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出國報告（出國類別：其他）

赴瑞士琉森參加歐盟第十屆 SOFC 燃料電池論壇公差報告

服務機關：核能研究所
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派赴國家：瑞士
出國期間：101 年 6 月 24 日~101 年 7 月 1 日
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摘　要

第十屆歐盟舉辦之 SOFC 國際論壇(European Fuel Cell Forum, EFCF)及燃料電池展，於 2012 年 6 月 26 日~6 月 29 日於瑞士 Lucerne 舉行，該會議為歐盟每兩年舉辦一次之 SOFC 論壇，本次會議主席為法國 CEA 燃料電池計畫主持人 Dr. Florence Lefebvre-Joud；會議及展示之主題涵蓋：電池片、連接板材料、電池堆、重組器、系統應用及開發等；該論壇為國際間此一領域之主要交流、溝通平台，內容涵蓋 SOFC 技術長期發展及未來產品化所需面臨之相關課題，國際間主要從事 SOFC 之研發機構皆派員與會；本次會議計有來自世界各地 4 百餘人的 SOFC 專業人士參加，其主題及展示範圍涵蓋：電池片、連接板材料、電池堆、重組器、系統應用、微小型 SOFC、中低溫 SOFC 及 SOEC 之開發等。

為掌握國際間 SOFC 燃料電池之發展趨勢，並拓展與國際 SOFC 主要發展機構成員之關係，本所派李員參加該項會議。李員目前擔任本所高溫燃料電池計畫主持人，與國際此領域之專家已有長期的接觸；其於 2011 年 3 月獲歐盟燃料電池論壇邀請為國際顧問專家委員會之一(International Board of Advisors of the EFCF)，該委員會於 6 月 26 日集會，商討論壇相關作業事宜。本次會議論文，"Development of SOFC Technology at INER"於論壇"Company & Major groups development status II (worldwide)"主題下做口頭報告，說明本所 SOFC 燃料電池之發展現況及願景；論文" Experimental Study of a SOFC Burner/Reformer"於"Fuels bio reforming"做海報展示。藉由本次會議，呈現本所過去幾年 SOFC 計畫的研發成果；此外，對於與國際間之資訊交流、人脈關係拓展，及後續國內 SOFC 研發策略及方向之擬訂及研發工作的推展，有相當大的裨益。

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一、目的

第十屆歐盟舉辦之 SOFC 國際論壇(European Fuel Cell Forum, EFCF)及燃料電池展，於 2012 年 6 月 26 日~6 月 29 日於瑞士 Lucerne 舉行，該會議為歐盟每兩年舉辦一次之 SOFC 論壇，本次會議主席為法國 CEA 燃料電池計畫主持人 Dr. Florence Lefebvre-Joud；會議及展示之主題涵蓋：電池片、連接板材料、電池堆、重組器、系統應用及開發等；該論壇為國際間此一領域之主要交流、溝通平台，內容涵蓋 SOFC 技術長期發展及未來產品化所需面臨之相關課題，國際間主要從事 SOFC 之研發機構皆派員與會；本次會議計有來自世界各地 4 百餘人的 SOFC 專業人士參加，約有 300 篇的專業技術報告，其中 110 篇論文做口頭簡報。其主題及展示範圍涵蓋：電池片、連接板材料、電池堆、重組器、系統應用、微小型 SOFC、中低溫 SOFC 及 SOEC 之開發等。

為掌握國際間 SOFC 燃料電池之發展趨勢，並拓展與國際 SOFC 主要發展機構成員之關係，本所派李員參加該項會議。李員目前擔任本所高溫燃料電池計畫主持人，與國際此領域之專家已有長期的接觸；其於 2011 年 3 月獲歐盟燃料電池論壇邀請為國際顧問專家委員會之一(International Board of Advisors of the EFCF)，該委員會於 6 月 26 日集會，商討論壇相關作業事宜。本次會議論文，"Development of SOFC Technology at INER"於論壇"Company & Major groups development status II (worldwide)"主題下做口頭報告，說明本所 SOFC 燃料電池之發展現況及願景；論文" Experimental Study of a SOFC Burner/Reformer"於"Fuels bio reforming"做海報展示。藉由本次會議，呈現本所過去幾年 SOFC 計畫的研發成果；此外，對於與國際間之資訊交流、人脈關係拓展，及後續國內 SOFC 研發策略及方向之擬訂及研發工作的推展，有相當大的裨益。

二、過程

(一) 概要說明

第十屆歐盟 SOFC 國際論壇及燃料電池展，於 6 月 26 日~6 月 29 日於瑞士 Lucerne 舉行；該會議為每兩年舉辦一次之 SOFC 論壇，會議主席為為法國 CEA 燃料電池計畫主持人 Dr. Florence Lefebvre-Joud；原德國 Jülich 能源發展研究中心暨歐盟 Real-SOFC 計畫主持人 Dr. Robert Steinberger-Wilckens 目前並任教於英國 University of Birmingham，為氫能及燃料電池研究中心主任，同時並仍為國際諮議委員會之主席。會議及展示之主題涵蓋：電池片、連接板材料、電池堆、重組器、系統應用、低溫 SOFC、微小型 SOFC 之開發等等；會議之主要議程安排參見表一，口頭簡報之議程參見表二，簡報包含 A、B 兩個 Section。Section A 著重於設計、操作及系統整合與應用； Section B 著重於組件之開發、診斷及模擬分析。參展廠商資料參見表三。

EFCF 論壇之創辦人 Dr. Bossel 於 2008 年時即已表示，由於論壇的規模日趨龐大，已超過其個人及其家族所能承受的負荷，故期盼國際間的法人組織，可提供部分的協助，以使論壇持續的進行下去。因此在 2011 年 EFCF 論壇之承辦單位做了調整，由瑞士長期投入 SOFC 技術開發 HTceramix（HTc）公司 Managing Director Mr. Olivier Bucheli 及 Dr. Michael Spirig 負責籌辦。本所與 HTc 公司已有良好的合作關係，李員並數度代表本所參與國際 SOFC 活動，與多位國際 SOFC 燃料電池專家已有過接觸或為舊識，故對彼此間的發展狀況都略知一二。本次會議投稿之兩篇論文，"Development of SOFC Technology at INER"於論壇"Company & Major groups development status II (worldwide)"主題下做口頭報告，說明本所 SOFC 燃料電池之發展現況及願景；論文" Experimental Study of a SOFC Burner/Reformer"於"Fuels bio reforming"做海報展示。經由本次會議，具體呈現本所過去幾年 SOFC 計畫的研發成果，對於與國際間之資訊交流、人脈關係拓展，及後續國內 SOFC 研發工作的推展，都有相當大的裨益。

(二) 行程說明

本次公差自 101 年 6 月 24 日至 7 月 1 日，赴瑞士 Lucerne 參與歐盟第十屆 SOFC 燃料電池論壇國際會議。6 月 24 日自桃園機場經德國法蘭克福國際機場，轉機至蘇黎世機場，再搭乘火車，於 6 月 25 日下午直接到達瑞士 Lucerne。6 月 26 日參加 EFCF 論壇召開的國際專家委員會，討論論壇目前及後續的相關作業事宜，以推廣燃料電池的技術及擴大影響層面。論壇於 6 月 26 日傍晚註冊，參與 6 月 26 日~6 月 29 日之 EFCF 研討會；6 月 27 日就本所 sofc 技術之發展做口頭報告，6 月 28 日就本所燃燒重組器之發展做海報展示與說明。6 月 30 日清晨自瑞士蘇黎世機場經荷蘭阿姆斯特丹國際機場搭機返台，於 7 月 1 日回到國內。

(三)　接洽人員

本所於 2005 年及 2006 年間於所內舉辦過兩次國際研討會，邀請國際 SOFC 知名專家與會；2005 年 8 月間，李員奉派赴歐洲參訪德國 FZJ 國家實驗室、荷蘭 ECN、瑞士 EPFL 科技大學、德國 IKTS 等能源研究中心，及瑞士 HTceramix 公司；復於 2006 年 10 月~12 月間赴德國 FZJ 能源研究中心參與 SOFC 相關測試工作，及參訪瑞士 EPFL、瑞士 HTceramix 公司及德國 ThyssenKrupp VDM 公司；2007 年 7 月 10-11 日參加於法國 Seyssins-Grenoble 舉行之歐盟第四屆 Real SOFC 專家研討會，2008 年 6 月 30 日-7 月 6 日奉派參加歐盟舉辦之第八屆 SOFC 燃料電池論壇及 IEA 會員舉行之內部會議；2009 年 10 月 11 ~18 月參加於大陸蘇州舉辦之第二屆世界材料峰會及參訪華中科技大學；2010 年 4 月 29 日-5 月 8 日赴加拿大蒙特婁參加 SOFC-XII 研討會；與國際 SOFC 發展之主要成員已有相當程度之接觸。本次奉派參加歐盟舉辦之第十屆 SOFC 燃料電池論壇及參與 EFCF 國際專家委員會討論會，就當前 SOFC 之發展現狀及未來趨勢交換意見，維持並拓展國際人脈關係，以期能與國際專家及研究機構維持良好的合作關係，加速本所 SOFC 計畫之進展，並利於國內 SOFC 技術產業化的進程。

三、心得

(一) 歐盟第一屆 SOFC 燃料電池論壇由 Dr. Bossel 創辦，於 1994 年在瑞士 Lucerne 舉行，其後持續每兩年舉辦一次，2000 年起固定於瑞士 Lucerne 舉辦，論壇已持續舉行 18 年，其中奇數年及雙數年分別舉行低溫型及高溫型燃料電池之研討會，本年度(2012)為歐盟第十屆的 SOFC 論壇。此一論壇提供國際間從事 SOFC 領域的研究人員及產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。參與此一論壇的人數及發表的論文數也持續的成長，本次會議計有來自全世界 4 百餘人參加。由於論壇的規模日趨龐大，創辦人 Dr. Bossel 於 2008 年表示，已超過其個人及其家族所能承受的負荷，故邀請國際間的法人組織接辦，以使論壇持續的進行下去。本年度即由 Olivier Bucheli 及 Michael Spirig 負責籌辦，秉持創辦人 Dr. Bossel 的理念，持續在 Lucerne 舉辦歐盟燃料電池論壇。

(二) 自第一次石油危機開始，瑞士及挪威即著手探討可行且具潛發性的新能源技術，並開始進行 SOFC 的研發工作。自 1989 年瑞士舉辦了 IEA 成員國第一次的 SOFC 研討會，並隨即成立國際間的合作夥伴關係，後續每年至少舉辦一次會員間資訊交流的研討會。雖 SOFC 技術日趨成熟，惟其製作數量未達商業量產的規模，成本仍屬偏高。面對全球暖化、電力需求增加及碳減排的壓力，各種節能減碳的技術都必須列入整體的評估考量。其中核能亦為國際間因應電力、需求不得不的選項之一。然而，2011 年 3 月 11 日發生的福島事件，使得國際間各國重新省思其所擬定能源政策的妥適性；例如同年 3 月 25 日，瑞士聯邦即訂出逐步降低對核能依賴（原占 38%）的政策，其將繼續沿用現有的核能發電設備，年限到期除役後不再興建，並將積極投入新能源領域的開發。在實務上，新能源技術的開發仍需假以時日，其單價仍然偏高，須仰賴政府在政策上的補貼；易言之，其經費的來源有賴於現有的架構支持。是以新能源技術的開發與傳統的技術間有相當大的依存度。2012 年 7 月，日本的評估報告顯示，福島事件起因為地震及海嘯，惟其導致嚴重後果的主因為一連串的人為疏失所致，後續可針對這些疏失進行改善以進一步提昇核能安全。即便如此，核能必須經過一段經驗回饋期，才會再復甦。此外，原由核能提供的電力及其所承擔碳減排的缺口，如何填補，對於高度仰賴核能發電的國家是一項嚴峻的考驗。例如；受到日本福島核災影響，德國提高了核電站安全監管標準，聯合政府並於 2011 年 5 月 30 日宣布，將於 2022 年全面關閉所有核電廠，並投入鉅資開發及擴大使用再生能源。德國是全球第四大、歐洲第一大經濟體，核發電占總發電量的 23%；環境部並宣稱：可再生能源將從目前占總發電量的 17%，在 10 年後提高到 40%。然而，2012 年 8 月 30 日，德國環境部長表示，由於消費者擔心廢核可能導致他們須承擔龐大費用，為減輕疑慮，故其綠能計畫恐需放緩。

(三) 從傳統不可再生的能源型態（含：石油、煤、天然氣、核能等等）過渡到可再生的能源型態（含：太陽能、風能、地熱能、生物質能、氫能、水能、海洋能等等），是

一條漫長且艱辛的歷程，但也是人類追求永續經營必走的路，因此目前國際各主要國家均將發展再生能源視為「無悔」的策略。可再生能源具零或極低排放的特點，其能量的來源無虞，有利於環境保護及減緩氣候變遷，是未來全球能源的必然選項；然而可再生能源受到氣候、晝夜、地理環境與位置等的限制，其能量密度低、分布分散，其經濟誘因不足，目前其所能提供的能量占比偏低，短時間內也無法取代傳統能源在能源結構上的地位。如何在諸多限制的情況下，善用資源、進行技術整合，以發揮最大的宏效，達到「能源安全」、「環境保護」、「經濟發展」三贏的局面，是主事者在盤點能源供應需求、重整能源結構、及擬定能源政策時，必須面對的課題。

(四) 自十八世紀六零年代工業革命後，人類大量開採及使用化石能源，促進現代文明的快速進展，生活型態產生巨大的變化；尤其在最近百餘年間所累積釋出的各式溫室氣體，已顯著造成氣候急劇異常變遷、全球平均氣溫迅速上升；此一全球性的溫室效應及暖化所衍生的效應，已嚴重破壞了生態及環境的平衡並威脅到人類的生存前景，故世界各國均積極的開發及應用節能、新能源或再生能源技術，以減緩暖化所造成的衝擊，期使社會能維持穩健的永續發展。目前全球初級能源供給雖日趨耗竭，惟受限於資源及技術能量，國際能源總署(IEA)2011 年世界能源展望分析顯示，在未來數十年間初級能源的主要來源仍為化石能源，預估 2035 年化石能源於全球能源消費的占比仍高達 74.7%。燃料電池是一項被看好的綠能技術，與傳統的內燃機、發電機相比，它本身不受卡諾循環(Carnot cycle)的限制，省略了機械結構、減少噪音，並可藉由電化學反應將燃料的化學能直接轉化為電能，具有較傳統發電為高的能量轉換效率。若以氫氣做為燃料，其生成物為水，無碳排放的問題。在不同型式的燃料電池當中，固態氧化物燃料電池(Solid Oxide Fuel Cell, SOFC)可使用氫氣、天然氣、生質燃料、煤合成氣及多種碳氫化合物作為燃料，為橋接化石能源至次世代新能源的重要技術，且為所有能源轉換裝置中效率最高者，為全世界各先進國家積極開發的一項新能源技術。目前世界各國已紛紛將其列為國家達成淨煤減碳目標的一項重要能源技術，並積極投入及佈署投入此項技術之開發與應用，預期 SOFC 產業將成為全球新興能源的重要產業之一。

(五) SOFC 燃料電池為一可模組化的發電系統，其主要應用範疇含輔助電源單元供應器及定置型發電系統，其功率範圍從一般家用的 kW 級、社區的百 kW 級至數百 MW 電廠，皆能維持高水平的發電效率；其應用面範圍廣，國際各先進國家皆積極投入，期望儘速將此綠色能源技術落實到產業化及商品化。SOFC 燃料電池操作在高溫條件下，利用特定的陶瓷材料在高溫情況下具有高的離子傳導性，經由電化學的反應，可有效的將化學能轉換為電能，其排放的尾氣主要為水及高濃度的二氧化碳，對於後續二氧化碳的捕捉及貯存作業，具有極高的商業利基；其電能效率可達 40~60%及整體效率 85~90%，遠高於傳統或其他類型的發電系統。此外， SOFC 系統產生的高階熱能可與熱泵技術相結合，使熱能得到充分的回收與利用，具有發電、發冷、發熱多重

功能及低碳排放之特性，是值得開發的高效率分散型能源技術。

(六) 國際先進國家自 1960 年代即相繼投入 SOFC 相關技術之研究開發，惟其技術門檻高，關鍵核心技術主要掌握在少數研究機構或廠家手中。經由長時間的技術開發，目前歐、美、日、澳等國已陸續有商品化產品，並進行大型實地驗證計畫，惟其尚未進入量產階段，單價仍屬偏高，故其推展速率相對平緩。2011 年 3 月 11 日發生的日本福島核安事故，對國際各國的能源政策造成相當大的衝擊，各國紛紛重新檢討能源政策並降低核能發電的配比，惟相對應的必須提昇節能效率及增加替代性能源的占比，以填補原核電所留下的電力缺口。高效率 SOFC 發電系統符合環境保護及節能減碳的需求，為一橋接型的新能源技術，若大量採用以取代傳統的發電設施，預期可創造無限的商機，為目前世界各國積極投入的熱點。SOFC 燃料電池發電系統的功率範圍，從小型熱電共生系統至大型 SOFC 發電廠，都有相當大的發展潛力，目前已到達早期市場驗證測試階段，在未來數年間將持續蓬勃的成長。

(七) 國際間各研究機構或廠家在 SOFC 燃料電池的開發已有顯著的成效，如：瑞士 Sulzer Hexis 公司、SOFCPower/HTC 公司、德國 Julich 及 IKTS 國家實驗室、英國 Ceres Power、Rolls-Royce 集團、丹麥 RISO/TOPSOE、美國 PNNL 及 NETL 國家實驗室及 SECA 六大工業團隊…等等，有興趣者可透過網路及報章雜誌取得相關訊息。以下僅舉數例提供參考。

(i) 日本政府目前透過補貼政策大力推動家用型熱電共生燃料電池發電機組(700W 型)，藉由階段性的實證測試，蒐集必要的測試數據、建構軟硬體設施及建立民眾採用燃料電池的信心，在各項條件成熟時，市場需求自然增加，即可逐步進入量產以降低成本；此外由於具高效率可有效節省電費，產品將極具競爭力，日本廠家估計在 2016 年將進入年產數十萬台的市場規模。此外，日本預備 2013 年開始受理輸出功率為 250kW 的 SOFC 電廠(混合動力系統的蒸汽渦輪機+固體氧化物燃料電池+燃氣渦輪+天然氣)替代火力發電廠，預計可減少 20%的二氧化碳排放量及 60%以上的傳輸能耗，發電效率預計達 55 %。後續並將組合大型 SOFC、燃氣輪機、蒸汽渦輪等機械，產出輸出功率達 80 萬 kW 的系統，實現 70%以上（LHV）的發電效率，比最新天然氣發電設備高 10%左右。

(ii) 澳大利亞 CFCL(Ceramic Fuel Cell Limited)公司開發的 2kW BlueGen 熱電共生系統，發電效率可達 60%，為當前國際間小型熱電共生系統開發的翹楚。CFCL 公司以其高發電效率的優勢，積極搶攻歐洲的市場。CFCL 的戰略思維認為，小型的熱電共生系統的市場需求相當龐大，如：家用的熱水器、微小型 CHP 的電力需求及節能減碳的效益，其市場需求量都相當的大。在市場的拓展策略上，其採取 go deep-> go wide->go large 等三階段的運作模式。第一階段的市場（主要為歐洲）需具備完善的法規配合度、具備充足的硬體建設及可承擔燃料電池的高單價；第二階段的市場（如美國、日本）需具有可開發成第一階段市場的潛力；第三階段為成本下降階段，市場拓展是全面性

的，蘇聯、印度、中國、巴西等等，都是此階段合作開發的對象。

(iii) 美國西屋公司自 1960 年代即開始管狀 SOFC 燃料電池技術的開發，其開發的系統具備高穩定度及極低的衰減率，惟其製造成本長期居高不下，故西屋公司於 2008 年將 SOFC 燃料電池計畫大幅縮編；隨後，美國通用電器公司評估認為該公司已具備充分的專利佈局，故亦縮小 SOFC 燃料電池的規模，將伺機而起。另一方面，美國 Bloom Energy 公司在 2006 年 1 月首度於田納西大學安裝一組 5kW 的 SOFC 發電系統，經過 18 個月的測試，其系統的可用率高達 99%；在政府的支持及各界的高度期待下，Bloom Energy 公司積極的拓展市場，以 100kW SOFC 機組為主要產品，發電效率 55%，於美國本土積極的開拓客戶源，如：Coca-Cola、Wal-Mart、eBay、 Adobe、Google、AT&T…等等二十餘家企業體，並持續的拓展相關業務。並於全世界尋找具充分製造能力的協力廠商，以維持產品的品質並進行成本降低的生產作業；目前國內數家公司，以其精湛的技術及成本效益上的優勢，已成為該公司產業鏈上的一環。

(iv) 美國 Versa Power 公司成立於 2001 年，為 Gas Technology Institute (GTI), Electric Power Research Institute(EPRI), Materials and Systems Research(MSR), and University of Utah 合資的公司，同時 Fuel Cell Energy(FCE)公司佔有相當比例的股份，並提供技術移轉給 Versa Power；其位於加拿大 Calgary 的工廠，實質上是承接原 SOFC 開發者 Global Thermoelectric 公司的團隊及資產。Global Thermoelectric 公司自 1997 年即積極投入 SOFC 技術之開發，建置完整的電池單元製作生產線，但問題是：只有電池單元卻無立即的應用端，公司難以承擔長期無效益的投資，遂於 2004 年 6 月以 22.75 百萬加幣的金額，將相關的資產轉讓給 FCE 公司。FCE 為一美國公司，長期投入 Direct FuelCell® (DFC, MCFC)技術的開發，其於 2003 年 4 月獲美國 DOE 選定為 SECA 的成員之一，獲得$139 百萬美元的資助，從事 SOFC 技術的開發，重點為 3~ 10kW 定置型 SOFC 發電系統的開發。FCE 公司將 SOFC 技術的開發視為下一世代的發電系統，為其後續的發展重點。定置型 SOFC 發電系統若能開發成功並商品化，將可與大型的 DFC 發電設施相輔相成。因此 Versa Power 公司正積極進行 2~10kWz8 發電原型系統之實地驗證，做早期市場推廣之準備。目前 Versa Power 公司正與芬蘭最大的船舶公司 Wärtsilä 合作開發燃料電池技術在商品化能源產品上（特別是船舶）的運用，其定位為 *stand-alone energy-generation and marine products*。

(v) 韓國政府於 2008 年 8 月宣布新的能源政策，規劃 20 年的長期能源政策，標示「Low Carbon, Green Growth Plan」，提出多項鼓勵措施，以提昇新及再生能源(New and Renewable Energy，NRE)的技術開發及應用。其中，燃料電池技術列為最優先項目。依目前的規劃，其 NRE 之裝置容量占比(占全國能源生產量之比值)將由目前的 2.4% 提昇至 10%(2022 年)。在策略的運用上，韓國政府強力支持其國內研究機構、學術單位及業界，積極從事新能源及相關的技術開發，並藉由引進國外技術，以加速技術之進展。2007 由 POSCO 引進 FCE 的技術，在 2007~2011 間已建置 50 MW 的 MCFC 系統，同時還在浦項建立了年產量達 100MW 規模的燃料電池製造工廠，以此來進行多

種產品的開發，帶動燃料電池的工業化及技術開發。SK 集團於 2012 年 5 月與丹麥 Topsoe Fuel Cell 簽訂合作協議共同開發新一代 SOFC，規劃在 2015 年實現燃料電池的商業化銷售。2012 年 6 月，LG 電子公司大手筆投資收購了 Rolls-Royce 集團 Fuel Cell Systems 51%的股權，並更名為 LG 燃料電池系統公司，繼續固態氧化物燃料電池於分散式電源之研究。此外，韓國 POSCO 能源集團於 2012 年 6 月底與大慶經濟區先進產業支援團，簽署了 3 年 SOFC 周邊設備(BOP)核心部件開發及實用等技術開發合作協議，計劃到 2014 年將 10kW 的建築用 SOFC 投入商業化運營，並掌握新一代燃料電池的原創技術，實現燃料電池的原料及零組件 100%國產化。並且計劃對 50kW 的 SOFC 進行商業化以加強產品競爭力，不斷擴大中小型建築用燃料電池市場。

(vi) 中國大陸隨著能源消費總量的擴張，已成為全球二氧化碳排放最大國；煤炭的使用率偏高(>70%)，為中國二氧化碳排放長期居高不下的主因。在 SOFC 的研究開發方面，中科院暨 10 餘所學術機構於 1970 年代起即陸續投入 SOFC 的研究與開發。最近幾年並投入大量的人力及物力資源，支持固態氧化物燃料電池技術開發；希冀藉由高效率的燃料電池技術，與蘊藏量豐富的煤炭做結合，達到能源高效率使用及碳減排的效果。中國稀土的蘊藏量及照明量全世界第一，該等物資為新能源及再生能源開發所必備的材料；中國自 2009 年開始嚴管稀土礦產出口，以維持其戰略物資的優勢。中國政府自 2000 年開始積極招募國外具經驗的學人回國，以加速 SOFC 的技術進展。目前於 863 計畫(2011~2015)投入可觀的經費及人力進行 SOFC 技術推展，973 計畫進行基礎研究開發，預計 2015 年可推出 SOFC 燃料電池發電系統。中國大陸以其原物料及人力上的優勢，為全世界爭取成本下降及市場拓展的重要據點，其未來發展潛力無窮。

(八) 拜耳集團於 2007 年 5 月以 12 億歐元的價格將旗下的 H. C. Starck 公司售與金融投資者 Advent International and Carlyle Group 組成的聯盟，以減輕拜耳集團的負債壓力。Advent and Carlyle 表示將持續 H. C. Starck 的業務，並公開銷售證卷。H.C starck 公司成立於 1920 年，總部設在德國薩克森州的戈斯拉爾（Goslar），是全球固態高分子電容器化學品、難熔金屬及精密陶瓷的主導供應商，其積極與全世界的主要供應商形成策略聯盟，為一家極具企圖心的國際公司。目前該公司為國際間電池片最主要的供應廠家之一，生產之電池片行銷全世界。其於 2005 年 5 月間與國際知名的汽車運輸產業零組件製造廠家 Webasto 公司各出資 50%共同成立 Staxera 公司，以推動 SOFC 燃料電池堆的銷售作業。H. C. Starck 與德國系統組件廠商 EBZ 公司及研究機構 Fraunhofer Institute for Ceramic Technologies and Systems (IKTS)亦有長期的策略聯盟及合作關係。之前荷蘭 ECN 能源國家實驗室所開發的電池單元，H.C.Starck 為其主要供應廠商之一，其提供的材料單價相對便宜並具穩定性及高品質；其後 ECN 電池單元開發的幾個主要成員自 ECN 離開(spinoff)成立 InDEC 公司，初期 ECN 占有 InDEC 公司的主要股份；其後，H.C.Starck 依據協議，逐步併購 InDEC 公司，於 2006 年完成併

購作業，並於德國 Selb 建立大型的電池片量產廠房，年產量 20 萬片電池片；2010 年 6 月下旬 H.C. Starck 又與精密陶瓷公司 Kerafol 形成策略聯盟，合作製造、出售及分享通路，其主要產品為電解質支撐型電池片(ESC10)，其效能優於原 H. C. Starck 生產之 ESC2 及 ESC4 電池片，參見表四。2012 年 8 月中旬 H.C. Starck 又與中國大陸江鎢集團簽署中德合資協議，在中國廣州市成立兩家合資公司，是該公司拓展業務的戰略佈局；根據協議，雙方共同投資總額將達 8 億元人民幣（合 8500 萬歐元），掌握及拓展稀土元素的應用市場。

(九) 自 1960 年代開始，國際間各國前仆後繼的投入 SOFC 技術之開發及應用，如西屋公司、GE 公司（Applied Signal, Honeywell）、Sulzer Hexis、Global Thermoelectric 公司等等，經過漫長的投資及開發後，由於仍未顯現明確的商機，故主事者不得不將規模縮小或由其他公司併購。SOFC 技術經過長時間的醞釀，雖有公司更迭的變化，但研發者之經驗及技術則持續的傳承及拓展；時至今日，技術重點已從單純的學術研究，拓展至產業發展，目前國際間已有商品化產品推出，並積極從事 SOFC 發電系統的開發及驗證，預期在數年內 SOFC 將達到技術產業化的階段。

(十) 原德國 Jülich 能源發展研究中心暨歐盟 Real-SOFC 計畫主持人 Dr. Robert Steinberger-Wilckens，接受英國 University of Birmingham 的聘請，為氫能及燃料電池研究中心主任(該中心由前主任 Prof. Kevin Kendall 於 2000 年主導成立)，並負責 SOFC 技術之開發；Jülich 能源發展研究中心 SOFC 計畫由 Prof. Ludger Blum 接任。PNNL 國家實驗室的燃料電池中心主任 Dr. Subhash C. Singhal 原服務於西屋公司，為固態氧化物燃料電池的泰斗之一，於 2012 年 1 月自 PNNL 退休，目前可提供 SOFC 技術之諮詢及顧問。Dr. Nguyen Minh 原為 GE 公司 SOFC 計畫之主任工程師，目前擔任加州大學聖地牙哥分效能源中心副主任，協助該校建立新能源技術及其應用與拓展。荷蘭 ECN 國家實驗室，於 2009 年 10 月間政策決定暫停 SOFC 計畫，原計畫主持人 Dr. Bert Rietvelt 及既有人力接受新的任務，轉而投入生質能、薄膜、淨煤及環境、及能源效率提昇相關技術之開發。本屆歐盟 SOFC 論壇，特頒金牌獎給 Dr. Bert Rietvelt，表彰他在 SOFC 技術開發上的卓越成效及技術推廣上的貢獻。CFCL 公司主任工程師 Dr. Karl Föger 為 CFCL 公司的創建人之一，長期從事 SOFC 技術之開發，其 2kW BlueGen 發電系統的電效率可達 60%，為當前國際間小型熱電共生系統開發的翹楚；為了理想的實現，Dr. Karl Föger 風塵僕僕移居德國將重心放在歐洲，積極搶攻歐洲的市場，期望 SOFC 技術的早日產業化。

(十一) 核能研究所從 2003 年起開始從事 SOFC 技術的開發，在研發過程中與國內諸多學術團體及業界已有緊密的合作關係。經由長期的努力，已掌握從材料粉末至發電系統(from powder to power) 所必要的關鍵核心技術，包含：電池單元、電池堆、觸媒材料、系統 BOP 設計製造、系統整合與控制等關鍵核心技術。電池單元為 SOFC 發電系統的心臟，為電化學反應發生的主要區域。目前本所已克服瓶頸技術，開發傳統刮

刀成型及金屬支撐型之平板式電池單元，相關技術達國際水平。在功率輸出、長期效能及可靠度方面，均有顯著的進展，在定電流 400 mA/cm^{2}的測試條件下，衰減率已低於 1%/khr。重覆組裝 18 片裝電池堆模組，每組功率皆可達 500W，其效能最大的差異在 2%以內。開發的創新型重組氣觸媒材料，具高度的穩定性，其天然氣的重組效能高於 95%。經由長期的實驗及數值分析，已完成整合型非預混式的重組器及續燃器的設計及製作，符合預期的功能需求。kW 級 SOFC 發電系統原型機已完成初期的建置及測試，配合系統的功能需求，系統之操作模式、數據擷取、功率調控、訊號量測、控制邏輯等，經過一系列的驗證測試，確認各組件本身及組件間的介面功能正常。使用天然氣為燃料源時，系統功率輸出 760W，燃料使用率 64%，電效率 35.1%。就整體面向而言，本所已成功建立 kW 級發電系統整合、儀電控制及關鍵熱工組件設計及製造的技術能量。

(十二) 核研所經過近十年在 SOFC 技術上的耕耘與努力，在學術上、專利技術及與產業合作上均已逐漸展現成效。建立研究團隊包括：SOFC 電池堆設計及組裝技術開發實驗室、SOFC 發電系統設計及驗證實驗室、SOFC 材料與元件研製與測試團隊與製作實驗室、及電漿噴塗鍍膜專業實驗室。為使開發的核心技術能量得以拓展及應用，需積極結合國內產官學研的能量，並與國內業界建立緊密的合作夥伴關係，希冀從國內組件製造的優勢，發展成系統整合技術的量能，以建立具國際競爭力的產業鏈。展望未來，高效率 SOFC 技術產業將成為我國及全球新興能源的重要產業之一。

(十三) 在後續的研發方向及策略上，燃料電池技術需與新能源之氣化與淨化做結合，以提昇能源使用效率、抑低二氧化碳排放量，包括：(1)建立分散式熱電併聯發電系統之技術與應用； (2)積極推動燃料電池之相關標準及系統驗證計畫；(3)建立 IGFC（Integrated Gasification Fuel Cell Combined Cycle）系統整合技術與應用之核心能量。此外，朝向開創綠能新興產業，促進綠能技術發展及創造就業機會，包括：(1)結合國內電力、油氣供應業者，建立示範計畫，獲得早期市場經驗；(2)尋求優質廠商達成高效率量產及成本降低技術；(3)技術移轉建立關鍵零組件供應鏈； (4)加強國際合作，以國內優勢之製造業利基，拓展行銷通路。

(十四) 面對未來電力短缺、石化能源日趨耗竭及價格持續飆漲，潔淨能源的需求日殷，高效率 SOFC 燃料電池為橋接石化能源至次世代能源的重要技術，預期 SOFC 產業將成為全球新興能源的重要產業之一。國際各國因應氣候變遷及環境保護的議題及全球對節能減排的要求日趨迫切情況下，已紛紛將 SOFC 及 IGFC 列為國家達成淨煤減碳目標的一項重要能源技術。國內擁有的初級能源相當匱乏，進口能源仰賴度達 99%以上，在全球能源價格持續飆漲下，勢必造成政府龐大財政支出負擔，削弱國家整體發展及產業競爭力。SOFC 技術具有提高能源效率、減少石化能源需求量及降低溫室氣體二氧化碳排放的優點，衡諸國際先進國家的發展趨勢，我國必須積極投入資源急起直追，以發展此新能源技術並建立相關能源產業。

(十五)　當前國內已建立 SOFC 發電技術之關鍵核心技術之基礎能量，業界並已有部分實務製造經驗，惟整體發展仍相對落後於先進國家，亟需迅速整合產、官、學、研資源，加強人才培訓，全力投入以掌握並建立自主之技術能量，並善用國內製造能力、系統整合及成本下降的特長；政府部門應定出產品法規及產業獎勵扶植辦法，加速產品實物、實地驗證的腳步，儘速於國內建立具國際競爭力的產業鏈，共同建構此一低碳、高效率之新興能源產業。

四、建議事項

(一)歐盟於瑞士琉森舉辦之 SOFC 國際論壇及燃料電池展，每兩年舉辦一次，提供國際間從事 SOFC 領域的研究人員及產業界一個優質的交流平台。為使國內 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，建議歐盟之 SOFC 論壇，計畫應規劃、派員參加，以呈現國內的研發成果、拓展國際人脈關係，及加速計畫之執行成效。

(二)目前亞洲地區日本已推出 SOFC 商品化產品、韓國及中國大陸政府均強力支持其國內研究機構、學術單位及業界，積極從事新能源及相關的技術開發，並藉由引進國外技術，以加速技術之進展；於每次的歐盟 SOFC 論壇上均派出多名研究/專業人員參加，展現對 SOFC 技術發展的強烈企圖心。中日韓並定期於三國輪流舉辦亞洲區 SOFC 論壇。以國內體制上的限制，及有限的經費及人力資源，雖目前本所 SOFC 計畫於各個面向均略有所成，然若無適當的因應對策，長期以往我國將有被邊緣化之虞。建議後續須強化與業界之合作，加速技術產業化的進程；本所並須與學界做連結，尋求學理基礎及技術應用面的重點突破，才能在未來國際 SOFC 的平台上佔有一席之地。

(三)高效率 SOFC 燃料電池為橋接石化能源至次世代能源的重要技術，預期 SOFC 產業將成為全球新興能源的重要產業之一。政府亟需迅速整合產、官、學、研資源，加強人才培訓，全力投入以掌握並建立自主之技術能量，並善用國內製造能力、系統整合及成本下降的特長；相關部門應定出產品法規及產業獎勵扶植辦法，加速產品實物、實地驗證的腳步，儘速於國內建立具國際競爭力的產業鏈，共同建構此一低碳、高效率之新興能源產業。

(四)在後續的研發方向及策略上，燃料電池技術需與新能源之氣化與淨化做結合，以提昇能源使用效率、抑低二氧化碳排放量，包括：(1)建立分散式熱電併聯發電系統之技術與應用；(2)積極推動燃料電池之相關標準及系統驗證計畫；(3)建立 IGFC（Integrated Gasification Fuel Cell Combined Cycle）系統整合技術與應用之核心能量。此外，朝向開創綠能新興產業，促進綠能技術發展及創造就業機會，包括：(1)結合國內電力、油氣供應業者，建立示範計畫，獲得早期市場經驗；(2)尋求優質廠商達成高效率量產及成本降低技術；(3)技術移轉建立關鍵零組件供應鏈；(4)加強國際合作，以國內優勢之製造業利基，拓展行銷通路。

表一、第十屆歐盟 SOFC 論壇會議議程

International conference on SOLID OXIDE FUELL CELL and ELECTROLYSER

10^{th} EUROPEAN SOFC FORUM 2012

26 - 29 June 2012

Kultur- und Kongresszentrum Luzern (KKL) Lucerne / Switzerland

Schedule of Events

Tuesday – 26 June 2012	10:00 - 16:00	Exhibition set-up
	10:00 - 16:00	**Tutorial** by Dr. Günther Scherer & Dr. Jan Van herle
	14:00 - 18:00	Poster pin-up
	16:00	Official **opening of the exhibition**
	16:00 - 18:00	Registration (continued on following days)
	18:00 - 19:00	**Welcome gathering** on terrace above registration area
	from 19:00	**Thank-You Dinner** according to special invitation and Networking meetings (in individual groups)
Wednesday – 27 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 18:00	Conference **Sessions 1-5** including **keynotes** on international overview from Europe, China, Japan, Korea and USA, **Poster presentation** by authors, networking and exhibition
	12:30	Press Conference (by invitation only)
	18:30 - 23:00	**Swiss Surprise Event** (optional, separate registration)
Thursday – 28 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 18:00	Conference **Sessions 6-10** including technical **keynotes** on advanced characterisation and diagnosis **Poster presentation** by authors, networking and exhibition
	09:00 - 18:00	Access to **poster** area
	19:30 - 23:00	**Great Dinner on the Lake**
Friday – 29 June 2012	08:00 - 09:00	Speakers Breakfast (World Café at ground floor KKL)
	09:00 - 16:00	Conference **Sessions 11-15** including **keynotes** on SOFC for Distributed Power Generation, networking and exhibition
	09:00 - 12:00	Access to **poster** area
	12:00 - 14:00	Poster removal
	16:00 - 17:00	**Award &** Closing Ceremony – Christian Friedrich Schönbein & Hermann Göhr Awards

Conference Session Overview

Session	Luzerner Saal (ground floor)	Session	Auditorium (1^{st} floor)
A01	**Plenary 1** - Opening Session & International Overview		
A02	**Plenary 2** - International Overview		
A03	in Club Rooms 3-8 (2^{nd} floor)		Poster Session I with topics from Sessions A04, A05, A07, A09, A10, B10*, A11, A12, A13 (* from Session II)
A04	Company & Major groups development status I (EU)	B04	Cell materials development I
A05	Company & Major groups development status II (WW)	B05	Diagnostic, advanced characterisation & modelling I
A06	**Plenary 3** - Advanced Characterisation and Diagnosis		
A07	Cell and stack design I	B07	SOE cell material development
A08	in Club Rooms 3-8 (2^{nd} floor)		Poster Session II with topics from Sessions B04, B05, B07, B09, *, B11, B12, B13 (* in Session I)
A09	Cell and stack design II (Metal Supported Cells)	B09	Cell materials development II (IT & Proton Conducting SOFC)
A10	Cell operation	B10	Diagnostic, advanced characterisation & modelling II
A11	SOE cell and stack operation	B11	Fuels bio reforming
A12	Cell and stack operation	B12	Interconnects, coatings & seals
A13	Stack integration, system operation and modelling	B13	Seals
A14	**Plenary 4** - SOFC for Distributed Power Generation		
A15	**Plenary 5** - Closing Ceremony		

10th EUROPEAN SOFC FORUM 2012 I-3

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程

Conference Schedule and Program

Wednesday, June 27, 2012

Morning — Luzerner Saal (ground floor) — Morning

09:00	**Opening Session** **Plenary 1 - International Overview** *Chair: Florence Lefebvre-Joud / Olivier Bucheli*	**A01**
09:00	**Welcome by the Organizers** Olivier Bucheli, Michael Spirig European Fuel Cell Forum; Luzern/Switzerland	A0101
09:05	**Welcome by the Chairwoman** Florence Lefebvre-Joud CEA/Liten; Grenoble/France	A0102
09:15	**Welcome to Switzerland the Smart Research Place** Rolf Schmitz Swiss Federal Office of Energy SFOE; Bern/Switzerland	A0103
09:30	**The Status of SOFC Programs in USA - 2012** Daniel Driscoll, Briggs M. White U.S. DOE National Energy Technology Laboratory; Morgantown/USA	A0104
10:00	**Current SOFC Development in China: Challenges and Solutions for SOFC Technologies** Wei Guo Wang Fuel Cell and Energy Technology Division, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences; Ningbo/China	A0105
10:30	**Intermittence** with Refreshments served on Ground Floor in the Exhibition	

International Board of Advisors

- **Prof. Robert Steinberger (Chair; FZJ / Germany)**
- Prof. Frano Barbir (Unido/Ichet / Croatia)
- Dr. Ulf Bossel (ALMUS AG / Switzerland)
- Dr. Niels Christiansen (TOFC / Danmark)
- Dr. Karl Föger (Ceramic Fuel Cells / Australia)
- Prof. Angelika Heinzel (ZBT / Germany)
- Prof. Ellen Ivers-Tiffée (KIT / Germany)
- Prof. Deborah Jones (CNRS / France)
- Prof. John A. Kilner (Imperial College London / United Kingdom)
- Dr. Jari Kiviaho (VTT / Finland)
- Dr. Ruey-yi Lee (INER / Taiwan)
- Dr. Florence Lefebrve-Joud (CEA / France)
- Prof. Göran Lindbergh, (KTI / Sweden)
- Dr. Mogens Mogensen (Risø / Denmark)
- Dr. Angelo Moreno (ENEA / Italy)
- Prof. Kazunari Sasaki (Kyushu University / Japan)
- Dr. Günther Scherer (PSI / Switzerland)
- Dr. Günter Schiller (DLR Stuttgart / Germany)
- Dr. Subhash Singhal (Pacific Northwest National Laboratory / USA)
- Dr. Martin Smith (Uni St. Andrews / United Kingdom)
- Prof. Constantinos Vayenas (University of Patras / Greece)
- Prof. Martin Winter (Uni Münster / Germany)
- Dr. Christian Wunderlich (IKTS / Germany)

Morning — Luzerner Saal (ground floor) — Morning

11:00	**Plenary 2 - International Overview** *Chair: Florence Lefebvre-Joud / Olivier Bucheli*	**A02**
11:00	**Europe's Fuel Cells and Hydrogen Joint Undertaking** Bert de Colvaneer FCH JU; Brussels/EU	A0201
11:30	**Commercialization of SOFC m-CHP in the Japanese Market** M. Atsushi Nanjou, Mr. Yamaguchi , Tomonari Komiyama, Toshiya Nakahara JX Nippon Oil & Energy Corporation; Tokyo/Japan	A0202
12:00	**High Temperature Fuel Cell Activities in Korea** Nigel Sammes, Jong-Shik Chung POSTECH; Pohang/South Korea	A0203
12:30	**Lunch Break** → Lunch is served on 2nd Floor - Terrace → Coffee is served on Ground Floor in the Exhibition	

Afternoon — Club Room 3-8 (2nd floor) — Afternoon

13:30	**Poster Session I** *Florence Lefebvre-Joud / Julie Mougin / Etienne Bouyer* Posters of sessions **A04, A05, A07, A09, A10, B10*, A11, A12, A13**	**A03** see page I-25 ff

*exception

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程(續)

Afternoon **Wednesday, June 27, 2012** Afternoon

	4A Luzerner Saal		4B Auditorium
14:30	**Company & Major groups development status I (EU) (A04)**	14:30	**Cell materials development I (B04)**
14:30	**SOFC System Development at AVL (A0401)** Jürgen Rechberger, Michael Reissig, Martin Hauth, Peter Prenninger; AVL List GmbH; Graz/Austria	14:30	**Fundamental Material Properties Underlying Solid Oxide Electrochemistry (B0401)** Mogens Mogensen, Karin Vels Hansen, Peter Holtappels, Torben Jacobsen, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, DTU; Roskilde/Denmark
14:45	**Status of the Solid Oxide Fuel Cell Development at Topsoe Fuel cell A/S and Risø DTU (A0402)** Niels Christiansen (1), Søren Primdahl (1), Marie Wandel (2), Severine Ramousse (2), Anke Hagen (2) (1) Topsoe Fuel Cell A/S; Lyngby/Denmark, (2) Risø DTU; Roskilde/Denmark	14:45	**La and Ca doped $SrTiO_3$: A new A-site deficient strontium titanate in SOFC anodes (B0402)** Maarten C. Verbraeken (1), Boris Iwanschitz (2), Andreas Mai (2), John T.S. Irvine (1) (1) University of St Andrews; St Andrews/UK, (2) Hexis AG; Winterthur/Switzerland
15:00	**Progress in the Development of the Hexis' SOFC Stack and the Galileo 1000 N Micro-CHP System (A0403)** Andreas Mai, Boris Iwanschitz, Roland Denzler, Ueli Weissen, Dirk Haberstock, Volker Nerlich, Alexander Schuler Hexis Ltd.; Winterthur/Switzerland	15:00	**Thermomechanical Properties of Re-oxidation Stable Y-$SrTiO_3$ Ceramic Anode Substrate Material (B0403)** Viacheslav Vasechko, Bingxin Huang, Qianli Ma, Frank Tietz, Jürgen Malzbender Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany
15:15	**Development and Manufacturing of SOFC-based products at SOFCpower SpA (A0404)** Massimo Bertoldi, Olivier Bucheli, Alberto V. Ravagni, SOFCpower SpA; Pergine Valsugana/Italy	15:15	**Doped $La_{2-x}A_xNi_{1-y}B_yO_{4+\delta}$ (A=Pr, Nd, B=Co, Zr, Y) as IT-SOFC cathode (B0404)** Laura Navarrete, María Fabuel, Cecilia Solís, José M. Serra, Instituto de Tecnología Química (Universidad Politécnica de Valencia – Consejo Superior de Investigaciones Científicas); Valencia/Spain
15:30	**Recent Results in JÜLICH SOFC Technology Development (A0405)** Ludger Blum (1), Bert de Haart (1), Jürgen Malzbender (1), Norbert Menzler (1), Josef Remmel (2), Robert Steinberger-Wilckens (3) (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany (2) Forschungszentrum Jülich GmbH, Central Institute of Technology (ZAT); Jülich/Germany (3) University of Birmingham, School of Chemical Engineering; Birmingham/UK	15:30	**Development and Characterization of LSCF/CGO composite cathodes for SOFCs (B0405)** Rémi Costa (1), Roberto Spotorno (1), Norbert Wagner (1), Zeynep Ilhan (1), Vitaliy Yurkiv (1), (2), Wolfgang G. Bessler (1), (2), Asif Ansar (1), (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany, (2) Universität Stuttgart, Institute of Thermodynamics and Thermal Engineering (ITW); Stuttgart/Germany
15:45	**Compact and highly efficient SOFC Systems for off-grid power solutions (A0406)** Matthias Boltze, Gregor Holstermann, Arne Sommerfeld, Alexander Herzog new enerday GmbH; Neubrandenburg/Germany	15:45	**Effect of Ultra-thin Zirconia Blocking Layer on Performance of 1 µm-thick Gadolinia-doped Ceria Electrolyte SOFC (B0406)** Doo-Hwan Myung (1), (2), Jongill Hong (2), Kyungjoong Yoon (1), Byung-Kook Kim (1), Hae-Weon Lee (1), Jong-Ho Lee (1), Ji-Won Son (1), Fuel Cells Forever, Inc.; Seoul/South Korea, (2) Yonsei University, Department of Materials Science and Engineering; Seoul/South Korea
16:00	Coffee Break – Ground Floor in the Exhibition and 2nd Floor in the Poster Session		

Afternoon **Wednesday, June 27, 2012** Afternoon

	5A Luzerner Saal		5B Auditorium
16:30	**Company & Major groups development status II (Worldwide) (A05)**	16:30	**Diagnostic, advanced characterisation and modelling I (B05)**
16:30	**Latest Update on Delphi's Solid Oxide Fuel Cell Stack for Transportation and Stationary Applications (A0501)** Karl Haltiner, Subhasish Mukerjee, Rick Kerr, Delphi Corporation; W. Henrietta/USA-NY	16:30	**Stroboscopic Ni Growth/Volatilization Picture (B0501)** J. Andreas Schuler (1), Boris Iwanschitz (2), Lorenz Holzer (3), Marco Cantoni (4), Thomas Graule (1), (1) EMPA; Dübendorf/Switzerland, (2) Hexis AG; Winterthur/Switzerland, (3) ZHAW; Winterthur/Switzerland, (4) EPFL; Lausanne/Switzerland
16:45	**Solid Oxide Fuel Cell Developmentat Versa Power Systems (A0502)** Brian Borglum, Eric Tang, Michael Pastula Versa Power Systems; Calgary AB/Canada	16:45	**Oxidation of nickel in solid oxide fuel cell anodes: A 2D kinetic modeling approach (B0502)** Jonathan P. Neidhardt (1), (2), Wolfgang G. Bessler (1), (2), (1) German Aerospace Centre (DLR), Inst. of Technical Thermodynamics; (2) Stuttgart Univ., Inst. of Thermodynamics and Thermal Engineering; Stuttgart/Germany
17:00	**BlueGen for Europe – Commercialisation of Ceramic Fuel Cells' residential SOFC Product (A0503)** Karl Föger, Ceramic Fuel Cells GmbH; Heinsberg/Germany	17:00	**NiO reduction studied by environmental TEM and in situ XRD (B0503)** Q. Jeangros (1), T. W. Hansen (2), J.B. Wagner (2), C.D. Damsgaard (2), R. E. Dunin-Borkowski (3), J. Van Herle (4), A. Hessler-Wyser (1), (1) EPFL, Interdisciplinary Centre for Electron Microscopy; Lausanne/Switzerland, (2) DTU, Center for Electron Nanoscopy; Lyngby/Denmark, (3) Jülich Research Centre, Ernst Ruska-Centre; Jülich/Germany, (4) EPFL; Laboratory for Industrial Energy Systems; Lausanne/Switzerland
17:15	**SOFC system integration activities in NIMTE (A0504)** Shuang Ye, Jun Peng, Bin Wang, Sai Hu Chen, Qin Wang, Wei Guo Wang Chinese Academy of Sciences, Fuel Cell and Energy Technology Division, Ningbo Institute of Materials Technology and Engineering; Ningbo/China	17:15	**LEIS of Oxide Air Electrode Surfaces (B0504)** John Kilner, Stephen Skinner, Monica Burriel, Manos Symianakis, Imperial College London, Department of Materials; London/UK
17:30	**Development of SOFC Technology at INER (A0505)** Ruey-yi Lee, Yang-Neng Cheng, Chang-Sing Hwang, Maw-Chwain Lee Institute of Nuclear Energy Research; Longtan Township/Taiwan ROC	17:30	**Impact of Surface-related Effects on the Oxygen Exchange Kinetics of IT-SOFC Cathodes (B0505)** Edith Bucher, Werner Sitte, Montanuniversität Leoben, Chair of Physical Chemistry; Leoben/Austria
17:45	**Techno-economical analysis of systems converting CO_2 and H_2O into liquid fuels including high-temperature steam electrolysis (A0506)** Christian von Olshausen sunfire GmbH; Dresden/Germany	17:45	**Anisotropy of the oxygen diffusion in $Ln_2NiO_{4+\delta}$ (Ln = La, Nd, Pr) single crystals (B0506)** Jean-Marc Bassat (1), Mónica Burriel (2), Rémi Castaing (1), (2), O. Wahyudi (1), A. Villesuzanne (1), M. Ceretti (4), W. Paulus (4), M. Zaghrioui (3), P. Veber (1), J. Grenier (1), J.A. Kilner (2), (1) Université de Bordeaux, CNRS, ICMCB; Pessac Cedex/France, (2) Imperial College London, Department of Materials; London/UK, (3) LEMA, UMR 6157-CNRS-CEA; Blois Cedex/France, (4) Université de Rennes; Rennes/France
18:00	End of Sessions		
18:30	Swiss Surprise — Registered Participants meet at the Lakeside of KKL around the large Fountain		

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程(續)

Thursday, June 28, 2012

Morning — Luzerner Saal (ground floor) — Morning

09:00	**Plenary 3 - Advanced Characterisation and Diagnosis** *Chair: John Kilner*	**A06**
09:00	**Studies of Solid Oxide Fuel Cell Electrode Evolution Using 3D Tomography** Scott A Barnett, J Scott Cronin, Kyle Yakal-Kremski Northwestern University, Department of Materials Science; Evanston/USA-IL	A0601
09:30	**Electrochemical Impedance Spectroscopy: A Key Tool for SOFC Development** André Leonide (1), André Weber (2), Ellen Ivers-Tiffée (2) (1) Siemens AG, CT T DE HW4; Erlangen/Germany (2) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe / Germany	A0602
10:00	**In-operando Raman spectroscopy of carbon deposition from Carbon Monoxide and Syngas on SOFC nickel anodes** Gregory J Offer (1), Robert C Maher (2) , Vladislav Duboviks (1), Edward Brightman (1), Lesley F Cohen (2) and Nigel P Brandon (1) (1) Imperial College London, Department of Earth Science Engineering and; London/UK (2) Department of Physics, Imperial College London, London/UK	A0603
10:30	**Intermittence** with Refreshments served on Ground Floor in the Exhibition	

Scientific Advisory Committee

- Dr. Florence Lefebvre-Joud, CEA, Grenoble, France (Chair)
- Dr. John Boegild Hansen, Haldor Topsoe, Denmark
- Dr. Annabelle Brisse, EIfER, Karlsruhe,Germany
- Dr. Agata Godula-Jopek, EADS Innovation Works, Munich, Germany
- Prof. Jean Claude Grenier, ICMCB, Bordeaux, France
- Dr. Anke Hagen Risoe Nat. Lab. / DTU, Roskilde, Denmark
- Prof. John T.S. Irvine, University of St. Andrews, UK
- Prof. Ellen Ivers-Tiffée, Karlsruhe Institute of Technology, Germany
- Prof. John A. Kilner, Imperial College London, London, UK
- Dr. Matti Noponen, Wartsila, Finlande
- Dr. Nathalie Petigny, Saint Gobain, Cavaillon, France,
- Dr. Lide Rodriguez, Ikerlan, Mondragon, Spain
- Dr. Massimo Santarelli, PoliTo,Torino, Italy
- Dr. Robert Steinberger-Wilckens, FZ Jülich, Jülich, Germany
- Dr. Jan Van herle, EPFL, Lausanne, Switzerland

The Scientific Advisory Committee has been formed to structure the technical program of the 10th EUROPEAN SOFC FORUM 2012. This panel has exercised full scientific independence in all technical matters.

Thursday, June 28, 2012

Morning — Morning

7A Luzerner Saal

11:00	**Cell and stack design I (A07)**
11:00	**Co-sintering of Solid Oxide Fuel Cells made by Aqueous Tape Casting (A0701)** Johanna Stiernstedt (1), (2), Elis Carlström (1), Bengt-Erik Mellander (2) (1) Swerea IVF AB; Möndal/Sweden (2) Chalmers University of Technology, Department of Applied Physics; Göteborg/Sweden
11:15	**Powder Injection Molding of Structured Anode-supported Solid Oxide Fuel Cell (A0702)** Antonin Faes (1), Amédée Zryd (1), Hervé Girard (1), E. Carreno-Morelli (1), Jan Van Herle (2), Zacharie Wuillemin (3) (1) University of Applied Science Western Switzerland, Design and Materials Unit; Sion/Switzerland (2) EPFL, Laboratory of Industrial Energy Systems (LENI); Lausanne/Switzerland (3) HTceramix – SOFCpower; Yverdon-les-Bains/Switzerland
11:30	**Inkjet Printing of Segmented-in-Series Solid-Oxide Fuel Cell Architectures (A0703)** Wade Rosensteel (1), Nicolaus Faino (1), Brian Gorman (2), Neal P. Sullivan (1) (1) Colorado School of Mines, Colorado Fuel Cell Center; Golden/USA-CO (2) Colorado Fuel Cell Center, Colorado School of Mines, Metallurgical and Materials Engineering Department; Golden/USA-CO
11:45	**Miniaturized free-standing SOFC membranes on silicon chips (A0704)** M. Prestat (1), A. Evans (1), R. Tölke (1), M. V.F. Schlupp (1), B. Scherrer (1), Z. Yáng (1), J. Martynczuk (1), D. Pecho (1), H. Ma (1), S. Laffranchini (1), A. Bieberle-Hütter (1), L.J. Gauckler (1), Y. Safa (2), T. Hocker (2), P. Muralt (3), Y. Yan (3), J. Courbat (4), D. Briand (4), N.F. de Rooij (4) (1) ETH Zurich, Nonmetallic Inorganic Materials; Zurich/Switzerland (2) Zurich University of Applied Sciences (ZHAW), Institute for Computational Physics; Winterthur/Switzerland (3) EPFL, Ceramics Laboratory; Neuchâtel/Switzerland, (4) EPFL, Sensors, Actuators and Microsystems Laboratory; Lausanne/Switzerland

7B Auditorium

11:00	**SOE cell material development (B07)**
11:00	**Step-change in $(La,Sr)(M,Ti)O_3$ solid oxide electrolysis cell cathode performance with exsolution of B-site cations (B0701)** George Tsekouras, Dragos Neagu, John T.S. Irvine University of St Andrews, School of Chemistry; St Andrews/UK
11:15	**Enhanced Performances of Structured Oxygen Electrode for High Temperature Steam Electrolysis (B0702)** Tiphaine Ogier (1), Jean-Marc Bassat (1), Fabrice Mauvy (1), Sébastien Fourcade (1), Jean-Claude Grenier (1), Karine Couturier (2), Marie Petitjean (2), Julie Mougin (2) (1) Université de Bordeaux, CNRS, ICMCB; Pessac Cedex/France (2) CEA-Grenoble, LITEN/DTBH/LTH; Grenoble Cedex 9/France
11:30	**Electrochemical Characterisation of High Temperature Solid Oxide Electrolysis Cell Based on Scandia Stabilized Zirconia with Enhanced Electrode Performance (B0703)** Nikolai Trofimenko, Mihails Kusnezoff, Alexander Michaelis Fraunhofer IKTS; Dresden/Germany
11:45	**Durability studies of Solid Oxide Electrolysis Cells (SOEC) (B0704)** Aurore Mansuy, Julie Mougin, Marie Petitjean, Fabrice Mauvy CEA Grenoble LITEN/DTBH/LTH; Grenoble/France

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程(續)

Afternoon **Thursday, June 28, 2012** Afternoon

8A Club Room 3 – 8

13:30 Poster Session II – B04, B05, B07, B09, B11, B12, B13

Afternoon **Thursday, June 28, 2012** Afternoon

9A Luzerner Saal

14:30 Cell and stack design II (Metal Supported Cells) (A09)

14:30 **Micro-SOFC supported by a thick Ni film (A0901)**
Younki Lee, Gyeong Man Choi, Pohang University of Science and Technology (POSTECH), Fuel Cell Research Center and Department of Materials Science and Engineering; Pohang/South Korea

14:45 **Thin Electrolytes on Metal-Supported Cells (A0902)**
S. Vieweger (1), R. Mücke (1), N. H. Menzler (1), M. Rüttinger (2), Th. Franco (2), H. P. Buchkremer (1)
(1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany
(2) PLANSEE SE Innovation Services; Reutte/Austria

15:00 **Advances in Metal Supported Cells in the METSOFC EU Consortium (A0903)** Brandon J. McKenna (1), Niels Christiansen (1), Richard Schauperl (2), Peter Prenninger (2), Peter Blennow (3), Trine Klemensø (3), Severine Ramousse (3), (1) Topsoe Fuel Cell A/S; Lyngby/Denmark, (2) AVL List Gmbh; Graz/Austria, (3) Risø DTU; Roskilde/Denmark

15:15 **Stack Tests of Metal-Supported Plasma-Sprayed SOFC (A0904)** Patric Szabo (1), Asif Ansar (1), Thomas Franco (2), Malko Gindrat (3), Thomas Kiefer (4), (1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany, (2) PLANSEE SE Innovation Services; Reutte/Austria, (3) Sulzer Metco AG; Wohlen/Switzerland, (4) ElringKlinger AG; Dettingen, Erms/Germany

15:30 **Tubular metal supported solid oxide fuel cell resistant to high fuel utilization (A0905)**
Lide M. Rodriguez-Martinez, Laida Otaegi, Amaia Arregi, Igor Villarreal, Ikerlan, Centro Tecnológico; Álava/Spain

15:45 **Quality Assurance Aspects for Metal-Supported Cells (A0906)**
M. Haydn (1), Th. Franco (1), R. Mücke (2), M. Rüttinger (1), N. H. Menzler (2), H. P. Buchkremer (2), A. Venskutonis (1), L. S. Sigl (1), (1) PLANSEE SE, Innovation Services; Reutte/Austria, (2) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research; Jülich/Germany

9B Auditorium

14:30 Cell materials development II (IT & Proton Conducting SOFC) (B09)

14:30 **Nanostructured Electrodes for Low-Temperature Solid Oxide Fuel Cells (B0901)**
Zhongliang Zhan, Da Han, Tianzhi Wu, Shaorong Wang, Tinglian Wen, Chinese Academy of Sciences (SICCAS), Shanghai Institute of Ceramics, CAS Key Laboratory of Materials for Energy Conversion; Shanghai/China

14:45 **Protonic Ceramic Fuel Cells based on reactive sintered $BaCe_{0.2}Zr_{0.7}Y_{0.103-\delta}$ electrolytes (B0902)**
Shay Robinson (1), Anthony Manerbino (1), (2), Sean Babinec (1), Neal P Sullivan (1), Jianhua Tong (1), W. Grover Coors (1), (2), (1) Colorado School of Mines, Department of Mechanical Engineering, Colorado Fuel Cell Center; Golden/USA-CO, (2) CoorsTek Inc.; Golden/USA-CO

15:00 **ITSOFC based on innovative electrolyte and electrodes materials (B0903)** Messaoud Benhamira (1), Annelise Brüll (2), Anne Morandi (4), M. Letilly (1), A. Le Gal La Salle (1), J. Bassat (2), J. Salmi (3), R. Laucournet (5), M. Caldes (1), M. Marrony (4), O. Joubert (1), (1) Inst. des Matériaux Jean Rouxel (IMN); Nantes/France, (2) Inst. de Chimie de la Matière Condensée de Bordeaux; PESSAC/France, (3) Marion Technologie (MT); Verniolle/France, (4) European Inst. for Energy Research; Karlsruhe/Germany, (5) CEA-Grenoble/LITEN/DTBH/LTH; Grenoble/France

15:15 **New Cercer Cathodes of Electronic and Protonic Conducting Ceramic Composites for Proton Conducting Solid Oxide Fuel Cells (B0904)** Cecilia Solís, Vicente B. Vert, María Fabuel, Laura Navarrete (1), José M. Serra (1), Francesco Bozza (2), Nikolaos Bonanos (2), Universidad Politécnica de Valencia, Instituto de Tecnología Química; Valencia/Spain, (2) DTU, Risø National Laboratory for Sustainable Energy, Fuel Cells and Solid State Chemistry Department; Roskilde/Denmark

15:30 **Cathode Materials for Low Temperature Protonic Oxide Fuel Cells (B0905)**
M.D. Sharp, J.A. Kilner, Imperial College London, Department of Materials; London/UK

15:45 **Characterisation of PCFC-Electrolytes Deposited by Reactive Magnetron Sputtering (B0906)**
Mohammad Arab Pour Yazdi (1), Pascal Briois (1), Samuel Georges (2), Alain Billard (1), (1) LERMPS-UTBM; Belfort cedex/France, (2) LEPMI, INPG, ENSEEG; Saint Martin d'Hères Cedex/France

16:00 Coffee Break – Ground Floor in the Exhibition and 2nd Floor in the Poster Session

Afternoon **Thursday, June 28, 2012** Afternoon

10A Luzerner Saal

16:30 Cell operation (A10)

16:30 **Ni-agglomeration in Solid Oxide Fuel Cells under different operating conditions (A1001)**
Boris Iwanschitz (1), Lorenz Holzer, Andreas Mai (1), Michael Schütze, (1) Hexis Ltd.; Winterthur/Switzerland

16:45 **Durability and Performance of High Performance Infiltration Cathodes (A1002)** Martin Søgaard, Alfred J. Samson, Nikolaos Bonanos, J. Hjelm, P. Hjalmarsson, S.P.V. Foghmoes, T. Ramos, Technical Univ. of Denmark, Risø National Lab for Sustainable Energy, Fuel Cells and Solid State Chemistry Division; Roskilde /Denmark

17:00 **Chromium Poisoning of $LaMnO_3$-based Cathode within Generalized Approach (A1003)** Harumi Yokokawa (1), Teruhisa Horita (1), Katsuhiko Yamaji (1), H. Kishimoto (1), T. Yamamoto (2), M. Yoshikawa (2), Y. Mugikura (2), T. Kabata (3), K. Tomida (3), (1) National Inst. of Advanced Industrial Science and Technology, Energy Technology Research Inst.; Nagasaki/Japan, (2) Central Research Inst. of Electric Power Industry (CRIEPI); Kanagawa/Japan, (3) Mitsubishi Heavy Industry, Ltd.; Nagasaki/Japan

17:15 **Chromium poisoning of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-\delta}$ in Solid Oxide Fuel Cells (SOFCs) (A1004)**
Soo-Na Lee, Alan Atkinson, John A Kilner, Imperial College London, Department of Materials; London/UK

17:30 **Evaluation of Sulfur Dioxide Poisoning for LSCF Cathodes (A1005)** Fangfang Wang, Katsuhiko Yamaji, Manuel E. Brito, Do-Hyung Cho, Taro Shimonosono, Mina Nishi, Haruo Kishimoto, Teruhisa Horita, Harumi Yokokawa, National Institute of Advanced Industrial Science and Technology (AIST); Ibaraki/Japan

17:45 **Reversibility of Cathode Degradation in Anode Supported Solid Oxide Fuel Cells (A1006)**
Cornelia Endler-Schuck (1), (2), André Leonide (1), André Weber (1), Ellen Ivers-Tiffée (1), (2), Karlsruher Institut für Technologie (KIT), (1) Institut für Werkstoffe der Elektrotechnik (IWE), (2) DFG Center for Functional Nanostructures (CFN); Karlsruhe/Germany

10B Auditorium

16:30 Diagnostic, advanced characterisation and modelling II (B10)

16:30 **Elementary Kinetics and Mass Transport in LSCF-Based Cathodes: Modeling and Experimental Validation (B1001)** Vitaliy Yurkiv (1), (2), Rémi Costa (1), Zeynep Ilhan (1), Asif Ansar (1), Wolfgang G. Bessler (1), (2)
(1) German Aerospace Centre (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany
(2) Universität Stuttgart, Institute of Thermodynamics and Thermal Engineering (ITW); Stuttgart/Germany

16:45 **Three dimensional microstructures and mechanical properties of porous LSCF cathodes (B1002)**
Zhangwei Chen, Xin Wang, Finn Giuliani, Alan Atkinson, Imperial College London, Dep. of Materials; London/UK

17:00 **Modelling of Coupled Transport Phenomena within Detailed Oxide Fuel Cell Electrode Microstructures (B1003)** Duncan A. W. Gawel, Jon G. Pharoah, Queen's University, Department of Mechanical and Materials Engineering; Kingston/Canada

17:15 **Mechanical Characteristics of Electrolytesassessed with Resonant Ultrasound Spectroscopy (B1004)**
Wakako Araki (1), Hidenori Azuma (1), Takahiro Yota (1), Y. Arai (1), J. Malzbender (2), (1) Saitama University, Graduate School of Science and Engineering; Saitama/Japan, (2) Forschungszentrum Jülich GmbH; Jülich/Germany

17:30 **3D FEM Impedance Modelfor LSCF-Cathodes (B1005)** Andreas Häffelin (1), Jochen Joos (1), Jan Hayd (1), (2), A. Weber (1), E. Ivers-Tiffée (1), (2), Karlsruher Institut für Technologie (KIT), (1) Institut für Werkstoffe der Elektrotechnik (IWE), (2) DFG Center for Functional Nanostructures (CFN); Karlsruhe/Germany

17:45 **Detailed electrochemical characterisation of large SOFC stacks (B1006)** R. R. Mosbæk (1), J. Hjelm (2), R. Barfod (2), J. Høgh (1), L. Mikkelsen (1), P. V. Hendriksen (1), (1) Technical University of Denmark, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy; Frederiksborgvej/Denmark, (2) Topsoe Fuel Cell A/S; Lyngby/Denmark

18:00 End of Sessions

19:20 Dinner on the Lake — Boarding 19:20, Lakeside of KKL pier 5/6 – back 23:30 (short stop in Brunnen 22:30 for early return by train)

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程(續)

Morning — Friday, June 29, 2012 — Morning

11A	Luzerner Saal	11B	Auditorium
09:00	**SOE cell and stack operation (A11)**	09:00	**Fuels bio reforming (B11)**
09:00	**High Temperature Co-electrolysis of Steam and CO_2 in an SOC stack: Performance and Durability (A1101)** Ming Chen (1), Jens Valdemar Thorvald Høgh (1), Jens Ulrik Nielsen (2), Janet Jonna Bentzen (1), Sune Dalgaard Ebbesen (1), Peter Vang Hendriksen (1), (1) Technical University of Denmark, Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy; Roskilde/Denmark, (2) Topsoe Fuel Cell A/S, Nymoellevej 66, Lyngby/Denmark	09:00	**Electrochemistry of Reformate-Fuelled Anode-Supported SOFC (B1101)** Alexander Kromp (1), André Leonide (1), André Weber (1), Ellen Ivers-Tiffée (1), (2), (1) Karlsruher Institut für Technologie (KIT), Institut für Werkstoffe der Elektrotechnik (IWE); Karlsruhe/Germany, (2) DFG Center for Functional Nanostructures (CFN), Karlsruher Institut für Technologie (KIT), Karlsruhe/Germany
09:15	**4 kW Test of Solid Oxide Electrolysis Stacks with Advanced Electrode-Supported Cells (A1102)** J.E. O'Brien (1), X. Zhang (1), R. C. O'Brien (1), G. K. Housley (1), L. Moore-McAteer (1), G. Tao (2) (1) Idaho National Laboratory; Idaho Falls/USA-ID, (2) Materials and Systems Research, Inc.; Salt Lake City/USA-UT	09:15	**Catalytic properties of a Ni-based anode under dry reforming of methane (B1102)** Cosimo Guerra (1), Andrea Lanzini (1), Pierluigi Leone (1), Massimo Santarelli (1), Nigel Brandon (2) (1) Department of Energetics, Politecnico di Torino; Torino/Italy, (2) Imperial College London, Department of Earth Science and Engineering; London/UK
09:30	**Enhanced Performance and Durability of a High Temperature Steam Electrolysis stack (A1103)** A. Chatroux, K. Couturier, M. Petitjean, M. Reytier, A. Brevet, J. Mougin, F. Lefebvre-Joud CEA-Grenoble, LITEN; Grenoble/France	09:30	**Minimising the Sulphur Interactions with a SOFC Anode based on Cu-Ca Doped Ceria (B1103)** Araceli Fuerte (1), Rita X. Valenzuela (1), María José Escudero (1), Loreto Daza (2), (1) Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT); Madrid/Spain, (2) ICP-CSIC; Madrid/Spain
09:45	**Electrolysis and Co-electrolysis performance of a SOEC short stack (A1104)** Stefan Diethelm (1), Jan Van Herle (1), Dario Montinaro (2), Olivier Bucheli (3), Ecole Polytechnique Fédérale de Lausanne, STI-IGM-LENI, ME A2 435; Lausanne/Switzerland, (2) SOFCPOWER; Mezzolombardo/Italy, (3) Htceramix; Yverdon-les-bains/Switzerland	09:45	**Gas Transport and Methane Internal-Reforming Chemistry in Ni-YSZ and Metallic Anode Supports (B1104)** Amy E. Richards, Neal P. Sullivan, Colorado School of Mines, Colorado Fuel Cell Center, Mechanical Engineering Department; Golden/USA-CO
10:00	**SOEC enabled Methanol Synthesis (A1105)** John Bøgild Hansen (1), Claus Friis Petersen (1), Ib Dybkjær (1), Jens Ulrik Nielsen (2), Niels Christiansen (2) (1) Haldor Topsøe A/S; Lyngby/Denmark, (2) Topsoe Fuel Cell A/S; Lyngby/Denmark	10:00	**High-efficient biogas electrification by an SOFC-system with combined steam- & dry-reforming (B1105)** Jana Oelze, Ralph-Uwe Dietrich, Andreas Lindermeir, Clausthaler Umwelttechnik-Institut GmbH; Clausthal-Zellerfeld/Germany
10:15	**Direct and Reversible Solid Oxide Fuel Cell Energy Systems (A1106)** Nguyen Q. Minh, Center for Energy Research, University of California, San Diego; La Jolla/USA-CA	10:15	**Adiabatic prereforming of ultra-low sulfur diesel: Potential for marine SOFC-systems and experimental results (B1106)** Pedro Nehter (1), Hassan Modarresi (1), Nils Kleinohl (2), John Bøgild Hansen (3), Ansgar Bauschulte (2), Jörg vom Schloss (2), Klaus Lucka (2), (1) TOPSOE FUEL CELL; Lyngby/Denmark, (2) Oel Waerme-Institut GmbH; Lyngby/Denmark, (3) Halder Topsoe A/S; Lyngby/Denmark
10:30	Coffee Break – Ground Floor in the Exhibition		

Morning — Friday, June 29, 2012 — Morning

12A	Luzerner Saal	12B	Auditorium
11:00	**Cell and stack operation (A12)**	11:00	**Interconnects, coatings & seals (B12)**
11:00	**Chemical Degradation of SOFCs: External impurity poisoning + internal diffusion-related phenomena (A1201)** Kazunari Sasaki (1), (2), (3), Kengo Haga (2), Tomoo Yoshizumi (2), H. Yoshitomi (2), K. Miyoshi (2), S. Taniguchi (1), Y. Shiratori (1), (2), (3), Kyushu Univ., (1) Intern. Research Center for Hydrogen Energy; Fukuoka/Japan, (2) Faculty of Engineering; Fukuoka/Japan, (3) Intern. Inst. for Carbon-Neutral Energy Research; Fukuoka/Japan	11:00	**SOFC Stack with Composite Interconnect (B1201)** Sergey Somov, Heinz Nabielek, Solid Cell, Inc.; Rochester/USA-NY
11:15	**Effect of pressure variation on power density and efficiency of solid oxide fuel cells (A1202)** Moritz Henke, Caroline Willich, Christina Westner, Florian Leucht, Josef Kallo, K. Andreas Friedrich German Aerospace Center (DLR), Institute of Technical Thermodynamics; Stuttgart/Germany	11:15	**Recent Development in Pre-coating of Stainless Strips for Interconnects at Sandvik Materials Technology (B1202)** Håkan Holmberg, Mats W Lundberg, Jörgen Westlinder AB Sandvik Materials Technology, Surface Technology R&D Center; Sandviken/Sweden
11:30	**CFY-Stack Technology: from electrolyte supported cells to high efficiency SOFC-stacks (A1203)** Stefan Megel (1), Mihails Kusnezoff (1), Nikolai Trofimenko (1), V. Sauchuk (1), J. Schilm (1), A. Michaelis (1), C. Bienert (2), M. Brandner (2), A. Venskutonis (2), S. Skrabs (2), L.S. Sigl (2), (1) Fraunhofer Institute of Ceramic Technologies and Systems; Dresden/Germany, (2) PLANSEE SE Innovation Services; Reutte/Austria	11:30	**Corrosion behaviour of steel interconnects and coating materials in solid oxide electrolysis cell (SOEC) (B1203)** Ji Woo Kim (1), Cyril Rado (2), Aude Brevet (2), Seul Cham Kim (3), Yong Seok Choi (3), Karine Couturier (2), Florence Lefebvre-Joud (2), Kyu Hwan Oh (3), Ulrich F. Vogt (1), Andreas Züttel (1) (1) Swiss Federal Laboratories for Materials Science and Technology, Hydrogen and Energy; Dübendorf/Switzerland, (2) CEA-Grenoble, LITEN; Grenoble Cedex 9/France, (3) Seoul National University, Dept. of Materials Science and Engineering; Seoul/South Korea
11:45	**Development of Robust and Durable SOFC Stacks (A1204)** Rasmus G. Barfod, Kresten Juel Jensen, Thomas Heiredal-Clausen, Topsoe Fuel Cell; Lyngby/Denmark	11:45	**Multifunctional nanocoatings on FeCr steels – influence on chromium volatilization and scale growth (B1204)** J. Froitzheim, S. Canovic, R. Sachitanand, M. Nikumaa, J.E. Svensson The High Temperature Corrosion Centre, Chalmers University of Technology; Göteborg/Sweden
12:00	**Long-term Testing of SOFC Stacks at Forschungszentrum Jülich (A1205)** Ludger Blum, Ute Packbier, Izaak Vinke, L. G.J. (Bert) de Haart, Forschungszentr. Jülich GmbH, Inst. of Energy + Climate Research (IEK); Jülich/Germany	12:00	**Characterization of a Cobalt-Tungsten Interconnect Coating (B1205)** Anders Harthoej, The Technical University of Denmark; Lyngby/Denmark
12:15	**Study on Durability of Flattened Tubular Segmented-in-Series Type SOFC Stacks (A1206)** Kazuo Nakamura (1), Takaaki Somekawa (1), Kenjiro Fujita (1), K. Horiuchi (1), Y. Matsuzaki (1), S. Yamashita (1), H. Yokokawa (2), T. Horita (2), K. Yamaji (2), H. Kishimoto (2), M. Yoshikawa (3), T. Yamamoto (3), Y. Mugikura (3), N. Kasagi (4), N. Shikazono (4), K. Eguchi (5), T. Matsui (5), S. Watanabe (6), K. Sato (6), T. Hashida (6), T. Kawada (6), K. Sasaki (7), Y. Shiratori (7), (1) Tokyo Gas Co., Ltd., (2) Nat. Inst. of Advanced Industrial Science + Technology, (3) Central Research Inst. of Electric Power Industry, (4) The Univ. of Tokyo; Tokyo/Japan, (5) Univ. Kyoto/Japan, (6) Univ. Tohoku/Japan, (7) Univ. Kyushu/Japan	12:15	**Barium-free sealing materials for high chromium containing alloys (B1206)** Dieter Gödeke, Jens Suffner, SCHOTT Electronic Packaging GmbH, Product Division Glass; Landshut/Germany
12:30	Lunch – 2nd Floor on the Terrace Coffee – Ground Floor in the Exhibition		

表二、 第十屆歐盟 SOFC 論壇口頭簡報議程(續)

Afternoon — **Friday, June 29, 2012** — Afternoon

13A	Luzerner Saal
13:30	**Stack integration, system operation and modelling (A13)**
13:30	**Coupling and thermal integration of a solid oxide fuel cell to a magnesium hydride tank (A1301)** Baptiste Delhomme (1), (3), Andrea Lanzini (2), Gustavo Adolfo Ortigoza-Villalba (2), Paolo Squillari (2), Patricia De Rango (3), Simeon Nachev (3), Philippe Marty (1), Massimo Santarelli (2), (1) UJF-Grenoble 1 – Grenoble-INP – CNRS; Grenoble/France, (2) Politecnico di Torino, Dipartimento di Energetica; Torino/Italy, (3) Institut Néel – CRETA; Grenoble cedex/France
13:45	**Effects of Multiple Stacks with Varying Performances in SOFC System (A1302)** Matti Noponen, Topi Korhonen, Wärtsilä, Fuel Cells; Espoo/Finland
14:00	**CFCL SOFC system tested at GDF SUEZ CRIGEN – thermal cycles, Electric Vehicle charging, and ageing (A1303)** Stéphane Hody, Krzysztof Kanawka, GDF SUEZ, Research & Innovation Division, CRIGEN; Saint-Denis la Plaine cedex/France
14:15	**Modeling of the Dynamic Behavior of a Solid Oxide Fuel Cell System with Diesel Reformer (A1304)** Michael Dragon, Stephan Kabelac, Leibniz Universität Hannover, Institute for Thermodynamics; Hannover/Germany
14:30	**System Concept and Process Layout for a Micro-CHP Unit based on Low Temperature SOFC (A1305)** Thomas Pfeifer, Laura Nousch, Wieland Beckert, Fraunhofer Institute for Ceramic Technologies and Systems IKTS; Dresden/Germany
14:45	**Large SOFC Systems: Challenges and Implications of Using Multiple Stacks (A1306)** Tero Hottinen, Wärtsilä Finland Oy, Fuel Cells; Espoo/Finland

13B	Auditorium
13:30	**Seals (B13)**
13:30	**Synthesis and characterization of glass ceramic seals for solid oxide fuel cells (B1301)** Maviael Jose Silva (1), Sonia R. H. de Mello Castanho (1), Signo Tadeu Reis (2). (1) Instituto de Pesquisas Energéticas e Nucleares-IPEN/USP; São Paulo/Brazil, (2) Saint-Gobain Innovative Materials; Northborough/USA-MA
13:45	**Development of glass-ceramic sealants by a sol-gel route for an SOFC application (B1302)** J. Puig (1), F. Ansart (1), P. Lenormand (1), J. Dailly (2), L. Antoine (3), R. Conradt (4), A. Pranger (4), S.Gross (5), Betriz Cela (5), (1) CIRIMAT; Toulouse cedex 9/France, (2) EDF/EIFER; Karlsruhe/Germany, (3) ADEME; Angers Cedex 01/France, (4) GHI, RWTH Aachen; Aachen/Germany, (5) FZJ; Jülich/Germany
14:00	**Strength Evaluation of Multilayer Glass-Ceramic Sealants (B1303)** Beatriz Cela (1), Sonja M. Gross (1), Dirk Federmann (1), Reinhard Conradt (2), (1) Forschungszentrum Jülich GmbH, Central Technology Division; Jülich/Germany, (2) RWTH-University Aachen, Department of Glass and Ceramic Composites, Institute of Mineral Engineering; Aachen/Germany
14:15	**Self-healing sealants as a solution for improved thermal cyclability of SOFC (B1304)** Sandra Castanie (1), Daniel Coillot (1), François O Mear (1), Lionel Montage (1), Renaud Podor (2) (1) Université Lille Nord de France, Unité de Catalyse et Chimie du Solide; Villeneuve d'Ascq/France (2) CEA-CNRS-UM2-ENSCM, Institut de Chimie Séparative de Marcoule; Bagnols-sur-Cèze cedex/France
14:30	**Long term stability of glasses in SOFC (B1305)** Lars Christiansen, Jonathan Love, Thomas Ludwig, Nicolas Maier, David Selvey, Xiao Zheng, Ceramic Fuel Cells Limited; Victoria/Australia
14:45	**Impact of thermal cycling in dual-atmosphere conditions on the microstructural stability of reactive air brazed metal/ceramic joints (B1306)** Jörg Brandenberg (1), Bernd Kuhn (1), Tilmann Beck (1), L. Singheiser (1), Moritz Pausch (2), Uwe Maier (2), Stefan Hornauer (2), (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany, (2) ElringKlinger AG; Dettingen; Erms/Germany

15:00	Coffee Break – Ground Floor around Registration Desk, 1st Floor in front of Auditorium

Afternoon — **Friday, June 29, 2012** — Afternoon

14A	Luzerner Saal
15:30	**Plenary 4 – SOFC for Distributed Power Generation (A14)**
15:30	**Potential and impact of distributed power generation for Europe (A1401)** Jonathan Lewis; London/UK

Afternoon — **Friday, June 29, 2012** — Afternoon

15A	Luzerner Saal
16:00	**Plenary 5 – Closing Ceremony (A15)**
16:00	**Summary by the Chairwoman (A1501)** Florence Lefebvre-Joud, CEA/DEHT/Liten; Grenoble/France
16:12	**Information on Next EFCF: 4th European PEFC (including all low temperature fuel cells) and H2 Forum 2013 (A1502)** Michael Spirig (1), to be announced, Olivier Bucheli (1), (1) European Fuel Cell Forum; Luzern/Switzerland
16:24	**Hermann Göhr Award for the Best Paper (A1503)** Norbert Wagner, German Aerospace Centre (DLR) and Zahner-Elektrik GmbH & Co. KG; Kronach/Germany
16:36	**Friedrich Schönbein Award for the Best Poster, Best Science Contribution, Medal of Honour (A1504)** Florence Lefebvre-Joud (1), Ulf Bossel (2), (1) CEA/DEHT/Liten; Grenoble/France, (2) European Fuel Cell Forum
16:48	**Thank you and Closing by the Organizers (A1505)** Olivier Bucheli, Michael Spirig, European Fuel Cell Forum; Luzern/Switzerland
17:00	End of Sessions – End of Conference

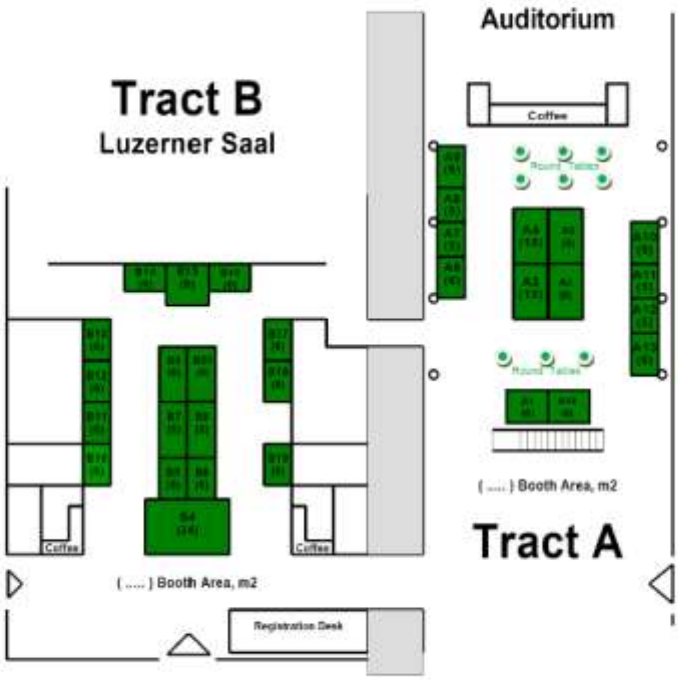
表三、參展廠商資料

List of Exhibitors

Registered by 13th of June 2012

10th EUROPEAN SOFC FORUM 2012

26 - 29 June 2012 KKL Lucerne / Switzerland



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表三、參展廠商資料(續)

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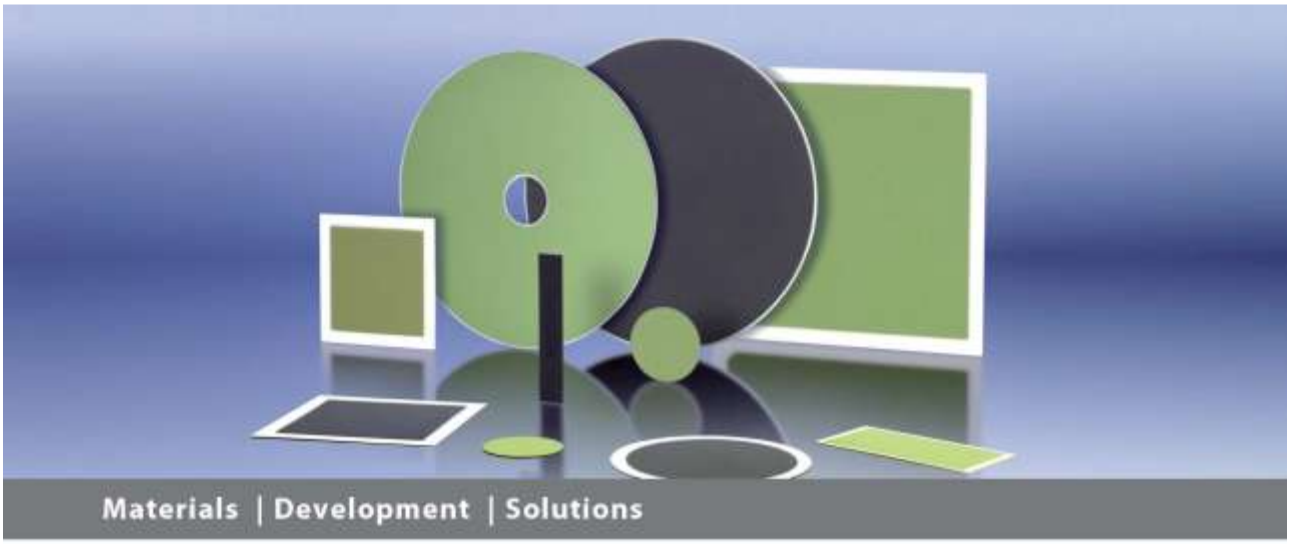
List of Booths

10th EUROPEAN SOFC FORUM 2012

26 - 29 June 2012 KKL Lucerne / Switzerland

Both	Exhibitor	Country	Contact
A02	H.C.Starck Ceramics GmbH	Germany	Ms Sandra Blechschmidt
A04	CEA LITEN	France	Mr Nicolas Bardi
A06	KNF Flodos AG	Switzerland	Mr Jean Delteil
A07	FLEXITALLIC	United Kingdom	Mr John Hoyes
A08	Fiaxell Sàrl	Switzerland	Mr Raphael Ihringer
A09	Treibacher Industrie AG	Austria	Ms Gudrun Leitgeb
A10	Deutsches Zentrum für Luft- und Raumfahrt DLR e.V.	Germany	Ms Sabine Winterfeld
A11	INRAG AG	Switzerland	Mr Uwe Scherner
A12	fuelcellmaterials.com	USA	Ms Michelle Trolio
A13	HAYNES International Nickel-Contor AG	Switzerland	Mr Felix Handermann
B04	Forschungszentrum Juelich GmbH	Germany	Dr. Manfred Wilms
B05	eZelleron GmbH	Germany	Ms Jenny Richter
B06	Bronkhorst (Schweiz) AG	Switzerland	Ms Chantal Gschwind
B07	EBZ GmbH	Germany	Ms Eva Spickenheuer
B08	CerPoTech AS	Norway	Ms Ruth Astrid Strøm
B09	ESL Europe	United Kingdom	Mr Ernst Eisermann
B09	HTceramix SA	Switzerland	Mr Olivier Bucheli
B09	SOFCpower SpA	Italy	Mr Olivier Bucheli
B10	KERAFOL GmbH	Germany	Ms Rilana Weissel
B11	Staxera	Germany	Mr Björn Erik Mai
B12	Fraunhofer IKTS	Germany	Ms Katrin Schwarz
B13	Plansee SE	Austria	Ms Brigitte Plangger
B14	FuelCon AG	Germany	Ms Andrea Bartels
B15	HERAEUS PRECIOUS METALS GmbH & Co. KG	Germany	Ms Anette Kolb
B17	Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, Division of Fuel Cell and Energy Technology	P.R. China	Ms Yi Zhang
B18	AVL List GmbH	Austria	Mr Jürgen Rechberger
B19	Hexis AG	Switzerland	Mr Volker Nerlich
B20	Elcogen AS	Estland	Mr André Koit

表四、3 種 ESC 電池片效能表現



Solid Oxide Fuel Cell Products

ESC 10

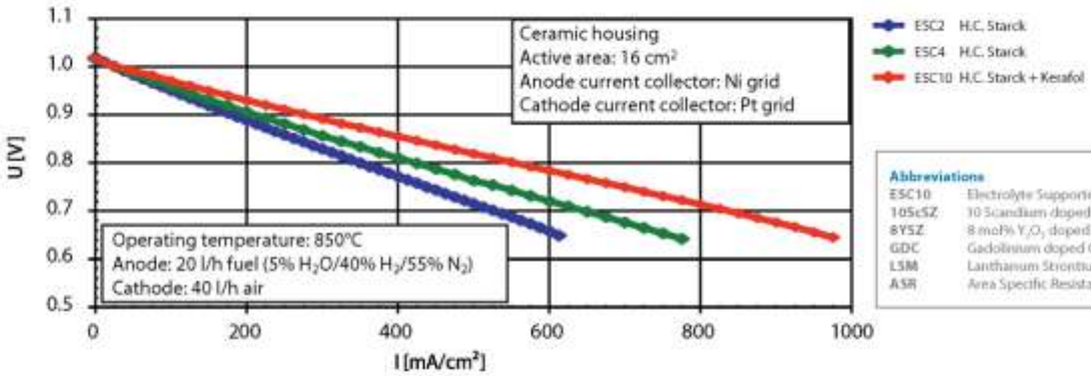
Electrolyte Supported Cell, type 10

Anode	Porous	NiO/GDC	30 – 50 µm
Electrolyte	Dense	10ScSZ	150 – 300 µm
Cathode	Porous	8YSZ/LSM-LSM double layer	30 – 50 µm

Features

> Superior Power Density
> Superior Resistance against Oxidation Reduction Cycles
> Stability under Sulphur Contaminated Gas
> Suitable for CrFe,-Interconnectors
> Operating Temperature above 800°C

Typical electrochemical performance



Abbreviations

ESC10	Electrolyte Supported Cell Type 10
10ScSZ	10 Scandium doped ZrO_2
8YSZ	8 mol% Y_2O_3 doped ZrO_2
GDC	Gadolinium doped Ceria
LSM	Lanthanum Strontium Manganese Oxide
ASR	Area Specific Resistance

H.C. Starck Ceramics GmbH & Co. KG and Kerafol GmbH jointly developed the new ESC10.

KERAFOL Keramische Folien GmbH

H.C.Starck Empowering High Tech Materials

附件

A0505/DeSoIn

Development of SOFC Technology at INER

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Abstract

The Institute of Nuclear Energy Research has committed to developing the SOFC technology since 2003. Through elaborate works for years, substantial progresses have been made on cell, stack, BOP components as well as system integration. Fabrication processes for planar anode-supported-cell (ASC) by conventional methods and metal-supported-cell (MSC) by atmospheric plasma spraying are well established. ASC cells with various compositions of electrodes and electrolytes are investigated for different applications. At this stage, the maximum power densities of INER's ASCs are 652 mW/cm^2 at 800 °C for IT-SOFC (600~800 °C) and 608 mW/cm^2 at 650 °C for LT-SOFC (400~650 °C). The power densities of INER's MSCs are 540 mW/cm^2 and 473 mW/cm^2 at 0.7 V and 700 °C for a cell and a stack tests, respectively. Durability test for MSCs at constant current densities of 300 mA/cm^2 and 400 mA/cm^2 indicates the degradation rate is less than 1%/khr. Procedures and techniques for stacking and cell/stack performance tests are continuously improved to enhance the quality and reliability. Comparable or higher power performance is now achieved with respect to the specs of commercial cells at similar operating conditions. Consistent performance within a variation of 2% is obtained for 3 modules of 18-cell stacks at a nominal power output of 500 W. Meanwhile, INER's MSC 18-cell stack has brought a power output higher than 500 W as well.
Innovative nano-structured catalysts, in which reduced Pt and CeO_2 particles dispersed onto the Al_2O_3 carriers can effectively prevent the migration and coalescence of the metal crystallites, are thermal stable and possess a conversion ratio higher than 95% for reforming of natural gas. A non-premixed after-burner/reformer is designed and fabricated, and it has passed the prerequisite functional tests. Layouts including stacks, components of BOP, power conditioning and control as well as gases and water supply, are designated for a 1-kW SOFC power system. In compliance with system requirements, operating modes, data acquisition, power conditioning, instrumentations, and control logics have been identified and settled. A series of system validation tests are carried out to check functions and interfaces of components and to resolve potential problems for a power system. After successive system validation tests, two modules of 18-cell stacks are allocated into the SOFC system. Test results indicate a thermal self-sustaining system on natural gas is achieved with a power output of around 760 watts.

Introduction

The lack of indigenous energy resources and high dependence on energy imports (~99%) indicate Taiwan's energy security is crucial. As a member of this global village, Taiwan has committed itself to fulfilling the obligation of common but differential responsibility with regard to the reduction of greenhouse gas (GHG) emissions. As a result of the nuclear accidents at Fukushima in Japan, a newly announced nuclear energy policy promises eventually to make the island 'nuclear free' and no life extensions will be granted to existing nuclear power plants in Taiwan. Countermeasures against electricity shortages and revised national energy policy, while keeping benign or moderate growth of economy and continuing reduction of carbon dioxide emissions to meet international goals, are being comprehensively pursued. Nowadays, the Solid Oxide Fuel Cell (SOFC) technology, with the main features of high fuel flexibility, modular design, less pollutant emissions and high energy conversion efficiency, is considered as a promising clean technology beneficial to resolve the dilemma of economic growth, energy security and environmental protection [1].

In compliance with the national energy policy, the SOFC project at the Institute of Nuclear Energy Research (INER) focuses on establishing manufacture capability of SOFC components and integration technology of SOFC power system. Since the commitment to developing the SOFC technology in 2003, this institute has set its short-term target of 1~5 kW SOFC distributed power generation systems and will then extend its long-term prospect to integration with the Integrated Gasification Combined Cycle (IGCC) technology for biomass and coal based central power generation and large demonstration systems. To accelerate the progress on SOFC development, three main sub-projects are formed, i.e., MEA development, stack development and power system development. Each sub-project has its own main tasks to identify the key technical issues and then to find out proper resolutions. Meanwhile, it should intensively incorporate with other sub-projects to clarify interfaces and avoid erroneous discrepancy among different groups.

After years of elaborate efforts, INER has now possessed the critical core technologies from powder to power for a distributed kilowatt SOFC power system. On the basis of current progress, a national SOFC technology roadmap from now to 2030 is proposed, where the operating temperatures, power densities, efficiencies, degradation rates, cost and power levels are discreetly projected. In what follows, the progressive achievements in the past few years on the SOFC research and development work at INER are briefly described.

1. MEA Development

The planar type SOFCs with Anode Supported Cell (ASC) and Metal Supported Cell (MSC), attributed to the merits of potentially higher power density and lower fabrication cost, are selected. For the ASC cells, key materials for anode, electrolyte, and cathode are NiO+8YSZ/NiO+SDC/NiO+GDC, 8YSZ/GDC/SDC/LSGM/BYCZ, and LSM/LSCF/BSCF/SSC/BSSC, respectively. Both anode and electrolyte substrates (dimensions: 10X10 cm^2, thickness: 150~800μm) are fabricated either via tape casting or innovative processes. The screen printer, plasma spray, sputtering and spin coating techniques are alternatively applied to fabricate SOFC-MEA for product orientation. The nano-scale powders of YSZ/LSGM/SDC/GDC/pyrochlore are prepared and processed as well as used for fabrication of SOFC-MEA with thin (<10μm) and dense films of electrolytes to obtain high power densities. The maximum power density (MPD) of INER-SOFC-MEA is over 600 mW/cm^2 (OCV>1.0 V for temperature range of 600-800 °C) and only slight degradation after a durability test for over 7000 hours. The quality is proven to be reliable and advanced [2-14]. Key parameters for three types of INER's ASC cells are summarized in Table 1 and Table 2. The LT-SOFC, IT-SOFC, and HT-SOFC are alternatively selected for diverse purposes in the INER's SOFC project. Among these three types, it is anticipated that the LT-SOFC would be one of the best candidates applicable in a hydrocarbon-based energy infrastructure [15]. Solid oxide fuel cells (SOFCs) based on the proton conducting $BaZr_{0.1}Ce_{0.7}Y_{0.2}O_{3-\delta}$ (BZCY) electrolyte are also studied and prepared for the development of LT-SOFC [12, 16-18].

Table 1 Main Compositions and thicknesses for three types of INER-SOFC-MEAs.

Temperature(°C)	Composition			thickness (μm)		
	cathode	electrode	anode	cathode	electrode	anode
700-1000 (HT)	YSZ+LSM/LSM, GDC-LSM/LSM, SDC/SSC-SDC	YSZ	NiO+YSZ	25	7	800
600-800 (IT)	SDC/SDC-SBSC	YSZ	NiO+YSZ	39	7.5	650
400-650 (LT)	SSC-SDC/SSC	SDC	NiO+SDC	45	15	900

Table 2 Power performance for three types of INER-SOFC-MEAs.

Temperature(°C)	OCV (V)	MPD (mW/cm²)	Degradation(%/khr)
700-1000 (HT)	1.074	400 (800°C)	2.3 (7000hr)
600-800 (IT)	1.099	652 (800°C)	1.0 (1400hr)
400-650 (LT)	0.882	607.68 (650°C)	3.0 (950hr)

The Atmospheric Plasma Spray (APS) system, its schematic diagram shown as Figure 1, has been successfully established at INER. The dc plasma torch is operated at medium currents from 320 to 550 amperes and voltages from 88 to 105 volts. Details of experimental apparatus and typical plasma spraying parameters are given in the previously published paper [19]. Commercial agglomerated powders of lanthanum chromite LSCM ($La_{0.8}Sr_{0.2}Cr_{0.5}Mn_{0.5}O_3$), LDC ($Ce_{0.55}La_{0.45}O_2$)/ NiO/C, LDC, LSGM ($La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$), LSGMC ($La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.15}Co_{0.05}O_3$), SDC ($Sm_{0.2}Ce_{0.8}O_2$), SDC/SSC ($Sm_{0.5}Sr_{0.5}CoO_3$) and SSC/C are employed as raw powders in the APS processes. Layers of lanthanum chromite LSCM, LDC/NiO, LDC, LSGM, LSGMC, SDC, SDC/SSC and SSC are subsequently plasma sprayed onto a well-prepared porous nickel-iron substrate to make a multilayered cell. The area of SSC current collector layer is 81 cm^2 and the substrate with permeability about 2 Darcy is typically 1.2 mm in thickness. After plasma coating, a post heat-treatment with a pressure of 0.8 kg/cm^2 at 850 °C for 4 hours is imposed on the cells to improve interface adhesion and minimize surface curvatures of cells [20].

To evaluate the power performance of MSC cells, a series of cell and single-cell stack tests are carried out. The open circuit voltages higher than 1.0 volt at elevated temperatures indicate that the multi-layer electrolyte is dense enough with minor permeation through the electrolyte. Figure 2a and Figure 2b show the results of an open cell and a single-cell stack tests at specific temperatures, where the gas flow rates of fuel (hydrogen) and oxidizer (air) are 800 ml/min and 2000 ml/min, respectively. The maximum power densities in cell tests reach to 650, 568 and 443 mW/cm^2 at 750 °C, 700 °C and 650 °C, respectively. While the maximum power densities of a single-cell stack test slightly decrease to 573 and 473 mW/cm^2 at 750 and 700 °C, respectively. The durability test of a single-cell stack at 700 °C and a constant current density of 400 mA/cm^2 indicates its degradation rate is lower than 1 %/khr. Comparisons with literature data [21, 22] show that the APS processes developed at INER, for instance: fabrication the Ni/Fe-LSCM-LDC/Ni-LDC-LSGM-LSGMC-SDC-SDC/SSC-SSC metal-supported cells, are successful with inspiring performance.

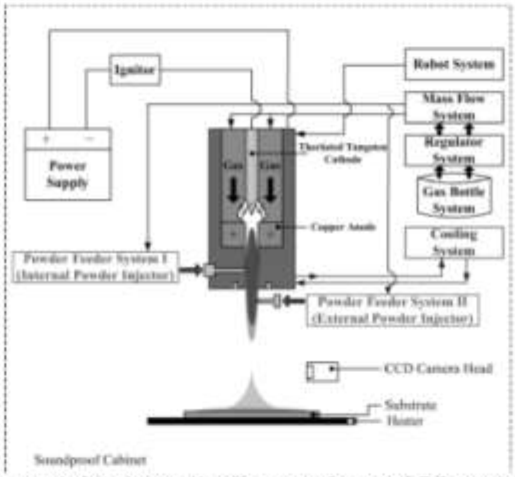

Figure 1 A schematic diagram for an APS system.

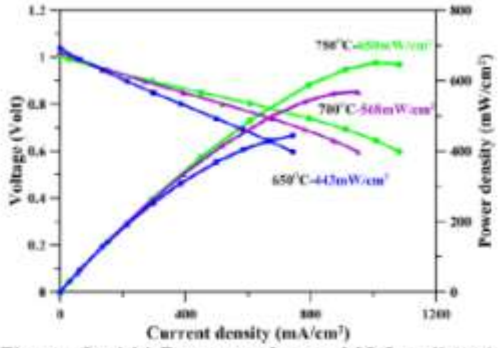

Figure 2a I-V-P curves for an MSC cell test.

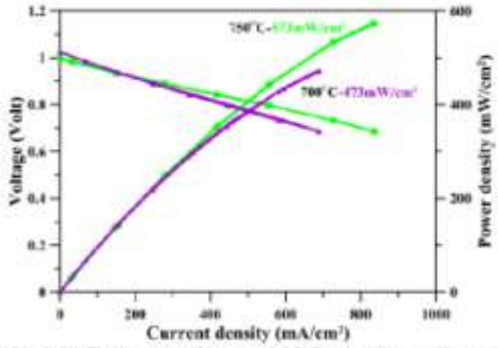

Figure 2b I-V-P curves for an MSC single-cell stack test.

2. Stack Development

The software and hardware as well as test stations associated with the SOFC cells and stacks have been stepwise established. These include: development and testing of sealants of different receipts, assessment of material properties of SOFC components at elevated temperatures, development of protective coating techniques on the metallic interconnects, design, steady/dynamic modeling and simulations for the SOFC stack, electrochemical characterization of SOFC cell and stack, establishment of test facilities, and improvement on stack design. In particular, standard operation procedures are established and revised on a regular basis to assure the safety and quality for the R&D works.

To evaluate the performance of planar SOFC cells, different configurations of test rigs are manufactured. Sophisticated fixtures for sealed and non-sealed compartments are designated and accordingly fabricated for different cell shapes and sizes. Current versus voltage measurement and long-term durability tests are carried out with DC electronic load units either in constant-current (CC) or in constant-voltage (CV) mode. The electrochemical characteristics of cells are evaluated by a Solartron AC impedance analyzer. MEAs from domestic or commercial markets are employed to evaluate their performance and meanwhile to improve the cell/stack performance testing capability. Figure 3 illustrates the annual progress for INER's cell performance testing in the past few years, where same types of cells and test conditions are imposed for consistent comparisons. By minimizing the gas leakage and improving the contact resistance, a remarkable progress is made in 2011.

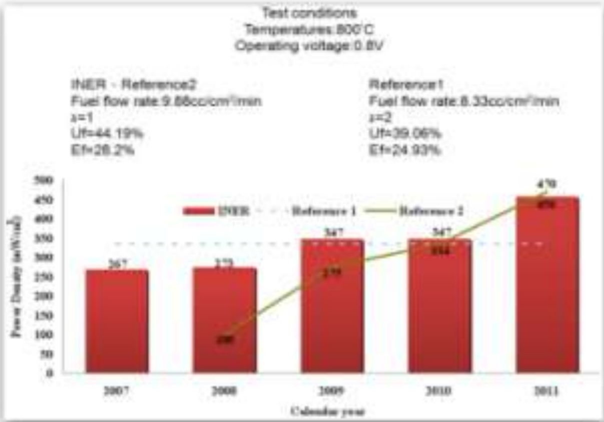

Figure 3 Annual progress of power performance for cells

Planar configuration of SOFC stack with anode-supported cells is employed in the project. Of which, the main features are: internal manifold with counter flow for fuel/oxidant gases, in parallel inlet/outlet gas channels, maximum operating temperatures below 800 °C, and employment of metallic interconnects. The glass ceramic GC-9, with good adherence, high wettability, high corrosion resistance, good chemical stability and compatible thermal expansion coefficients with adjacent components, is developed as sealant materials [22, 23]. A series of short stack tests with cells from different sources are performed. Figure 4 shows the performance of an INER's MSC single-cell stack in a durability test. It indicates the degradation rate is below 1%/khr under test conditions of a constant current of 400mA/cm^2 and at a nominally operating temperature of 700 °C. The 5-cell stack, where commercial cells are used, indicates the degradation rate is about 1.2%/khr and its fuel utilization 60.4%, as shown in Figure 5.

Figure 6 illustrates power performance of three modules of 18-cell stacks, where same type of commercial ASC cells inside, is consistent within a variation of 2%. The power output of an 18-cell stack with INER's MSC cells inside is comparable or higher than the previous ones under similar test conditions, as shown in Figure 7. A remarkable progress on stack power performance, as shown in Figure 8, is also made at the end of 2011.

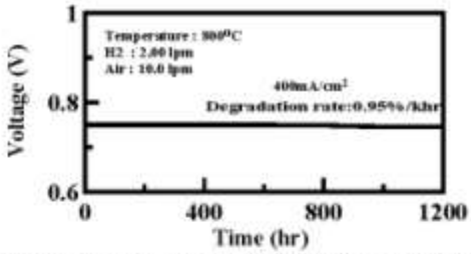

Figure 4 Durability test for an INER-MSC single-cell stack

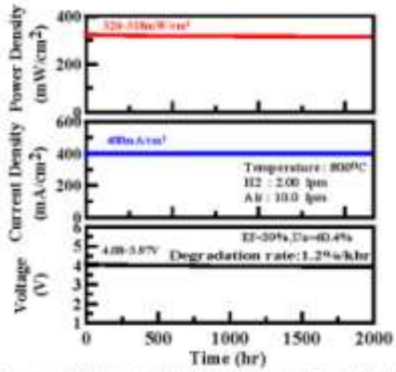

Figure 5 Durability test for a 5-cell stack

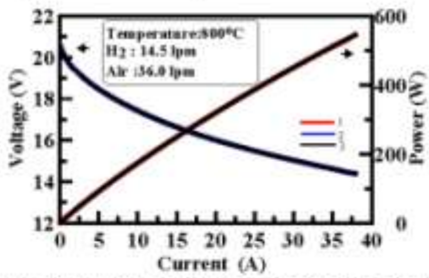

Figure 6 Comparisons of power performance for 3 modules of 18-cell stacks

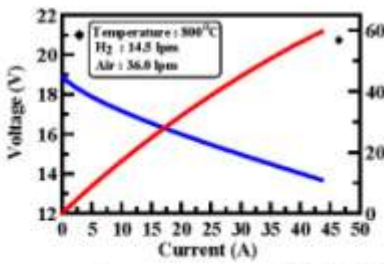

Figure 7 Power performance for an INER-MSC 18-cell stack

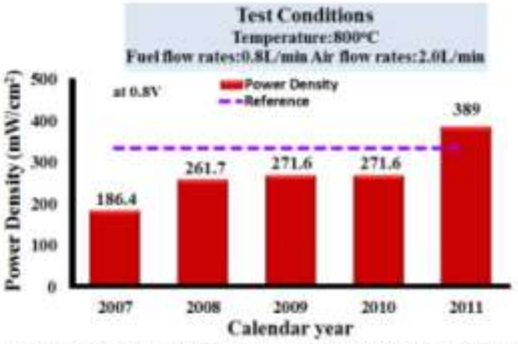

Figure 8 Annual progress of power performance for stacks

3. Power System Development

At the first stage of INER's SOFC project, a residential SOFC system with one kilowatt grade power output is first pursued. Major system components includes: stack, reformer, afterburner, heat exchanger, fuel/oxidant gas supply system, power conditioning system, data acquisition system, instrumentation and control logics, water treatment system, piping and other balance of plant (BOP) units. Two sets of 18-cell stacks, as mentioned in the previous paragraph, are installed onto the system upon the eligibility of system performance is proven after successive system validation tests. A non-premixed after-burner/reformer is designed and fabricated. An experimental study of a SOFC burner/reformer is addressed in the Fuel Bio Reforming section in this forum (B1122). Innovative nano-structured catalysts, as shown in Figure 9, where reduced Pt and CeO_2 particles dispersed onto the Al_2O_3 carriers can effectively prevent the migration and coalescence of the metal crystallites, are thermal stable and possess a conversion ratio higher than 95% for reforming of natural gas [24].

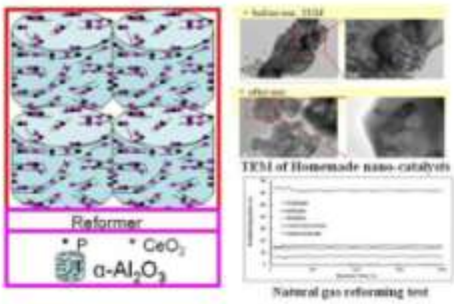

Figure 9 Nano-catalysts and the result of TEM and reforming test

System configurations, thermal managements, and efficiencies for the power system associated with BOPs are preliminarily analyzed by the General Computational Toolkit (GCTool) package, version 2.4, developed by the U.S. Argonne National Laboratory (ANL) [25, 26]. Operation modes include start-up, normal/abnormal operation, normal/emergency shutdown, and other related conditions. For the concern of safety and long-term operation, the methodology of Features, Events and Processes (FEP) is employed to check relevant consequences of 'what ifs' scenarios and find out proper remedy actions and thereafter be implemented into operation and control logics. The programmable controller is written by using LabVIEW 8.5, where the Real-Time Compact FieldPoint is employed as the core of control system and linked by the local-internet to accomplish system control and data acquisitions.

Separate tests for major components as well as series of system validation tests are carried out to check functions and interfaces of components and to resolve potential problems for a power system. Dummy and shorts stacks are used to demonstrate the eligibility of system performance. After successive system validation tests are confirmed, two sets of 18-cell stacks are installed onto the system to perform power performance evaluation. The OCV reaches to 39.6 V (1.1V/cell) under dilute gas conditions. As the fuel shifted to natural gas, the OCV slightly decreases to 37 V (1.03V/cell). Under the test conditions : temperature 780 °C, flow rates of natural gas, air, and water in the anode side at 3.99 lpm, 3.3 lpm, and 5.49cc/min, respectively, and cathode air 38 lpm, the power output reaches to 760 watts (current 28A and stack voltage 27.2 V). The fuel utilization and electric efficiency are 58.8% and 35.1% (LHV), respectively.

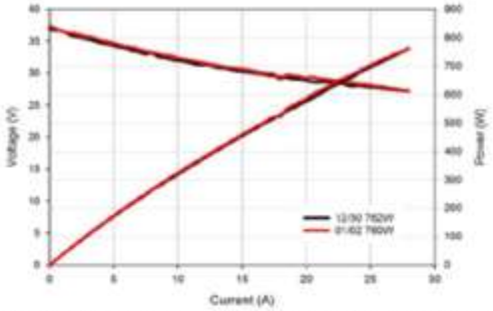

Figure 10 Power performance for a SOFC power system

4. Conclusion

After years of elaborate efforts, substantial progresses are made at INER in MEA, Stack and Power System developments. Innovative inventions of the Intellectual property/patents have been granted from Taiwan, Japan, the USA and European Union. Establishments of strong capability and firmed facilities both hardware and software will facilitate the industrial development on SOFC technology. Nevertheless, continuous improvements are required to make the SOFC become commercially viable with high reliability, longevity, and low cost. Conclusion remarks are outlined as follows:

(1) The application of SOFC technology to increase the energy conversion efficiency of the hydrocarbon fuels from chemical energy to electrical power, to benefit the target of carbon reduction or to mitigate the greenhouse effect is well confirmed.

(2) It is a key milestone to have a SOFC power system with natural gas essentially thermally self-sustaining. Apparently, we are on the way to commercialization though some technical issues still remain to be resolve. First of all, quality and quantity of MEAs are the bases of the development of SOFC technology. A small scale of pilot production of INER's SOFC-MEA is scheduled in 2012 and 2013. Meanwhile, reliability and power performance of MEAs should be continuously improved further to meet commercial target, i.e., degradation rate less than 0.1%/khr and operating lifetime higher than 40,000 hours.

(3) The automation processes are under way for quicker and reliable assembling of the SOFC stacks. Additionally, compact system design, water recovery and treatment, control and diagnosis, human-friendly operation modes, combined heat and power configurations are task forces to be worked on as prerequisites for a robust SOFC system.

(4) The approach from laboratory to demonstrative pilot and then to commercialization is

essential to move forward the SOFC technology. Meanwhile, the government has to provide new initiatives, such as: deregulations on power net, power purchase agreements, subsides and incentives etc., to promote the high efficiency energy technologies. Now it is the high time to have international joined cooperative projects to foster industrial partners for the commercialization of the SOFC technology.

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附件二、會議論文：核研所 SOFC 燃燒/重組器之研究

B1122/SOFCBR

Experimental Study of a SOFC Burner/Reformer

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Abstract

Experimental and numerical analyses are performed for a self-designed non-premixed combustion after-burner/reformer of a solid oxide fuel cell system. The innovative after-burner/reformer is partitioned into four compartments: water evaporator, heat exchanger, reformer and porous media burner. The major functions of burner/reformer are to having a better mixture of gases, preheating anode and cathode gases, and providing thermal power for fuel reforming.

In this study, experiments at different operating temperatures and fuel compositions are executed to identify proper operating conditions for sufficient reforming efficiencies. When operated below a maximum temperature of 900 °C, a total concentration of hydrogen and carbon monoxide reaches to 80.43 % while flow rates of inlet air, methane and water are respectively 1.75 LPM, 2.1 LPM, and 3.05 cc/min. Additionally, numerical calculations are carried out to reveal the temperature distribution of the burner/reformer, especially in the region of porous media, so as to find suitable operating ranges. The calculated results are in good agreement with the measured data.

Keywords: SOFC; burner; reformer; non-premixed; combustion

Introduction

Of the various clean energy technologies available, the fuel cell has the potential to become one of the most feasible energy conversion tools for this generation. Fuel cell technology shows benefits concerning high fuel efficiency, low emissions and less noise pollution. Fuel cell systems include fuel cell stack, fuel processors, heat exchangers, after burner, blowers and reformer. Solid oxide fuel cells (SOFCs) produce electrical energy by oxidizing appropriate fuels such as hydrogen, carbon monoxide or methane. SOFCs represent an important solution for meeting this requirement for a wide variety of applications, from simple auxiliary power units to large-scale power plant systems.

Many experimental of SOFCs power generation systems are employed to investigate the effects of different fuels, fuel flow rates, pressures and stack temperatures. Liso et al. [1] described in a qualitative and quantitative way to evaluate the performance of a micro combination heat and power (CHP) system based on SOFCs. In their system, it fuelled by nature gas with steam reforming and partial oxidation reforming. They found the efficiency is significantly affected by the heat loss due to high temperature operation. The increase of fuel flow rate and operation temperatures enhance energy conversion efficiency, though both the electricity efficiency and overall efficiency would decrease. Furthermore, an increase of air pressure ratio will enhance the electricity efficiency and overall energy conversion efficiency. Wang et al. [2] also presented that the compression ratios and air flow rates have significant effects on the exergy destruction of SOFCs system with Kalina cycle. According to Georgis et al. [3], two configurations considered for the design and operation of energy integrated SOFCs systems for hydrogen production and energy generation. Of which, one configuration was the hot steams from fuel cell mixed and combusted in a burner, and the other one was the hot steams used to provide heat to the endothermic reforming reaction (like steam reforming) before the energy integration.

Kazempoor et al. [4] reported two different integrated SOFCs designs with internal combustion would significantly save in energy and reduce carbon dioxide (CO_2) emission. In a SOFC system, an unexpected production of CO_2 indicated a decrease in catalyst activity, while as temperature higher than 1000 K it would lead to an increase of the methane conversion rate [5]. Chung et al. [6, 7] indicated that the overall efficiency increases as the fuel utilization and air to fuel ratio (A/F) decreases. Barra et al. [8] indicated that the stable operating limits are significantly affected by the conductivity, the volumetric heat transfer coefficients, and the radiative extinction coefficients. Hayashi et al. [9] employed a one-step reaction model to perform three-dimensional analyses of the flows within a two-layer porous media burner.

The purposes of the present research are to perform the experimental data and numerical simulations to analyse the premixed combustion problem with the after burner/reformer in a kW SOFC power system developed by INER. In the present study, the fuel (and the anode-off gas) includes hydrogen, CO and methane. Numerical results for temperature profiles and flame behavior are compared with available experimental data and the effects of porosity of porous media are discussed.

Experimental

Figure 1 presents a schematic of after-burner/reformer experiment apparatus. As illustrated, the gas supply system includes air, hydrogen, nitrogen, methane and liquid water. The cathode off-gas (air) is supplied by a compressor and is pre-heated to a specified temperature (Ta2) by heat-exchanger before entering the burner/reformer. Meanwhile, the water is heated to steam and flow mixing with the hydrogen and air in the anode side. The anode off-gas is substantially heated by after-burner. The temperature (Tf2) is regulated using a Eurotherm PID controller. During the ignition and warm-up stage, the after-burner is supplied with methane via mass flow controller 3 (MFC-3). The after-burner is also fed with air for cooling purposes via MFC-8. During the experiments, the gas and liquid mass flow rates are controlled using a digital Alicat control unit. The temperature distribution within the after-burner is measured using K-type thermocouples in the porous media zone (Tg1-Tg3), the pre-mixing zone (Tf1, Tf2 and Tg6), and the combustion zone (Tg4 and Tg5).

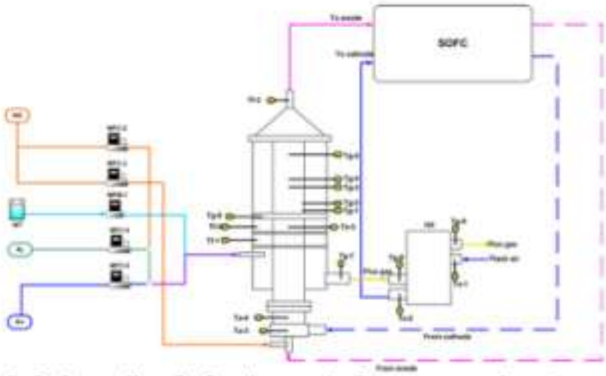

Figure 1: Schematic of after-burner/reformer experiment apparatus

The schematic sketch of after-burner/reformer with the heat transport is shown as Figure 2. It comprises a mixing chamber, a porous media section and reforming section. During operation, the flame is stable in the porous media zone and its energy produced by the burned gases is delivered away by radiation, convection and conduction. It also provides thermal energy for the reaction of stream reforming.

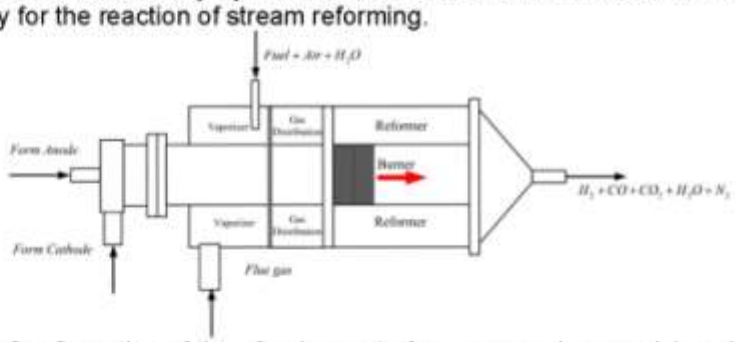

Figure 2: Configuration of the after-burner/reformer comprises a mixing chamber, a porous media section and a reforming section.

In general, selecting an appropriate material for the porous media in an after-burner is a crucial task. The materials should possess the ability to withstand severe thermal and chemical stresses to prevent from initialization or propagate of cracks at elevated temperatures. In the present experimental trials, the combustion zone is fabricated using SiC in the form of metal foam with a pore density of approximately 10 pores per inch (ppi). The empirical properties of the porous media are summarized in Table 1. The gas permeability and thermal conductivity can be obtained as follows.

Gas permeability

$$K_{permeability} = \gamma^{n+1} / C(1-\gamma)^{n} \quad (1)$$

Thermal conductivity

$$k_{eff} = k_s(1-\gamma) + k_g\gamma \quad (2)$$

Table 1: The empirical properties of the porous media.

Porous media	density ρ (kg/m^3)	Thermal conductivity κ (W/m-K)	Specific heat Cp (J/kg-K)	Porosity γ	Gas permeability K (m^2)
SiC	3100	34.8	1300	0.87	$1.675e^{-6}$

Mathematical model and numerical method

The computational domain is 180 (mm) long and consists of combustion (porous media) and non-combustion sections. Figure 3 shows a sketch of the after-burner in the numerical model. In this study, assumptions used in the model are briefly summarize as follows (1) porous ceramics act as black homogeneous media, (2) two dimension steady laminar flow is employed, (3) the ideal gas law and incompressible flow is utilized, (4) gas radiation is not considered, (5) potential catalyst effects of the porous ceramic at high temperatures are ignored (6) Dufour effect, bulk viscosity and body forces are negligible, (7) the heat dissociation effect is adequately small to be neglected.

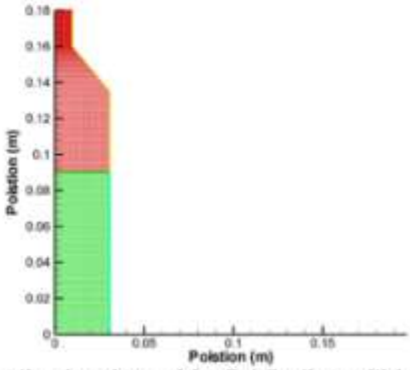

Figure 3: Schematic showing grids distribution within meshed burner.

In the modelling, multi-step kinetic which consists of 3 reactions and 7 chemical species are considered. The two-dimensional model, which includes the effects of energy, radiation, spices diffusion and chemistry, is express as:

Continuity equation

$$\nabla \cdot \left(\gamma \rho \vec{\upsilon}\right) = 0 \ . \tag{3}$$

Momentum equation

$$\nabla \cdot \left(\gamma \rho \vec{\upsilon} \vec{\upsilon}\right) = -\gamma \nabla p + \nabla \cdot \left(\gamma \vec{\tau}\right) - \left(\frac{\mu}{K} + \frac{C_2 \rho}{2} \left|\vec{\upsilon}\right|\right) \vec{\upsilon} \ . \tag{4}$$

Energy equation

$$\nabla \cdot \left(\vec{\upsilon}\left(\rho_f E_f + p\right)\right) = \nabla \cdot \left[k_{eff} \nabla T - \left(\sum_i h_i J_i\right) + \left(\vec{\tau} \cdot \vec{\upsilon}\right)\right] \ . \tag{5}$$

Radiation equation

$$q_r = -\frac{1}{3(a + \sigma_s) - C\sigma_s} \nabla G \ . \tag{6}$$

Species conservation equation

$$\gamma \rho \vec{\upsilon_i} \cdot \nabla Y_i + \nabla \cdot \left(\gamma \rho Y_i D_i\right) = \gamma R_i \ . \tag{7}$$

State equation

$$P = \rho_g RT_g / \overline{W} \ . \quad (8)$$

For the chemical kinetics, one-step chemical mechanism is used for the hydrogen, methane and CO with air combustion.

$$H_2 + \frac{1}{2}(O_2 + 3.76N_2) \rightarrow H_2O + 1.88N_2 \ , \quad (9)$$

$$Co + \frac{1}{2}(O_2 + 3.76N_2) \rightarrow CO_2 + 1.88N_2 \ , \quad 10)$$

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2 \ . \quad (11)$$

In general, the chemical reaction of the species is given by

$$\sum_{i=1}^{N} \chi'_{i,r} M_i \xrightarrow{R_{f,r}} \sum_{i=1}^{N} \chi''_{i,r} M_i \ , \quad (12)$$

$$R_{fuel} = AT^{\beta} [Fuel]^{b} [O_2]^{c} \exp\left(-\frac{Ea}{R_u T}\right) . \quad (13)$$

Where $R_{f,r}$ is the forward rate constant for reaction r, R_{fuel} is computed using the Arrhenius expression and A is the pre-exponential factor. The present simulations consider the one-step global forward chemical reaction involved in the combustion process. [Fuel] and [O2] denote the concentrations of fuel and oxygen, respectively. The superscripts b and c are the corresponding concentration exponents.

At the inlet,

$$\vec{\upsilon} = \vec{\upsilon}_{in} \ , \ T_g = T_{g0} \ , \ Y_k = Y_{k0} \ , \ q_r^{+} = \pi I_b(T) \quad (14)$$

At the exit,

$$\frac{\partial \vec{\upsilon}_k}{\partial x} = 0 \ , \ \frac{\partial T_k}{\partial x} = 0 \ , \ \frac{\partial Y_k}{\partial x} = 0 \ , \ q_r^{-} = \pi I_b(T) \quad (15)$$

By using commercial software FLUENT, the solutions are obtained by solving the governing equations. In FLUENT, the SIMPLE (semi-implicit method for pressure-linked equation) algorithm has been employed to solve the pressure and velocity coupling momentum equations. The convection terms and the diffusion terms are approximated by the first-order upwind scheme. The under-relaxation factor is used to prevent divergence in the iterative processes.

Results and discussions

This section presents the experimental results for the after-burner/reformer performance, where the fuel is methane-base reformate gas. The temperature profiles of after-burner, and the effect of porosity are delineated.

Influence of fuel reforming rate and operation temperature on the after-burner/reformer

A series of experiments are performed using methane-based reformate gas as fuel to study the effect of different operation temperatures and fuel reforming rate (R_f) on the rate of hydrogen production and methane un-transformation. Table 2 shows the compositions of the input gases to the after-burner/reformer for values of R_f at 760°C. In Figure 4, it illustrates the effect of fuel reforming rate of the stack on the temperature distribution with the burner/reformer for a cathode off-gas flow rate of 60 LPM. In general, a lower fuel reforming rate implies a lower reformer power is needed and a higher temperature gradient around the after-burner/reformer might exist. The reaction gases are made by steam reforming, partial oxidation reforming and water-gas shift reaction on the burner-reformer. As a result, the temperature within the burner/reformer decreases and thus additional excess methane is required to maintain the temperature of the combustion zone.

Table 2: The compositions of the input gases to the after-burner/reformer for values of R_f during the range from 0.5 to 0.7 at 760°C.

Reformer fuel (CH_4, Air: LPM, H_2O:cc min^{-1})			
R_f	CH_4	Air	H_2O
0.5	2.1	1.75	3.05
0.6	2.52	2.1	3.66
0.7	2.94	2.45	4.27

Figure 5 presents the effect of the burner/reformer operation temperature on the reforming hydrogen and unreacted methane concentration. In this experiment, the fuel reforming rate of R_f = 0.5. The result show that when the burner/reformer is operated from 860 to 900°C, the hydrogen concentration is increased from 59.97 to 61.26% and the unreacted methane is decreased from 3.89 to 3.24%. In other words, a higher operation temperature contributes the chemical reaction of reformer. As steaming reforming is an endothermic reaction (the reaction energy is 242 $KJmole^{-1}$) and thus a higher operation temperature enhances the catalyst reaction on the reformer.

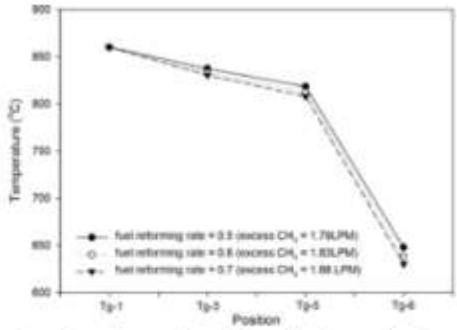

Figure 4: The effect of fuel reforming rate of the stack on the temperature distribution with the burner/reformer.

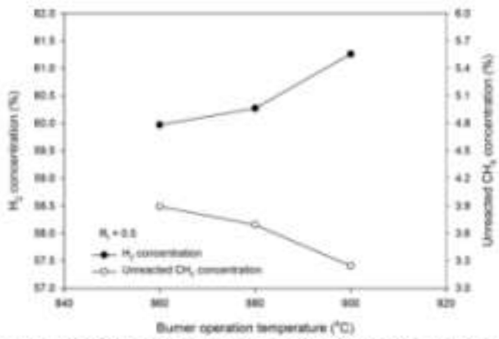

Figure 5: The effect of the burner/reformer operation temperature on the reforming hydrogen and unreacted methane concentration.

After-burner/reformer gas compose from start-up to long-term operation

During the experiments, the operating cycles of the after-burner/reformer includes two distinct phases,

(a) Phase 1: Burner/reformer ignition to system heating up with dilute gas
(b) Phase 2: Transition from the dilute gas to anode off-gas and cathode off-gas with different burner/reformer operation temperature.

Figure 6 shows the time-based variations of the gas composition in the burner/reformer at different operating temperatures. During phase 1, i.e., the ignition and warm-up phase, the after-burner/reformer is supplied with dilute gas and its temperature maintains around 860°C. However, as temperatures in the combustion zone become stable, and the dilute gas is replaced by the reforming gas, the fuel reforming rate would increase. In the phase 2, the H_2 and CO concentration are respectively higher than 55 and 15%, and the unreacted CH_4 is below 5%. There is no need for extra cooling air for the after-burner/reformer.

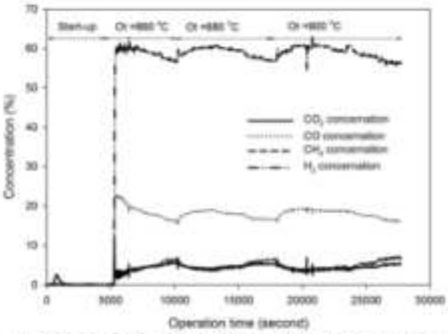

Figure 6: Variation of the gas composition from start-up to normal operation.

Validations of the numerical model

Before commencing the simulations, a grid independence test was performed using three different grid sizes, 31 x 144, 31 x 180 and 31 x 360, respectively. Figure 7 illustrates the results for these three grid sizes for the temperature profile along the y-axis at the center of the burner. The results indicate insignificant difference with regard to different grid sizes. Thus, the mesh size of 31 x 180 is selected for the calculations.

To verify the numerical model, temperature at the center of the porous media and free space section are calculated and compared to the experimental data, as shown in Figure 8. A good agreement is obtained. The discrepancy between the simulation results and the experimental data is quantified by,

$$\frac{T_{exp} - T_{num}}{T_{num}}. \qquad (16)$$

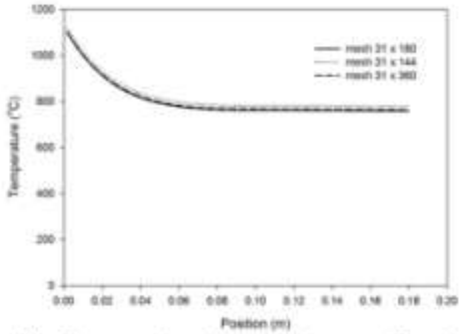

Figure 7: Effect of grid refinement on temperature profile at center of the burner.

The maximum differences are respectively 9% and 5% for the porous media and the free space sections.

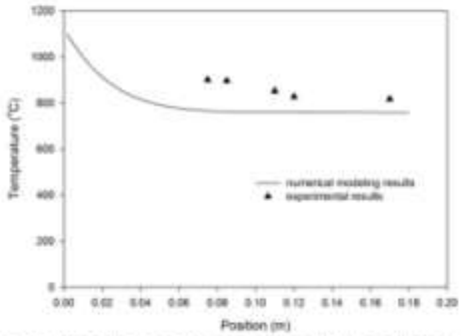

Figure 8: The Comparison of experimental and simulation results

Effect of the porosity on the temperature distribution of porous media burner

Figure 9 shows the effect of porosities on temperature profiles of the after-burner. The result indicates that a higher porosity would yield higher temperatures as it can provide more reactant sites for gas to get burned. The maximum temperature occurs in the porous section involving combustion, however, the variation of average temperature is subtle in the free space section. When the porosity of porous media is 0.9, the maximum temperature is 1163°C in the porous media and the average temperature is 807°C.

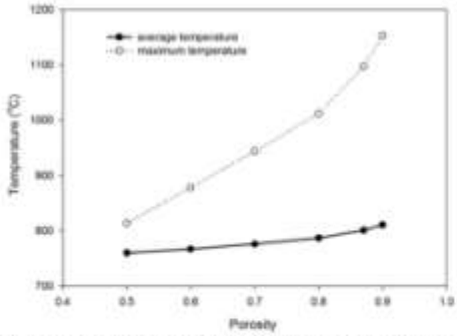

Figure 9: Effect of different porosities on the temperature profiles of the after burner.

Conclusion

This study carries out experimental and numerical investigations for an after-burner/reformer with reforming gas. In the experimental part, effects of the fuel reforming rates, operation temperatures of burner, and reforming gas compositions are evaluated. In the numerical modelling, a laminar flow model is employed and multi-step chemical reaction model is used to deal with the combustion processes. The major conclusions of this study are summarized as follows:

[1] In the experiment, while the burner/reformer operated from 860 to 900°C, the hydrogen concentration increases from 59.97 to 61.26% and the methane concentration decreases from 3.89 to 3.24%.

[2] A good agreement is observed between the simulation results and the experimental data for the temperature distribution in the porous media and free space sections.

[3] A higher porosity of porous media on the after burner will yield a higher temperature in the porous section. after-burner design is to for a temperature profiles for the after-burner.

Nomenclatures

C	Kozeny-Carman constant
G	radiation intensity
K	gas permeability
R	gas constant
T	Temperature
W	molecular weight
Y	mass fraction of species
a	spectral absorption coefficient
d_m	pore diameter

Greek symbols

p	pressure
γ	porosity
ρ	density
μ	viscosity
v	velocity
σ_s	scattering coefficient
k	thermal conductivity

Superscripts and subscripts

eff	efficiently
exp	experimental
g	gas
num	numerical
s	solid

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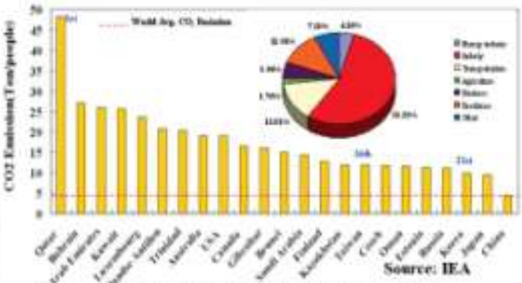
附件三、會議論文簡報：核研所 SOFC 技術發展

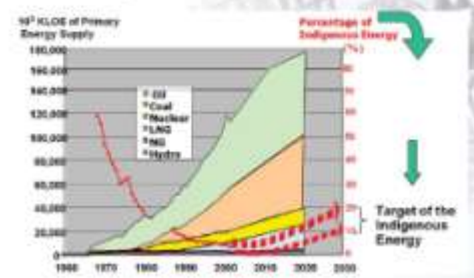
1. Introduction

- Energy Demand
  - Short of Energy Resources
  - Commitment to the reduction of GHG emissions
  - Impact of Fukushima nuclear accidents
- INER's Approach
  - Define Target
  - Construct Working Breakdown Structure
- Current Status
  - A thermal self-sustaining power system is achieved.
  - A SOFC technology roadmap is proposed.
  - Industrial partners are highly interested on the way to the commercialization of SOFC technology.

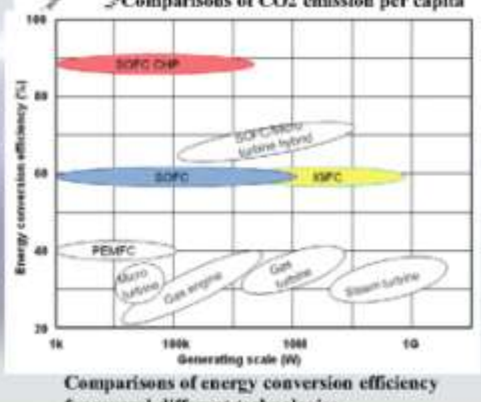
1. Introduction (Cont'd)



Comparisons of CO2 emission per capita



Energy Security – Less Than 2% Indigenous Energy



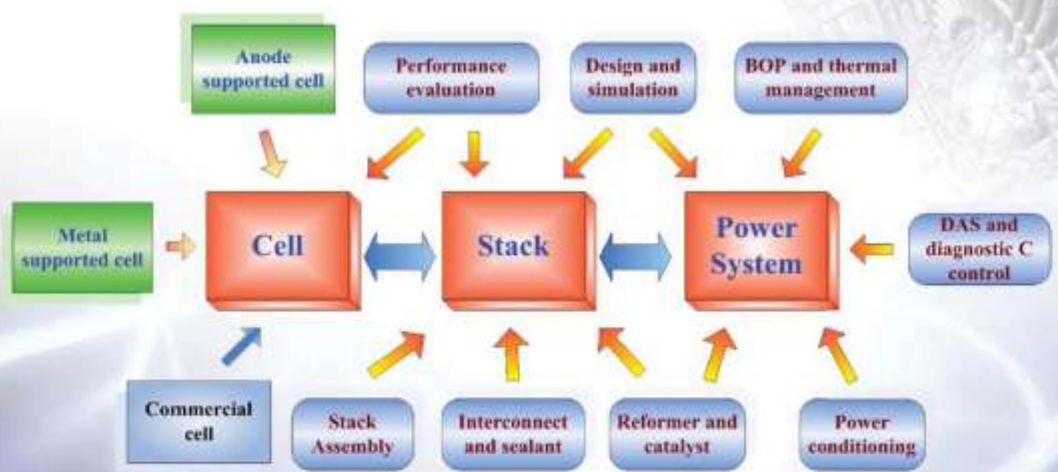
Comparisons of energy conversion efficiency for several different technologies.

- SOFC technology is an essential bridge from fossil-fuels to next generation power systems, and it is beneficial to
  - Energy security
  - Economic growth
  - Environmental protection

1. Introduction (Cont'd)

- INER's Approach
  - Initialization of SOFC Project in 2003
    - Shift from nuclear to renewable energy fields
    - Possess experienced researchers in chemical, physic, material, mechanical, power electronics, etc.
    - Set critical mass for technology development
  - Define Target
    - Short term target: 1~5 kW combined heat and power SOFC distributed power generation.
    - Long term target: Integration with IGCC for biomass and coal based central power systems.
  - Construct Working Breakdown Structure

1. Introduction (Cont'd)



Linkage among INER's SOFC research groups

1. Introduction (Cont'd)

> ### *Current Status*

- A thermal self-sustaining power system is achieved.

  - Critical core technologies from powder to power for a distributed kilowatt SOFC power system are established.

- A SOFC technology roadmap is proposed.

  - Operating temperatures, power densities, efficiencies, degradation rates, cost and power levels are discreetly projected.

- Aspects of academics, research institute, industry, and government.

  - Alliance are being formed among parties.

  - Industrial partners are highly interested on the way to the commercialization of SOFC technology.

1. Introduction (Cont'd)

A proposed SOFC Technology Roadmap

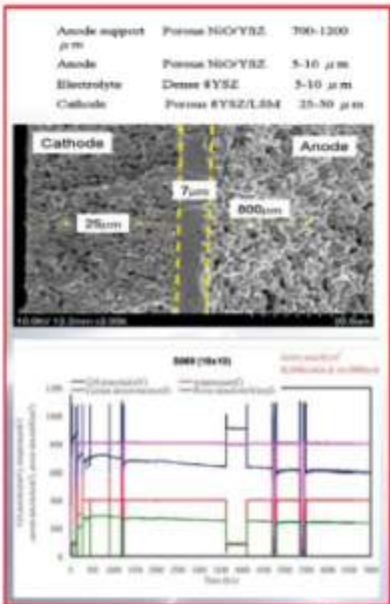
Solid Oxide Fuel Cell (SOFC) Technology Roadmap

			Present~2015					2016~2020					2021~2030				
			T °C	P mW/cm²	DR %/kh	η_e (%)	η_t (%)	T °C	P mW/cm²	DR %/kh	η_e %	η_t %	T °C	P mW/cm²	DR %/kh	η_e %	η_t %
Small CHP SOFC Power System (1~10 kW)	Laboratory		700	600	0.2	60	90	600	1000	0.1	60	90	500	1000	0.1	60	90
	Demonstrative Pilot	Specifications	750	650	0.5	55	85	650	800	0.2	60	90	600	1000	0.1	60	90
		Life time & Cost	40,000hr, 10$/W					60,000hr, 7$/W					80,000hr, 5$/W				
	Commercialization	Specifications	800	400	1	50	80	700	600	0.5	55	85	600	800	0.2	60	90
		Life time & Cost	40,000hr, 4$/W					60,000hr, 3$/W					80,000hr, 2$/W				
Business-use CHP SOFC Power System (100 kW)	Laboratory		750	600	0.5	60	90	650	1000	0.1	60	90	600	1000	0.1	60	90
	Demonstrative Pilot	Specifications	750	600	0.5	60	90	700	800	0.2	60	90	650	1000	0.1	60	90
		Life time & Cost	40,000hr, 8$/W					60,000hr, 4$/W					80,000hr, 3$/W				
	Commercialization	Specifications	800	400	1	55	85	750	600	0.5	55	85	700	800	0.2	60	90
		Life time & Cost	40,000hr, 4$/W					60,000hr, 2$/W					80,000hr, 1~2$/W				
SOFC Power Generation System (MW)	Demonstrative Pilot	Specifications	Technological challenges in development and demonstration					750	600	0.2	60	90	700	800	0.1	60	90
		Life time & Cost						60,000hr, 4$/W					80,000hr, 3$/W				
	Commercialization	Specifications	Conceptual design & Early market introduction					750	400	0.5	55	85	700	600	0.2	60	90
		Life time & Cost						40,000hr, 2$/W					80,000hr, 1~2$/W				

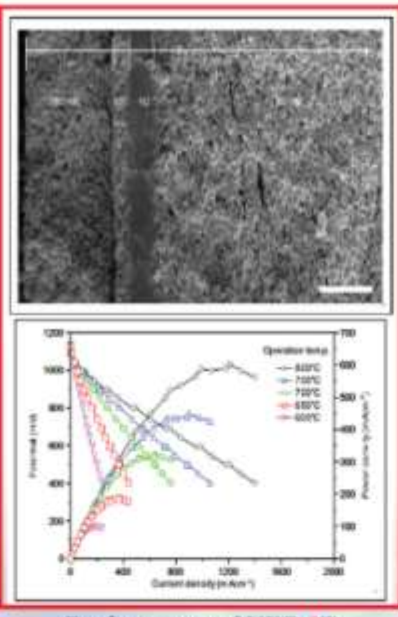
2. Technology Development

- MEA Development
  - Planar type SOFCs
    - Anode Supported Cell (ASC)
    - Metal Supported Cell (MSC)
  - Techniques to fabricate HT, IT and LT SOFC cells are well developed.
  - Cells are continuously improved with inspiring performance.
  - A pilot production is under way in 2012 and 2013.

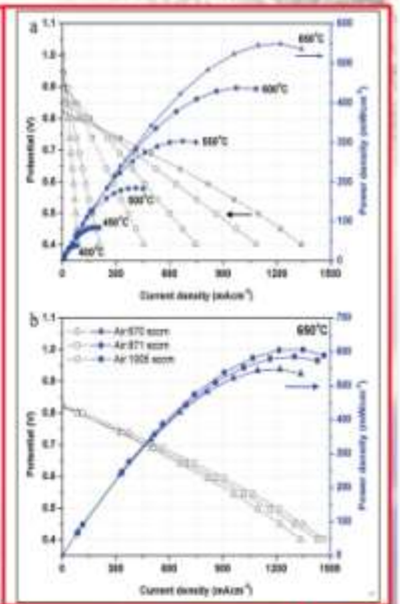
2. Technology Development (Cont'd)



Performance of NER-HT-SOFC-MEA full cell

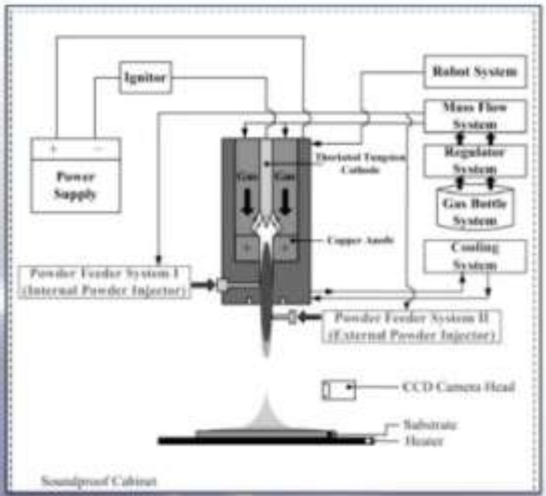


Performance of NER-IT-SOFC-MEA full cell

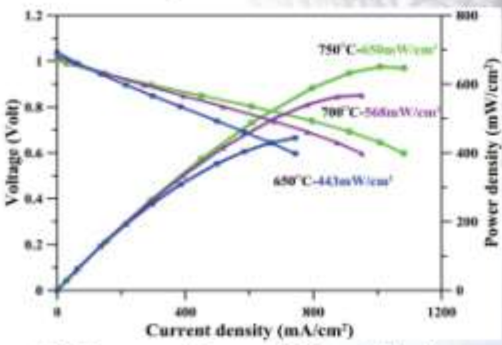


Performance of NER-LT-SOFC-MEA full cell

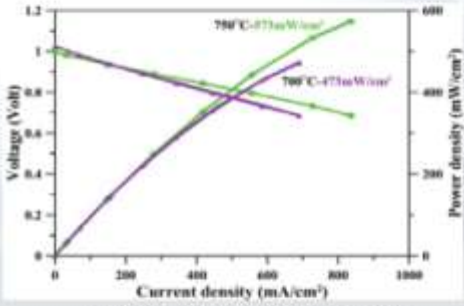
2. Technology Development (Cont'd)



A schematic diagram for an APS system



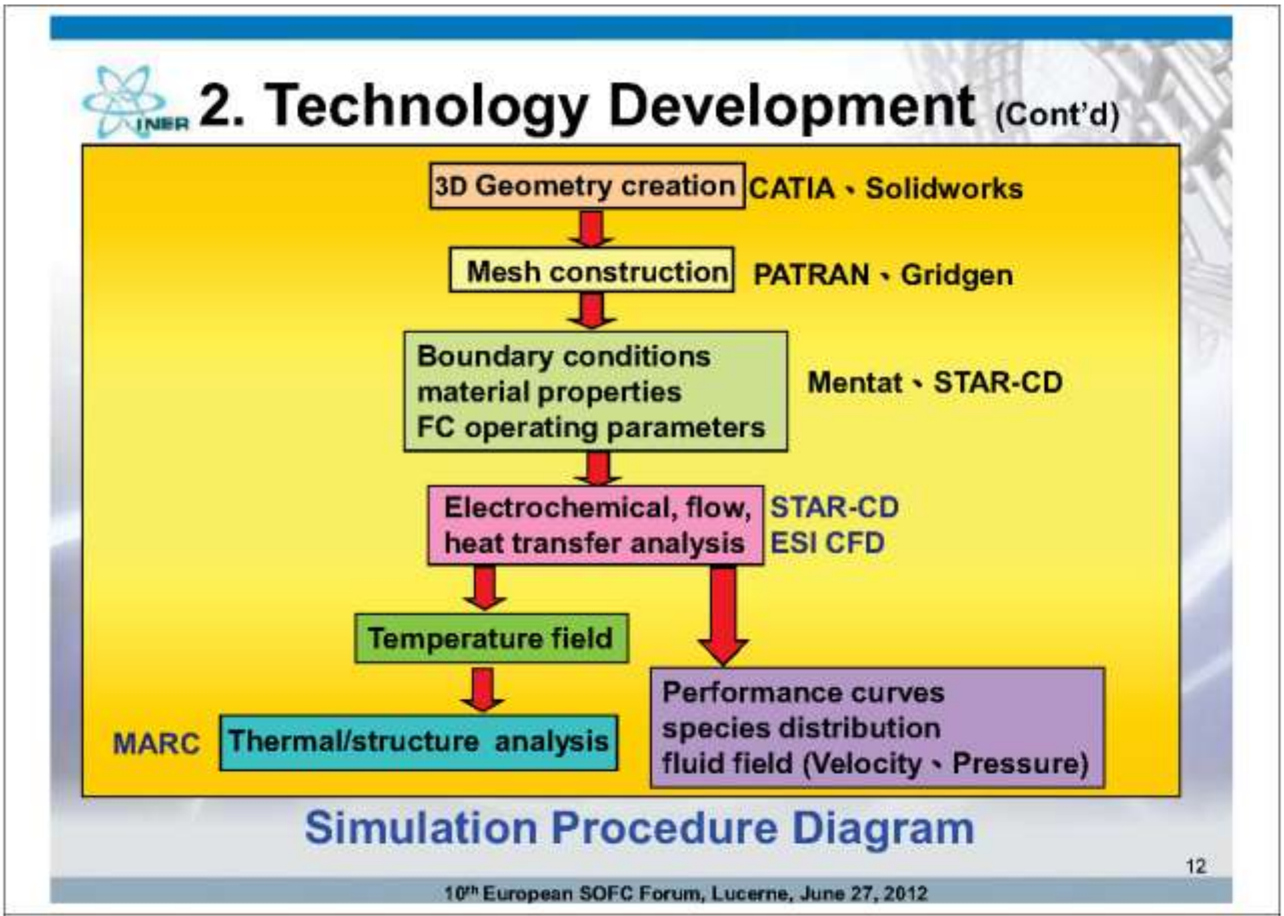
I-V-P curves for an MSC cell test

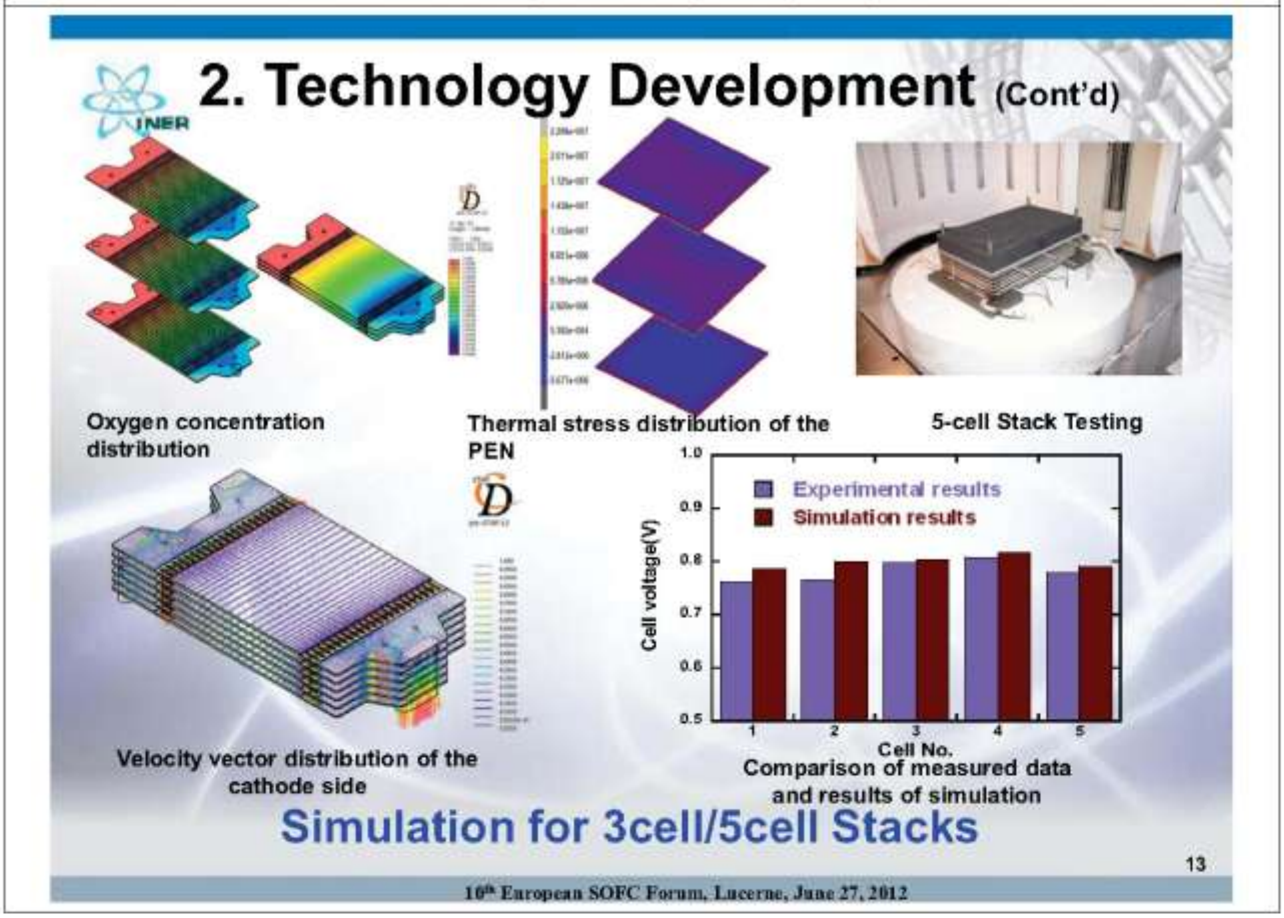


MSC single-cell stack test

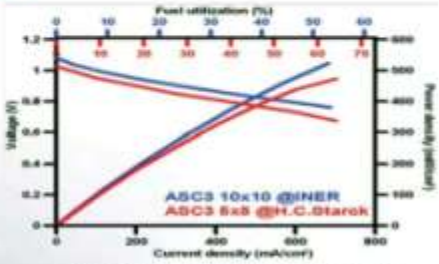
2. Technology Development (Cont'd)

- Stack Development
  - Planar configuration with ASC cells is employed.
    - Internal manifold with counter flow for fuel/oxidant gases
    - In parallel inlet/outlet gas channels
    - metallic interconnects
  - Glass ceramic GC-9 is developed as sealant materials.
  - Capability on design/simulation/analysis are established.
  - Standard operational procedures (SOPs) are established.
  - Techniques to enhance cell/stack performance are continuously improved.
  - Consistent and conceivable performance is achieved for stack modules.

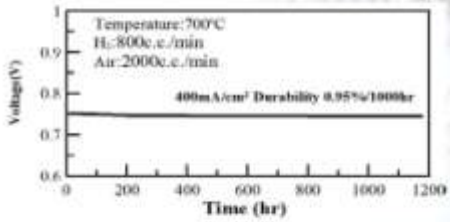

2. Technology Development (Cont'd)
3D Geometry creation
CATIA、Solidworks
Mesh construction
PATRAN、Gridgen
Boundary conditions
material properties
FC operating parameters
Mentat、STAR-CD
Electrochemical, flow,
heat transfer analysis
STAR-CD
ESI CFD
Temperature field
MARC
Thermal/structure analysis
Performance curves
species distribution
fluid field (Velocity、Pressure)
Simulation Procedure Diagram
12
10th European SOFC Forum, Lucerne, June 27, 2012


2. Technology Development (Cont'd)
Oxygen concentration distribution
Thermal stress distribution of the PEN
5-cell Stack Testing
Experimental results
Simulation results
Cell voltage(V)
Cell No.
Comparison of measured data and results of simulation
Velocity vector distribution of the cathode side
Simulation for 3cell/5cell Stacks
13
10th European SOFC Forum, Lucerne, June 27, 2012

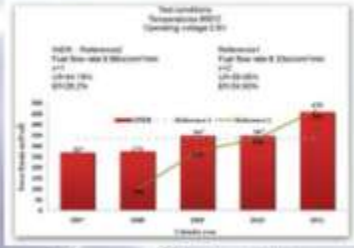
2. Technology Development (Cont'd)



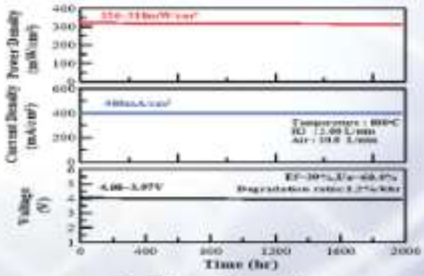
Performance test for a single cell



INER-MSC stack test



Progress of single cell tests



5-cell stack durability test

Cell/stack performance evaluation

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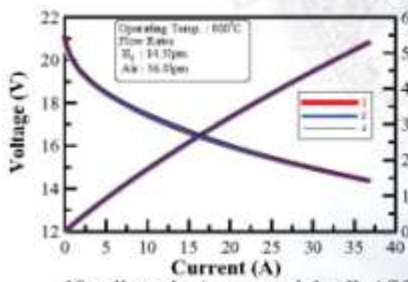
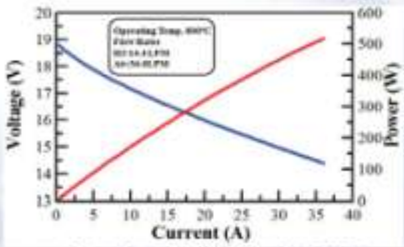
2. Technology Development (Cont'd)

Test conditions Temperature :800°C Fuel flow rates:0.8L/min Air flow rates:2.0L/min						
	Reference	2007 Single stack test	2008 Single stack test	2009 Single stack test	2010 Single stack test	2011 Single stack test
OCV	1.02V	1.102V	1.12V	1.12V	1.12V	1.13V
0.8V Current Density Power Density	420 336	230.8 186.4	327.2 261.7	339.5 271.6	339.5 271.6	486.4 389.0
0.7V Current Density Power Density		256.8 266.7	493.8 345.6	564.2 395.1	564.2 395.1	Line Resistance
Durability test 400mA/cm²		7%/1khr	[illegible]	1.2%/1khr	1.2%/1khr	[illegible]

Progress of 1-cell stack tests



18-cell stacks (commercial cell, ASC)



18-cell stack (INER cell, MSC)

Cell/stack performance evaluation

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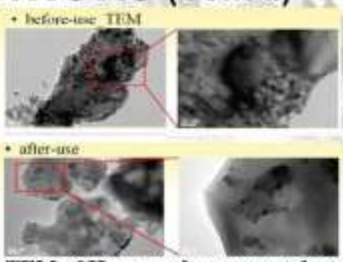
2. Technology Development (Cont'd)

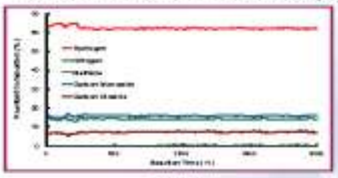
- Power System Development
  - Development of thermal stable, high efficiency nano-catalysts for natural gas reforming.
  - BOP components - reformer, after-burner and heat exchanger are designated and fabricated.
  - Techniques for power conditioner are developed.
    - High SOFC DC/DC Converter & DC/AC Grid-tied Inverter
    - Power conditioner
  - Techniques to build up a SOFC power system are being established.
    - System design
    - Data acquisition and control
    - Interfaces among components
  - Integration of components into a power system.

2. Technology Development (Cont'd)

Homemade nano-catalysts (patent pending)



TEM of Homemade nano-catalysts

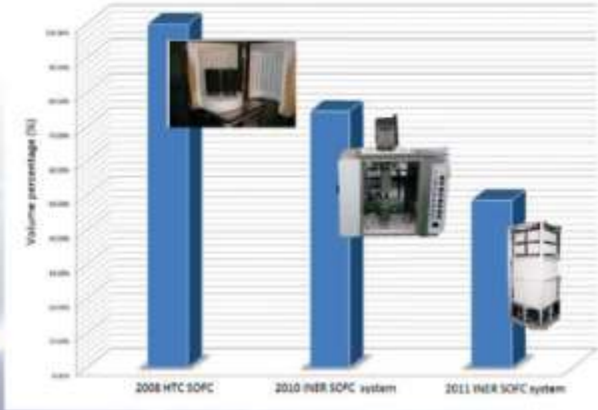


Natural gas reforming test

1. High durability >2,000 hours
2. High natural gas conversion > 95%
3. High thermal stability >1,000℃
4. The interaction of reduced Pt and Ce oxide inhibits Pt sintering by surface diffusion
5. The innovative nano-catalysts design helps in the retention of surface area and prevents the migration and coalescence of the metal crystallites

Nano-catalysts for natural gas reforming

2. Technology Development (Cont'd)



Case	T_{avg} (°C)	H_2 (%)	CO (%)	CH_4 (%)	CO_2 (%)	Equivalence ratio (Φ)
C-1	869.92	61.26	19.17	3.243	3.792	0.36
C-2	868.6	59.07	18.83	4.751	3.789	0.28
C-3	865.2	57.84	17.62	5.687	4.541	0.29
C-4	862.6	55.91	16.24	7.103	5.214	0.30

Commercial burner → INER burner → INER burner & reformer

Development of BOP components

2. Technology Development (Cont'd)

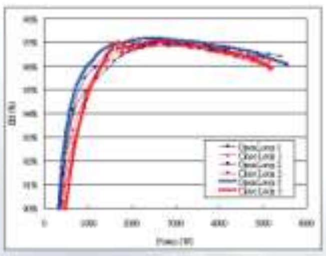
Specs for converter

- Input: 48 Vdc (nominal, ±25%)
- Output: 400 Vdc (ripple ±2%)
- Efficiency: 97.1% (peak), >96% @ 20~100% loading

Specs. for inverter

- Input: 400 Vdc (nominal, ±25%)
- Output: 110/220 Vac (ripple ±2%)
- Efficiency: 98% (peak), >97% @ 20~100% loading

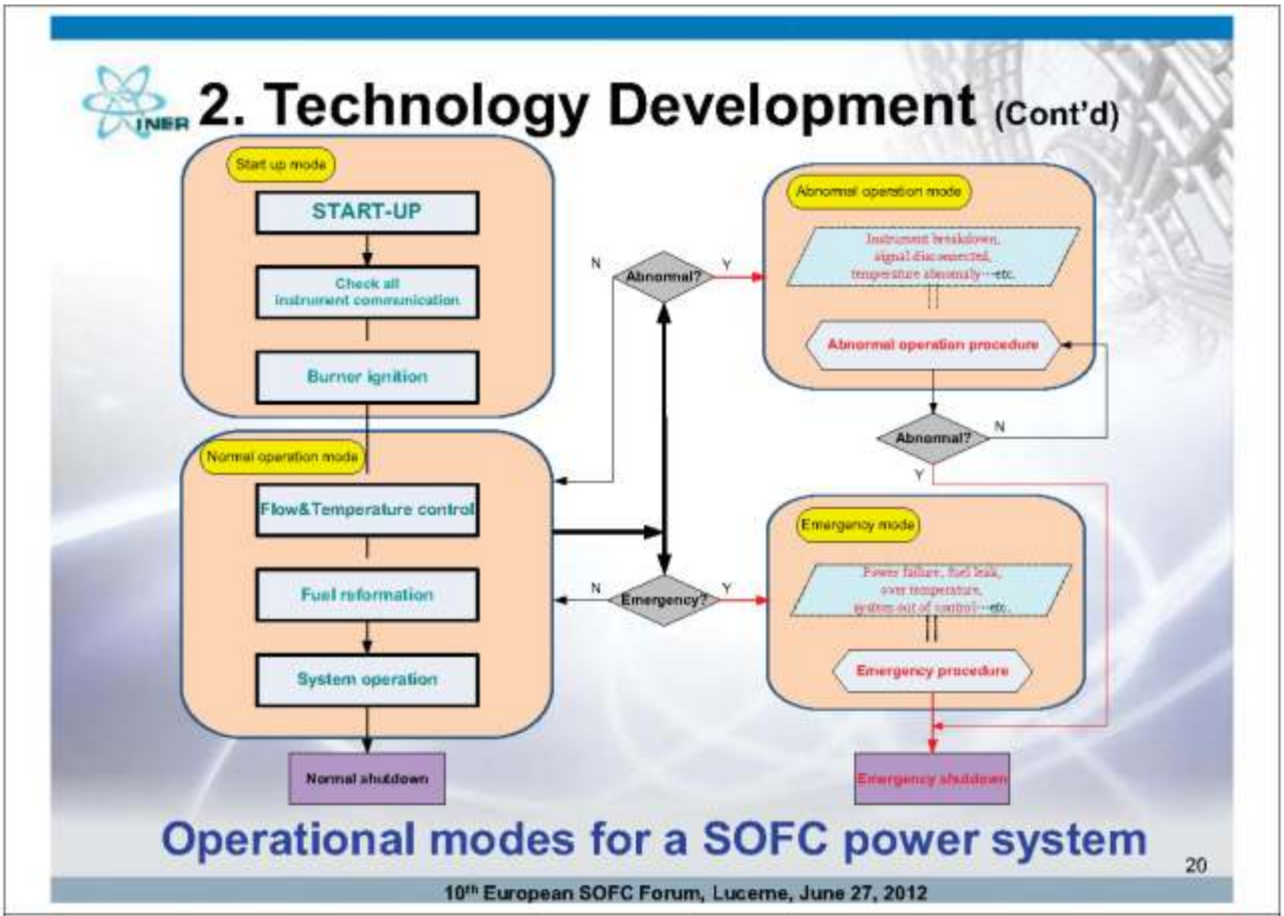
Components for a 5-kW DC/DC converter



Efficiency of a 5-kW DC/DC converter

Components for a 5-kW DC/AC grid-tied inverter

5-kW SOFC DC/DC Converter & DC/AC Grid-tied Inverter



2. Technology Development (Cont'd)
Start up mode
START-UP
Check all instrument communication
Burner ignition
Normal operation mode
Flow&Temperature control
Fuel reformation
System operation
Normal shutdown
Abnormal?
N
Y
Emergency?
N
Y
Abnormal operation mode
Instrument breakdown, signal disconnected, temperature abnormally…etc.
Abnormal operation procedure
Abnormal?
N
Y
Emergency mode
Power failure, fuel leak, over temperature, system out of control…etc.
Emergency procedure
Emergency shutdown
Operational modes for a SOFC power system
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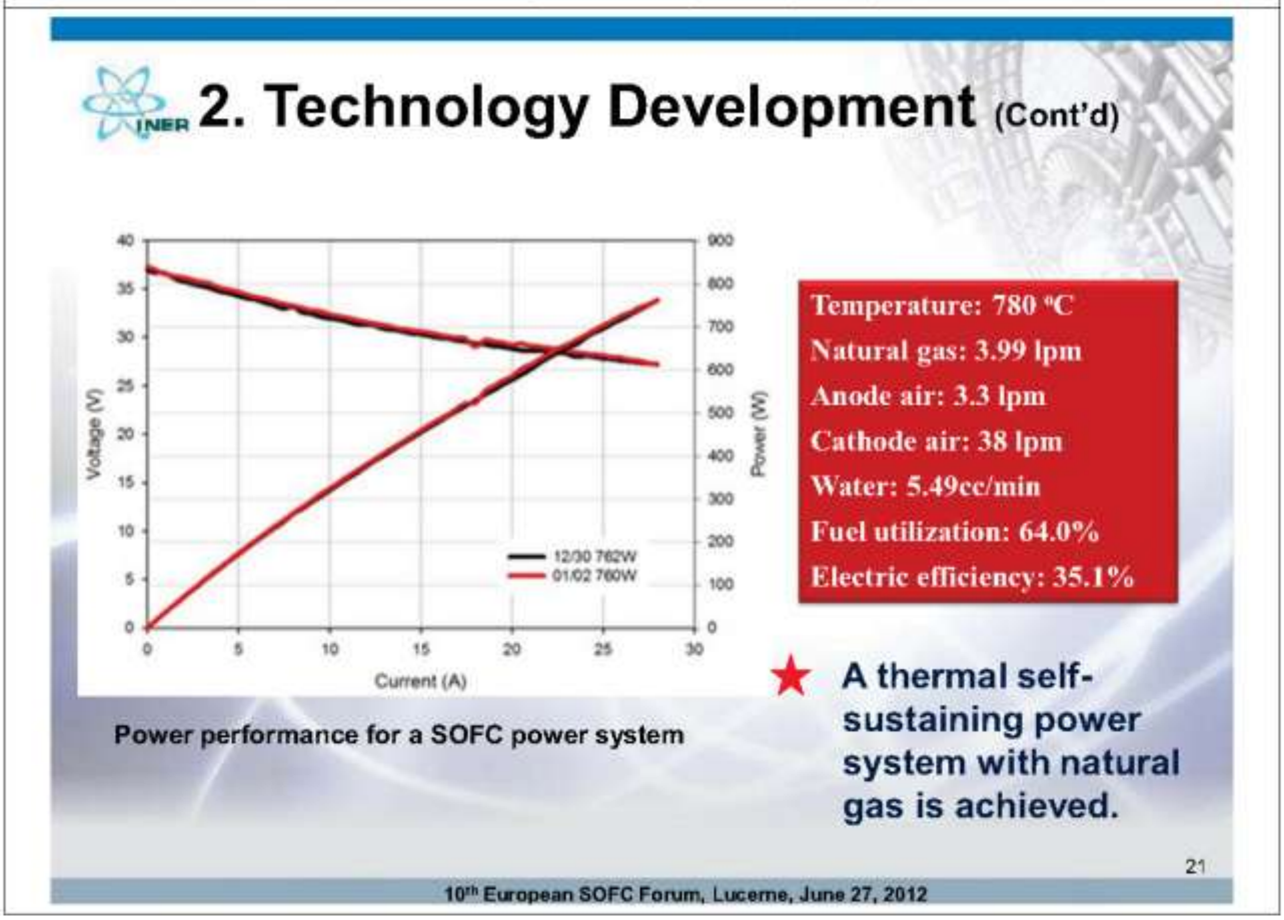
10th European SOFC Forum, Lucerne, June 27, 2012



2. Technology Development (Cont'd)
Voltage (V)
Power (W)
Current (A)
12/30 762W
01/02 760W
Temperature: 780 ℃
Natural gas: 3.99 lpm
Anode air: 3.3 lpm
Cathode air: 38 lpm
Water: 5.49cc/min
Fuel utilization: 64.0%
Electric efficiency: 35.1%
Power performance for a SOFC power system
★ A thermal self-sustaining power system with natural gas is achieved.
21
10th European SOFC Forum, Lucerne, June 27, 2012

3. Conclusions

- Core technologies for the SOFC **from powder to power** are being developed at INER with inspiring performance.
- A key milestone to have a SOFC power system with **natural gas essentially thermally self-sustaining** is achieved.
- Continuous efforts will be paid to prerequisites for a **compact and robust CHP system.**

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3. Conclusions (cont'd)

- **Automation processes** are under way for quicker and reliable assembling of SOFC stacks.
- **New initiates**, such as : deregulation on power net, power purchase agreements, subsides and incentives, **are proposed** to government to promote high efficiency energy technologies.
- **International jointed cooperative projects** to foster industrial partners and establish industrial chains for the **commercialization of the SOFC technology** are highly recommended.

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附件四、會議論文海報：核研所 SOFC 燃燒/重組器之研究