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出國報告（出國類別：其他）

赴美國參加第十五屆國際固態氧化物燃料電池研討會出國報告

服務機關：核能研究所
姓名職稱：楊昇府　副工程師
派赴國家：美國
出國期間：106 年 7 月 24 日~106 年 7 月 31 日
報告日期：106 年 9 月 18 日

摘要

本文為核能研究所物理組楊昇府博士(作者)奉派於 2017 年 7 月 24 日起至 2017 年 7 月 31 日期間，赴美國佛羅里達州好萊塢(Hollywood)市參加由美國電化學學會(The Electrochemical Society, ECS)與日本固態氧化物燃料電池協會(The Solid Oxide Fuel Cell Society of Japan)共同主辦之第十五屆國際固態氧化物燃料電池研討會(The Fifteenth International Symposium on Solid Oxide Fuel Cells, SOFC-XV)，進行口頭論文發表“Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique”，並與固態氧化物燃料電池研究發展領域、關鍵性技術及測試設備研發等專家進行技術與學術交流的國外公差報告。

作者藉由參加第 15 屆 SOFC 國際研討會發表論文，可促進技術與學術交流，掌握關鍵技術，並了解國際趨勢，進而建立合作管道及對象，有助於計畫之執行，並對我國推廣 SOFC 產業及其相關領域研發有很大的助益，會議結束後，對於可能互訪或合作之事宜，仍需持續關注。而透過與國際專家討論交流會議，可拓展研究深度與提升國際同業審查應對能力，並提升本所固態氧化物燃料電池相關技術能力。未來應持續規劃與派員參加該國際會議，真實呈現國內的研發成果、研究近況、拓展國際人脈關係，加速計畫之進展。經由口頭發表論文，本所 SOFC 能源領域成果備受重視及肯定。本所研發的金屬支撐型固態氧化物燃料電池具有領先的優勢，未來可投入更多人力與經費，持續掌握領先優勢，積極研發朝實用化的角度去發展。國際各先進國家(如美國、歐盟和日本)於 SOFC 領域進行國家各層級研究單位、工業和政府部門間之橫向及縱向聯繫整合與其能源政策、經費投入程度的相關作為，值得國內參考與借鏡。

目次

一、目的

美國電化學學會(The Electrochemical Society, ECS)與日本固態氧化物燃料電池協會(The Solid Oxide Fuel Cell Society of Japan)共同主辦之第十五屆國際固態氧化物燃料電池研討會(The Fifteenth International Symposium on Solid Oxide Fuel Cells, (SOFC-XV))於 2017 年 7 月 23 日~2017 年 7 月 28 日在美國佛羅里達州好萊塢(Hollywood)舉行，內容涵蓋: SOFC 電池片(Cells)、電池堆(Stacks)和電池系統(Systems)之設計、效能、與耐久性探討；陽極材料(Anodes)、電解質材料(Electrolytes)、陰極材料(Cathode)製程和效能；連接板與鍍保護膜(Interconnects and Interconnect Coatings)、模擬(Modeling)、相容性燃料運轉(Fuels and Fuel Compatibility)、固態氧化物電解電池(Solid Oxide Electrolysis and reversible Cells, SOEC)等議題。此國際會議於 28 年前(1989)於同一地方舉辦第一屆，後續於歐洲(希臘雅典、德國亞琛、法國巴黎、奧地利維也納、英國蘇格蘭格拉斯哥)、北美(美國夏威夷兩次、加拿大魁北克、加拿大蒙特婁)、日本(橫濱、筑波、奈良、沖繩)三個地區輪流，每兩年舉辦一次，已成為國際 SOFC 領域最重要的資訊交流平台。為有效掌握國際間固態氧化物燃料電池發展趨勢，並拓展與國際間 SOFC 主要發展機構成員關係，楊昇府博士獲邀參加該項會議(邀請函如附錄一)，藉由參與本次會議展現本所於 SOFC 領域的研發成果，並且加強本所與國際間之資訊交流與人脈關係拓展，有益於後續國內 SOFC 研發策略方向擬訂及研發工作的推展。主要目的如下所述：-赴美國佛羅里達州好萊塢參加美國電化學學會與日本固態氧化物燃料電池協會共同主辦之第十五屆國際固態氧化物燃料電池研討會，並口頭發表金屬支撐型固態氧化物燃料電池之研發成果論文(摘要與全文接受通知如附錄二和三)，與固態氧化物燃料電池一流專家進行技術探討，建立合作管道，並於此國際資訊交流之重要平台，收集廣泛且深入的技術資訊，掌握國際之最新發展技術，使本所之研究發展可與國際接軌，有助於計畫之執行，並對國內 SOFC 產業及其相關領域研發有很大的助益。

二、過程

(一) 概要說明

第十五屆國際固態氧化物燃料電池研討會於2017年7月23日~2017年7月28日在美國佛羅里達州(如圖1)好萊塢市(如圖2)舉行，為目前國際上公認針對固態氧化物燃料電池議題研討最重要的會議。好萊塢市是是美國佛羅里達州布勞沃德縣的一個城市，位於佛羅里達半島東部，面臨大西洋，為此國際會議於28年前舉辦第一屆的地點。本屆會議主席為美國西北太平洋國家實驗室Dr. Subhash C. Singhal及東北大學Professor Professor Tatsuya Kawada，總計共有28場學術議題研討會，來自世界各地40個國家五百餘位專業人士參加，372篇論文投稿，口頭發表233篇，海報發表139篇。

圖 1 佛羅里達州於美國相對地理位置

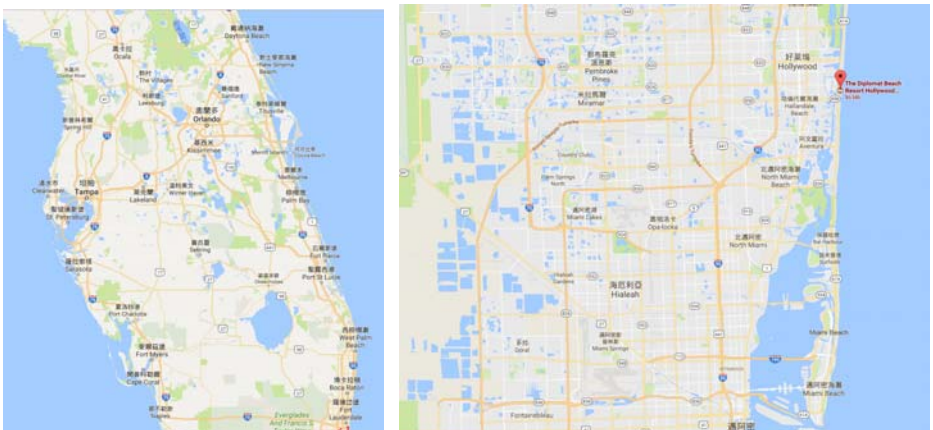


圖 2 美國佛羅里達州好萊塢市

(二) 行程說明

1. 去程

A. 7月24 日(星期一)

08:00由台灣桃園國際機場搭乘長榮航空BR-30班機(如圖3)起飛前往美國佛羅里達州好萊塢市，於美國時間10:45抵達紐約約翰·菲茨傑拉德·甘迺迪國際機場停留5小時，轉機飛往佛羅里達邁阿密國際機場(如圖4)，於美國時間晚上18:58抵達邁阿密國際機場，辦理完成出關手續後，轉搭計程車前往本屆會議舉辦場地The Diplomat Beach Resort。

圖 3 台灣桃園國際機場搭乘長榮航空班機前往美國

圖 4 轉機搭乘之美國航空

2. 參加會議

美國電化學學會與日本固態氧化物燃料電池協會共同主辦之第十五屆國際固態氧化物燃料電池研討會於2017年7月23日~2017年7月28日，在美國佛羅里達州好萊塢市The Diplomat Beach Resort 會議中心(圖5)舉行。

圖 5 The Diplomat Beach Resort會議中心

第十五屆國際固態氧化物燃料電池研討會內容涵蓋SOFC電池系統發展和驗證、不同電池組成(包括陽極材料、電解質材料、陰極材料、連接板與鍍保護膜等)所使用材料的製程和表現的探討、電池片、電池堆和系統之設計、效能、測試與耐久性探討、其他新的應用包括固態氧化物電解電池和儲能、模擬、相容性燃料運轉等議題。會議過程中，與國際學者及專家進行多方之交流，俾利於本國SOFC 之技術發展與國際接軌，及SOFC產業聚落之形成，為國內創造一新興能源產業。會議之主要議程安排、口頭簡報和海報展示之議程如附錄四。詳細之大會議程表內容(https://ecs.confex.com/ecs/sofc2017/webprogram/programs.html)可參考本次第十五屆國際固態氧化物燃料電池研討會會議於美國電化學學會內之網站：http://www.electrochem.org/sofc-xv?utm_source=Informz&utm_medium=Email&utm_campaign=ECS+Website。本所於本屆會議總計發表口頭論文1篇、海報論文1篇，分別為：

I. 口頭論文發表(摘要如附錄五)

楊昇府等人之論文題目：

Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using

Thermal Plasma Technique。

II. 海報論文發表(摘要如附錄六)

陳佑明等人之論文題目：

Applications of the Glycine Nitrate Combustion Method for Powder Synthesis on the LSGM-based Electrolyte-Supported Solid Oxide Fuel Cells。

A. 7月24日(星期一)

本日為會議進行第一天，大會議程首先由大會主席Dr. Singhal進行簡短引言，報告國際SOFC最新之技術進展，隨即進入時程為2.5小時的Plenary Session，共有7場(摘要內容如附錄七)，每場20分鐘。每場內容簡述如下：

1. 發表人及單位：S. D. Vora (National Energy Technology Laboratory), W. L. Lundberg, and J. F. Pierre (KeyLogic Systems)。 題目：Overview of U.S. Department of Energy Office of Fossil Energy' s Solid Oxide Fuel Cell Program。

國家能源技術實驗室(NETL) Vora博士針對美國能源部辦公室化石能源的固態氧化物燃料電池計畫做一回顧。根據數個計劃參與單位的研究結果顯示，鉻對電池陰極的污染與毒化已經確認是電池系統電性衰退和可靠度不佳的主要原因。對於鉻污染的問題，NETL SOFC計畫近期啟動13個方案來應對這個重要的議題。NETL SOFC計畫提供計畫經費給於具有成本低、可靠度高、可以超越目前陽極支撐片狀SOFC性能的創新性研究、發展與驗證，以此概念所發展的電池正進行5-10 kW等級的封裝堆疊測試。MW等級的天然氣為燃料的分散式發電系統測試也都在進行中。

2. 發表人及單位：S. J. Litzelman, M. J. Pouy (Booz Allen Hamilton), P. S. Albertus, and G. L. Soloveichik (Advanced Research Projects Agency-Energy (ARPA-E))。題目：Fuel Cells Operating at 200 to 500Celsius: Lessons Learned from theARPA-E REBELS Program。

美國能源高等研究計劃署(Advanced Research Projects Agency-Energy, ARPA-E)電化學系統可靠電力專案(Reliable Electricity Based on Electrochemical Systems, REBELS) 計畫目標為尋找替代燃料電池材料和操作條件，降低系統操作成本和新的電化學功能。博思艾倫漢密爾頓控股公司(Booz Allen Hamilton) Dr. Litzelman敘述中溫燃料電池(Intermediate Temperature Fuel Cells; range between 200℃~500℃)操作時具有潛力的優點，目前研究成果為以甲烷為燃料，操作溫度500℃，在0.78 V時電流密度為200 mA/cm^2，無積碳產生。

3. 發表人及單位：H. Nirasawa (New Energy and Industrial Technology Development Org.). 題目：Current Status of National SOFC Projects in Japan。

   日本新能源產業綜合開發機構(New Energy and Industrial Technology Development Organization, NEDO) Dr. Nirasawa 闡述日本國家級SOFC計畫的近況及促進SOFC商業化的技術發展最新趨勢。

4. 發表人及單位：A. Aguilo-Rullan, M. Atanasiu, B. Biebuyck, N. Lymperopoulos, C. Marenco, and D. Tsimis (Fuel Cells and Hydrogen Joint Undertaking). 題目：The Status of SOFC and SOEC R&D in the European Fuel Cell and Hydrogen Joint Undertaking Programme。

   歐盟燃料電池暨氫氣聯合企業(Fuel Cells and Hydrogen Joint Undertaking, FCH-JU) Dr. Aguilo-Rullan報告SOFC和SOEC在燃料電池暨氫氣聯合企業的計畫(2014－2020)中的研究與發展現況。目前主要目標期望藉由單元系統運用讓運輸、定置型發電和產氫，在整個歐盟地區適當且適量建置SOFC和SOEC，來降低成本。

5. 發表人及單位：N. Minh (University of California, San Diego), J. Mizusaki (Tohoku University), and S. C. Singhal (Pacific Northwest National Laboratory). 題目：Advances in Solid Oxide Fuel Cells: Review of Progress through Three Decades of the InternationalSymposia on Solid Oxide Fuel Cells。

   加州大學聖地牙哥分校能源研究中心Dr. Minh針對過去30年來，回顧每2

年一度的SOFC國際研討會文章和報告的進展，包括SOFC相關材料發展、SOFC單電池的電極反應、內部化學作用、設計、電性、耐久度和操作等的瞭解、多電池電池堆和發電系統。目前正在SOFC商業化發展的前期階段。

6. 發表人及單位：H. Ghezel-Ayagh and B. P. Borglum (FuelCell Energy, Inc.). 題目：Review of Progress in Solid Oxide Fuel Cells at FuelCell Energy。

燃料電池能源公司(FuelCell Energy, Inc.) Ghezel-Ayagh博士報告該公司陽極支撐電池技術在放大刮刀成型薄帶、網印功能層和燒結(Tape Casting-Screen Printing-Sintering, TSC)製作程序的進展。目前可製作電池尺寸最大為1000 cm^2，在製作標準SOFC電池堆時所使用的電池尺寸為550 cm^2，每一電池堆單元由120片550 cm^2電池所組成，發電功率16 kW。和DOE共同合作的50 kW全自動SOFC系統已完成測試，200 kW系統正在設計建置中，未來將朝MW等級的SOFC電廠邁進。

7. 發表人及單位：R. T. Leah, A. Bone, E. Hammer, A. Selcuk, M. Rahman, A. Clare, S. Mukerjee, and M. Selby (Ceres Power Ltd.). 題目：Development Progress on the Ceres Power Steel Cell Technology Platform: Further Progress Towards Commercialization

Ceres Power Leah博士闡述該公司的不銹鋼電池(Steel Cell)的發展和商務現況。最新一代的不銹鋼金屬支撐電池技術代號為“v4.0”，以天然氣為燃料的700 W微型汽電共生或熱電聯產系統(Micro combined heat and power, micro-CHP)完成驗證，於英國天然氣公司(British)補助及合作下，在英國數個地方建置此系統進行實地驗證(Field trial)。與日本Nissan合作評估不銹鋼金屬支撐電池技術應用於電動車的的可能性。除了目前和日本Honda公司共同合作契約持續進行中之外，也獲得DOE同意和康明斯(Cummins)公司共同建置一個5 kW定置型發電裝置供其資料中心使用。

ECS Plenary Session結束後，下午開始進行各議題的研討，包括SOFC System

Ⅰ、SOFC Electrolytes和SOFC Cathodes Ⅰ。7月24日晚上18:00~20:00為第一場海報論文發表(Poster Session 1)，主題包括Cathodes和Anodes。

B. 7月25日(星期二)

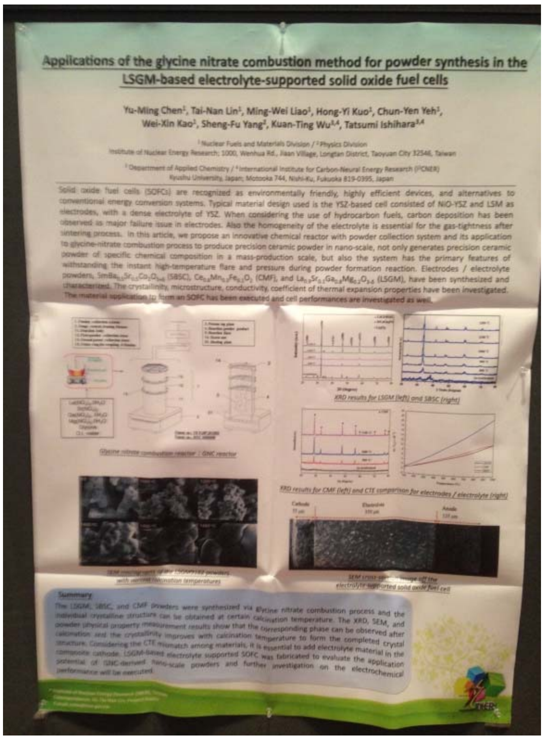
本日為會議進行第二天，因出國天數與行程安排楊員於是日進行報到、資料領取及熟悉會場附近環境，並且完成大會報到註冊，如圖6所示。本屆會議主席由美國太平洋西北國家實驗室(Pacific Northwest National Laboratory, PNNL) Dr. Subhash C. Singhal以及日本東北大學(Tohoku University) Professor Tatsuya Kawada共同擔任，此外28場學術研討會於The Diplomat Beach Resort 會議中心五個大型會議室舉行(ATLANTIC 1, ATLANTIC2, , ATLANTIC 3, Grand BALLROOM East, Grand BALLROOM WEST)，各分組議程基本上邀請兩位協同主席，主持、提出問題與引導會議進行。

圖 6 報到註冊

早上08:20開始，議程包括SOFC Systems、Interconnects、Contact Materials and Seals Ⅰ、SOFC Cathodes Ⅱ。下午14:00開始進行其它各議題的研討，包括Interconnects, Contact Materials and Seals Ⅱ、SOFC Cathodes Ⅲ、Solid Oxide

Electrolysis/Reversible Cells and Systems I。

7月25日晚上18:00~20:00為第二場海報論文發表(Poster Session 2)，主題包括SOFC Cells, Stacks and Systems，楊員協助陳佑明等人發表之海報論文Applications of the Glycine Nitrate Combustion Method for Powder Synthesis on the LSGM-based Electrolyte-Supported Solid Oxide Fuel Cells，如圖7所示，現場記錄相關問題詢問和回答，並帶回相關資訊供該團隊參考。



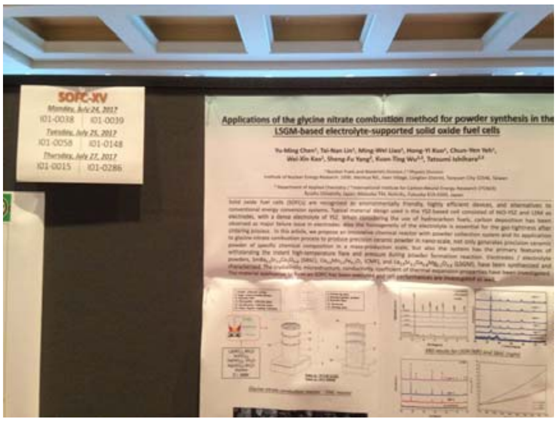
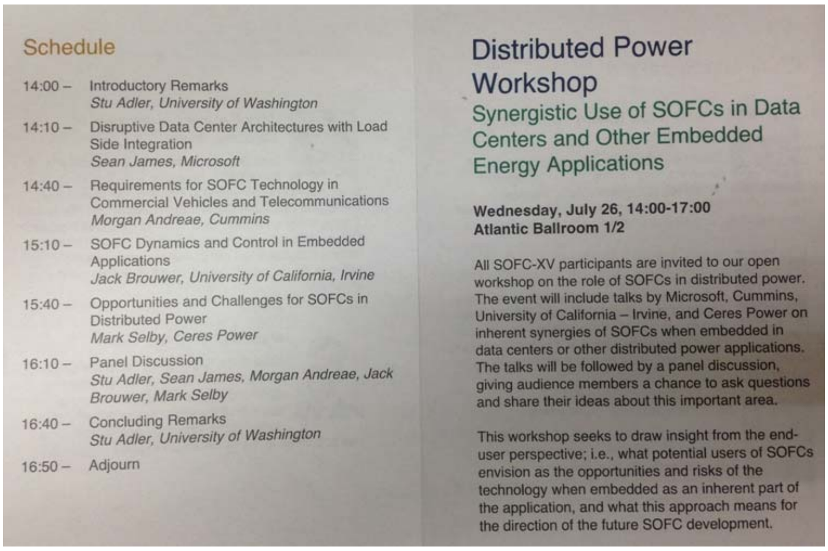


圖 7 陳佑明等人發表之海報論文

C. 7月26日(星期三)

今天是研討會舉行的第三天，早上08:20開始，議程包括SOFC Cathodes IV、SOFC Fuels和Solid Oxide Electrolysis/Reversible Cells and Systems II。下午14:00開始進行Workshop on Synergistic Use of Solid Oxide Fuel Cells (SOFCs) in Data Centers and Other Embedded Energy Applications，如圖8和圖9所示，針對SOFC系統在資料中心或其它分散式電源所扮演角色做一探討，由華盛頓大學Adler教授擔任主席及引言人，邀請Microsoft、Cummins、University of California - Irvine、Ceres Power等公司及研究單位進行報告、與談、討論及接受提問，從使用端的觀點來了解SOFC

未來可能的應用方向與潛在的使用者。



Schedule

14:00 – Introductory Remarks
Stu Adler, University of Washington

14:10 – Disruptive Data Center Architectures with Load Side Integration
Sean James, Microsoft

14:40 – Requirements for SOFC Technology in Commercial Vehicles and Telecommunications
Morgan Andreae, Cummins

15:10 – SOFC Dynamics and Control in Embedded Applications
Jack Brouwer, University of California, Irvine

15:40 – Opportunities and Challenges for SOFCs in Distributed Power
Mark Selby, Ceres Power

16:10 – Panel Discussion
Stu Adler, Sean James, Morgan Andreae, Jack Brouwer, Mark Selby

16:40 – Concluding Remarks
Stu Adler, University of Washington

16:50 – Adjourn

Distributed Power Workshop
Synergistic Use of SOFCs in Data Centers and Other Embedded Energy Applications

Wednesday, July 26, 14:00-17:00
Atlantic Ballroom 1/2

All SOFC-XV participants are invited to our open workshop on the role of SOFCs in distributed power. The event will include talks by Microsoft, Cummins, University of California – Irvine, and Ceres Power on inherent synergies of SOFCs when embedded in data centers or other distributed power applications. The talks will be followed by a panel discussion, giving audience members a chance to ask questions and share their ideas about this important area.

This workshop seeks to draw insight from the end-user perspective; i.e., what potential users of SOFCs envision as the opportunities and risks of the technology when embedded as an inherent part of the application, and what this approach means for the direction of the future SOFC development.

圖 8 Workshop on Synergistic Use of SOFC (Ⅰ)

Chair and Speakers

Stuart Adler (Chair) - University of Washington
Stuart B. Adler is an Associate Professor of Chemical Engineering at the University of Washington. Professor Adler's research interests include high temperature electrocatalysis, fuel cells, air separation, and electrosynthesis of renewable fuels.

Sean James - Microsoft
Sean James runs Microsoft's datacenter research and development program within the Microsoft Cloud Infrastructure and Operations (MCIO) group. MCIO provides the foundational cloud infrastructure for over 1 billion customers, 20 million businesses, and 200+ Microsoft online services, in 90 markets.

Morgan Andreae - Cummins
Morgan Andreae is currently Director of the Cummins Growth Office. In this role, he is responsible for the identification of new business opportunities, and the management of the portfolio of new business investments.

Jack Brouwer - University of California, Irvine
Jack Brouwer is an associate Professor of Mechanical, Aerospace, Civil, and Environmental Engineering at University of California, Irvine, and Associate Director of the Advanced Power and Energy Program (APEP) and National Fuel Cell Research Center (NFCRC). Professor Brouwer's research interests include integrated fuel cell power systems, electric vehicles, power infrastructure, and technology for the smart grid.

Mark Selby - Ceres Power
Mark Selby is the Chief Technical Officer of Ceres Power. He joined Ceres Power in 2006 and is responsible for leading all aspects of the strategy and delivery of the SteelCell™ technology development. He was appointed to the Ceres Board in 2014.

圖 9 Workshop on Synergistic Use of SOFC (Ⅱ)

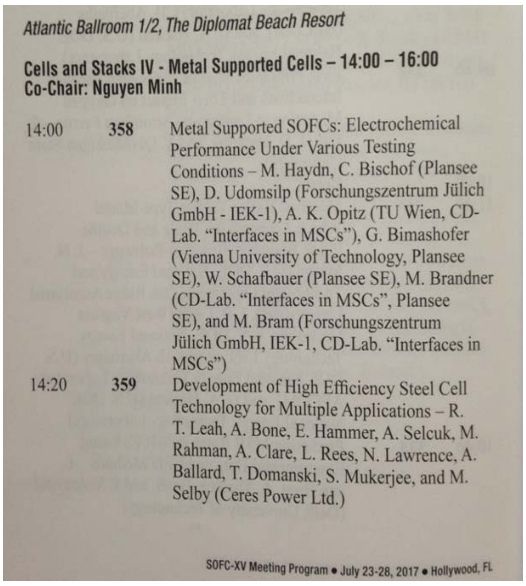
D. 7月27日(星期四)

會議進行第四天，口頭論文發表議程包括Cells and Stacks I、SOFC Anodes I、Solid Oxide Electrolysis/Reversible Cells and Systems III、Cells and Stacks II - Characterization and Testing、Modeling I及SOFC Anodes II，於休息時間與加州大學聖地牙哥分校能源研究中心Dr. Nguyen Minh進行討論與交流，傳達核能研究所與李瑞益副組長問候之意。7月27日晚上18:00~20:00為第三場海報論文發表(Poster

Session 3)，主題包括Solid Oxide Electrolysis/Reversible Cells、SOFC Modeling 和Electrolytes。發表本屆會議之海報論文發表議程於今日結束。

E.　7月28日(星期五)

今日為本屆會議最後一天，議程包括Cells and Stacks III - Durability and Reliability、Modeling II、SOFC Anodes III、Cells and Stacks IV - Metal Supported Cells、Cells and Stacks V - Proton Conducting Cells、SOFC Anodes IV。楊員下午15:00在Cells and Stacks IV - Metal Supported Cells議程(圖10)，於Atlantic Ballroom口頭發表論文" Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique "，報告大尺寸(10 × 10 cm^2)鎳鉬多孔金屬合金支撐基板模具加壓成型研製， 包括起始物料噴霧造粒增加流動性與塑性作為多孔金屬基板的加壓成型前驅原料，compression molding 最佳成型操作條件建立及適宜煅燒溫度探討，加壓成型後的生胚試體煅燒溫度區間為1000℃~1250℃可獲得完整多孔金屬合金基板，再藉由大氣電漿噴塗技術將功能層(包括陽極、電解質和陰極)被覆於合金基板上完成SOFC電池片，並且測試電池片性能及金屬基板機械強度。會中展現本所於金屬支撐型固態氧化物燃料電池片之技術進展，簡報內容(如附錄八所示)受到與會成員關注並熱烈提問，於休息時間再與其他專家學者深入討論。


Atlantic Ballroom 1/2, The Diplomat Beach Resort

Cells and Stacks IV - Metal Supported Cells – 14:00 – 16:00
Co-Chair: Nguyen Minh

14:00	358	Metal Supported SOFCs: Electrochemical Performance Under Various Testing Conditions – M. Haydn, C. Bischof (Plansee SE), D. Udomsilp (Forschungszentrum Jülich GmbH - IEK-1), A. K. Opitz (TU Wien, CD-Lab. "Interfaces in MSCs"), G. Bimashofer (Vienna University of Technology, Plansee SE), W. Schafbauer (Plansee SE), M. Brandner (CD-Lab. "Interfaces in MSCs", Plansee SE), and M. Bram (Forschungszentrum Jülich GmbH, IEK-1, CD-Lab. "Interfaces in MSCs")
14:20	359	Development of High Efficiency Steel Cell Technology for Multiple Applications – R. T. Leah, A. Bone, E. Hammer, A. Selcuk, M. Rahman, A. Clare, L. Rees, N. Lawrence, A. Ballard, T. Domanski, S. Mukerjee, and M. Selby (Ceres Power Ltd.)

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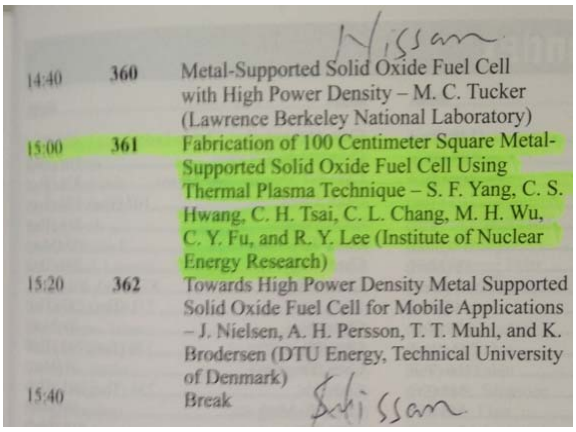

14:40	360	Metal-Supported Solid Oxide Fuel Cell with High Power Density – M. C. Tucker (Lawrence Berkeley National Laboratory)
15:00	361	Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique – S. F. Yang, C. S. Hwang, C. H. Tsai, C. L. Chang, M. H. Wu, C. Y. Fu, and R. Y. Lee (Institute of Nuclear Energy Research)
15:20	362	Towards High Power Density Metal Supported Solid Oxide Fuel Cell for Mobile Applications – J. Nielsen, A. H. Persson, T. T. Muhl, and K. Brodersen (DTU Energy, Technical University of Denmark)
15:40		Break

圖 10 楊員於Cells and Stacks IV - Metal Supported Cells口頭發表論文議程

本屆會議之廠商參展於今日結束，共有13家廠商參與展覽，如圖11所示，分別為AVL List GmbH、CAP CO., LTD、The Electrochemical Society、Fiaxell Sàrl、Fuel Cell Materials、FuelCon AG、Gamry Instruments、Haiku Tech, Inc.、PAR/Solartron、Praxair Surface Technologies, Inc.、Process Systems Enterprise、Quantachrome Instruments和Scribner Associates, Inc.。

圖11 本屆會議之參展廠商

最後Closing Session會議主席Dr. Singhal宣佈兩年後，2019第十六屆國際固態氧化物燃料電池研討會(The Sixteenth International Symposium on Solid Oxide Fuel Cells, SOFC-XVI)將於日本京都Kyoto Terrsa舉行，如圖12所示，歡迎大家再次共享盛舉，與燃料電池一流專家進行技術探討，並於此國際資訊交流之重要平台，收集廣泛且深入的技術資訊。

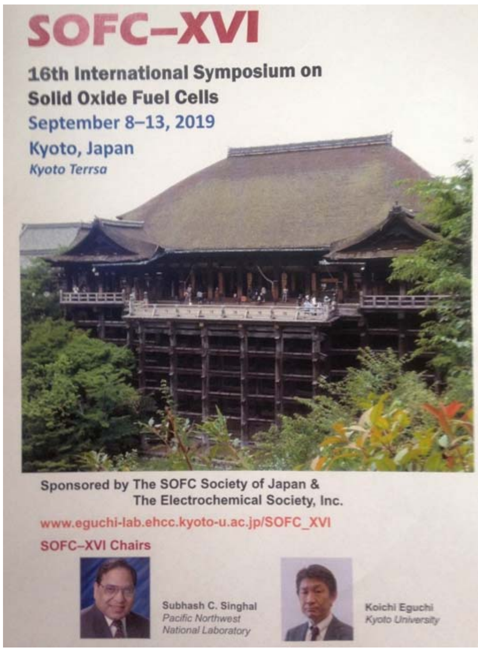


圖 12 2019第十六屆國際固態氧化物燃料電池研討會訊息

3. 回程

本次國際會議於美國時間2017年7月28日下午結束，楊員於7月29日返程，回程路線及航班安排與來程相同，由佛羅里達邁阿密國際機場起飛，抵達紐約約翰·菲茨傑拉德·甘迺迪國際機場後轉機返回台灣桃園國際機場。

A. 7月29日(星期六)

15:30於佛羅里達邁阿密國際機場辦理完成轉機登機手續，17:46搭乘美國航空AA2254班機至紐約約翰·菲茨傑拉德·甘迺迪國際機場。

B. 7月30日(星期日)

23:00於紐約約翰·菲茨傑拉德·甘迺迪國際機場辦理完成出境手續，7月31日01:25搭乘長榮航空公司BR-31班機返回台灣桃園國際機場。

C. 8月1日(星期二)

於04:55抵達台灣桃園國際機場，順利完成出國公差任務。

三、心得

(一) 作者本次赴美國佛羅里達州好萊塢市參加第十五屆國際固態氧化物燃料電池研討會並順利完成口頭論文發表。此國際固態氧化物燃料電池研討會於1989年開始舉辦，每兩年舉辦一次，持續至今已28年，為國際SOFC領域最重要的資訊交流平台。本次大會舉辦總計共有28(包括Plenary Session)場學術議題研討會，來自世界各地40個國家五百餘位專業人士參加，372篇論文投稿，口頭發表233篇，海報發表139篇，SOFC-XI、SOFC-XII、SOFC-XIII及SOFC-XIV投稿論文分別為 363篇、349篇、373篇及420篇。參加人員主要來自歐美國家、日本、中國與韓國，台灣有3個單位，分別為核能研究所、成功大學、中央大學，共投稿論文4篇。本所在台灣為固態氧化物燃料電池研究與發展的領頭羊，在此大型國際會議與重要新能源議題，站上講台為本所與台灣發聲實屬難得，未來應提供充足經費與支援，持續派人參加此SOFC重要會議並與國際人士進行交流。

(二) 國際固態氧化物燃料電池研討會為此領域的指標性會議，提供國際間從事SOFC研究的研發人員及業界一個優質的交流平台，並建立國際間彼此的連結及促進友好關係。本次公差主要接觸的國際學者有會議主席美國西北太平洋國家實驗室Dr. Subhash C. Singhal、加州大學聖地牙哥分校能源研究中心Dr. Nguyen Minh、加拿大國家研究委員會Dr. Xinge Zhang、九州大學Professor Tatsumi Ishihara、Fiacell Sarl SOFC Technologies Dr. Pierre Coquoz進行討論與交流，楊員於會議期間展現研究成果，會後分享研究心得，研發成果受到肯定。

(三) 固態氧化物燃料電池科技已經朝商業化邁進，特別在1 kW級SOFC結合汽電共生(Combined Heat and Power, CHP)的民生住宅應用和大於200 kW等級定置式SOFC電力產生器(Stationary Power Generation)。為了讓燃料電池獲得更好的電性表現、系統穩定度、減少建置成本和促進燃料電池科技被普遍接受和使用，燃料電池相關的研究和發展仍然是相當重要的。

(四) 美國能源部化石能源辦公室(Department of Energy Office of Fossil Energy)國家能源技術實驗室(NETL)主導、執行與推動固態氧化物燃料電池研究發展計畫，主要發展低成本、高效率固態氧化物燃料電池系統，以天然氣或煤碳為發電主要燃料來源，同時達到碳捕捉的目的；維持電池發展和核心技術的研究來增加電池、電池堆和系統的可靠度、耐用性和耐久性；提供價格具有競爭力的SOFC分散式電源。

(五) IGFC and NGFC Pathway Studies – Estimation of Stack Degradation Costs and Salient Results 研究報告中之概念設計分析顯示皆有裝設碳捕捉封存系統的煤炭氣化-燃料電池複循環發電系統(Integrated Gasification Fuel Cell, IGFC)和天然氣燃料電池(Natural Gas Fuel Cell, NGFC)發電系統，相對於目前世界上使用中和改良的發電系統如傳統粉煤發電系統(Pulverized coal, PC)、氣化複循環發電系統(Integrated Gasification Combined Cycle, IGCC) 和天然氣發電系統(Nature gas combined cycle, NGCC)具有較低發電成本(IGFC：78.8美元/MWh；NGFC：68.7美元/MWh；IGCC：135.4美元/MWh；NGCC：82.9美元/MWh；PC：134.2美元/MWh)和較高的發電效率(IGFC：54.1%；NGFC：64.7%；IGCC：32.6%；NGCC：46%；PC：32.5%)，如圖13所示。

(六) NETL SOFC計畫對於發電系統的研究工作將SOFC技術應用在大型發電廠使用，並拓展於以天然氣為燃料的分散式發電單元。傳統小型發電廠以天然氣為燃料，使用引擎和氣渦輪的熱電科技，商業化分散式發電系統已是相當成熟的設備和技術，藉由開發模組化可有效降低設置成本，但是由圖14可以發現它們的發電效率低、燃料轉換率不佳和排放大量污染物(CO_2、NO_x、SO_x)。分散式電力系統若是和高溫SOFC結合模組化可以提供最低300 kW、最高1200 kW的電力需求，具有較佳的發電效率：45-50% (單一循環組態)、60% (結合或混和循環模式)。天然氣為燃料的高溫SOFC分散式發電單元以它高效率的潛力及對使用者和環境的優勢，搭配各種租稅減免(Tax credits)及政府發起

的獎勵補助或出資建置，將可減少目前的高建置成本，最終建置成本將與傳統分散式電力技術等值，具有競爭力。

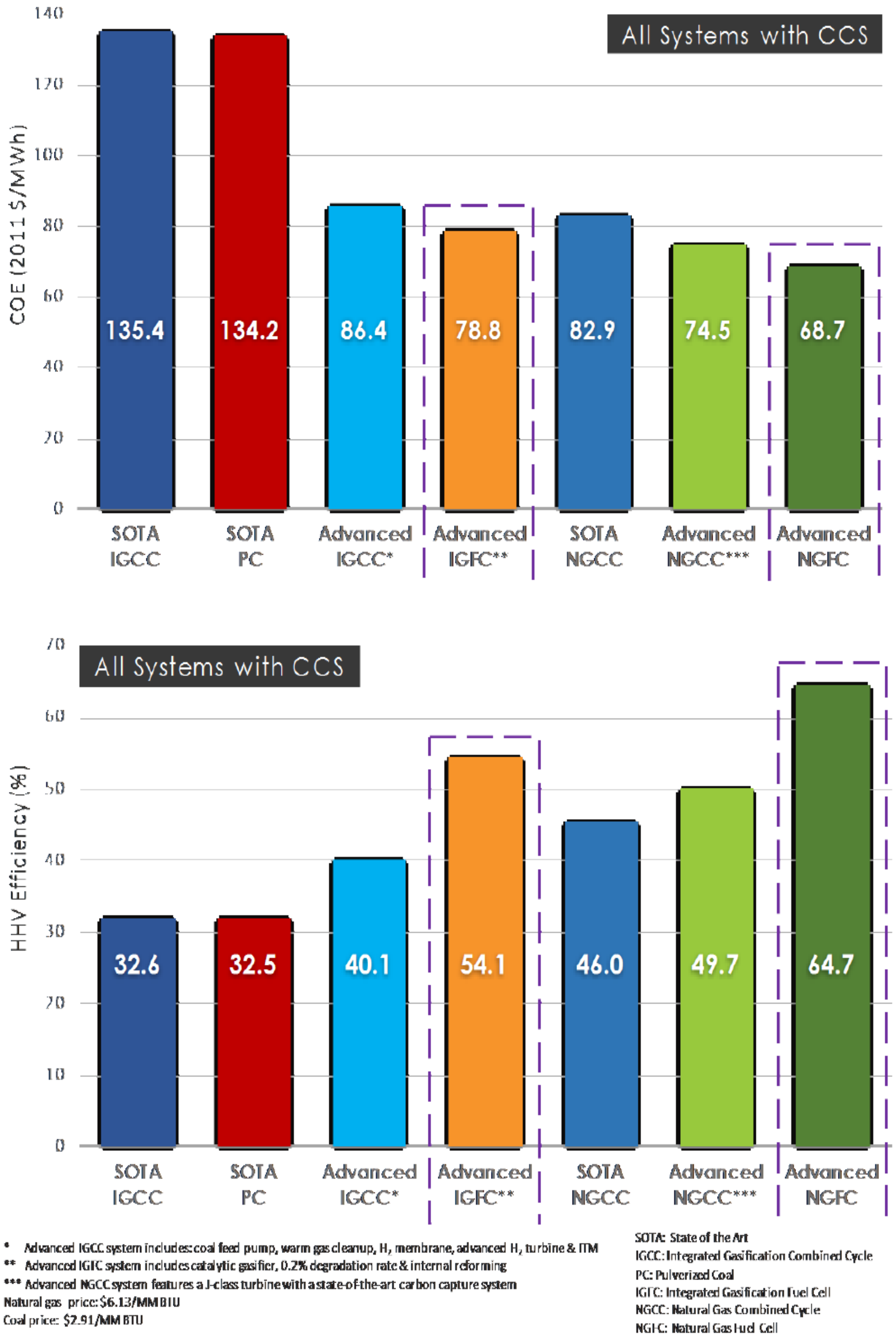
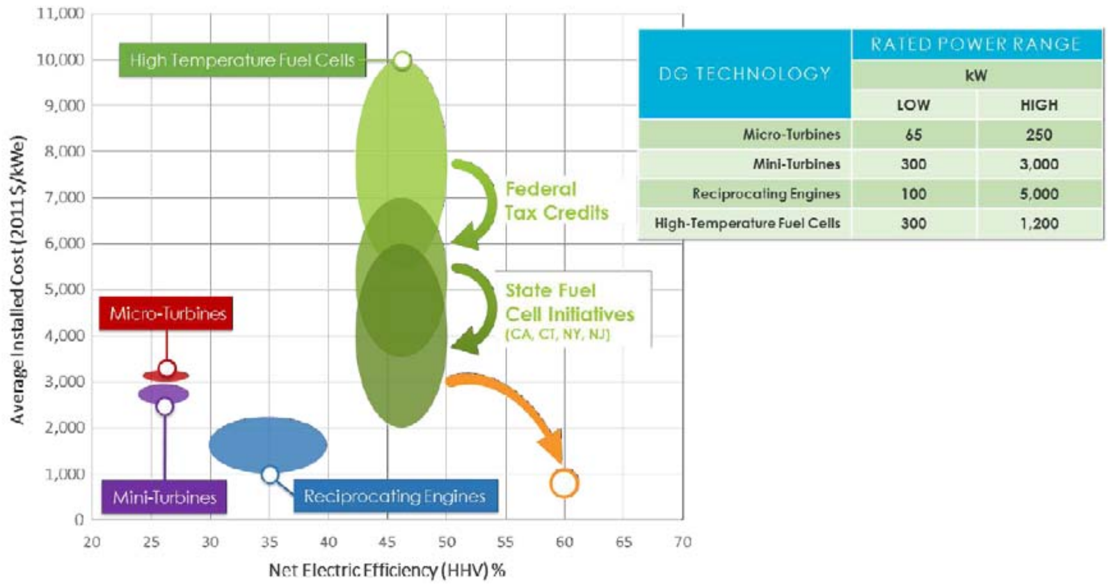


圖 13 SOFC、傳統天然氣和煤合成氣發電裝置的發電成本及效率的比較



DG TECHNOLOGY	RATED POWER RANGE kW	
	LOW	HIGH
Micro-Turbines	65	250
Mini-Turbines	300	3,000
Reciprocating Engines	100	5,000
High-Temperature Fuel Cells	300	1,200

圖 14 分散式發電技術現有及已規劃的容量和成本

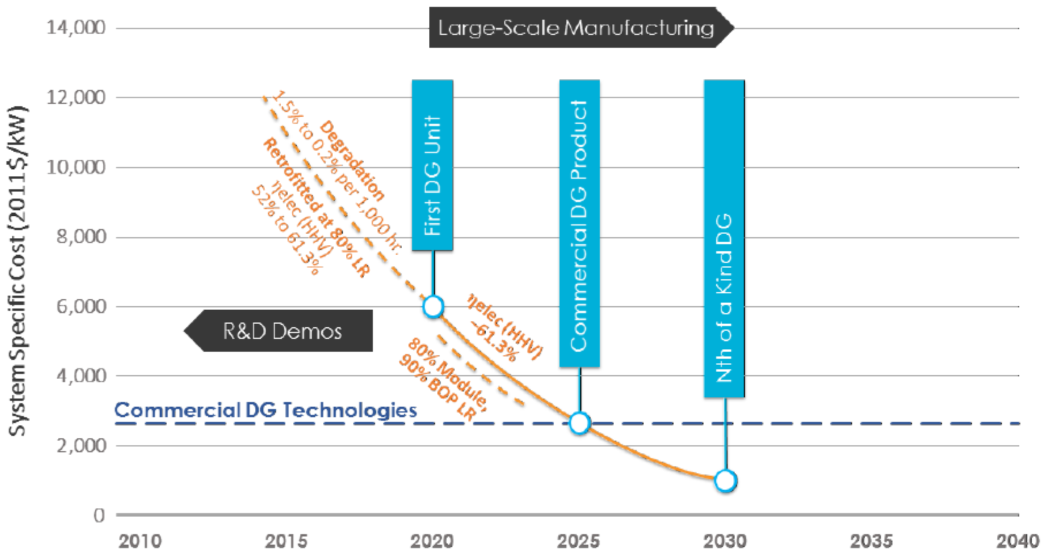


圖 15 藉由計劃的進展和大尺寸製造推行SOFC分散式發電系統成本降低趨勢

(七) Assessment of the Distributed Generation Market Potential for Solid Oxide Fuel Cells

研究計畫使用學習曲線來發展一個SOFC系統建置成本，相對於時間的可靠估算方法來解釋2030年建置成本抑減如何來達成。如圖15所示，藉由SOFC計畫的研究和發展，如針對電池表現及衰退率、大尺寸設備的製造技術和操控介面的改善，2020降低成本為6000美元/kW的目標。之後5年期間2020-2025，NETL預估當以天然氣為燃料的高溫SOFC分散式發電系統使用量占分散式發電系統市場比例一小部份(< 1%)，也就是累積發電量大概佔25

MW，將會使系統成本降低到2500美元/kW，開始對傳統技術分散式電源系統產生具有影響力的競爭。在2030年，市場上使用累積發電量達到1000 MW，此時系統建置成本將少於1000美元/kW。

(八) 表1指出NETL SOFC計畫發電系統的表現、成本和漸進式目標。表2則為NETL SOFC計畫關鍵里程碑。目前發展狀況為系統建置成本為12000美元/kW，SOFC發電衰退率為小於1.0%/1,000 h，50 kW和200 kW發電系統完成驗證，400 kW建置中，預計2020年完成1 MW系統建置。

表 1 NETL SOFC計畫發電系統發展目標

Metric	Current Status	2020 Target	2030 Target
System Cost	~$12,000/kWe	$6,000/kWe	$900/kWe
SOFC Power Degradation Rate	~1.0%/1,000h	0.5 – 1.0%/1,000h	0.2%/1,000h
Cell Manufacturing Approach	Batch	Semi-Continuous	Continuous
Demonstration Scale	50 kWe & 200 kWe POC Systems – Intended Initial Operations Completed 400 kWe Prototype System – Design of First System in Process 250 kWe – 500 kWe Prototype Systems Two additional needed	1 – 5 MWe DG, Integrated Systems	10 – 50 MWe Integrated Systems

表 2 NETL SOFC計畫關鍵里程碑

Year	Key Program Milestones
FY16/17	Demonstrate Multi-100 kWe-Class Proof-of-Concept Systems
FY18	Demonstrate Integrated 400 kWe Prototype Systems
FY20	Demonstrate First-of-a-Kind 1 MWe Pilot System (NG Fuel)
FY30	Demonstrate 10-50 MWe First-of-a-Kind IGFC/NGFC Pilot System(s)

(九) NETL SOFC計畫關鍵技術包括電池發展及系統發展和研究目標如圖16所示。電池發展(Cell development)部份目前共有22個方案在執行(圖17)，技術發展里程碑以及技術成熟度分級(TRL)為2-5，目標在增加功率密度、降低衰退率和製作成本。數個計劃研究結果顯示，鉻對電池陰極的污染與毒化已經確認是電池系統電性衰退和可靠度不佳的主要原因。對於鉻污染的問題，NETL SOFC計畫近期啟動13個方案來應對這個重要的議題。核心技術(Core technology)部份主要改善溫度梯度、氣流分佈不良及降低成本，包括改善電池堆的可靠度、耐久度和強度、確認造成電池堆性能衰退的問題、降低電池

堆成本、發展計算工具和模擬、封裝、連接板材料和天然氣燃料重組開發，目前共有13個方案在執行，TRL為2-5。系統發展(System development)部份主要目標在促進各元件整合、降低複雜度和建立最佳操控策略，包括電池及電池堆放大製作整合為一模組、硬體發展、製造程序發展、實驗室規模電池堆測試、概念性及先導型系統驗證，目前共有12個方案在執行，TRL為4-8。

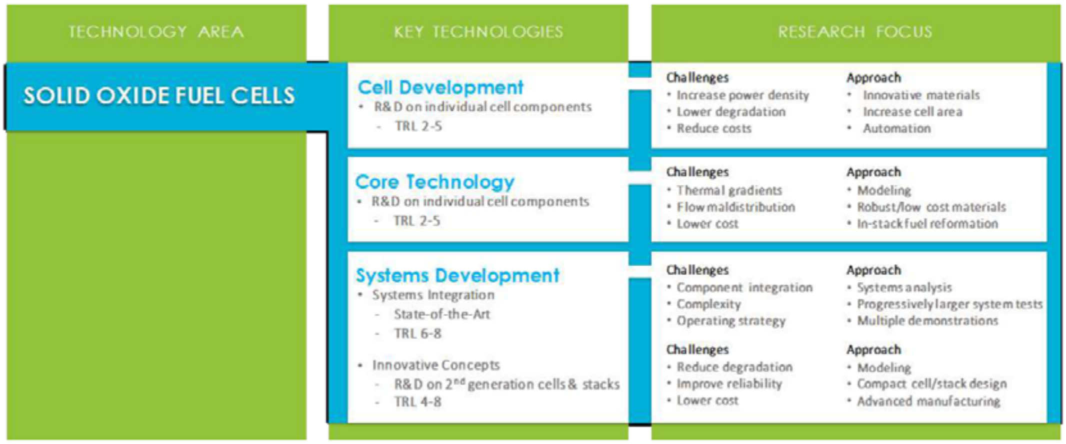


圖 16 NETL SOFC計畫關鍵技術和研究目標

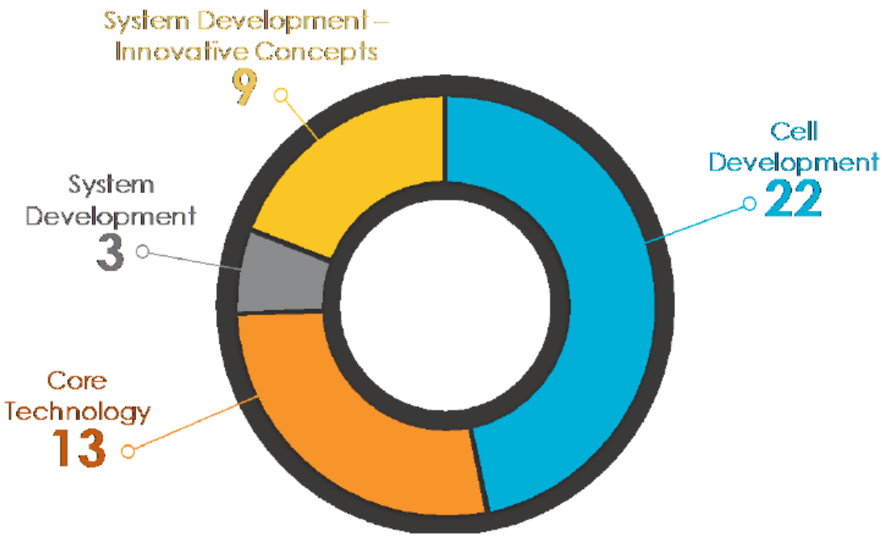


圖 17 NETL SOFC計畫關鍵技術各研究計畫比例

(十) NETL SOFC計畫從2000年開始至今已第17年，過去16年間總計畫補助金額大約為6億5千萬美元，計畫參與相關單位提供額外2億5千萬美元成本分攤。NETL SOFC計畫從2000年開始至今提供將近260個方案(圖19)給115個產學研機構執行，65個企業、40個大學和10個國家實驗室，獲得相當好商業化成果。

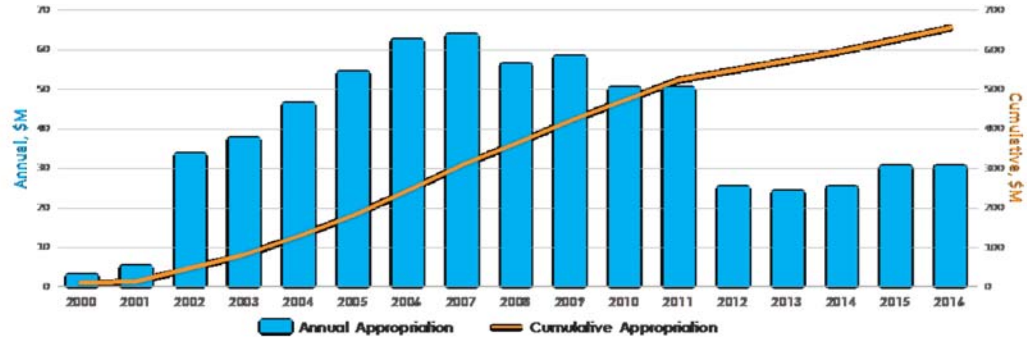


圖 18 NETL SOFC計畫補助金額歷史

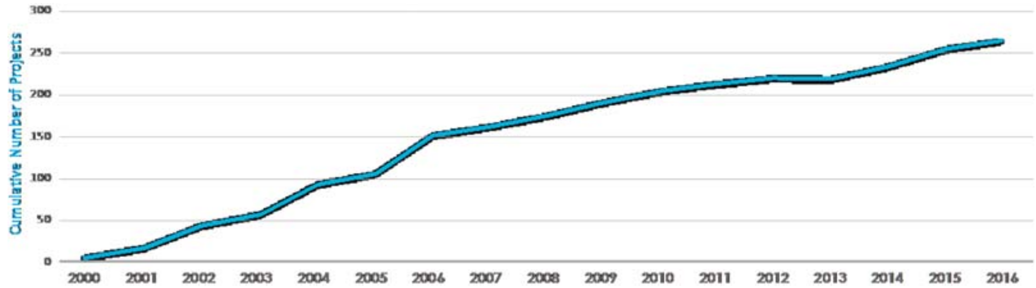


圖 19 NETL SOFC計畫累積的補助方案數量

(十一) 兩個概念性驗證SOFC發電系統，以天然氣為燃料，已分別被FuelCell Energy (FCE)和LG Fuel Cell Systems (LG)成功建置和運轉，TRL=6，如圖20所示。FCE建置和測試的50 kW SOFC發電系統和電網結合，發電量將近50 kW的交流電，發電效率為55%，衰退率每一千小時為0.9%，連續操作時間超過1,500小時。LG建置和測試的200 kW SOFC發電系統一樣和電網結合，發電量將近200 kW的交流電，發電效率為57%，連續操作時間超過2,000小時。

圖 20 概念性驗證SOFC發電系統

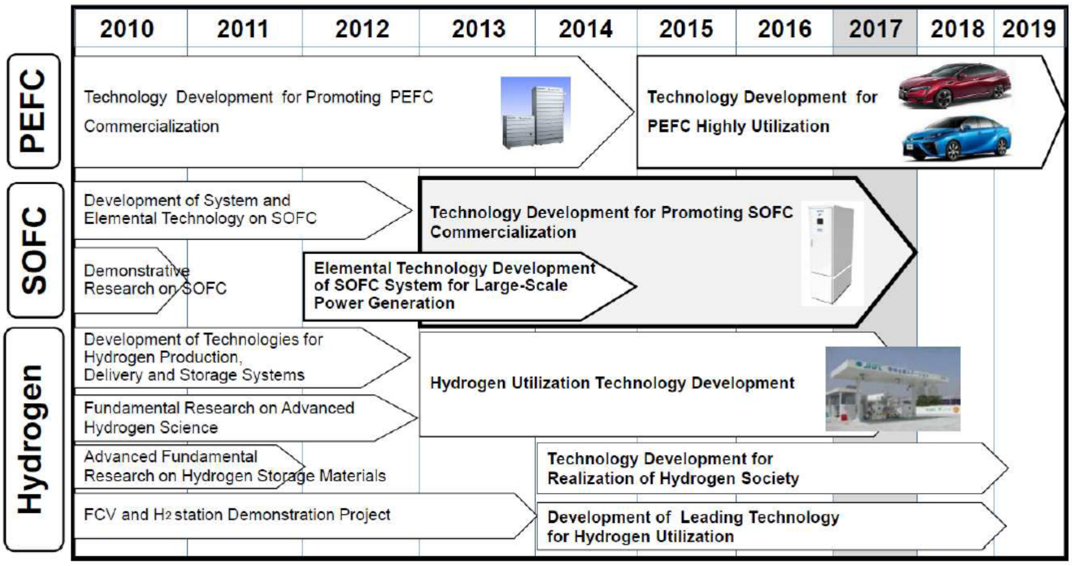


圖21 近期完成和執行中的NEDO SOFC、PEFC、氫能源科技計畫

(十二) 日本SOFC相關研究計畫主要由經濟產業省(Ministry of Economy, Trade and Industry, METI)轄下的獨立行政法人新能源產業綜合開發機構(NEDO)來組織、管理、執行和宣傳成果。PEFC-based CHP系統(ENE-FARM)和SOFC-based CHP系統(ENE-FARM type S)分別在2009和2011開始有商業化的產品販售，2016年12月的統計數據顯示兩種系統建置數量合起來超過198,500套，未來進一步的商業化推廣，如何減少建置成本和增加耐久性方面仍然是一個非常重要的議題。NEDO於2013年開始執行促進固態氧化物燃料電池技術商業化應用發展的計畫(2013~2017)，如圖21所示，全程預計投入68億5千8百萬日圓，主要發展：1. SOFC衰退率快速評估方法(目標是90,000小時，約10年)的基本研究。2017年3月為止，日本國內7間公司所發展7種電池堆裝置的改善狀況如表3所示；2. SOFC系統商業化應用的驗證研究，如Miura公司於2016年完成5 kW SOFC系統商業化應用驗證，熱和電總效率為90%。三菱日立發電系統(MHPS)與Toyota、Tokyo Gas於2016年完成合作驗證管狀SOFC (250 kW)及氣體渦輪混和系統，運轉時間超過4000小時。Fuji Electric驗證50 kW SOFC系統，發電效率可超過55%；3. 發展下個世代SOFC技術，如使用可逆式固態氧化物燃料電池(Reversible SOFC)來高效率轉換的電力儲存和生產低成本氫

氣。NEDO估計日本SOFC系統商業化使用市場(圖22)，住家為kW等級；一般商業場所(洗衣店、理髮店、旅館)為10 kW等級；在大型飯店和辦公大樓等商業化使用SOFC為100 kW等級，工廠則為1 MW等級。

表 3 日本國內7間公司所發展7種電池堆裝置的改善狀況

Cell Stack Type	Version	Degradation Rate (%/1,000 hour)	Operating time (hour)
SIS Tubular (MHPS)	Type VI(No.10)	0.10	23,000
Flatten tubular(Kyocera)	2016	0.29	7,000
Micro tubular(TOTO)	2013	0.36	6,000
Planer(NGK SPAK PLUG)	2014	0.64	7,000
SIS flatten tubular (NGK INSULATORS)	2015	0.36	8,000
All ceramics planer(Murata Manufacturing)	2016	1.26	6,000
planer(DENSO)	2016	-	3,000

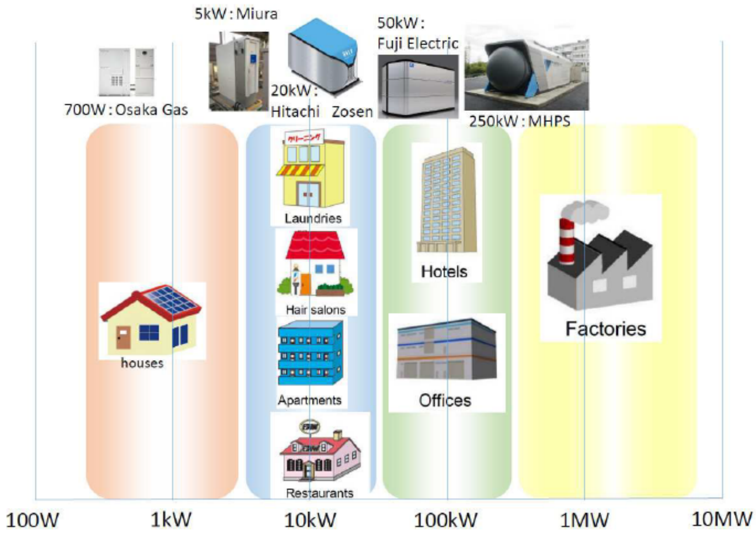


圖22 日本SOFC系統商業化使用市場

(十三) 歐盟燃料電池暨氫氣聯合企業(Fuel Cells and Hydrogen Joint Undertaking, FCH-JU)在2008年設立，主要在加強產業間、歐盟區域國家層級與歐盟層級的研究單位之間彼此橫向聯繫，增進所有相關公、私部門之間彼此的配合與努力，以確保區域、國家和歐盟各層級間研究單位、工業和政府部門能密切合作，加速燃料電池及氫氣新能源技術發展，並在2020年之前朝商業化目標邁進。FCH-JU藉由鼓勵增加燃料電池單元於定置型燃料系統的應用，如家用與商業用微型汽電共生系統，於歐盟區域的應用和普及化(圖23)，2016年補助3千4百萬歐元給5家製造商，鼓勵每一家至少實體建置500座燃料電池微

型汽電共生系統，目前實際建置量為2650座，每一家廠商估計減少成本30%以上，並以每一系統(若系統大於1 kW發電量則以每kW來計算)kW單價小於10000歐元為目標。

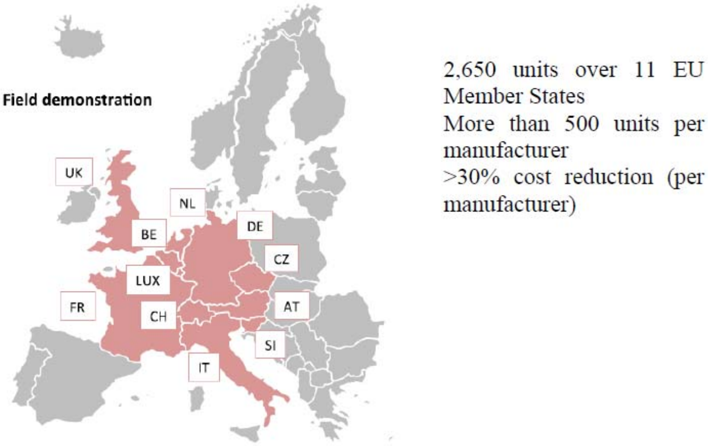


圖23 在11個歐盟國家中9家製造商2650組燃料電池單元系統分佈情形

(十四) FCH-JU在過去8年共補助204個計劃，共7億3千2百萬歐元的經費，其中1億7千6百萬歐元的經費用於補助發展SOFC和SOEC技術相關的49個計畫，佔補助能源領域計畫經費的40%，顯示固態氧化物燃料電池或電解電池相對於太陽能與風力等再生能源具有潛力及可靠的效率，因此歐盟燃料電池暨氫氣聯合企業積極投入SOFC和SOEC相關材料及系統之研發及測試，目前市場應用如手提式設備及攜帶式發電機；定置型燃料系統的應用如家用與商業用汽電共生系統；在大型市場應用如交通運輸工具的應用，商業化程度將準備就緒。

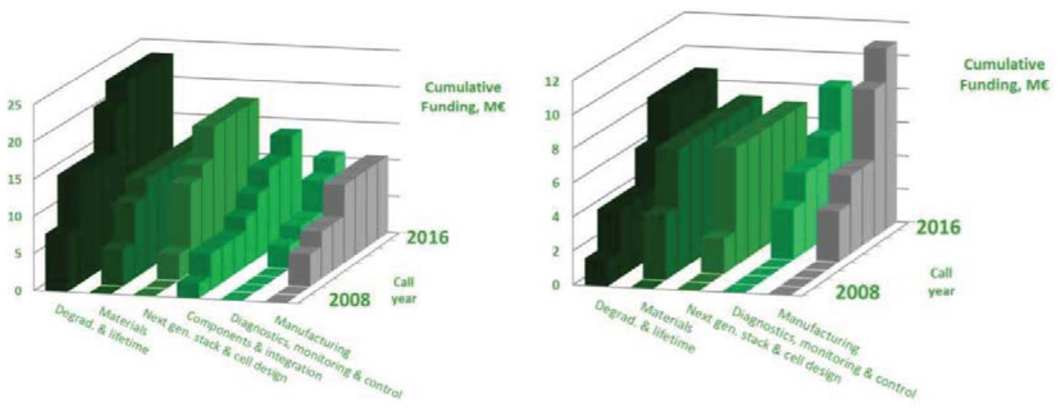


圖24 FCH-JU對於所有定置式燃料電池技術(左邊)和SOFC(右邊)的研究經費補助

四、建議事項

本次出國公差前往美國佛羅里達州好萊塢市參加由美國電化學學會與日本固態氧化物燃料電池協會共同主辦之第十五屆國際固態氧化物燃料電池研討會進行口頭論文發表，汲取國際第一手研究內容，並與專家學者互動討論，個人建議如下：

(一) 由此屆國際會議的發表論文數目(口頭發表233篇，海報發表139篇)、參加人數(超過500人)與國家(非洲、亞洲、澳洲、歐洲、北美洲和南美洲共40個國家)可以發現，世界上對於SOFCs和SOECs的研究及商業化發展的關注持續增加。每兩年舉辦一次的國際固態氧化物燃料電池研討會，儼然成為國際間SOFC領域相當重要且主要的交流平台。建議計畫未來應持續規劃與派員參加該國際會議，真實呈現國內的最新研發成果及研究近況、拓展國際人脈關係以加速計畫之進展，使得所內與國內SOFC的研發可與國際接軌，並掌握國際間之發展現況及未來趨勢。

(二) 此屆國際固態氧化物燃料電池研討會每天皆有3個口頭論文發表場地同時進行，總計共有28場學術研討會，另外還有3場海報論文發表研討會於晚間18:00~20:00進行。經由親身參與口頭發表論文，使本所SOFC能源領域議題備受重視及肯定，而參與會議期間向與會專家學者請益，可以促進及充實本職學能。建議於會議結束後，對於可能互訪或合作之事宜，仍需持續關注或追蹤。

(三) 金屬支撐固態氧化物燃料電池的論文發表逐漸增加，本次會議在Cells and Stacks section之下獨立進行一場金屬支撐電池議題之口頭發表，楊員在口頭報告時聽講人數與之後受到與會者們的踴躍提問可以發現對此研究領域的關注越來越多，相較於本屆會議所發表的固態氧化物燃料電池相關數據而言，本所研發的金屬支撐型固態氧化物燃料電池具有領先的優勢，建議未來可投入更多人力與經費，持續掌握領先優勢，積極研發朝實用化的角度去發

展。建議未來可與相關研究單位建立合作管道，進行互訪、合作或派員交流實習，促進技術與學術交流，掌握關鍵技術，並了解國際趨勢，有助於計畫之執行，並對我國SOFC領域研發有很大的助益。透過雙方緊密的國際交流與專家討論，可拓展研究深度與提升國際同業審查應對能力，並提升本所固態氧化物燃料電池相關技術能力。

(四)歐盟、美國和日本等世界上主要國家，皆由政府單位或國家級研究機構負責管理與協調研究團隊之合作方向、決定技術發展優先次序，整合產、官、學、研，積極加強所有相關公、私部門彼此的配合與努力，以確保各層級研究單位、工業和政府部門能密切合作，並且提供相當充足的經費。國際各先進國家於SOFC橫向及縱向聯繫整合、能源政策、經費投入程度的相關作為，值得國內各界參考與借鏡。

(五) 為了達到汽車零排放和溫室氣體減量的目標，世界上各汽車製造商如德國賓士汽車(Mercedes-Benz)、日本本田汽車(Honda)、豐田汽車(Toyota)、南韓現代汽車(Hyundai)皆針對氫燃料電池汽車進行基礎研究與實車組裝測試及販售，期望達到取得容易與低污染性的目標。日本打算在2020年的東京奧運上大力推廣使用氫燃料電池車和氫燃料電池巴士運送選手， 從選手村進入會場與場館之間的聯絡，以及可能擴大使用範圍，正積極為打入全球市場試水溫。豐田汽車目標於2020年銷售氫燃料電池車達3萬輛，是2017年燃料電池生產量的10倍。豐田也對外表示，希望在2020年東京奧運之前有100輛氫燃料巴士到東京都區使用。本次會議在Cells and Stacks section之下獨立進行金屬支撐電池議題會淺之口頭發表中有三個單位(Lawrence Berkeley National Laboratory、Technical University of Denmark、Ceres Power Ltd.)獲得日產汽車(Nissan)大量經費支持，進行高電功率密度金屬支撐燃料電池基礎研究及汽車用商業化開發。裕隆為台灣專責汽車設計開發公司，2009年停用裕隆品牌後發表的第一個自有品牌納智捷(LUXGEN)，建議本所固態氧化物燃料電池可與該公司建立

燃料電池車合作開發管道進行技術交流，拓展燃料電池應用領域，並協助規劃與政府聯合出資設立基金扶持汽車產業，做為發展氫燃料電池技術、燃料電池車、加氫站設施及推廣環保科技之用，期望達到雙贏效益。

五、附錄

附錄一、第十四屆國際固態氧化物燃料電池研討會邀請函

The Fifteenth International Symposium on Solid Oxide Fuel Cells (SOFC-XV)

July 23-28, 2017
Diplomat Resort & Spa, Hollywood, Florida, USA

March, 8, 2017

Dr. Sheng-Fu Yang
Institute of Nuclear Energy Research
No. 1000, Wenhua Rd., Jiaan Village, Longtan Township
Taoyuan County, 32546
Taiwan

Dr. Sheng-Fu Yang,

We are pleased to inform you that your paper, "*Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique*," has been accepted for presentation at SOFC-XV in Hollywood, Florida, July 23-28, 2017; (ECS Abstract Number 100585). The Meeting is sponsored by the Electrochemical Society and the SOFC Society of Japan and is expected to be attended by over 500 participants from over 35 countries.

The entire technical program, including abstracts, for the meeting, as well as meeting registration and hotel reservation information, will be available on the meeting website, www.electrochem.org/sofc-xv, in late April.

Your paper represents an important contribution to the success of the SOFC-XV Meeting and we greatly appreciate your participation.

Sincerely,

S.C. Singhal

Dr. Subhash C. Singhal
Pacific Northwest National Laboratory, USA (singhal@pnnl.gov)
Chair, SOFC-XV

附錄二、會議投稿摘要接受通知

楊昇府 Tim Yang

寄件者:	ecs@confex.com
寄件日期:	2017年1月18日星期三 上午 1:30
收件者:	楊昇府 Tim Yang; d95541006@ntu.edu.tw
主旨:	ECS Abstract #100585 - SOFC-XV: 15th International Symposium on Solid Oxide Fuel Cells (July 23-28, 2017)

This message serves as confirmation that your submission was received as noted below:

Title: Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique
ID: 100585
Password: 975769

You submitted this for SOFC-XV: 15th International Symposium on Solid Oxide Fuel Cells (July 23-28, 2017) (Fuel Cells, Electrolyzers, and Energy Conversion).

You may revise your submission until Friday, 3 February 2017.

Be aware that the information relating to your abstract will be published exactly as you entered it, so it is important that you have confirmed it is correct and free of any spelling errors.

To see your submission, simply click on the link below.

https://ecs.confex.com/ecs/sofc2017/i/papers/index.cgi?username=100585&password=975769

Thank you for using the ECS Online Abstract Submission System.

附錄三、會議投稿全文接受通知

楊昇府 Tim Yang

寄件者:	ecs@confex.com
寄件日期:	2017年3月28日星期二 上午 3:14
收件者:	楊昇府 Tim Yang
主旨:	ECS Transactions: Manuscript # Decision Letter

Dear Dr. Sheng-Fu Yang,

I am pleased to inform you that your manuscript, "Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique", has been reviewed and accepted for publication in the Fifteenth International Symposium on Solid Oxide Fuel Cells issue of "ECS Transactions" (ECST) from the ECS Hollywood meeting. This issue is scheduled to be published July 14, 2017.

Authors whose papers will be published in ECST are also urged to submit their papers to an ECS journal. ECS recently began publishing three new peer-reviewed scientific journals, which join the flagship Journal of The Electrochemical Society. This exciting news was covered in the spring 2012 issue of Interface magazine. Click here to read about it: http://www.electrochem.org/dl/interface/spr/spr12/spr12_p017_027.pdf. While the expectation is that six months is sufficient time to revise an ECST paper to meet the stricter standards of the journals, there is no deadline for submission. Submissions to the journals must be made using the online submission system. Click here for author instructions: http://ecsdl.org/site/ecs/manuscript_submissions.xhtml.

Thank you for contributing your work to ECST. If you have any questions or comments, please feel free to contact the ECST staff at ecst@electrochem.org.

Sincerely,

Dr. Subhash C Singhal
Editor, Fifteenth International Symposium on Solid Oxide Fuel Cells "ECS Transactions", Volume 77

Further Reviewer Comments (if any):

- The figures were included in the text.

附錄四、會議議程

SOFC-XV: 15th International Symposium on Solid Oxide Fuel Cells (July 23-28, 2017)

MONDAY, 24 JULY 2017

Monday | Tuesday | Wednesday | Thursday |Friday | top

09:00-12:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Plenary Session and SOFC Systems
Grand Ballroom West
Chair(s): Subhash C. Singhal and Tatsuya Kawada

14:00-17:40

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Cathodes I
Grand Ballroom West
Chair(s): Koji Amezawa and Eric D. Wachsman

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Electrolytes
Atlantic Ballroom 3
Chair(s): Tatsumi Ishihara and Uday Bhanu Pal

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Systems I
Atlantic Ballroom 1/2
Chair(s): Mark Christopher Williams and Mihails Kusnezoff

18:00-20:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Poster Session I (Cathodes and Anodes)
Grand Ballroom East
Chair(s): Subhash Singhal and Tatsuya Kawada

TUESDAY, 25 JULY 2017

Monday | Tuesday | Wednesday | Thursday |Friday | top

08:20-12:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Interconnects, Contact Materials and Seals I
Atlantic Ballroom 3
Chair(s): Takuya Hashimoto and Venkataraman Thangadurai

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Cathodes II
Grand Ballroom West
Chair(s): Kazunari Sasaki and Elisabeth Djurado

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Systems II
Atlantic Ballroom 1/2
Chair(s): Yoshio Matsuzaki and Robert Steinberger-Wilckens

14:00-17:40

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Interconnects, Contact Materials and Seals II
Atlantic Ballroom 3
Chair(s): Jong-Ho Lee and Srikanth Gopalan

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Cathodes III
Grand Ballroom West
Chair(s): Teruhisa Horita and Stuart B. Adler

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS

Atlantic Ballroom 1/2
Chair(s): Mogens Bjerg Mogensen and Xiao-Dong Zhou

18:00-20:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Poster Session II (SOFC Cells, Stacks and Systems)
Grand Ballroom East
Chair(s): Tatsuya Kawada and Subhash C. Singhal

WEDNESDAY, 26 JULY 2017

Monday | Tuesday | Wednesday | Thursday |Fri

08:20-12:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
SOFC Cathodes IV
Grand Ballroom West
Chair(s): Harumi Yokokawa and Julie Mougin

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
SOFC Fuels
Atlantic Ballroom 3
Chair(s): Koichi Eguchi and Neal P Sullivan

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Solid Oxide Electrolysis/Reversible Cells and Systems II
Atlantic Ballroom 1/2
Chair(s): Ludger Blum and S Elangovan

14:00-16:50

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Workshop on Synergistic Use of Solid Oxide Fuel Cells (SOFCs) in Data Cent and Other Embedded Energy Applications
Atlantic Ballroom 1/2

18:00-21:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Reception and Banquet
South Lagoon Deck & South Palm Court

THURSDAY, 27 JULY 2017

Monday | Tuesday | Wednesday | Thursday |Fri

08:20-12:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Cells and Stacks I
Atlantic Ballroom 3
Chair(s): Hiroyuki Uchida and Sean R. Bishop

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
SOFC Anodes I
Grand Ballroom West
Chair(s): Katsuhiko Yamaji and Jason D. Nicholas

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Solid Oxide Electrolysis/Reversible Cells and Systems III
Atlantic Ballroom 1/2
Chair(s): Jack Brouwer and Anke Hagen

14:00-17:40

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Cells and Stacks II - Characterization and Testing
Atlantic Ballroom 3
Chair(s): Olivera Kesler and Enn Lust

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELL
Modeling I
Atlantic Ballroom 1/2

Chair(s): Brian J Koeppel and Naoki Shikazono

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Anodes II
Grand Ballroom West
Chair(s): Anil V. Virkar and Toshiaki Matsui

18:00-20:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Poster Session III (Solid Oxide Electrolysis/Reversible Cells; SOFC Modeling and Electrolytes)
Grand Ballroom East
Chair(s): Subhash C. Singhal and Tatsuya Kawada

FRIDAY, 28 JULY 2017

Monday | Tuesday | Wednesday | Thursday |Friday |

08:20-12:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Cells and Stacks III - Durability and Reliability
Atlantic Ballroom 3
Chair(s): Jeffry W Stevenson and Minfang Han

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Modeling II
Atlantic Ballroom 1/2
Chair(s): Michihisa Koyama and Yixiang Shi

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Anodes III
Grand Ballroom West
Chair(s): Keiji Yashiro and Kevin Kendall

14:00-16:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Cells and Stacks IV - Metal Supported Cells
Atlantic Ballroom 1/2
Chair(s): Nguyen Minh

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Cells and Stacks V - Proton Conducting Cells
Atlantic Ballroom 3
Chair(s): Enrico Traversa

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
SOFC Anodes IV
Grand Ballroom West
Chair(s): Xiao-Dong Zhou

16:00-17:00

I01: FIFTEENTH INTERNATIONAL SYMPOSIUM ON SOLID OXIDE FUEL CELLS
Closing Session
Grand Ballroom West
Chair(s): Subhash Singhal and Tatsuya Kawada

附錄五、楊昇府等人之口頭論文發表摘要

Cells and Stacks IV - Metal Supported Cells

Friday, 28 July 2017: 14:00-16:00
Atlantic Ballroom 1/2 (The Diplomat Beach Resort)

	Chair:	*Nguyen Minh*
14:00	**169**	Study on the Fabrication and Performance of Very Low Pressure Plasma Sprayed Porous Metal Supported Solid Oxide Fuel Cell *J. T. Gao, Y. P. Wang (Xi'an Jiaotong University), C. X. Li (Xi'an Jiaotong university), S. L. Zhang, G. J. Yang, and C. J. Li (Xi'an Jiaotong University)*
14:20	**359**	Development of High Efficiency Steel Cell Technology for Multiple Applications *R. T. Leah, A. Bone, E. Hammer, A. Selcuk, M. Rahman, A. Clare, L. Rees, N. Lawrence, A. Ballard, T. Domanski, S. Mukerjee, and M. Selby (Ceres Power Ltd.)*
14:40	**360**	Metal-Supported Solid Oxide Fuel Cell with High Power Density *M. C. Tucker (Lawrence Berkeley National Laboratory)*
15:00	**361**	Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique *S. F. Yang, C. S. Hwang, C. H. Tsai, C. L. Chang, M. H. Wu, C. Y. Fu, and R. Y. Lee (Institute of Nuclear Energy Research)*
15:20	**362**	Towards High Power Density Metal Supported Solid Oxide Fuel Cell for Mobile Applications *J. Nielsen, A. H. Persson, T. T. Muhl, and K. Brodersen (DTU Energy, Technical University of Denmark)*
15:40		Break

See more of: I01: Fifteenth International Symposium on Solid Oxide Fuel Cells
See more of: Fuel Cells, Electrolyzers, and Energy Conversion

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361
Fabrication of 100 Centimeter Square Metal-Supported Solid Oxide Fuel Cell Using Thermal Plasma Technique

Friday, 28 July 2017: 15:00
Atlantic Ballroom 1/2 (The Diplomat Beach Resort)

S. F. Yang, C. S. Hwang, C. H. Tsai, C. L. Chang, M. H. Wu, C. Y. Fu, and R. Y. Lee (Institute of Nuclear Energy Research)

In this study, the large-scale mold for compression molding process is prepared and a compression load of 120 ton is applied to form a porous alloy specimen with dimension of 12×12×1.2 cm. The carbon is used as pyrolyzable filler in the period of manufacturing processes in order to produce porous interconnected networks of molybdenum (Mo)-containing nickel (Ni)-based alloy. The specimens are sintered in hydrogen at the temperature of 1250°C to obtain porous alloy substrate. The flexural strength of porous alloy supporting component is measured in this work. The strength of porous alloy substrate (Sintered at 1250°C) in three-point flexure at 25°C and 750°C are 188 MPa and 76.5 MPa, respectively. Metal-supported solid oxide fuel cells (MS-SOFCs) are fabricated by thermal plasma spraying technique and the anode ($Ce_{0.55}La_{0.45}O_{2-\delta}$ - NiO, LDC-NiO), electrolyte ($La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-\delta}$, LSGM) and cathode ($Sm_{0.5}Sr_{0.5}CoO_{3-\delta}$, SSC) functional layers are deposited onto porous alloy substrate. The 10×10 cm^2 MS-SOFC with effective electrode area of 81 cm^2 shows the open circuit voltages is 1.09 V at 700°C. The measured maximum output power densities (@0.76V) of this cell has reached 588 mW/cm^2 at 700°C by employing hydrogen as fuel and air as oxidant.

See more of: Cells and Stacks IV - Metal Supported Cells
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Poster Session II (SOFC Cells, Stacks and Systems)

Tuesday, 25 July 2017: 18:00-20:00
Grand Ballroom East (The Diplomat Beach Resort)

Chairs: *Tatsuya Kawada and Subhash C. Singhal*

58 Applications of the Glycine Nitrate Combustion Method for Powder Synthesis on the LSGM-based Electrolyte-Supported Solid Oxide Fuel Cells
Y. M. Chen, T. N. Lin, M. W. Liao, H. Y. Kuo, C. Y. Yeh, W. X. Kao, S. F. Yang (Institute of Nuclear Energy Research), K. T. Wu (Kyushu University), and T. Ishihara (wpi-I²CNER, Kyushu University)

148 Solid Oxide Fuel Cells: Opportunities for Economic Growth in Japan
N. Behling (Kyushu University) and M. C. Williams (Tohoku University)

149 The Demosofc Project: Preliminary Results from an Industrial-Size Biogas-Fed Solid Oxide Fuel Cell
M. Gandiglio, A. Lanzini, M. Santarelli (Politecnico di Torino), T. Hakala (Convion Oy), and M. Rautanen (VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD)

150 Development of Small Power Sources Based on a Micro-SOFC System Operated on Liquid Fuels for Mobile Electric Devices
S. Takahara, K. Kato, F. Iguchi, M. Shimizu, and H. Yugami (Tohoku University)

151 Fabrication and Characterization of High Performance Intermediate Temperature Micro-Tubular Solid Oxide Fuel Cells
C. Ren, Y. Gan, M. Lee, C. Yang, F. He, Y. Jiang, G. Dong (University of South Carolina), R. Green (NASA Glenn Research Center), and X. Xue (University of South Carolina)

152 Design and Performance Characteristics of Portable, Self-Sustaining and Quick-Start Micro-Tubular SOFC Stacks
U. Mushtaq (Korea Institute of Energy Research), S. J. Park, R. H. Song (Korea Institute of Energy Research (KIER), Korea University of Science and Technology (UST)), T. H. Lim (Korea University of Science and Technology (UST), Korea Institute of Energy Research), J. W. Lee, and S. B. Lee (Korea Institute of Energy Research (KIER), Korea University of Science and Technology (UST))

153 Fabrication and Electrochemical Characterization of Freeze-Cast Tubular Solid Oxide Fuel Cells
Y. Du (Kent State University, Yanhai Power, LLC), J. Persky (Perkielski LLC.), K. Zhao (Washington State University), H. Ilkhani, T. Woodson (Kent State University), B. Emley (Yanhai Power, LLC), and N. Hedayat (Kent State University)

154 Novel SOFC Design with a Co-Sintered and Inert-Supported Cell Concept
A. Haeffelin, J. C. Njodzefon, E. Matte, and P. Lupetin (Robert Bosch GmbH)

155 Advances in Low Temperature Coatings for Solid Oxide Fuel Cell Components
N. J. Kidner, S. Ibanez, M. M. Seabaugh, and S. Swartz (Nexceris, LLC)

156 Developing Redox Stability of Ceramic Anode Supported Intermediate Temperature Solid Oxide Fuel Cells
Y. Kim, S. Y. Jo, and J. Y. Park (Sejong University)

58

Applications of the Glycine Nitrate Combustion Methodfor Powder Synthesis on the LSGM-based Electrolyte-Supported Solid Oxide Fuel Cells

Tuesday, 25 July 2017
Grand Ballroom East (The Diplomat Beach Resort)

Y. M. Chen, T. N. Lin, M. W. Liao, H. Y. Kuo, C. Y. Yeh, W. X. Kao, S. F. Yang (Institute of Nuclear Energy Research), K. T. Wu (Kyushu University), and T. Ishihara (wpi-I²CNER, Kyushu University)

Solid oxide fuel cells (SOFCs) are recognized as environmentally friendly, highly efficient devices, and alternatives to conventional energy conversion systems. Typical material design used is the YSZ-based cell consisted of NiO-YSZ and LSM as anode and cathode, with a dense electrolyte of YSZ. When considering the use of hydrocarbon fuels, carbon deposition has been observed as major failure issue. $Ce_{0.6}Mn_{0.3}Fe_{0.1}O_2$(CMF) has been studied recently because of the high tolerance against coke deposition and it also exhibited high catalytic activity. In this work, Cu-doped CMF powders were synthesized by glycine nitrate combustion process (GNC). The structure, microstructure, conductivity, coefficient of thermal expansion properties were investigated. Cu-doped CMF powders were utilized as anode material in Sr- and Mg-doped $LaGaO_3$ (LSGM)-based electrolyte-supported solid oxide fuel cell for power performance test. The cell with structure of (Cu-doped CMF) | LSGM | LSCF was operated from 600 to 800 °C with humidified H_2 as a fuel and ambient air as oxidant to evaluate the electrochemical properties.

keywords：$Ce_{0.6}Mn_{0.3}Fe_{0.1}O_2$, glycine nitrate combustion process, Sr- and Mg-doped $LaGaO_3$

See more of: Poster Session II (SOFC Cells, Stacks and Systems)
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附錄七、Plenary Session 摘要內容

1
Overview of U.S. Department of Energy Office of Fossil Energy's Solid Oxide Fuel Cell Program

Monday, 24 July 2017: 09:20
Grand Ballroom West (The Diplomat Beach Resort)

S. D. Vora (National Energy Technology Laboratory), W. L. Lundberg, and J. F. Pierre (KeyLogic Systems)

The primary mission of the U.S. Department of Energy's Office of Fossil Energy (FE) is to ensure the nation can continue to rely on its indigenous fossil fuel resources for clean, secure, and affordable energy. A component of that effort is the Solid Oxide Fuel Cell (SOFC) Program, administered by FE's National Energy Technology Laboratory (NETL). The SOFC Program is committed to: developing efficient, low-cost electricity from natural gas or coal with intrinsic carbon capture capabilities for distributed generation and central power generation applications; maintaining cell development and core technology research to increase the reliability, robustness, and durability of cell, stack, and system technology; and providing the technology base to permit cost-competitive distributed generation applications. The program recently initiated two focused efforts: addressing cell and system reliability and an Innovative Concepts initiative.

Based on feedback from several program participants, chromium contamination of cathode was identified as a major contributor to performance degradation and reduced system reliability. NETL has launched an initiative to address the issue of chromium contamination. The SOFC Program portfolio presently has 13 projects addressing this critical issue.

The SOFC Program is also funding an Innovative Concepts initiative that supports the research, development, and demonstration (RD&D) of SOFC technology that has the potential to surpass current anode supported planar SOFC technology in terms of cost and reliability. Program participants are developing novel cell and stack architectures and/or material sets. This next-generation SOFC technology development in the near-term includes nominally 5-10 kWe-scale stack tests using cells envisioned in the developer's future commercial systems.

The status of these strategically oriented research programs, along with the status of the program's integrated systems tests and the roadmap to deploy a MWe-class natural gas-fueled distributed generation system, will be presented.

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2
Fuel Cells Operating at 200 to 500 Celsius: Lessons Learned from the ARPA-E REBELS Program

Monday, 24 July 2017: 09:40
Grand Ballroom West (The Diplomat Beach Resort)

S. J. Litzelman, M. J. Pouy (Booz Allen Hamilton), P. S. Albertus, and G. L. Soloveichik (Advanced Research Projects Agency-Energy (ARPA-E))

In 2014, the Advanced Research Projects Agency-Energy (ARPA-E) launched the Reliable Electricity Based on ELectrochemical Systems (REBELS) program with the goal of pursuing alternate fuel cell materials and operating conditions that could enable system cost reductions and new electrochemical functionality. This presentation will briefly revisit the original REBELS vision by elaborating the potential benefits of operation in an intermediate temperature range of 200-500 C. Trends in the U.S. electrical grid will be discussed, which reveal the benefits of enhanced fuel cell functionality such as in-situ charge storage and gas-to-liquids (GTL) capabilities. The most significant technical accomplishments from REBELS project teams will be highlighted, including several examples in which the program objective of a current density of 200 mA/cm2 at 0.78 V and 500 C on methane fuel was achieved. Furthermore, teams were able to demonstrate thousands of hours of operation on internally-reformed methane fuel at 500 C with no evidence of coke formation. Fuel cells with charge storage functionality in or near the anode showed a more rapid response to large changes in current density and a lower voltage decrease with high fuel utilization. The needs for further techno-economic assessment to evaluate this concept will be highlighted. Progress towards fuel cells that can also convert methane to liquid fuels will be summarized. Finally, overall lessons learned from the REBELS program will be discussed, such as the ability of ceramic proton conductors to deliver high current density at 500 C on non-hydrogen fuels with minimal degradation. The need for future work in this field will be stressed, especially a continued examination of whether stacks in this temperature range possess the appropriate combination of performance and cost to accelerate the commercialization of high efficiency fuel cells worldwide.

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3
Current Status of National SOFC Projects in Japan

Monday, 24 July 2017: 10:20
Grand Ballroom West (The Diplomat Beach Resort)

H. Nirasawa (New Energy and Industrial Technology Development Org.)

The New Energy and Industrial Technology Development Organization (NEDO) has been conducting technology development and demonstrative research programs related to SOFC, as one of the most important and promising technologies for CO_2 reduction and realizing dispersed power sources. One of their achievements was the-first-in-the-world commercialization of SOFC-based combined heat and power (CHP) system “ENE-FARM type S” in 2011.

In June 2014, the Ministry of Economy, Trade and Industry (METI) has compiled a Strategic Road Map for Hydrogen and Fuel Cells. It was established, releasing fuel cells for commercial and industrial use onto the market in 2017 as one of the processes of expanding the use of fuel cell technology. NEDO’s activities and recent trends on SOFC, including a program “Technology development for promoting SOFC commercialization” , will be overviewed.

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4
The Status of SOFC and SOEC R&D in the European Fuel Cell and Hydrogen Joint Undertaking Programme

Monday, 24 July 2017: 10:40
Grand Ballroom West (The Diplomat Beach Resort)

A. Aguilo-Rullan, M. Atanasiu, B. Biebuyck, N. Lymperopoulos, C. Marenco, and D. Tsimis (Fuel Cells and Hydrogen Joint Undertaking)

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) was set up in 2008 to accelerate the development of fuel cells and hydrogen technologies in Europe towards commercialization from 2015 onwards. To reach this target the FCH JU intends to bring together resources under a cohesive public-private partnership to ensure commercial focus, to match RTD activities to industry's needs and expectations and to scale-up and intensify links between the Industry Community and the Research Community. The applications are open to all fuel cells technologies, SOFC being mostly developed for the stationary applications, including back-up powers and APUs for transportation (trucks, planes). Applications are also open to SOEC technologies. There are different groups working in Europe and supported partially by the FCH JU on the SOFC/SOEC technologies. By supporting such a project portfolio, FCH JU is going to reach most of the objectives set-up at European level mainly in terms of potential reduction of costs through sufficient number of units demonstrated across Europe in transport, stationary and hydrogen production applications. The EU public support continues for the period of 2014-2020 for activities with an advanced TRL, moving towards market penetration of the FCH technologies.

As a public-private partnership, the FCH JU has enabled a range of businesses and industry, in particular SMEs, and research communities to commit to longer term developments. It has fostered an impressive level of collaboration between the research and industry community. This unique public-private partnership is already supporting research and demonstration projects in the different areas of application of fuel cells and hydrogen (i.e. 38-39% in transportation and related refuelling infrastructure, with additional 15-16% for the hydrogen production routes and associated storage and distribution paths; 30-31% in stationary applications, mainly for combined heat and power generation in residential and industrial applications; 7-8% for early market applications like forklifts, back-up powers and 3-4% for support activities in terms of RCS, education and promotion/awareness of these technologies) and 5-6% for overarching activities covering more than one of the areas just mentioned. The applications are open to all fuel cells technologies, SOFC being mostly developed for the stationary applications, including back-up powers and APUs for transportation (trucks, plains).

The €732 million in grants already allocated under FCH1JU and FCH2JU to 204 projects (around half of this have already been completed) have contributed to bring some applications near to market readiness (e.g. passenger vehicles, material handling, back-up power systems, and portable power generation). However, taking to market those applications with the strongest potential for addressing energy security and climate change issues (e.g. road transport, public urban transport, stationary power generation, combined heat and power, hydrogen from renewable energy sources and electricity storage) requires both further key technical developments and demonstrations to achieve large scale production volumes fast.

So far € 176 million have been allocated to support 48 projects which address specifically the SOFC or SOEC technologies (almost 40% of the energy-type of projects); these projects cover the whole value chain in the Energy systems from long-term and breakthrough orientated research (degradation and lifetime fundamentals related to materials and typical operation environments for relevant power ranges) to technology validation (proof-of-concept fuel cell and electrolyser systems and their interactions with supply & demand interfaces i.e. other power generation devices, cooling/heating systems, and with the infrastructure i.e. grid interface, fuel supply and local power output) and market capacity building across all applications (full scale field demonstrations of proven systems in real end user environment), including 4 projects addressing APU for transportation (e.g. trucks) and 1 project dealing with the development test procedures for SOC cell/stack assembly.

The proposed paper will provide an update on the current status of the above mentioned FCH JU funded projects, on the outcomes achieved to date and on the expected results still to come.

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5

Advances in Solid Oxide Fuel Cells: Review of Progress through Three Decades of the International Symposia on Solid Oxide Fuel Cells

Monday, 24 July 2017: 11:00
Grand Ballroom West (The Diplomat Beach Resort)

N. Minh (University of California, San Diego), J. Mizusaki (Tohoku University), and S. C. Singhal (Pacific Northwest National Laboratory)

Solid oxide fuel cell (SOFC) technology has made significant progress in the past 30 years and is currently in the early commercialization stage. The progress of the technology can be seen clearly through review of the papers and presentations at the biennial International Symposium on Solid Oxide Fuel Cells series initiated in 1989. This paper details the growth and evolution of the Symposium series as the technology progressed, and highlights key advances in materials development, understanding of electrode reactions and chemical interactions, and design, performance, durability and operation of SOFC single cells, multi-cell stacks and power systems as documented in the Symposium proceedings.

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6

Review of Progress in Solid Oxide Fuel Cells at FuelCell Energy

Monday, 24 July 2017: 11:20
Grand Ballroom West (The Diplomat Beach Resort)

H. Ghezel-Ayagh and B. P. Borglum (FuelCell Energy, Inc.)

Significant progress has been made towards the development of Solid Oxide Fuel Cell (SOFC) at FuelCell Energy Inc. (FCE). The genesis of the advances in the technology is rooted in scale-up of the Company's anode-support technology made by the TSC (Tape Casting-Screen Printing-Sintering) Process. The anode supported thin electrolyte planar cell platform was adopted for its higher power density at reduced operating temperature (600-800°C). Traditional materials, such as Ni/YSZ anodes, YSZ electrolytes and perovskite cathodes have been utilized in a basic cell structure. Research and development has been successful in developing better electrochemical functional areas at both cathode/electrolyte and anode/electrolyte interfaces. This was achieved through materials advancement, microstructure optimization, and manufacturing process integration. Cell materials development advancements have been made in performance, endurance, cell size (area) scale-up and cost reduction. These advancements led to an enhanced cell performance by reducing cell ASR (Area Specific Resistance) while reducing cell cost through cell design changes and materials reduction. Scaled-up cell size of up to 1000 cm2 have been made and tested with the current baseline cell size of 550 cm2 as the standard unit size for building SOFC stacks. The baseline stack design has been successfully scaled-up from 120-cell 550 cm2 cell area (16 kW nominal) stack. Using standardized manifolds and gas-electrical interconnects, these stacks have been successfully integrated into stack towers and arrays.

FCE recently designed, built, and tested a 50 kW fully automated SOFC system under a Co-operative Agreement with Department of Energy. In a follow-on DOE supported project, currently, FCE is engaged in design and construction of larger 200kW units that utilize baseline factory-built stack blocks representative of the future MW-scale power plants.

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7
Development Progress on the Ceres Power Steel Cell Technology Platform: Further Progress Towards Commercialization

Monday, 24 July 2017: 11:40
Grand Ballroom West (The Diplomat Beach Resort)

R. T. Leah, A. Bone, E. Hammer, A. Selcuk, M. Rahman, A. Clare, S. Mukerjee, and M. Selby (Ceres Power Ltd.)

Ceres Power is continuing to make excellent progress in the development of its low-temperature metal supported SOFC design (the 'Steel Cell') based predominantly around the use of ceria. This unique design architecture allows for a robust, low cost, subsidy free fuel cell product, whilst retaining the advantages of fuel flexibility, high efficiency and low degradation.

Over the last year, several significant technological and commercial developments have taken place. The latest generation of SteelCell technology (v4.0) has completed validation and verification testing, and is now the standard version of the technology offered to customers. The v4.0 cell/stack technology has a significantly simplified and lower-cost manufacturing process relative to earlier technology generations, whilst offering improved performance and comparable degradation. v4.0 stacks have been incorporated into natural-gas fuelled Ceres Power SteelGen 700W_e micro-CHP demonstrators, which have been deployed in several locations in the UK as part of a field trial in association with British Gas funded by the European Ene.field program. In addition to this Ceres is also working with Nissan to evaluate the application of SteelCell technology to an electric vehicle range extender application, taking advantage of the thermal cycle and mechanical robustness of the technology, which is at least an order of magnitude better than published data from any other SOFC stack developer.

In addition to an ongoing joint development agreement with Honda, Ceres has also been granted a US DoE grant working with Cummins on a 5kW_e-class stationary power generator for use in data centers. Ceres has also announced a joint development and licensing agreement with another large global OEM to develop a multi-kW_e-scale micro CHP system.

A major focus of ongoing technology development is to further improve stack power density, durability and efficiency in line with the technology roadmap for next generation products. Significant progress has been demonstrated at the R&D level on all of these requirements, and the design improvements to achieve them will be incorporated into the next generation of SteelCell technology.

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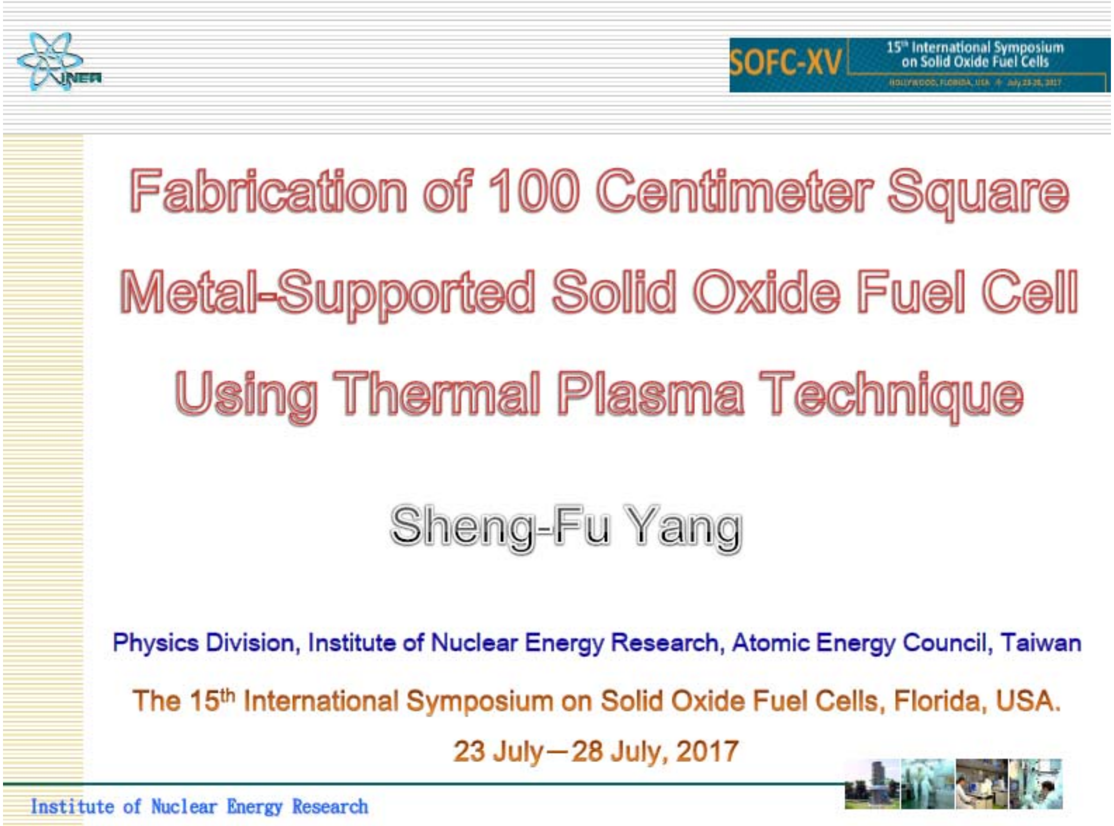
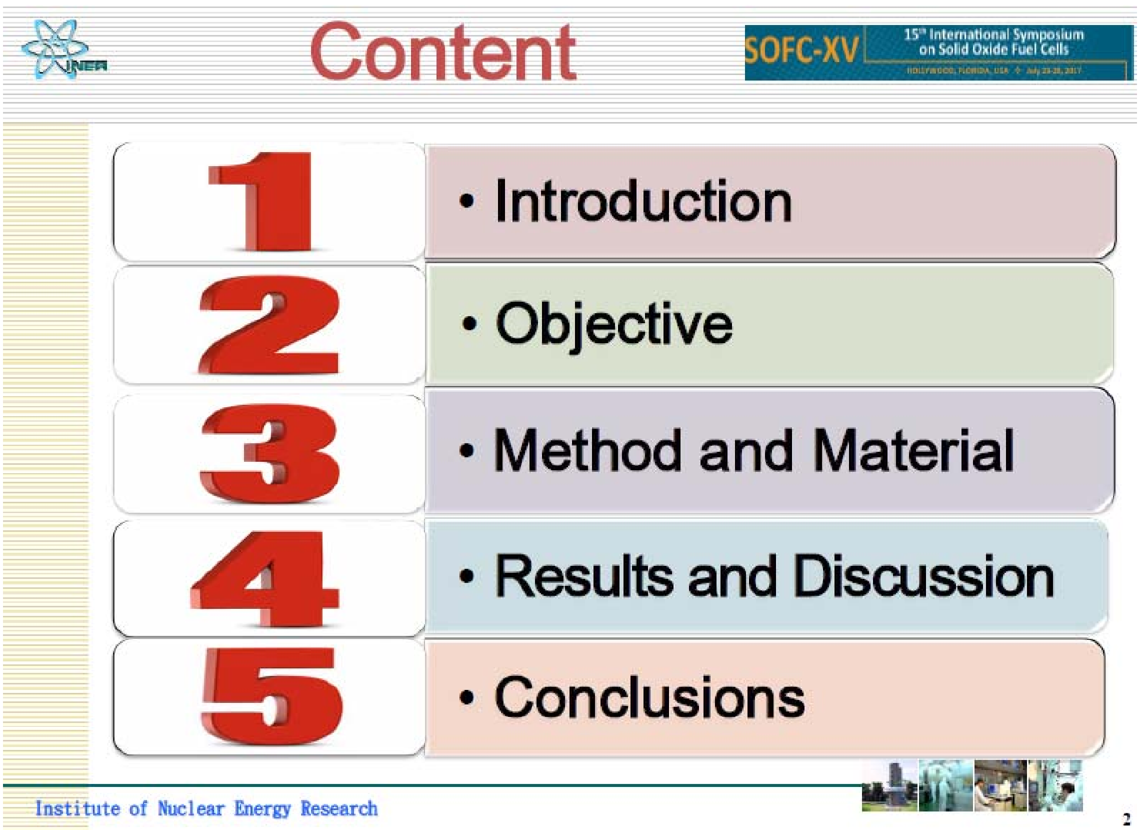




Introduction

SOFC-XV 15th International Symposium on Solid Oxide Fuel Cells

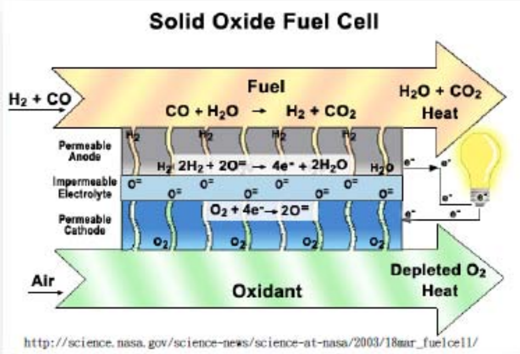
Solid Oxide Fuel Cell (SOFC)

Advantage

- Convert chemical energy directly into electrical energy
- High efficiency
- High power density
- Fuel flexibility
- Low levels of pollution emissions

Types

- Tubular SOFC
- Planar SOFC



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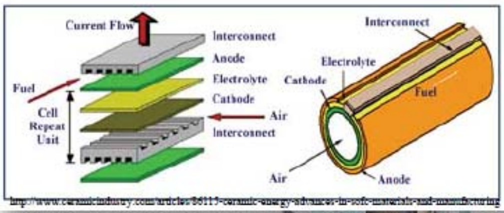


Introduction

SOFC-XV 15th International Symposium on Solid Oxide Fuel Cells

Metal-Supported SOFCs, the third generation of cells have been obtaining popularity in the recent years.

In comparison to traditional all ceramic cells, the advantages are listed as below:

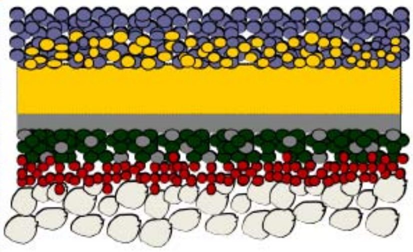
Advantage	Advantage
• High thermal conductivity • Improve heat transfer • High electrical conductivity • High redox stability • High mechanical strength	• Lower operation temperature • Lower material cost • Easier cells assembling • Ability to withstand repeated and rapid thermal cycles.

Introduction

SOFC-XV 15th International Symposium on Solid Oxide Fuel Cells

Thermal plasma technique is a fast sintering process, it allows to reduce the interaction between metallic substrate and functional layers that can be caused during conventional high temperature sintering processes.

It has high material deposition rate, can change component composition and microstructure through adjustment of thermal plasma operation parameters.



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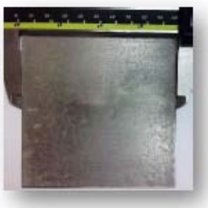
Objective

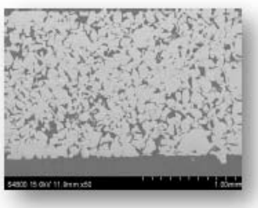
SOFC-XV 15th International Symposium on Solid Oxide Fuel Cells

To construct spray drying, compression molding and sintering processes for producing Ni-Mo porous alloy substrate.

To fabricate positive, electrolyte and negative functional layers using thermal plasma technique.

To evaluate the electrical performance of planar MS-SOFC.





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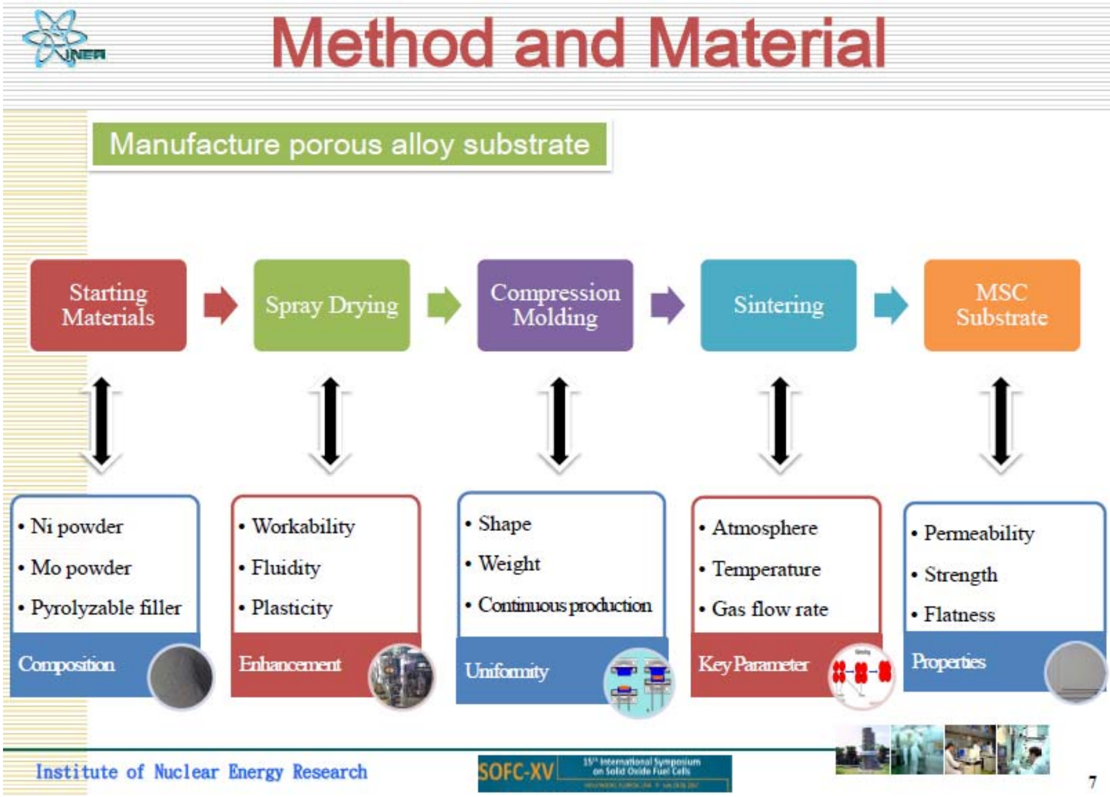
Method and Material
Manufacture porous alloy substrate
Starting Materials
Spray Drying
Compression Molding
Sintering
MSC Substrate
• Ni powder
• Mo powder
• Pyrolyzable filler
Composition
• Workability
• Fluidity
• Plasticity
Enhancement
• Shape
• Weight
• Continuous production
Uniformity
• Atmosphere
• Temperature
• Gas flow rate
Key Parameter
• Permeability
• Strength
• Flatness
Properties
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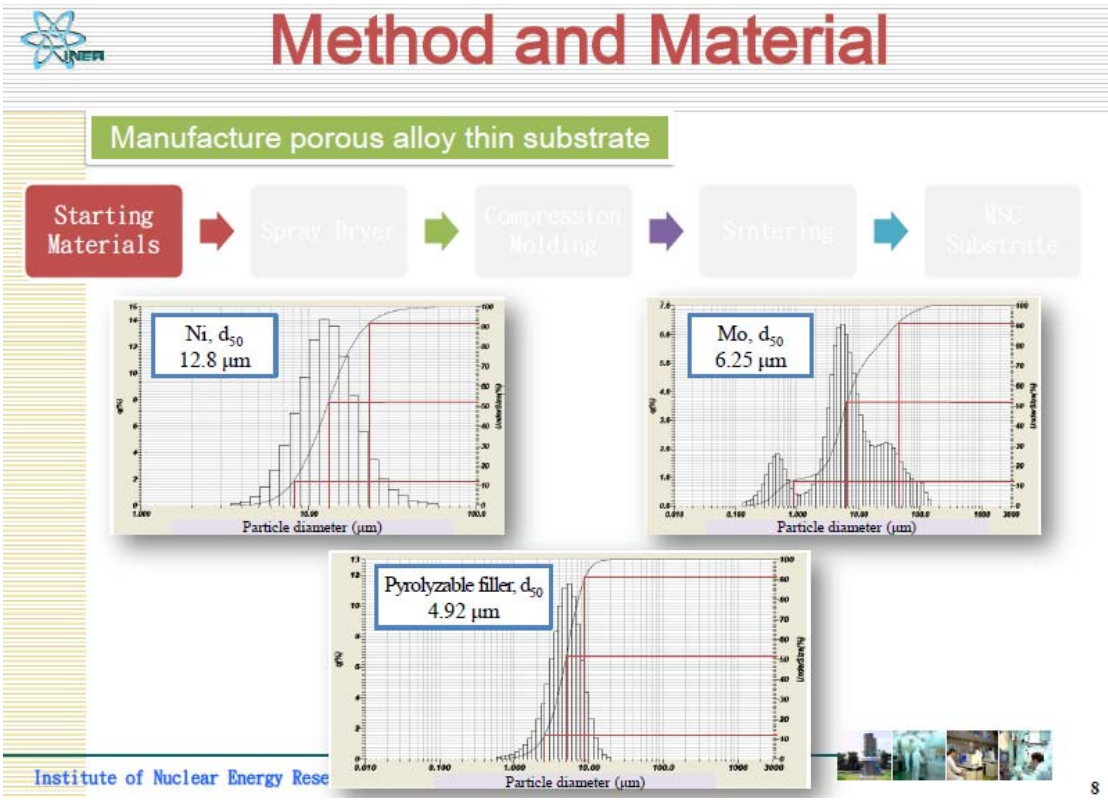
Method and Material
Manufacture porous alloy thin substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Ni, d50
12.8 μm
Particle diameter (μm)
Mo, d50
6.25 μm
Particle diameter (μm)
Pyrolyzable filler, d50
4.92 μm
Particle diameter (μm)
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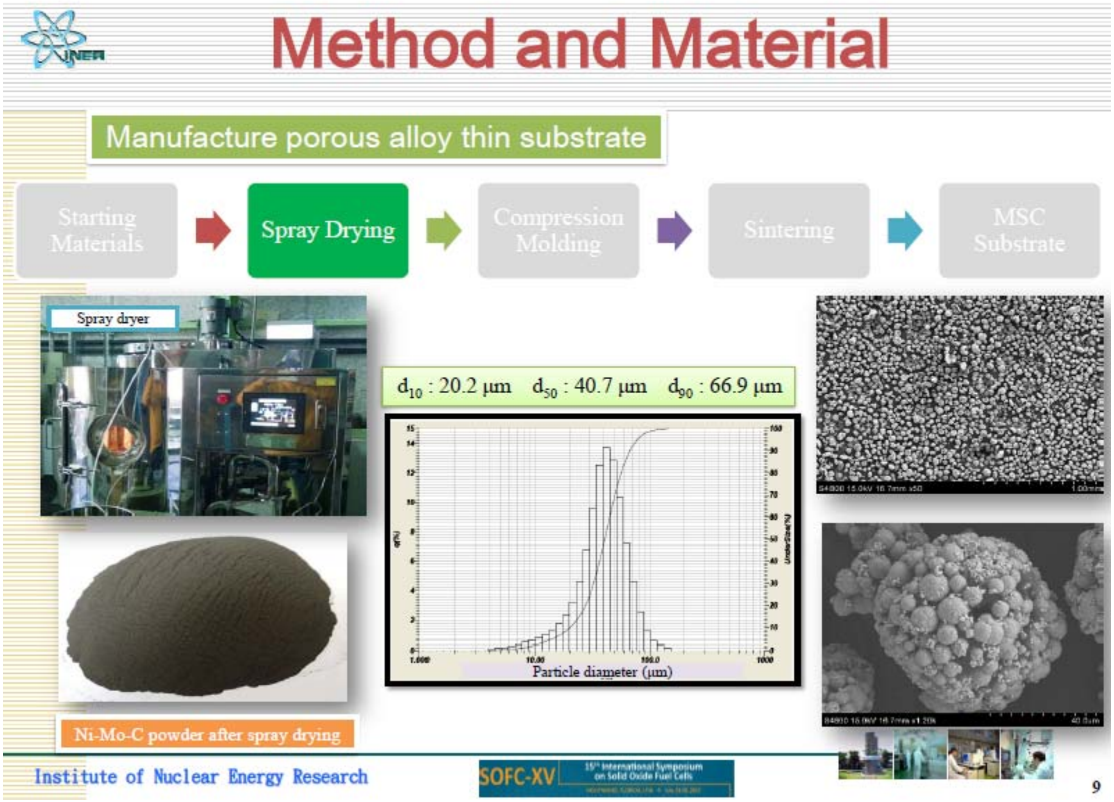
Method and Material
Manufacture porous alloy thin substrate
Starting Materials
Spray Drying
Compression Molding
Sintering
MSC Substrate
Spray dryer
d10 : 20.2 μm d50 : 40.7 μm d90 : 66.9 μm
Particle diameter (μm)
Ni-Mo-C powder after spray drying
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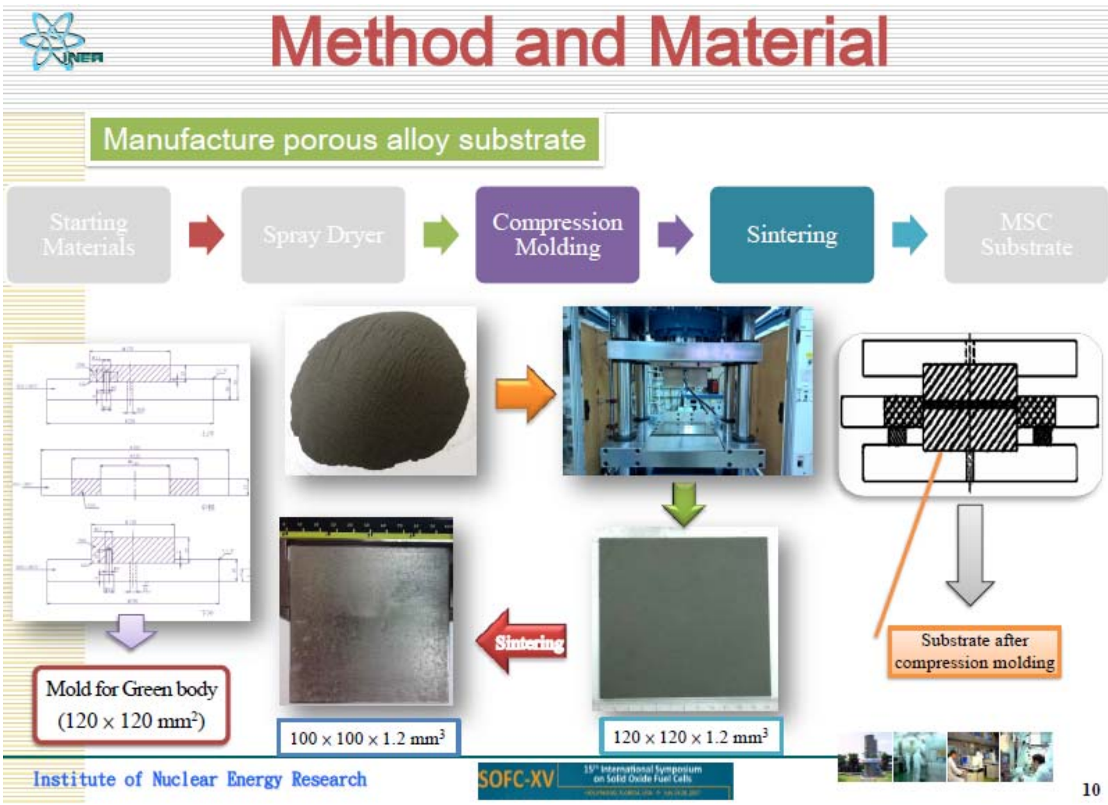
Method and Material
Manufacture porous alloy substrate
Starting Materials
Spray Dryer
Compression Molding
Sintering
MSC Substrate
Mold for Green body
(120 x 120 mm²)
100 x 100 x 1.2 mm³
Sintering
120 x 120 x 1.2 mm³
Substrate after compression molding
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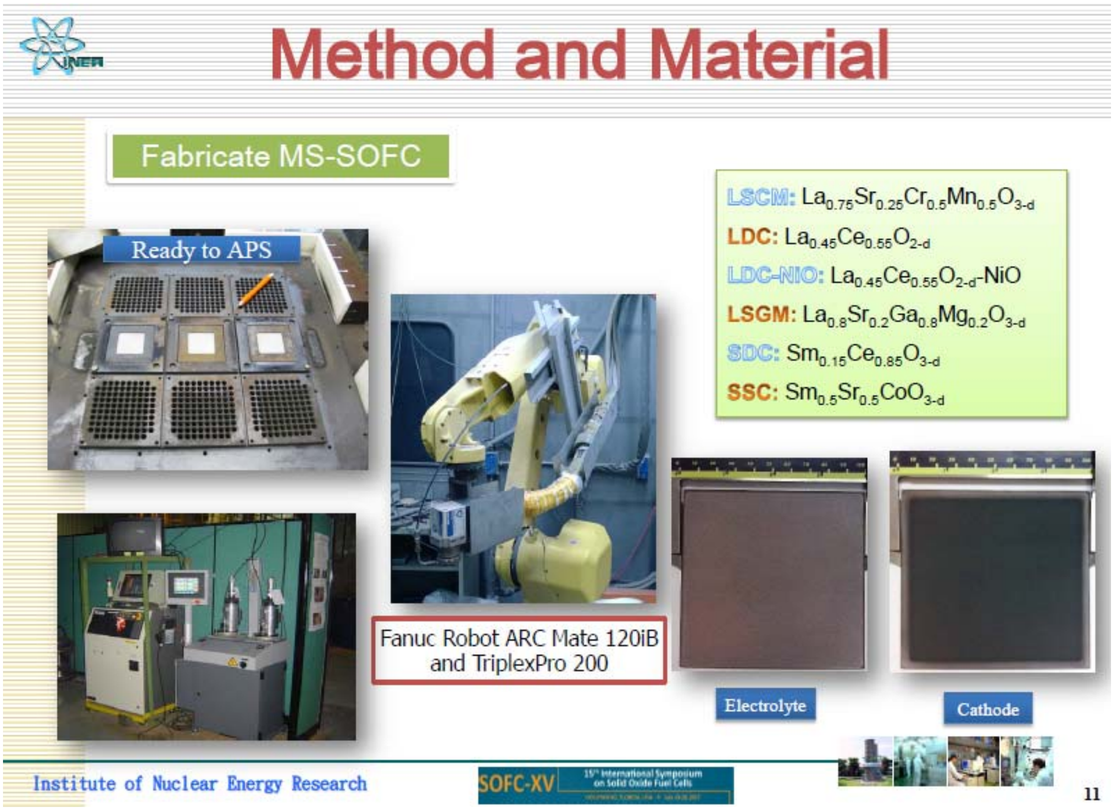
Method and Material
Fabricate MS-SOFC
Ready to APS
Fanuc Robot ARC Mate 120iB and TriplexPro 200
LSCM: $La_{0.75}Sr_{0.25}Cr_{0.5}Mn_{0.5}O_{3-d}$
LDC: $La_{0.45}Ce_{0.55}O_{2-d}$
LDC-NiO: $La_{0.45}Ce_{0.55}O_{2-d}$-NiO
LSGM: $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-d}$
SDC: $Sm_{0.15}Ce_{0.85}O_{3-d}$
SSC: $Sm_{0.5}Sr_{0.5}CoO_{3-d}$
Electrolyte
Cathode
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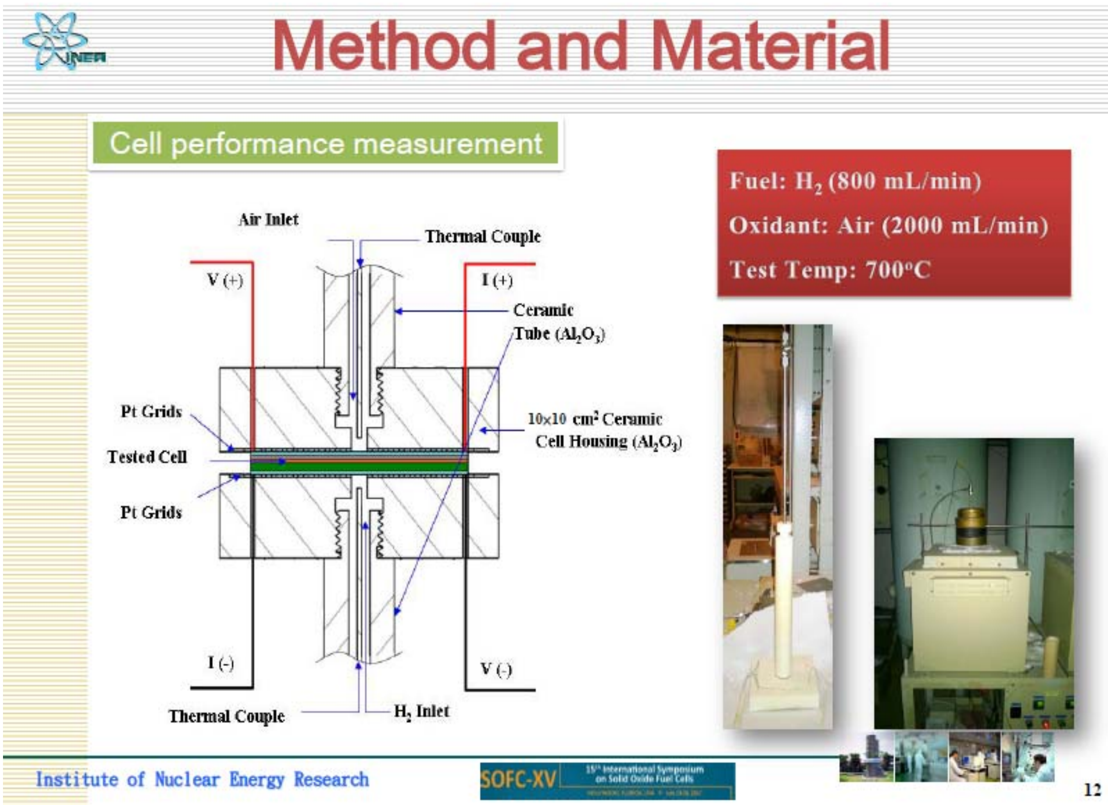
Method and Material
Cell performance measurement
Air Inlet
Thermal Couple
V (+)
I (+)
Ceramic Tube (Al_2O_3)
Pt Grids
Tested Cell
Pt Grids
10x10 cm^2 Ceramic Cell Housing (Al_2O_3)
I (-)
V (-)
Thermal Couple
H_2 Inlet
Fuel: H_2 (800 mL/min)
Oxidant: Air (2000 mL/min)
Test Temp: 700°C
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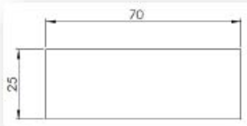
Method and Material

Three-point flexural strength of porous alloy substrate

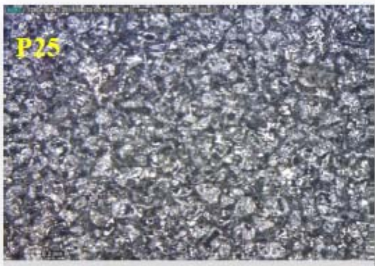
Summary

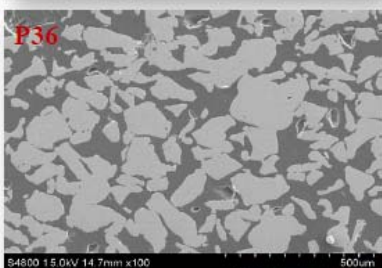
1. The alloy substrates (Sintered at 1000, 1100, 1200, 1250°C) are sliced into rectangular shapes 70 mm length × 25 mm wide.
2. A crosshead speed of 0.5 mm/min is applied until the load decreased less than 95 % of the peak load or the specimens are broken.



Results and Discussion

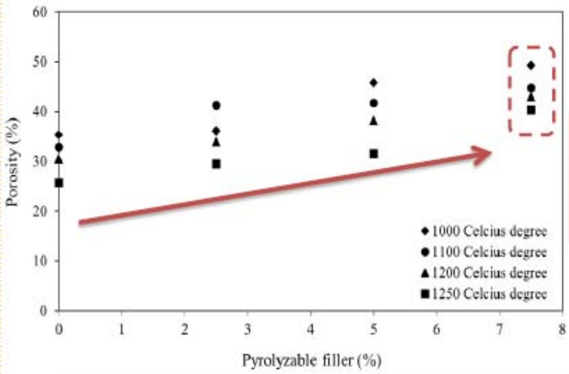
Surface and internal structure of porous Ni-Mo alloy substrate





Results and Discussion

Porosities of porous Ni-Mo alloy substrate



$$Bulk\ density\ (g\ cm^{-3}) = \frac{W_1}{\frac{W_2 - W_3}{D_w} - \frac{W_2 - W_1}{D_{wax}}}$$

W_1 = mass of specimen in air, g,
W_2 = mass of water-proof specimen in air, g,
W_3 = mass of water-proof specimen in water, g,
D_w = density of water at immersion temperature, g cm-^{3},
D_{wax} = density of wax, g cm-3.

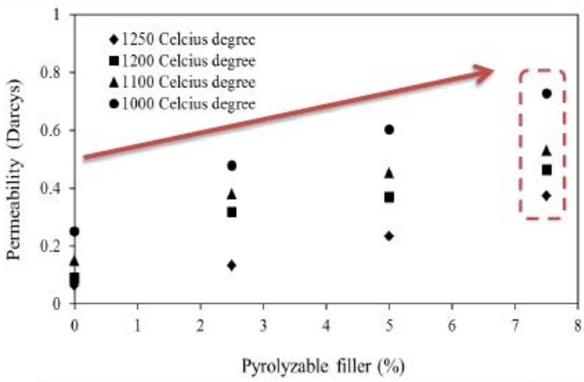
$$Porosity\ (\%) = \left(1 - \frac{Bulk\ density}{True\ density}\right) \times 100$$

The higher sintering temperature results in more sintering shrinkage and the percentage of volume reduction is 16%–27.8% from 1000°C to 1250°C.

Through reactions that occur in the period of sintering, strengthening and densification of porous alloy takes place, leading to a reduction in volume and porosity.

Results and Discussion

Permeability of porous Ni-Mo alloy substrate



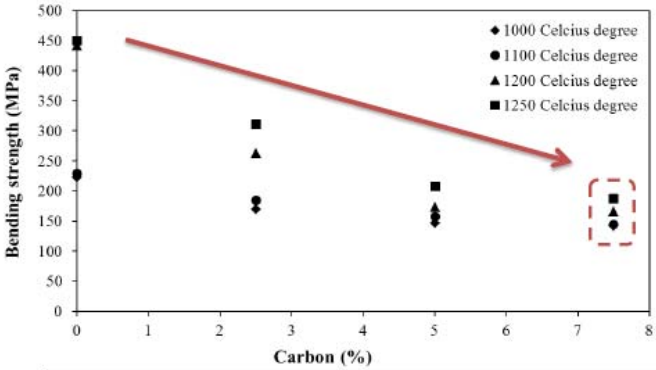
	1000°C	1100°C
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	55 x 55	54 x 54
	1200°C	1250°C
Size of green body (mm^2)	60 x 60	60 x 60
After sintering (mm^2)	52 x 52	51 x51

The permeability of specimen without introducing pyrolyzable filler at 1250°C is 0.064 Darcy.

After the pyrolyzable filler is added (Range, 2.5% - 7.5%), the permeability increases and rise to the range of 0.13 Darcy - 0.37 Darcy.

Results and Discussion

Three-point flexural strength of porous Ni-Mo alloy substrate



	25°C	750°C
Compress molding	188	76
Hand-made	150	54
Tape casting	156	60

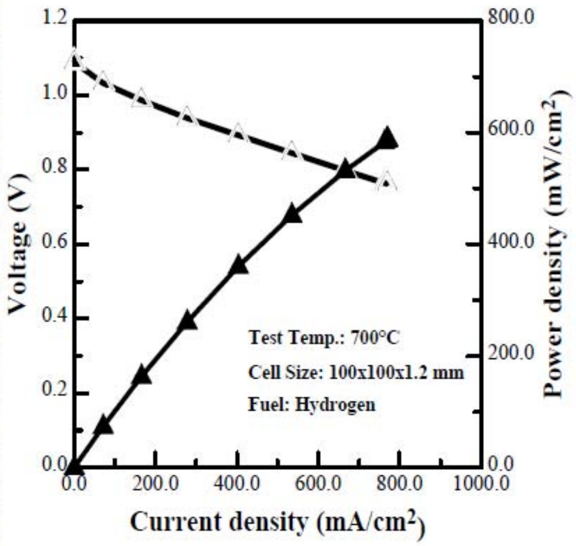
Unit: MPa
Specimen: sintered at 1250°C

The porous alloy sintered at 1250˚C is raised 32% bending strength as compared with the specimen sintered at 1000˚C while the carbon additive is 7.5%.

The strength can upgrade 25% (@25˚C) and 27.5% (@750°C) than previous manufacturing process (Hand-made and tape casting).

Results and Discussion

Cell performance



SUMMARY

1. The open circuit voltage (OCV) of 10×10 cm² metal-supported cell is 1.1 V at 700°C.
2. The maximum power density at 0.76 V is 588 mW/cm² at 700°C.
3. Our previous work with Ni-Mo-Fe alloy, the maximum power density is 15%–20% lower than the cell produced in this study.

Conclusions

A proper and effective fabricating process is revealed to produce 100 cm^2 porous alloy substrate as a supporting component for MS-SOFC.

The LSGM electrolyte (50 μm) is dense to avoid reaction gases to penetrate. The cell with 81 cm^2 active area has power density of 588 mW/cm^2 at 700°C.

The long term durability test of MS-SOFC with dimension of 100×100×1.2 mm^3 will be executed in the future work.

The properties (e.g. oxidation behavior and thermal conductivity) of porous alloy substrate will discuss in the further study.

Acknowledgements

Special thanks to INER SOFC project manager Dr. Ruey-Yi Lee, MSC group leader Dr. Chang-Sing Hwang and thanks all the co-workers of SOFC team at INER.

Thank you ~