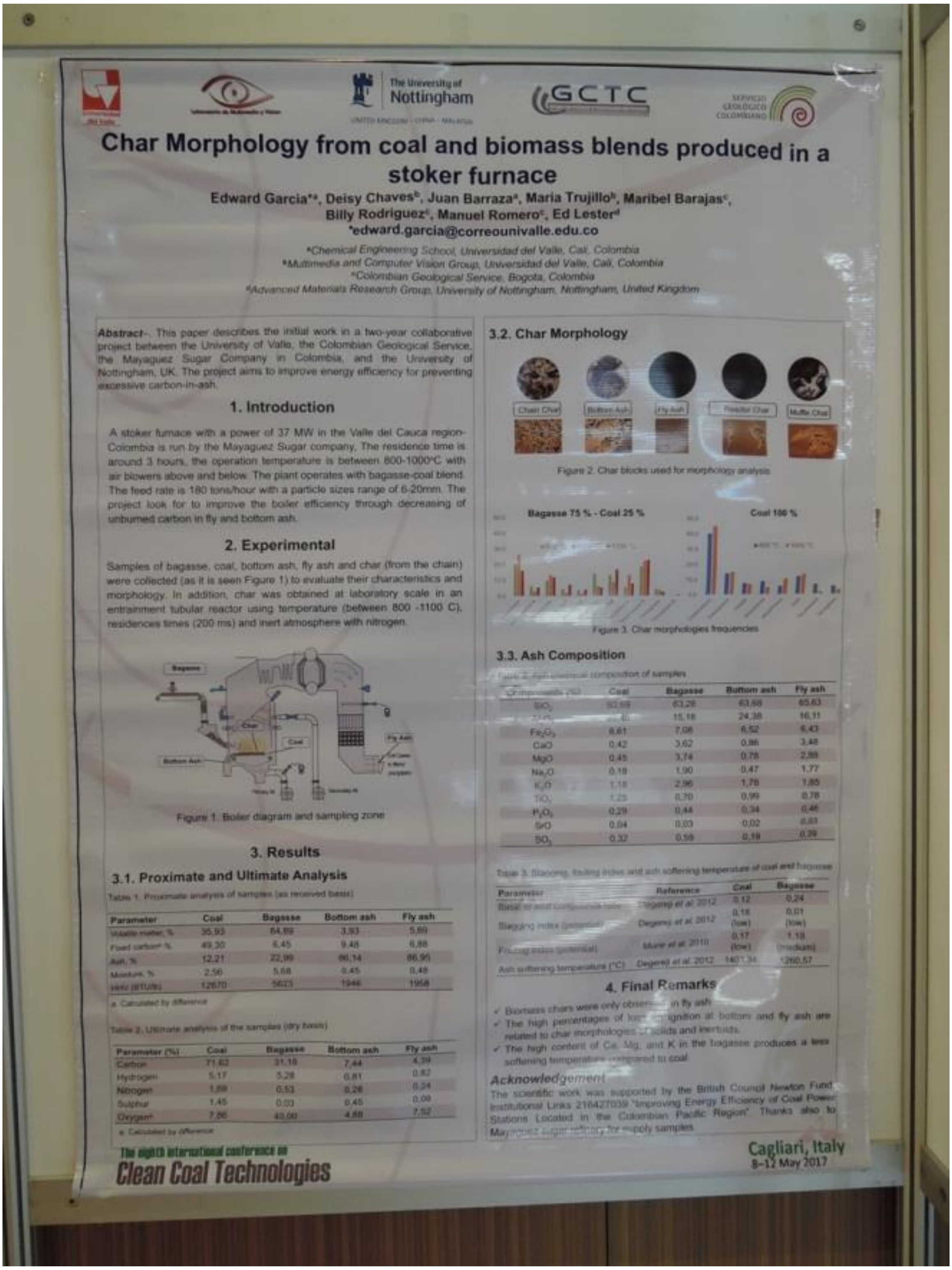
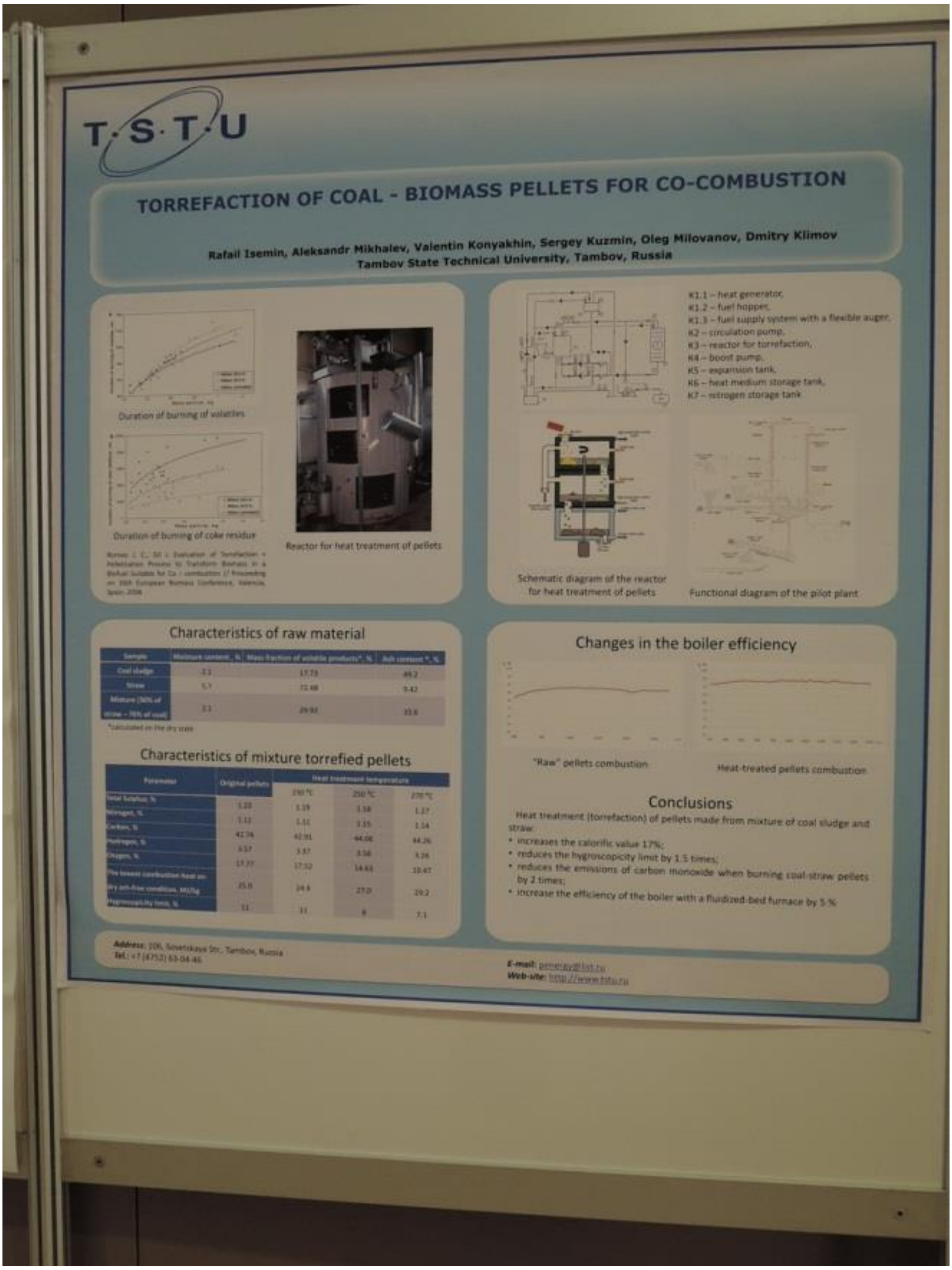

The University of Nottingham
GCTC
Char Morphology from coal and biomass blends produced in a stoker furnace
Edward Garcia*a, Deisy Chavesb, Juan Barrazaa, Maria Trujillob, Maribel Barajasc, Billy Rodriguezc, Manuel Romeroc, Ed Lesterd
*edward.garcia@correounivalle.edu.co
aChemical Engineering School, Universidad del Valle, Cali, Colombia
bMultimedia and Computer Vision Group, Universidad del Valle, Cali, Colombia
cColombian Geological Service, Bogota, Colombia
dAdvanced Materials Research Group, University of Nottingham, Nottingham, United Kingdom
Abstract-. This paper describes the initial work in a two-year collaborative project between the University of Valle, the Colombian Geological Service, the Mayaguez Sugar Company in Colombia, and the University of Nottingham, UK. The project aims to improve energy efficiency for preventing excessive carbon-in-ash.
1. Introduction
A stoker furnace with a power of 37 MW in the Valle del Cauca region-Colombia is run by the Mayaguez Sugar company. The residence time is around 3 hours, the operation temperature is between 800-1000°C with air blowers above and below. The plant operates with bagasse-coal blend. The feed rate is 180 tons/hour with a particle sizes range of 6-20mm. The project look for to improve the boiler efficiency through decreasing of unburned carbon in fly and bottom ash.
2. Experimental
Samples of bagasse, coal, bottom ash, fly ash and char (from the chain) were collected (as it is seen Figure 1) to evaluate their characteristics and morphology. In addition, char was obtained at laboratory scale in an entrainment tubular reactor using temperature (between 800 -1100 C), residences times (200 ms) and inert atmosphere with nitrogen.
Figure 1. Boiler diagram and sampling zone
3. Results
3.1. Proximate and Ultimate Analysis
3.2. Char Morphology
Figure 2. Char blocks used for morphology analysis
Bagasse 75 % - Coal 25 %
Coal 100 %
Figure 3. Char morphologies frequencies
3.3. Ash Composition
4. Final Remarks
Acknowledgement
The eighth international conference on
Clean Coal Technologies
Cagliari, Italy
8-12 May 2017

圖 III.1.3-7：


T·S·T·U
TORREFACTION OF COAL - BIOMASS PELLETS FOR CO-COMBUSTION
Rafail Isemin, Aleksandr Mikhalev, Valentin Konyakhin, Sergey Kuzmin, Oleg Milovanov, Dmitry Klimov
Tambov State Technical University, Tambov, Russia
Duration of burning of volatiles
Duration of burning of coke residue
Reactor for heat treatment of pellets
K1.1 – heat generator,
K1.2 – fuel hopper,
K1.3 – fuel supply system with a flexible auger,
K2 – circulation pump,
K3 – reactor for torrefaction,
K4 – boost pump,
K5 – expansion tank,
K6 – heat medium storage tank,
K7 – nitrogen storage tank
Schematic diagram of the reactor for heat treatment of pellets
Functional diagram of the pilot plant
Characteristics of raw material
Characteristics of mixture torrefied pellets
Changes in the boiler efficiency
"Raw" pellets combustion
Heat-treated pellets combustion
Conclusions
Heat treatment (torrefaction) of pellets made from mixture of coal sludge and straw:
• increases the calorific value 17%;
• reduces the hygroscopicity limit by 1.5 times;
• reduces the emissions of carbon monoxide when burning coal-straw pellets by 2 times;
• increase the efficiency of the boiler with a fluidized-bed furnace by 5 %
圖 III.1.3-8：

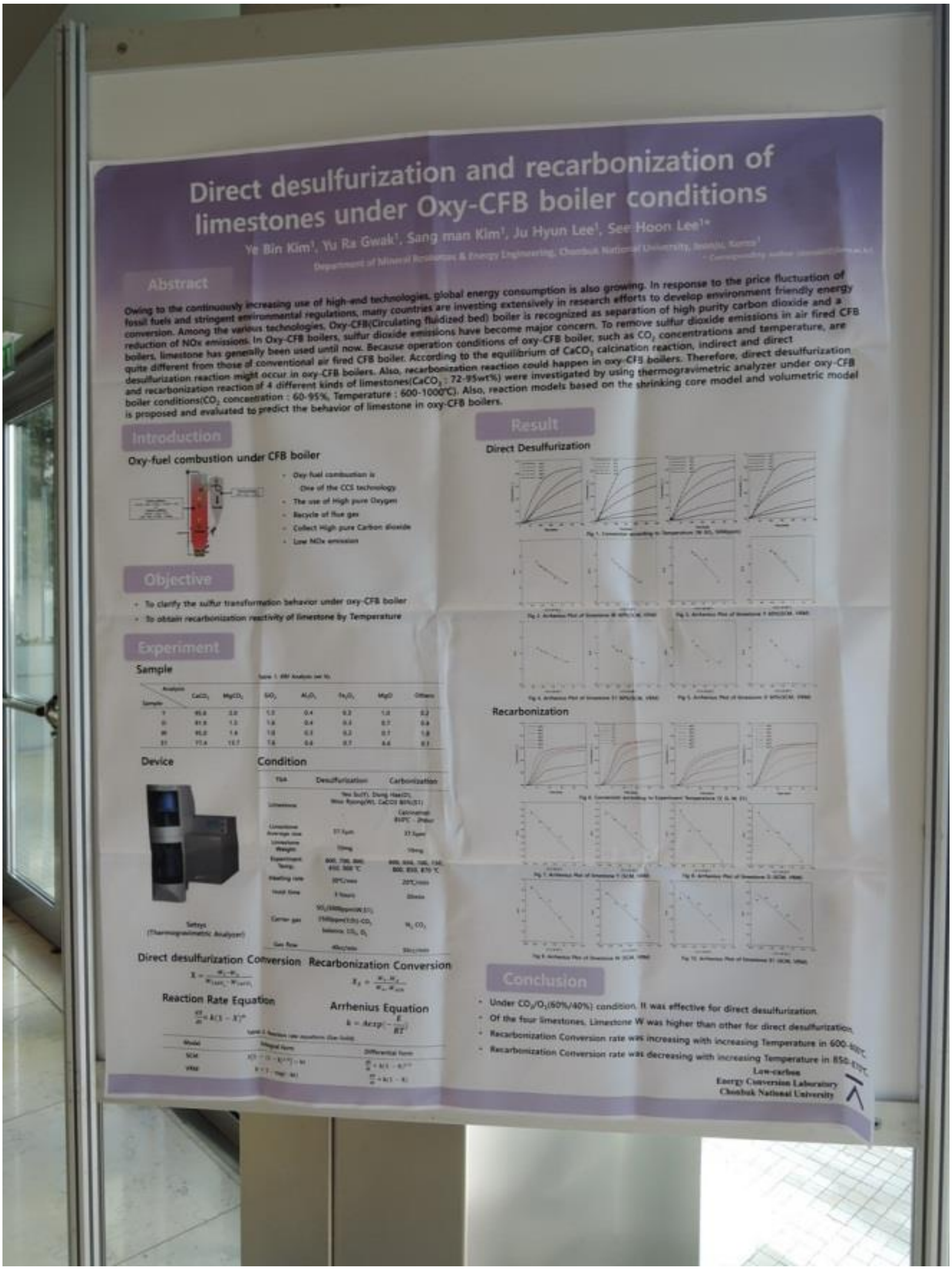

Direct desulfurization and recarbonization of limestones under Oxy-CFB boiler conditions
Ye Bin Kim[1], Yu Ra Gwak[1], Sang man Kim[1], Ju Hyun Lee[1], See Hoon Lee[1*]
Abstract
Introduction
Oxy-fuel combustion under CFB boiler
Objective
To clarify the sulfur transformation behavior under oxy-CFB boiler
To obtain recarbonization reactivity of limestone by Temperature
Experiment
Sample
Device
Condition
Direct desulfurization Conversion
Recarbonization Conversion
Reaction Rate Equation
Arrhenius Equation
Result
Direct Desulfurization
Recarbonization
Conclusion
Of the four limestones, Limestone W was higher than other for direct desulfurization
Low-carbon
Energy Conversion Laboratory
Chonbuk National University

圖 III.1.3-9：

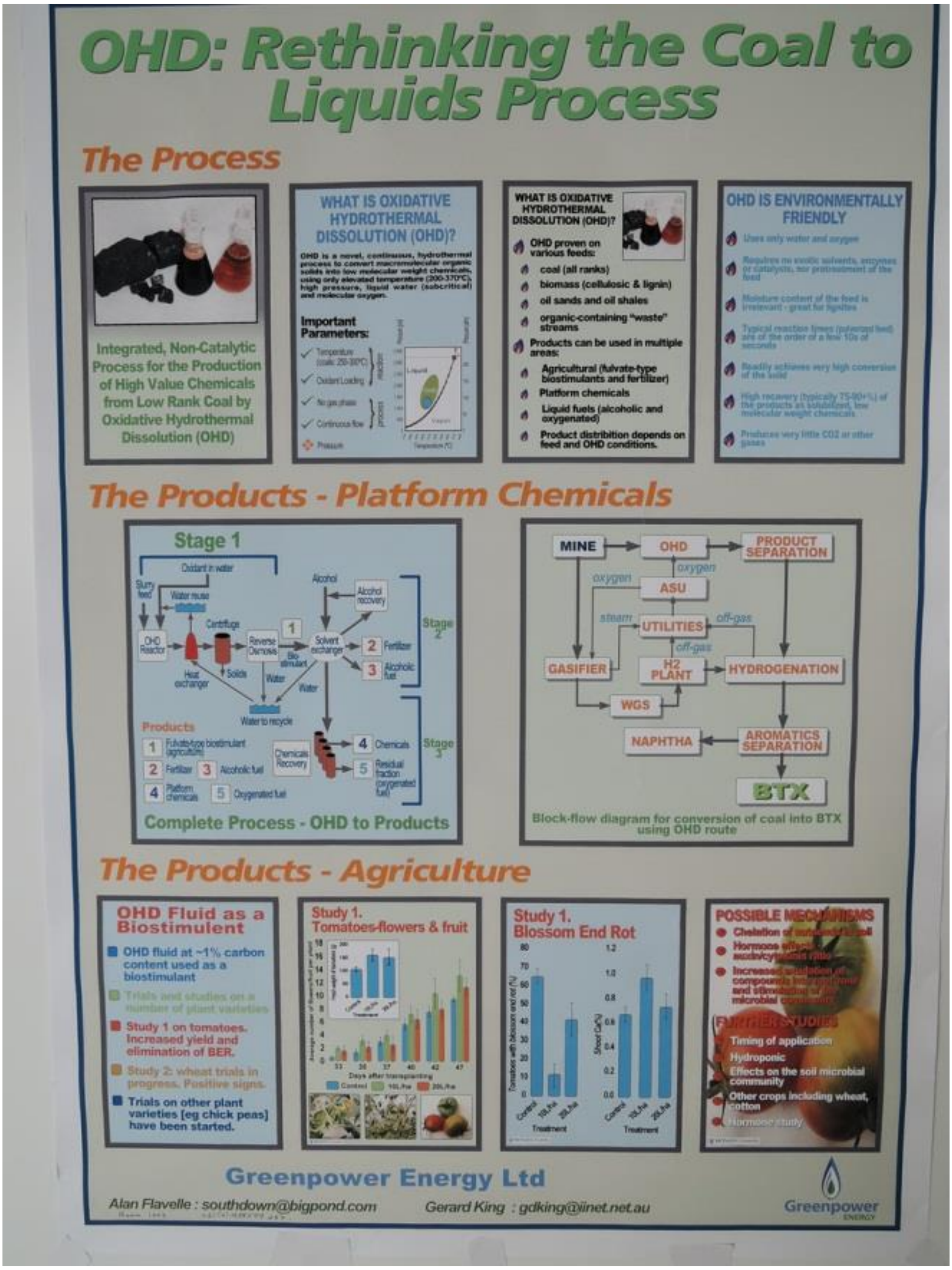
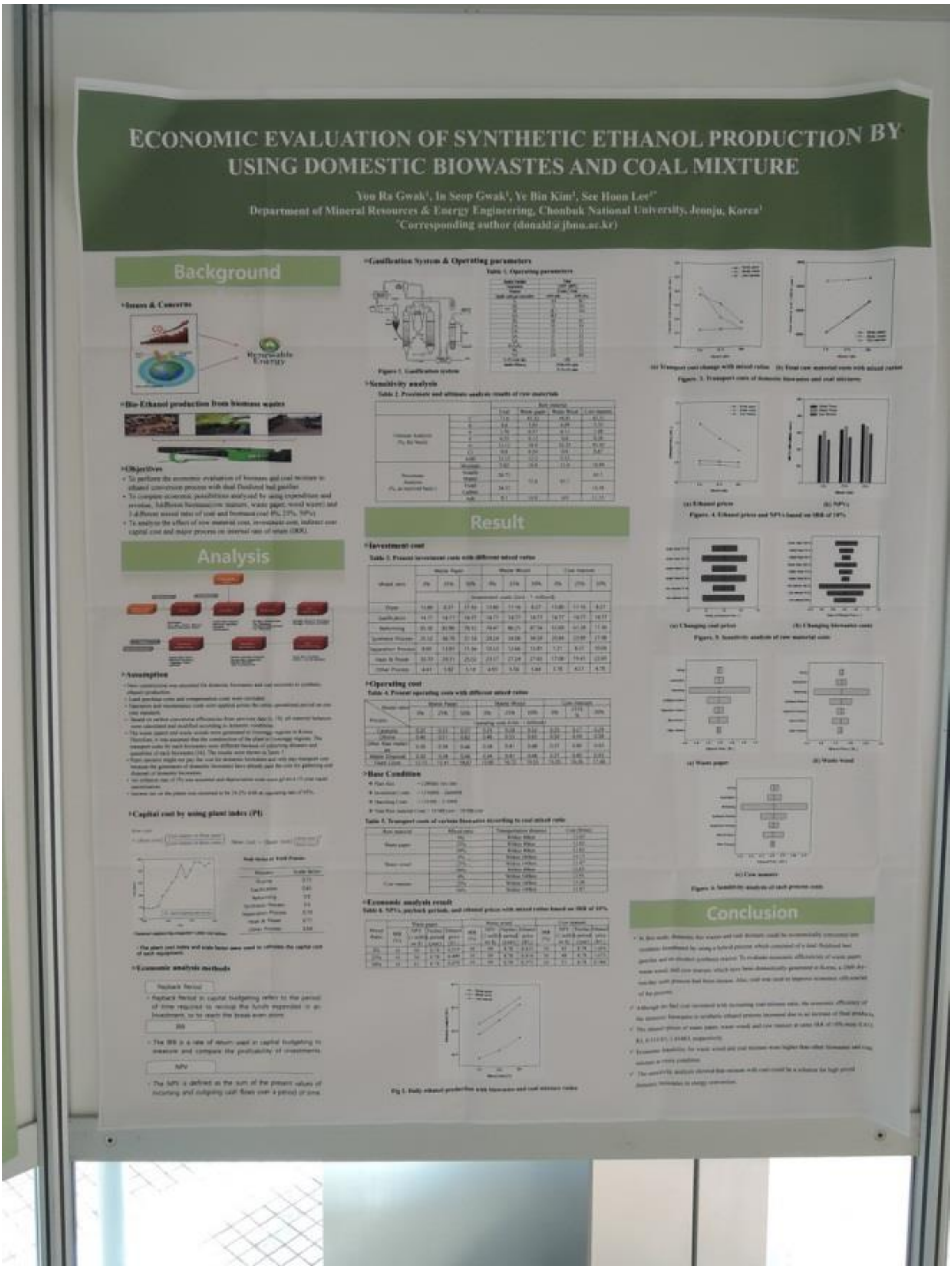

OHD: Rethinking the Coal to Liquids Process
The Process
Integrated, Non-Catalytic Process for the Production of High Value Chemicals from Low Rank Coal by Oxidative Hydrothermal Dissolution (OHD)
WHAT IS OXIDATIVE HYDROTHERMAL DISSOLUTION (OHD)?
OHD is a novel, continuous, hydrothermal process to convert macromolecular organic solids into low molecular weight chemicals, using only elevated temperature (200-370°C), high pressure, liquid water (subcritical) and molecular oxygen.
Important Parameters:
Oxidant Loading
Continuous flow
WHAT IS OXIDATIVE HYDROTHERMAL DISSOLUTION (OHD)?
OHD proven on various feeds:
coal (all ranks)
biomass (cellulosic & lignin)
oil sands and oil shales
organic-containing "waste" streams
Products can be used in multiple areas:
Agricultural (fulvate-type biostimulants and fertilizer)
Platform chemicals
Liquid fuels (alcoholic and oxygenated)
Product distribition depends on feed and OHD conditions.
OHD IS ENVIRONMENTALLY FRIENDLY
The Products - Platform Chemicals
Stage 1
Stage 2
Stage 3
Products
Complete Process - OHD to Products
MINE
OHD
PRODUCT SEPARATION
oxygen
ASU
steam
UTILITIES
off-gas
GASIFIER
H2 PLANT
HYDROGENATION
WGS
NAPHTHA
AROMATICS SEPARATION
BTX
Block-flow diagram for conversion of coal into BTX using OHD route
The Products - Agriculture
OHD Fluid as a Biostimulent
OHD fluid at ~1% carbon content used as a biostimulant
Study 1 on tomatoes. Increased yield and elimination of BER.
Trials on other plant varieties [eg chick peas] have been started.
Study 1. Tomatoes-flowers & fruit
Study 1. Blossom End Rot
POSSIBLE MECHANISMS
FURTHER STUDIES
Timing of application
Hydroponic
Effects on the soil microbial community
Other crops including wheat, cotton
Greenpower Energy Ltd
Alan Flavelle : southdown@bigpond.com
Gerard King : gdking@iinet.net.au
Greenpower

圖 III.1.3-10：



ECONOMIC EVALUATION OF SYNTHETIC ETHANOL PRODUCTION BY USING DOMESTIC BIOWASTES AND COAL MIXTURE
You Ra Gwak1, In Seop Gwak1, Ye Bin Kim1, See Hoon Lee1*
Department of Mineral Resources & Energy Engineering, Chonbuk National University, Jeonju, Korea1
*Corresponding author (donald@jbnu.ac.kr)
Background
Analysis
Result
Conclusion

圖 III.1.3-11：

四、建　議　事　項

聯合國發佈之 IPCC 第五次評估報告（AR5）考慮了氣候變化的新證據，其係建立在對氣候系統觀測、古氣候檔案、氣候過程理論研究和氣候模式類比等的獨立科學分析基礎之上，已明確揭櫫氣候變遷之相關警訊；另外，於 2015 年底 COP21 發佈之「巴黎協議」已完成多數國家簽署門檻，揭櫫抑制氣候變遷之明確目標。台灣於 2015 年 6 月已正式通過「溫室氣體減量及管理法」，其減量目標為 2050 年的溫室氣體（GHG）排放量要降為 2005 年的 50%以下；這意味著較低含碳料源或先進的低碳能源技術將成為選項，以減少二氧化碳的排放。為推動國家減碳政策，近年來，核能研究所積極進行**能源國家型科技計畫**領域之**「淨碳技術發展」**研究計畫，冀望能為我國減碳情景略盡綿薄之力。此外，該計畫亦從永續發展觀點推動**自主性潔淨能源技術之建立**，研發淨煤、多元氣化與應用、碳捕捉與分離等技術，藉以**提升能源自主性、降低國內的碳排放**。

此次公差行程之建議事項可分為數個面向分述如下：

(一) 技術研發領域

1. IEA 主導之 CCT 大會由淨煤技術肇始，亦概括生質能、sCO_2 循環、電廠運轉實務、社環困境之範疇，強調跨領域整合**低碳潔淨能源研究**，建議本所**應積極參與**後續活動。
2. CCT 大會**重要議題**亦涵蓋國際趨勢、高效低排 (HELE) 電廠、氣化、污染控制、燃燒、煤料處理等重要領域**，具備未來性與競爭力**，將為實現永續發展發揮著重要作用。
3. 生質物與煤**共氣化**議題及相關**技術應用**是 CCT 大會的重點項目，**為未來永續能源轉換的重要平台**，亦顯示**核研所淨碳技術計畫的主要內容符合國際主流趨勢**，值得持續推動**。**
4. **減碳程序技術**亦為大會議題的重要支柱，包含化學迴路、富氧燃燒、碳捕存等，代表未來在永續發展過程的可能途徑，提供能源、環境與經濟的整合解決方案，**值得持續關注**。
5. 本所淨碳團隊發表之大會論文被安排在化學迴路領域，主題聚焦於化學迴路燃燒 (CLC) 研究；該篇論文亦獲大會推薦，轉投稿知名 SCI 期刊，未來或可**推動國際合作項目。**

(二) 國際交流合作領域

1. 美國 DOE 與 IEA 等國外機構之**技術展望藍圖**頗具參考價值，由此可先行**了解國際技術發展之趨勢**，並評估推動後續技術研究之先期作業**，支持永續發展**的概念。

五、附　錄

（一） **第 8 淨煤技術國際研討會議 (The 8^{h} International Conference on Clean Coal Technologies CCT2017** 之 Scientific program

CCT2017 Programme

Tuesday 9th May

Time	Congress Hall T1	Congress Hall T3	Congress Hall T4
09:00–10:30	**Welcome from our hosts: Sotacarbo and the Region of Sardinia**		
	Keynote session I **Jean-Francois Gagné** - *Head of Energy Technology Policy, International Energy Agency* **Ashok Ganesan** - *General Manager of Steam Plant Solutions, GE Power Services*		
10:30–10:50	Coffee break		
10:50–12:30	**High-efficiency plant** **Chair: Andrew Minchener**	**Biomass I** **Chair: Nelia Jurado**	**Chemical looping I** **Chair: Yngve Larring**
	MHPS`s activity for clean coal technologies – *Yasuhiro Yamauchi, Mitsubishi Hitachi Power Systems LTD, Japan*	Co-firing high ratios of woody biomass with coal in a 150 MW pulverized coal boiler: Properties of initial deposits and the effect on tube corrosion – *Dedy Eka Priyanto, IHI Corporation, Japan*	Dynamic simulation of fluidized bed chemical looping combustion process with an iron-based oxygen carrier – *Ana-Maria Cormos, Babes-Bolyai University, Faculty Chemistry and Chemical Engineering, Romania*
	DEWA and coal – *Neil Grant, Dubai Electricity and Water Authority, United Arab Emirates*	Nitrogen partitioning during pyrolysis and combustion of biomass fuels – *Juan Riaza, University of Edinburgh, UK*	Performance of Mn-Fe-based oxygen carriers in coal combustion by iG-CLC and CLaOU processes – *Juan Adánez, Instituto de Carboquimica-CSIC, Spain*
	China's national demonstration coal power project achieves around 50% net efficiency with a 600°C class material – *Li Li, Waigaoqiao Power Plant, China*	Biomass-coal blends behaviour under different atmospheres using thermogravimetric analysis and mass spectrometry (TA-MS) – *Iñigo Rodilla, CIEMAT, Spain*	Selecting a low-cost oxygen carrier in Southwestern Colombia, and its use in in-situ gasification chemical looping combustion technology – *Carmen Rosa Forero, Universidad del Valle, Columbia*
	Firing straw and other fuels at the Avedøre power plant Unit 2 – *Preben Messerschmidt, Ramboll Energi, Denmark*	Briquettes from sugarcane crop residue as a potential fuel for co-firing biomass-coal in the South-West Colombian region – *Jesus Agualimpia, Universidad del Valle, Colombia*	Reduction kinetic studies of Indian Ilmenite as an oxygen carrier for chemical looping combustion – *Prabakaran Viswanathan, Indian Institute of Technology Madras, India*
	Beneficial effects of dry bottom ash extraction and recycling in modern PCF power plants – *Simone Savastano, Magaldi Power S.p.A., Italy*	Phosphorus transformation characteristics during co-firing of municipal sewage sludge and cotton stalk – *Qiangqiang Ren, Institute of Engineering Thermophysics, Chinese Academy of Sciences*	A reaction mechanism study of methane and Ni-based oxygen carrier for chemical looping reforming – *Xin Guo, Huazhong University of Science and Technology, China*
12:30–13:30	Lunch		
13:30–15:10	**Power plant operation** **Chair: Yue Guangxi**	**Biomass and industrial CCS** **Chair: Giorgio Cau**	**Combustion studies** **Chair: Alberto Pettinau**
	Optimization of coal and combustion air distribution – *Kitae Kang, Korea Southern Power*	Bio-energy with carbon capture and storage (BECCS): Opportunities for efficiency improvement – *Mai Bui, Imperial College London, UK*	Solid fuels co-combustion modelling in a stoker furnace – *Ewa Marek, University of Nottingham, UK*
	Supercritical power plant, life assessment methodology and a case study – *Saravana Bavan Balakrishnan, WSP | Parsons Brinckerhoff, UK*	Modeling and economic evaluation of carbon capture and storage technologies integrated into coal and biomass MTG plants – *Claudia Bassano, ENEA, Italy*	A study of the relationships between the micro-Raman spectral parameters and the combustion characteristics of 32 kinds of Chinese coal – *Jun Xu, Huazhong University of Science and Technology, China*
	Improvement of operational flexibility of 225 MWe power unit in EDF Polska's Rybnik Power Plant – *Daniel Nabagło, EDF, Poland*	Carbon capture and utilisation technologies applied to energy conversion systems and other industrial applications – *Calin-Cristian Cormos, Babes-Bolyai University Cluj-Napoca, Romania*	Pyrolysis and combustion characterization of coal, biomass and their blends by thermogravimetric analysis – *Mauro Mureddu, Sotacarbo S.p.A. Italy*
	A predictive method for low-load off-design operation of a lignite fired power plant – *Konstantinos Atsonios, Centre for Research & Technology Hellas / Chemical Process & Energy Resources Institute, Greece*	Process analysis of co-firing of coal and biomass in a power generation system integrated with CO_2 capture and compression system – *Usman Ali, University of Sheffield, UK*	Effect of bagasse composition, devolatilization temperature, particle size and type of devolatilization atmosphere on char morphology of coal-bagasse blends – *Eliana Paredes, Universidad del Valle, Colombia*
	Commercialising low cost, clean drying technologies for power and industry – *Miri Zlatnar, Coomtech, UK*		Prediction of syngas composition from pyrolysis of waste-derived feedstocks in the UK using Aspen Plus – *Nelia Jurado, Cranfield University, UK*
15:10–15:40	Coffee break		
15:40–17:20	**NOx controls** **Chair: Charles Soothill**	**Biomass II** **Chair: Mohammed Pourkashanian**	**Gasification** **Chair: Tatiana Bogatova**
	Guaranteed reductions in NOx emissions and fuel consumption for Drax`s 660MW biomass boilers – *Dietrich-Georg Ellersiek, Siemens, Germany*	Wood pellet co-firing – some topics of conducted conversions – *Falk Hoffmeister, Mitsubishi Hitachi Power Systems Europe GmbH, Germany*	Towards high-fidelity simulations of coal gasification – *Michele Vascellari, TU Freiberg, Germany*
	SNCR for large combustion plants - most recent application at a 380 MWe lignite-fired boiler – *Zoltan Teuber, ERC Technik GmbH, Germany*	Black Pellets: Status Update – *Michiel Carbo, ECN, Energy Research Centre of the Netherlands*	DEM simulations of coal particles in entrained-flow slagging gasifiers: particle-particle interaction at different burning levels – *Francesco Saverio Marra, Istituto di Ricerche sulla Combustione - CNR, Italy*
	Large furnace SNCR experience with multiple coals – *Piers de Havilland, Fuel Tech, USA*	On cofiring as a strategy to mitigate ash deposition during combustion of a high-alkali Xinjiang coal – *Dunxi Yu, Huazhong University of Science and Technology, China*	Reaction behaviour of fuels of different quality in entrained flow gasifiers – *Andreas Geißler, TU München - Energy Systems, Germany*
	Adaptions of Polish coal-fired power plants to meet existing (IED) and new emission limits (BAT conclusions/BREF) based on Patnow Power Plant – *Robert Żmuda, SBB ENERGY S.A., Poland*	Drying and torrefaction of a coal/biomass mixture by using COMB Technology – *Sihyun LEE, Korea Institute of Energy Research, South Korea*	Impact characteristics of particles onto a flat wall relevant to entrained-flow gasifiers – *Maurizio Troiano, Università degli Studi di Napoli Federico II, Italy*
	First evaluation of a multicomponent flue gas cleaning concept using chlorine dioxide - Experiments on chemistry and process performance – *Anette Heijnesson Hultén, Akzo Nobel, Sweden*	Assessment of biomass co-firing under oxy-fuel conditions on Hg speciation and ash deposit formation. – *Miuisa Contreras, CIEMAT, Spain*	Study on the reactivity and structural characteristics of alkali-rich biomass chars in coal co-hydrogasification – *Xingjun Wang, East China University of Science and Technology, China*
17:20–18:30	Poster session – Refreshments served in the T Hotel garden		

The 8th International Conference on Clean Coal Technologies – **CCT2017**

Wednesday 10th May

Time	Congress Hall T1	Congress Hall T3	Congress Hall T4
08:30–09:20	**Keynote session II** **Scott Smouse** – *US Department of Energy, USA* **Partha Mazumder** - *NTPC, India (to be confirmed)*		
09:25–10:45	**IGCC** **Chair: Chris Higman**	**Fluidised bed combustion** **Chair: Nathan Weiland**	**Particulate controls** **Chair: Ian Barnes**
	NEDO's clean coal technology development for reduction of CO_2 emissions – *Eiji Nishioka, New Energy and Industrial Technology Development Organization, Japan*	The research and development of CFB coal combustion in China – *Guangxi Yue, Tsinghua University, China*	The influence of discharge electrode geometry and the associated discharge characteristics on electrostatic precipitator performance – *David Branken, North-West University, South Africa*
	Technical solutions for perspective IGCC – *Tatiana Bogatova, Ural Federal University, Russia*	Development of advanced CFB technology in light of changing fuel trends – *Kalle Nuortimo, Amec Foster Wheeler Energia Oy, Finland*	Experimental study on combustion of gasification fly ash preheated by a CFB burner – *Ziqu Ouyang, Institute of Engineering Thermophysics Chinese Academy of Sciences, China*
	Energy efficiency evaluation of Shell's entrained-flow gasifier by different coal ranks and Exergy analysis of IGCC with carbon capture – *Chang-Ha Lee, Yonsei University, South Korea*	The formation of the fluidized bed hydrodynamic structure, optimal for burning of low-grade coals and biomass – *Dmitry Klimov, Clean Energy Ltd, Russia*	Current Tools & Techniques for Maximizing Performance on Existing Electrostatic Precipitators (ESPs) – *James J Ferrigan, Fuel Tech, USA*
	Experimental investigation of alkali sorption with mineral getter materials for IGCC Power Plant – *Florian Kerscher, TU München, Germany*	CFD simulation of binary particle mixing in a baffled downer reactor for coal topping – *Nan Zhang, Institute of Process Engineering, Chinese Academy of Sciences, China*	Particle matter filtration from iron-ore sintering flue gas in a magnetically stabilized fluidized bed – *Yang Xu, Huazhong University of Science and Technology, China*
10:45–11:20	**Coffee break**		
11:20–13:00	**Coal in a low carbon world** **Chair: Toby Lockwood**	**Mercury controls** **Chair: Lesley Sloss**	**Chemical looping II** **Chair: Juan Adanez**
	Operational and strategic considerations for coal plants in the context of changing market design and growing renewable energy penetration – *Ashutosh Shastri, EnerStrat Consulting, UK*	Research progress of mercury emission and control in China – *Yongchun Zhao, Huazhong University of Science & Technology, China*	Long-term pilot testing of the carbonate looping process in at 1 MWth scale – *Jochen Hilz, Institute for Energy Systems and Technology (EST) - Technische Universität Darmstadt, Germany*
	Thermal power generations in India: The challenges from renewable energy source power generation – *Avijit Mallick, Reliance Power Ltd, India*	Control of mercury emissions - alternative methods – *John Meier, Nalco Water, USA*	Calcium looping combustion for high-efficiency low-emission power generation – *Dawid Hanak, Cranfield University, UK*
	Consequences of the German energy transition on the operation regime and the availability of coal-fired power plants – *Oliver Then, VGB Powertech, Germany*	Mercury removal and its fate in wet flue gas desulphurization slurry enhanced with reagents and without any treatment – *Renata Krzyzynska, Wroclaw University of Technology, Poland*	On the evaluation of ilmenite as an oxygen carrier for natural/synthesis gases in chemical-looping combustion – *Yau-Pin Chyou, INER, Taiwan*
	HELE perspectives for selected Asian countries – *Ian Barnes, IEA Clean Coal Centre, UK*	Mercury capture by a structured Au/C regenerable sorbent under oxycoal combustion conditions – *M Teresa Izquierdo, Instituto de Carboquímica - CSIC, Spain*	Performance of CLOU process in the combustion of different types of coal with CO_2 capture with a Cu-Mn oxygen carrier – *Iñaki Adánez-Rubio, Instituto de Carboquímica - CSIC, Spain*
	Impacts of re-opening of Czech Brown coal mines on energy system and deep decarbonisation target – *Lukáš Rečka, Charles University Environment Center, Czech Republic*	Multi-pollutant control using structured sorbent/catalyst modules – *Jeff Koide, Gore, USA*	COMPOSITE Process: Highly efficient IGCC power generation with CO_2 capture by integration of CLAS and CLC – *Yngve Larring, SINTEF, Norway*
13:00–14:00	**Lunch**		
14:00–15:20	**Supercritical CO_2 power cycles** **Chair: Scott Smouse**	**CCS: Sorbents and membranes** **Chair: Thomas Sarkus**	**Social and environmental issues** **Chair: Andrew Minchener**
	State-of-the-art in supercritical CO_2 power cycles – *Qian Zhu, IEA Clean Coal Centre, UK*	Simulation and cost analysis of structured adsorbent capture technology with advances in materials – *Rebecca Gardiner, Inventys Inc., Canada*	A closed carbon cycle through sector coupling? Challenges posed by path dependency in the socio-technical system – *Roh Pin Lee, IEC, TU Bergakademie Freiberg, Germany*
	Techno-economic analysis of an integrated gasification direct-fired supercritical CO_2 power cycle – *Nathan Weiland, National Energy Technology Laboratory, USA*	Enhancement of CO_2 capture capacity of mesoporous sorbents via functionalization with an amino acid ionic liquid – *Marco Balsamo, Università degli Studi di Napoli Federico II, Italy*	Social acceptance of clean coal mining and combustion – *Vladimir Budinsky, SD Severoceske doly a.s., Czech Republic*
	Coal-fired power plant efficiency boost through retrofitting with supercritical CO_2 Brayton cycle – *Huiqi Wang, EDF, China*	Post-combustion CO_2 capture using N-(isopropyl)-tetraethylenepentamine-based solid sorbent – *Hidetaka Yamada, Research Institute of Innovative Technology for the Earth (RITE), Japan*	UCG: supposed environmental issues - myths and realities – *Chris Cuff, C&R Consulting, Australia*
	Development of a mean-line model of axial supercritical CO_2 turbine – *Yili Xiong, EDF, China*	Ultra-thin zeolite membranes for gas separations – *Jonas Hedlund, Luleå University of Technology, Sweden*	
15:20–15:40	**Coffee break**		
15:40–17:20	**Panel session: The Energy Trilemma – Chair: Samantha McCulloch** **Liam McHugh** – *World Coal Association* / **Nick Butler** – *Kings College and Financial Times* / **Charles Soothill** – *Zero Emissions Platform* **Chandra Bhushan** – *CSE India* / **Craig Morris** – *Institute for Advanced Sustainability Studies* / **Alessandro Lanza** - *Sotacarbo*		
19:30–23:00	CCT2017 - conference gala dinner		

Thursday 11th May

Time	Congress Hall T1	Congress Hall T3	Congress Hall T4
09:00–10:40	**Carbon capture and storage** **Chair: Noel Simento**	**Materials and slagging** **Chair: Oliver Then**	**Lignite and low rank coal** **Chair: Sarma Pisupati**
	20 Years of CCS: Accelerating Future Deployment – *Samantha McCulloch, International Energy Agency, France*	Development of an advanced ultra-supercritical component test facility including 760°C superheater and steam turbine – *Horst Hack, Electric Power Research Institute, USA*	How to utilize low grade coals below 1000kcal/kg – *Falk Hoffmeister, Mitsubishi Hitachi Power Systems Europe GmbH, Germany*
	An update on the ROAD project – *Andy Read, ROAD CCS Project, Netherlands*	Investigation of the hot corrosion behaviors of Sanicro™ 25 - a potential candidate for superheater and reheaters in high efficiency AUSC fossil power plants – *Yanyan Bi, Sandvik, China*	Small technical scale parametric investigation of co-firing of hard coal and pre-dried lignite under part load conditions in the scope of enhancing the flexibility of hard coal fired power stations. – *Ioannis Papandreou, University of Stuttgart, Germany*
	Overview and status update of carbon capture & geologic storage major demonstration & commercial projects in North America – *Thomas Sarkus, National Energy Technology Laboratory, USA*	Assessment of materials data for advanced coal plants – *Nigel Simms, Cranfield University, UK*	Study on the structural evolution of molecular skeleton and mobile phase during pyrolysis process of a Chinese low-rank coal – *Song Hu, Huazhong University of Science and Technology, China*
	Development of energy efficient CO_2 capture technologies – *Svein Gunnar Bekken, Gassnova SF, Norway*	Advanced monitoring of the fouling process on water walls – *Matthias Reiche, TU Dresden, Germany*	Co-Liquefaction of Yatağan lignite and waste tires under catalytic conditions – *Cemil Koyunoglu, Istanbul Technical University, Turkey*
		Thermooptical measuring technique - A highly efficient tool to increase the efficiency of coal combustion and minimize negative emmissions – *Andreas Diegeler, Fraunhofer Society, Germany*	
10:40–11:10	**Coffee break**		
11:10–12:50	**CCS: Solvents** **Chair: Vladimir Zuberec**	**Pollutant controls** **Chair: Yongchun Zhao**	**Underground coal gasification** **Chair: Chris Cuff**
	Long term operation results for an advanced PCC system at coal-fired power plant – *Yasuro Yamanaka, IHI Corporation, Japan*	Regulatory reforms in technology and pollution standards in the coal based thermal power sector in india – *Chandra Bhushan, CSE, India*	Environmental performance of the exergy UCG Technology: Groundwater protection and global warming impacts – *M.S. Blinderman Ergo Exergy Technologies Inc, Canada*
	Pilot plant improvement and experimentation for CO_2 capture with amine solvents – *Paolo Delana ENEA - Italian Agency for New Technologies, Energy and Sustainable Economic Development, Italy*	Study of elemental mercury oxidation over SCR-catalysts under oxy-fuel combustion conditions – *M. Mercedes Díaz Somoano, Instituto Nacional del Carbón – CSIC, Spain*	Underground coal gasification - efficient in-situ CO_2 capture and conversion – *Johan van Dyk, Africary, South Africa*
	Metal aerosol emissions from coal and biomass combustion for carbon capture applications – *Karen N. Finney, University of Sheffield, UK*	Long-term monitoring of selenium in flue gas desulfurization wastewater with fully automated online process monitor – *Seiichi Ohyama, Central Research Institute of Electric Power Industry, Japan*	Experimental simulations of underground coal gasification with hydrogen for methane-rich gas production – *Krzysztof Kapusta, Główny Instytut Górnictwa, Poland*
	Panel session **A way forward for CCS**	Experimental and modelling analysis of seawater scrubbers for sulphur dioxide removal in coal-fired power plants – *Domenico Flagiello, University of Naples, Federico II - DICMaPI, Italy*	Environmental controls for underground coal gasification: A successful demonstration from the Queensland government UCG Pilot program – *Cliff Mallett, Carbon Energy Limited and China University of Mining and Technology, Australia/China*
	Samantha McCulloch – *IEA* **Keith Whiriskey** – *Bellona* **Thomas Sarkus** – *NETL* **Andy Read** – *ROAD CCS Project*	Investigation of MoS_2 nanosheet containing adsorbents for Hg0 Capture: an experimental approach – *Tao WU, The University of Nottingham Ningbo, China*	
12:50–14:00	**Lunch**		
14:00–15:20	**Coal conversion** **Chair: Calin-Christian Cormos**	**Oxyfuel combustion** **Chair: M Teresa Izquierdo**	**Coal beneficiation** **Chair: Krzysztof Kapusta**
	Toward realization of a hydrogen energy supply chain – *Ryo Chishiro, Kawasaki Heavy Industries, Ltd., Japan*	CO_2-free coal-fired power generation by partial oxy-fuel and post-combustion CO_2 capture. Part 1: performance assessment – *Vittorio Tola, University of Cagliari, Italy*	Dry separation of coal using an autogenous medium – *Davaasuren Jambal, University of Science and Technology (UST), KIGAM, South Korea*
	New markets for coal - chemicals and performance materials – *Richard Horner, University of Wyoming, USA*	CO_2-free coal-fired power generation by partial oxy-fuel and post-combustion CO_2 capture. Part 2: economic analysis – *Alberto Pettinau, Sotacarbo S.p.A., Italy*	Na and Ca removal from Zhundong coal by a novel CO_2-water leaching method and the fusion behavior of the leached coal ash – *Yaxin Gao, Huazhong University of Science and Technology, China*
	Design and modelling of a biomass/coal co-pyrolysis unit for advanced fuel synthesis – *Konstantinos Atsonios, Centre for Research & Technology Hellas / Chemical Process & Energy Resources Institute, Greece*	Thermodynamic and exergetic analysis of oxy-combustion and efficiency improvement via process integration – *Renato Manuel Pereira Cabral, Imperial College London, UK*	Porosity, morphology and structural ordering of Pittsburgh no.8 coal chars generated at high temperatures and elevated pressures – *Sarma Pisupati, The Pennsylvania State University, USA*
	Towards CO_2-emission-free coal technology – *Christian Wolfersdorf, TU Bergakademie Freiberg, Institute for Energy Process Engineering and Chemical Engineering, Germany*	Experimental study of the ignition temperature of five coals under oxyfuel atmospheres – *Lei Cai, Huazhong University of Science and Technology, China*	Separation of fine coal using an enhanced gravity separator – *Youjun Tao, China University of Mining & Technology, China*
15:20–15:40	**Coffee break**		
15:40–17:00	**Closing plenary session**		
	Key drivers of Turkish coal policy – **Mücella Ersoy**, *Chief Engineer, TKI, Turkish Coal Enterprises*		
	EU legal framework impact and technological issues related to the power sector in Poland – **Kazimierz Szynol**, *Tauron Wytwarzanie, Poland*		
	Closing statements – **Andrew Minchener**		