INER-F1418 INER-F1418

出國報告（出國類別：其他）

參加歐盟第 15 屆 SOFC&SOE 燃料電池論壇(視訊報告)

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派赴國家/地區：臺灣，中華民國
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摘　要

本文為參加歐盟燃料電池論壇(European Fuel Cell Forum, EFCF)第十五屆 SOFC 及 SOE 國際研討會及燃料電池展之視訊會議報告。會議於 2022 年 7 月 5-8 日在瑞士琉森(Lucerne) 舉辦，主席為法國 CEA 氫能技術部門主任 Dr. Julie Mougin 及資深研究員 Dr. Jerome Laurencin。大會統計，本次投稿會議論文 253 篇；參加總人數合計 525 人，參加實體會議者計 450 人，受全球疫情影響，另有 75 位以視訊方式參與(主要為美國及亞洲地區之人員)。本次會議內容涵蓋面持續擴展，包含:燃料電池、電解質、電化學反應器及二氧化碳排放、減量及再利用等面向。會議概分為**技術發展**(Session A, Technology Development) 及**科技成就**(Session B, Scientific Achievements)等兩項主軸，平行進行。透過論壇之資訊交流、溝通平台，有助於掌握國際間燃料電池領域之發展脈動及趨勢，做為後續技術發展、研發策略擬定之參考。

本次會議本所由李瑞益博士及吳宜靜小姐以視訊方式參加，李員自 2011 年受邀擔任該論壇之國際諮議委員(International Board of Advisors, IBA)，在 7 月 5 日論壇開議前的國際諮議委員會議上，獲邀續任為 IBA 委員。本次會議提報之論文「SOFC stack development at INER」，由吳員依據大會設定之格式，製作影音檔供與會者參考。本文彙整會議之背景、行程及會議內容提要、心得及建議事項，做為後續相關作業之參考。

固態氧化物電池/電解技術，具有**高**能量**轉換效率**、**模組化**、可採**多元燃料**、可**共電解**水及二氧化碳產生合成氣，為**橋接化石能源**至**次世代能源**架構的**低碳能源**技術，與國家設定之**淨零排放(Net Zero Emissions, NZE)**路徑及策略，高度契合。在**節能減碳**、**能源轉型**及**低碳社會**議題上，SOFC/SOEC 為可資運用及推廣之低碳能源技術。結合氣化及燃料系統的**複合氣化燃料電池**(Integrated Gasification Fuel Cell, **IGFC**)，具有最佳的**減碳迴避成本**(Cost of CO_2 emissions Avoided, **CCA**)，可成為我國**淨零排放**發展的重點項目。著眼於燃料電池技術在能源轉型、低碳社會所具的潛在龐大商機，國際各大企業彼此結盟，有形成**卡特爾**(Cartel)集團**閉鎖模式**(Lock-in model)的態勢。國內具有**能源轉型**及**市場需求**、完整**自主技術**能量，且國內業者具有**精湛零組件製作**能量及**靈活度**；若能結合**技術**、**需求**、**供應**、及**通路**的優勢，**聚焦**此一具有龐大**產業效益**之能源技術，在本土即可有很好的發展機會。建議政府投入資源支持**自主技術**之**整合驗證**測試系統及推展，以利於國家**節能**、**低碳社會**及**淨零排放**整體目標之達成，並開創一新興**能源產業**。

關鍵字:

EFCF: European Fuel Cell Forum, 歐盟燃料電池論壇

CCA: Cost of CO_2 emissions Avoided, 減碳迴避成本

IBA : International Board of Advisors, 國際諮議委員會

IGFC: Integrated Gasification Fuel Cell, 複合氣化燃料電池

NZE: Net Zero Emissions, 淨零排放

SOE: Solid Oxide Electrolyser, 固態氧化物電解池

SOFC: Solid Oxide Fuel Cell, 固態氧化物燃料電池

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一、目的

歐盟燃料電池論壇(European Fuel Cell Forum, EFCF)舉辦之第十五屆 SOFC 及 SOE 研討會及燃料電池展，於 2022 年 7 月 5-8 日在瑞士琉森(Lucerne)舉行，該會議每兩年舉辦一次。會議主席為法國 CEA 氫能技術部門主任 Dr. Julie Mougin 及資深研究員 Dr. Jerome Laurencin。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& SOE 技術長期發展及未來產品化所需面臨之相關課題，國際間主要從事高溫燃料電池之研發機構皆派員與會；本次會議計有來自世界各地 5 百餘專業人士參加，其主題及展示範圍涵蓋：電池片、電解池、連接板材料、電池堆、重組器、系統應用、微小型 SOFC、中低溫 SOFC 及 SOE 之開發等。

本次會議本所由李瑞益博士及吳宜靜小姐以視訊方式參加，提報會議論文「SOFC stack development at INER」，以呈現計畫階段性進展，藉由參加會議，以掌握國際 SOFC 燃料電池之發展趨勢，並拓展與國際主要發展機構成員之關係，強化國際人脈關係及促進資訊交流；俾利於後續 SOFC 研發策略及方向之擬訂，契合國家淨零排放之目標，加速國內產業聚落之形成，開創一新興能源產業。

二、過程

(一) 概要說明

歐盟燃料電池論壇(European Fuel Cell Forum, EFCF)自 1994 年首度舉辦，每兩年舉辦一次，今年為第十五屆。本屆 EFCF-2022 論壇及燃料電池展於 7 月 5-8 日在瑞士琉森(Lucerne)KKL 會議中心舉辦，採實體與視訊並行方式進行。2020 年初，COVID-19 新冠疫情爆發、形勢嚴峻，李員以 IBA 委員的角度，於 2020 年 3 月間，評析當時的疫情發展情勢及可能演化情節，致函主辦單位，提議大會考量延後該年度第十四屆論壇的舉辦時間(原定 7 月初舉辦)；由於當時國際間疫苗仍在開發階段，各國對於來自不同國家的旅客，設定嚴謹的隔離及限制措施，不利於國際人員的流動，主辦單位最後決定將當年度 EFCF 論壇延後至 2020 年 10 月 20 日-23 日，並首度採用全視訊方式辦理。在國際各醫療團隊積極作為下，在 2020 年下半年即開發多種可有效抑制新冠病毒的疫苗，各國政府透過疫苗緊急使用授權(Emergency Use Authorization, EUA)的方式，實施疫苗施打，並迅速提高疫苗普及率。歐盟於 2021 年 7 月 1 日正式啟用「歐盟數位新冠肺炎證明」，以利歐盟成員國對入境旅客通關查驗；對於其他地區的旅客，亦逐漸採取鬆綁的旅遊限制。不過，由於國內仍採取相對嚴謹的隔離措施，且相關的不確定因素仍高，故以視訊方式參加論壇會議。本屆 EFCF 論壇，以實體會議為主；大會考量參與本項論壇的人員來自歐美亞等不同區域，部分人員可能因疫情因素無法參與實體會議，遂於 6 月下旬開放未能親臨會場者以視訊方式參與，論壇首度以實體及視訊(Physically and Virtually)二者並行方式進行。

會議於 2022 年 7 月 5-8 日在瑞士琉森(Lucerne) 舉辦，籌辦者為 Mr. Olivier Bucheli & Dr. Michael Spirig，本屆大會主席為法國 CEA-Liten 氫能技術部門主任 Dr. Julie Mougin 及資深研究員 Dr. Jerome Laurencin，EFCF-2022 SOFC &SOE 論壇及本次會議主席之簡歷，參見圖一。大會統計，本次投稿會議論文 253 篇，與往年相當；參加總人數合計 525 人，較往年增加，以親臨瑞士琉森參加實體會議(450 人)為主，受限於疫情，計有 75 位以視訊方式參與(主要為美洲及亞洲地區之人員)。會議首日(7/5)，大會提供視訊與會者，可參加 Dr. Gunther G. Scherer 及 Dr. Jan Van herle 開設的 FCH Tutorial 訓練課程，或 Dr. André Weber 及 Dr. Dino Klotz 開設的 EIS Tutorial 訓練課程，兩項課程的排程，參考表一及表二。

7 月 5 日下午 16:00~18:00 (TPE 時間 p.m. 10:00~12:00)，舉行國際諮議委員(IBA)會議，主席為 Prof. Dr. K. Andreas Friedrich (Institute of Engineering Thermodynamics l Electrochemical Energy Technology, Stuttgart, Germany)。本項會議，採實體及視訊(Physically and Virtually)並行方式進行，Dr. Andreas 因疫情因素未克親臨會場，以視訊方式主持。會議過程中，針對國際發展情勢，燃料電池/氫能相關領域之科技研究、發展、市場需求等等不同面向進行廣泛的意見交流，從而聚焦 EFCF 論壇的因應對策及作為。其次，並就 IBA 委員的候選資格及任期，進行檢討。依據新近擬定的 IBA 規章，IBA 委員任期 6 年，得連選連任，已擔任 IBA 超過 6 年以上者，必須

重新遴選，以利於 EFCF 注入 IBA 新血，活絡相關的活動。目前 IBA 委員會有 36 位委員，如表三所示，大會列舉多人已超過 6 年任期，需重新遴選。李員為國際知名燃料電池領域專家，自 2011 年受邀擔任 IBA 委員，已超過 6 年的任期，依規章亦在重選名單之列；在本次 IBA 會議中，大會經程序邀請 13 位歐美亞地區的成員續任 IBA 委員(丹麥 3 位、英國 2 位、德國、法國、芬蘭、義大利、美國、台灣、日本、韓國等各 1 位)，為各國燃料電池領域的專家代表。亞洲地區，李員為名單委員之一，日本代表為九州大學(Kyushu University) Prof. Kazunari Sasaki；韓國代表為韓國科學技術院(Korea Advanced Institute of Science and Technology, KAIST) Prof. Joongmyeon Bae。此外，大會針對 EFCF-2023 及 EFCF-2024 的會議時間及主席團及本次會議相關資料，進行簡要說明。

7 月 6 日由論壇籌辦人 Mr. Olivier Bucheli 做開場白，說明論壇的宗旨、特色、會議主軸、會議參與者之禮節及注意事項、新冠疫情爆發後所造成的影響及 EFCF 的對策，對於上一屆論壇主辦單位丹麥 DTU Prof. Anke Hagen 及 Prof. Peter Vang Hendriksen 籌辦全程視訊會議，及本屆論壇主辦單位法國 CEA-Liten，投入的人力、物力及時間，表達謝忱；並感謝所有實體及視訊參與者的支持，共同見證 EFCF 論壇之順利進行，期待下屆會議，與會者都能實體參與在瑞士琉森舉辦的論壇，持續推廣燃料電池及氫能技術的發展。

論壇的主要議程集中於 7 月 6-8 日，概分為**技術發展**(Session A, Technology Development) 及**科技成就**(Session B, Scientific Achievements)等兩項主軸，平行進行，請參考表四及表五。為掌握國際技術的發展脈動，本次視訊會議以參加 Session A 為主。在 Session A 的議程中，口頭發表部分除了 A1201(Metal-Supported Solid Oxide Cells for Chemical Conversion, Electrolysis, and Power Production, LBNL, USA), A1505(Process Development of Synthetic Liquid Fuel Production with Solid Oxide Electrolysis Cell and FT synthesis, AIST, Japan), 及 A1605(Results of 200kW SOFC power generation using biomethane gas from wastewater treatment process, Ahahi & Kyushu, Japan)等三篇，以預錄方式發表外，其餘於現場做口頭發表。

議程於 7 月 8 日下午告一段落，由主席團做一綜合性的回顧，以科學化的圖表彙整口頭簡報及海報在各相關領域投稿的數量、主題、研究範疇等資訊，並就**後續**可投入的**重點**方向提出建議，例如:**耐久性**、**微結構分析**、**加速實驗**、**EIS/結構/化學耦合**、**物理多元耦合**及**多尺度模式**及**系統整合**等等。大會預告，低溫型燃料電池論壇 **EFCF-2023** 預定於 **2023 年 7 月 4-7 日**，於瑞士琉森 KKL 會議中心舉行，**會議主席**預定為 **Prof. Michael Eikerling** (Forchungszentrum Jülich, Germany)，請參考圖二。下一屆(第十六屆)**EFCF-2024 SOFC &SOE** 論壇定於 **2024 年 7 月 2-5 日**，於瑞士琉森 KKL 會議中心舉行，**會議主席**預定為 **Prof. Albert Tarancón** (ICREA and head of the Nanoionics and Fuel Cells group at IREC, Spain)，請參考圖三及圖四。

本次獲頒 EFCF-2022 Gold Metal(Christian Friedrich Schönbein)獎牌者為奧地利 Prof. Jürgen Fleig (Institute of Chemical Technologies and Analytics, TU Wien, Vienna/Austria)，以表彰其在 SOC

領域的卓越貢獻。Prof. Jürgen 以“Advanced tools and concepts for investigating electrode kinetics in SOCs”，就SOC內離子的傳輸動力學進行深入淺出的專題演講。最後，籌辦者Mr. Olivier Bucheli & Dr. Michael Spirig 再次提醒下屆會議的時間，期待大家能於下屆論壇於瑞士琉森再相會!

(二) 行程說明

第十五屆歐盟燃料電池論壇及燃料電池展，於 7 月 5-8 日於瑞士琉森(Lucerne)舉行，因應各國之新冠疫情尚未停歇，大會採取**實體為主、視訊為輔**方式進行。隨著全球新冠疫情趨緩，國內疫苗普及率水平達解封條件，對疫情管理採逐漸鬆綁模式，惟仍設定嚴謹隔離措施，相關之前置及行政作業能否及時完成以參與實體會議，存在高度不確定因素，爰以視訊方式全程參與本屆會議。大會以 ZOOM 為視訊交流平台，於會議開議前數小時，提供連結給視訊與會者。此外，李員於 7 月 5 日下午參加 EFCF 論壇 IBA 召開的國際諮議專家委員視訊會議，參與論壇規章、發展方向、策略等相關事宜討論，獲邀續任國際諮議委員，有利於維繫國際人脈連結、資訊交流及燃料電池技術之推廣及應用。

(三) 會議內容提要

論壇首日提供視訊參與者參與燃料電池暨氫能(FCH)或電化學阻抗頻譜儀(EIS)兩場課程之一。 論壇第二天至第四天有兩場議程(Session A 及 Session B)同步進行，請參考附件一及附件二。**Session A** 議程主要包含(1)**歐美日韓的研究進展**/合作計畫；(2)**國際**業者之**產業進展**；(3)**電池單元/電池堆**的**設計、製作、效能**及**壽命評估**；(4)**系統設計、周邊組件**(Balance of Plant, BoP)及**效能評估**；(5)**氫氣生產、電轉氣**及**電轉化學品**(Power to Gas and Power to X)；(6) **其他類型燃料**(如氨氣)；(7)**SOC 整合**系統；(8)**產品示範**及**創新**概念。**Session B** 議程著重於**科技進展**，主要包含**燃料**及**氧電極、共電解、二氧化碳電解、電池單元壽命、電池堆**及**系統**的**模型建構、質子傳導物質、連接板、鍍膜、接觸層**及**封裝材料、電池單元**的**設計**及**製造**等。本次以視訊方式，參與第十五屆歐盟燃料電池論壇，爰以參加視訊會議必須遵守之準則，就會議內容提要說明如下。

1. 燃料電池暨氫能(FCH)及電化學阻抗頻譜儀(EIS)兩場課程，分別由 Dr. Günther G. Scherer、Dr. Jan Van herle 及 Dr. André Weber、Dr. Dino Klotz 主講。燃料電池暨氫能課程包含燃料電池操作原理、熱力學、動力學、效率、中心概念(例如電解質離子導電性、電極過電位、三相介面、能斯特方程式、燃料重組、電池單元及電池堆構造及設計、不同形式燃料電池(SOFC, MCFC, PAFC, PEFC/DMFC, AFC)之特性及所使用之燃料(含化石及再生能源)。EIS 課程主要針對已對固態氧化物電池(Solid Oxide Cells)熟悉的有經驗使用者，課程含六場專題演講，包含:基本原理、進階應用至複雜案例及實際經驗，固態氧化物電池材料及電極分析、電池單元及電池堆分析、評估阻抗頻譜圖、阻抗之模擬、以及 EIS 的挑戰等。
2. EFCF 論壇於瑞士琉森舉辦，援例由瑞士聯邦能源辦公室(Swiss Federal Office of Energy, SFOE) 發言人 Dr. Stefen Oberholzer 致歡迎詞；Dr. Stefen 於簡報中表示，瑞士每年所需電

力為 300 TWh，其中 75%能源仰賴進口(包括煤炭、石油、天然氣及核能等)，天然氣供電占比約 33 TWh(15%)，65%電力為化石燃料提供，每年能源所需的費用高達 24G€歐元，佔國內生產總額(GDP)的 4%。溫室氣體排放公共運輸占 31.5%為最大宗，其次為家庭占 17.9%，工業占 10.4%，服務業及廢棄物(能源)各占 8.8%及 8.6%，合計約 77%。在氫能方面發展，2020 年六月 HYDROSPIDER AG 公司沿著瑞士北部 Gösgen 的河岸邊建造 2 MW 質子交換膜電解(Proton Exchange Membrane electrolysis)設備，每年可提供燃料電池大客車 300 噸潔淨氫氣；同時計畫在 2022 年在瑞士第三大城市 Basel 建造 2.5 MW 電解設備，預計每年可提供 260 噸潔淨氫氣給燃料電池大客車。除此之外，規劃在 2022 年九月及 2023 年分別在東北部 Wägenwaldstrasse 的代表性建築物 Kubel 及 Schiffenen 河岸建造 2 MW 質子交換膜電解設備。目前瑞士有約 50 輛燃料電池大客車，運用**燃料電池大客車**有三個主因，其一為每台大客車(以每年 30-50 次載客量計算) 每年僅需 5~7 噸的氫氣，所需的加氫站相對少，有利於**早期驗證示範**之實踐；如此，**投資成本**較低為第二層考量；其三為**政府補助**之**額度可**有效**掌控**，包含大型車費用及礦物石油稅的免稅額度；以每年四十次載客次數、里程十萬公里的大客車，每台大客車免稅額度為八萬六千歐元，加上每 100 公里消耗約 32 公升石油的兩萬三千歐元礦物石油稅金的減免。由 2020 年 6 月開始，瑞士公共加氫站由原本 1 個至 2022 年 7 月增加至 11 個 (預計 2023 年約 30 個)，而大客車數量至 2022 年 7 月已增至 46 台(預計 2022 年底可達 100 台以上)。電解產氫規模由 2020 年 6 月 2 MW 至 2022 年 7 月已達 2 MW+4.5 MW(2023 年底前可達~20 MW)。透過循序漸進的操作模式，逐步擴大氫能的應用範疇。

3. 電池堆為 SOFC 發電系統中最重要的核心組件，在本所與**台灣 SOFC 產業聯盟**(Taiwan SOFC Industry Alliance, **TSIA**)成員的共同合作下，完成一系列的電池堆測試，驗證電池單元、電池堆設計、組裝、測試之再現性及穩定性。本次投稿會議論文"**SOFC stack development at INER**"(A0608)，因未克參與實體會議，依大會建議將論文簡報由吳員以預錄方式呈現，供與會者參考，投稿之論文及簡報資料，請參見附件三及附件四。論文內容，簡要說明如下:本所在固態氧化物燃料電池之研究發展已累積多年經驗，從**粉末至發電系統** (from Powder to Power)所涉及的組件，包含電池單元、封裝材料、連接板、電池堆、觸媒、熱工組件、周邊輔助設備(Balance of Plant, BoP)及系統整合，均有一定程度之進展。由電池片、封裝材料、連接板、接觸層材料以及鍍膜層所構成的電池堆，為固態氧化物燃料電池發電系統的核心要素。透過一系列不同條件的測試可逐步掌握電池單元/堆的特性、效能，優化相關的操作程序，建置**標準作業程序**，以利**品質管控**，在相關組件效能穩定時，可達到電池堆的**一致性**及**再現性**；換言之，電池堆效能之穩定，體現各相關組件可達到所設定的功能需求。研究中，使用兩種不同形式的電池單元及連接板，進行電池堆之設計、製作、組裝及測試。其一為使用**商用陽極支撐型電池單元**(Elcogen)及商用肥粒鐵不銹鋼**連接板 Crofer22H(VDM)**，製作 5 組 30 片裝電池堆，效能測試顯示，在操作溫度 700 ℃ 下，5 組電

池堆的效能一致，電池堆的開路電壓約 33.6 V(~1.12 V/cell)，當電池堆電壓為 28.2 V(平均每片 0.94 V)，輸出**功率 1.2 kW(~330 mW/cm^2)**，驗證電池堆裝作及測試之穩定度及一致性。其二為使用**本所製作**的**金屬支撐型電池片**(Metal-supported Cells, **MSC**)及**台灣保來得**公司以**鐵鉻合金**為基材，經由公司的專利粉末冶金製程，製作成型的連接板，並藉由 TSIA 相關業者提供的封裝陶瓷墊片、保護層噴塗作業及零組件，組裝 5 組 36 片裝金屬支撐型電池堆；效能測試顯示，在操作溫度 750 ℃，5 組電池堆的效能一致，電池堆的開路電壓約 37.8 V(~1.05 V/cell)，當電池堆電壓為 30.6 V(~0.85 V/cell)，輸出**功率 1.2 kW(~420 mW/cm^2)**。對於不同來源及形式的電池單元，透過適當的**機械**、**流場設計**及**組裝程序**，可達到**一致**及**穩定**的**效能**。

4. 在本次論壇中，歐美日韓之研究近況，僅日本提供論文資料，其餘僅做摘要說明。歐盟部分由 Ms. Mirela Atanasiu (Head of Unit Operations and Communications)簡報 「EU R&I Activies on Solid Oxide technologies」， 說明歐盟 Clean Hydrogen Partnership，Clean Hydrogen Joint Undertaking 等相關資訊。資料顯示，總投入 1.08 billions€，287 個項目，主要皆與氫能相關；其中投入 SOC 研究佔總經費 17%，58 項計畫，經費 184.8 M €，所設定的 SOFC 投資成本單價，2020、2024 及 2030 年分別為 10,000、5,500 及 3,500 €per kWe，**系統電效率 47~60%，整體效率 85~90%**，系統**可用率 90~99%，電池堆 4~8 萬小時耐久性**。依據該聯盟的統計資料，2011~2021 年間，國際間在 SOFC 及 SOEC 領域發表的論文、專利，排名依序為中國、歐盟、美國、日本、韓國。之前台灣曾名列其中，不過目前已不在所列名單之上，隱示國內**研發**投入的**量能**趨於**弱化**。基礎**科技創新**研究之**短缺**，對於後續之**永續發展**，為一隱憂。藉由歐盟內部經濟、基金的互相結盟，從燃料電池/氫能的**生產製造**、**儲存分配**、**終端使用**、**橫向連結**，有著完整的**交互連結**及**佈局規劃**，形成一完整之**區域聯盟**結構，期能為歐盟創造更大的商機。

5. 美國由 Dr. William T. Gibbons(Technology Manager, U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office) 簡報「U.S. Department of Energy Hydrogen Activities Update」。依據美國能源情報署(Energy Information Administration, EIA)的資訊顯示，2022 年 4 月美國能源需求 97.8 萬億 BTU (quadrillion British thermal Unit, BTU) 初級能源端由天然氣 (~36%)、石油(~31%)、煤(~12%)、核能(~8%)、再生能源(~13%)供應。目前美國碳排約 59 億噸，主要來自運輸交通(~36%)、工業(31%)，家用及商用約佔 16%及 15%。就能源生產端而言，得力於太陽能及風機的成本逐年降低，安裝量迅速增加，再生能源的占比已高於煤及核能。資料顯示，加州於 2022 年 5 月再生能源的產量首度超過能源需求量。著眼於氫能可有效達成淨零減排的標的，美國 DOE 投資 9.5 billions US$於潔淨氫(clean hydrogen)的議題上，包含**基礎建設**、**電解產氫**、**示範驗證**、**生產回收**及區域**集氣中心**等，規劃 **2026** 年達到潔淨**氫成本 2 US$/kg**。藉由國家氫氣發展策略及藍圖，在**“Hydrogen Shot”**計畫項下，設定”111”的標的，規劃在 **10 年內**，將潔淨**氫**的生產**成本**設定為 **1 US$/kg**，展現其在氫

能發展的強烈企圖心。美國 DOE 預期在 2030、2040 及 2050 年時，每年氫能的需求量分別達到 5、20 及 50 MMT，具有龐大的商業利基。

6. 日本由產業技術綜合研究院主任資深研究員堀田照久博士(Dr. Teruhisa Horita, Director, National Institute of Advanced Industrial Science and Technology, AIST, Japan) 簡報「Recent achievements of advanced evaluation and analysis technologies for the durability of Solid Oxide Fuel Cells stacks in Japan」，就日本 NEDO(New Energy and Industrial Technology Development Organization)氫燃料電池及 SOFC 計畫進行回顧及闡述願景發展，並以具體數據呈現電池堆的長期測試的高效能表現及分析結果。**NEDO** 於 2020 啟動一新的 **Hydrogen** & **Fuel Cell Program**，2021 年經費 70 M$，包含 50 項計畫，其中 10 項與 SOFC 相關，包含質子傳輸電池單元、可逆式 SOFC、金屬支撐型電池單元、低碳排先進 SOFC 系統實地測試、及先進效能及耐久性評析技術。電池堆耐久性先進評析技術發展(Development of advanced evaluation and analysis technologies for the durability of Solid Oxide Fuel Cells stacks)的計畫主持人由 Dr. Horita 擔任，為電池堆製造商、研究機構及大專院校共提的合作計畫，研究主題有三，包含: (1) **長時效電池單元/堆效能評估**；(2) **多用途**電池單元/堆之**先進評估方法**開發；(3)**先進評析技術**之發展，該計畫的架構參見圖五。會議中，Dr. Horita 列舉 Kyocera (Flat tube)、MORIMURA (Planar)、DENSO (Planar)等三家業者不同型式電池堆之長期效能表現，參見表五，整體而言，電池堆經數千小時以上測試，燃料使用率 80%以上，電池堆的**衰退率**皆小於 **1%/kh 以下**。除傳統檢測技術外，計畫規劃開發運用**人工智慧**(Artificial Intelligence, AI)、**機器學習**(Machine Learning, ML)進行**微結構**的**演化分析**，以提升、加速計畫之進展及成效。Dr. Horita 並預告，下年度**(2023) 5 月 28 日- 6 月 1 日**將於美國**波士頓**舉辦**第十八屆 SOFC 國際研討會**(18th International Symposium on Solid Oxide Fuel Cells, SOFC-XVIII)，該研討會由美國化學學會(The Electrochemical Society, ECS)主辦，日本 SOFC 協會(The SOFC Society of Japan)長期協辦，主席為美國馬利蘭大學能源創新中心(Maryland Energy Innovation Institute)主任兼教授 Prof. Eric Wachsman， Dr. Horita 為共同主席，他邀請大家預留時間參加明年舉辦的 SOFC-XVIII 研討會。

7. 韓國原預定由南韓能源技術評估及計畫(Korean Energy Technology Evaluation and Planning, KETEP) 主任 Kisuk Chung 簡報「Overview of the Korean Hydrogen and Fuel Cell Program」，未克前往瑞士，改由 Fuel Cell Innovations 公司執行長 Dr. Tae-Won Lee 簡報「An Example of strategic industrial cooperation between Asia and MENA region for the industrialization of Hydrogen and fuel cells」。於簡報中，說明南韓設定的氫經濟藍圖，預定在 2030 年達到供應 15 GW 燃料電池的產量，達到 40%減碳量，符合韓國設定達成巴黎協定所需的國家自主減量貢獻(Nationally Determined Contributions, NDC)的減量需求。**Fuel Cell Innovations** 公司係由 Samsung 集團集結南韓 14 家公司，集資 37.3 billions US$的創投公司，主要目標為**氫能**及**燃料電池**的發展。在 Samsung 及 Posco 等集團的合作下，成立 MCFC/SOFC 及 Hybrid 技術平台，投

入產業基礎建設以建構完整的組件製造及供應鏈、累積數 MW 級發電系統的運轉及操作量能。在國際平台上，與燃料電池大廠如 FCE(FuelCell Energy)、BE(Bloom Energy)維持鏈結，加速技術的進展，投入程序開發，同步產電、生產藍氫(Blue Hydrogen)及二氧化碳捕捉，預定 2023 年生產 500 kW SOFC 電池堆應用於船舶發電系統。在 SOE(Solid Oxide Electrolyzer) 電解產氫部分，規劃 2023-2027 年，將結合再生能源及核能電廠，製作 500 kW 的 SOE 模組，以生產綠氫(Green Hydrogen)。因應全球碳減排的趨勢，中東地區為全球石油的主要生產地之一，兼具豐富的再生能源資源，體認到氫能及燃料電池的減排及商業潛力，期待引入氫能及燃料電池相關技術。南韓掌握此一契機，積極拓展與中東以及北非地區（Middle Eastand North Africa, MENA）的策略聯盟。沙烏地阿拉伯聯合大公國，將氫能認定為 2030 能源轉型的願景項目，以達到**碳循環經濟**(Circular Carbon Economy)的標的，投資額度相當於 500 billions US$。2022 年 1 月 19 日*，南韓與沙烏地阿拉伯進行策略結盟，初步簽訂共同投入於氫經濟的發展，依據協議，沙烏地阿拉伯將穩定提供碳中和的氫氣及氨氣給南韓，南韓則協助氫能車及加氫站在沙烏地阿拉伯首都利雅德(Riyadh)的穩定操作，達到互惠互利的效益。**南韓**依據其所設定的**氫及燃料電池發展藍圖**，集結**國家**、**財團**及**研究機構**的量能，持續透過**國際**之**結盟**及合作，逐步擴大其技術量能及產業規模，在國際氫能及燃料電池的舞台上，展現其不可輕忽的實力。

8. 燃料電池技術發軔於歐洲，毋庸置疑英國及歐盟各國之學界、研究機購及產業為 SOFC 發展的先行者，產學研間有很強的鏈結及合作關係。學界單位如瑞士的 École polytechnique fédérale de Lausanne(EPFL), Paul Scherrer Institute (PSI), 英國的 University of Birmingham, Imperial College, 丹麥的 Danmarks Tekniske Universitet(DTU)、德國的 Karlsruhe Institute of Technology(KIT)等, 研究機構如 Forschungszentrum Jülich, Fraunhofer Institute for Ceramic Technologies and Systems (Fraunhofer, IKTS), Deutsches Zentrum für Luft-und Raum-fahrt (DLR),法國 CEA-Liten, 荷蘭的 Energy Research Centre of the Netherlands(ECN),丹麥 Haldor Topsoe 等，為 SOFC/SOEC 的研發重鎮。

   (1) 位於愛沙尼亞(Estonia)的 Elcogen 公司，為 SOC 燃料電池單元生產之佼佼者，其產品之品質及效能優異，廣為各界採用，公司為擴大版圖，使用肥粒鐵不鏽鋼為連接板材披覆 $MnCoO_4$ 保護層，已開發 elcoStack®E3000 電池堆產品，參見圖六、**Elcogen** 製作的 **elcoStack® E3000 (119** 片電池單元，空氣通道)及電流、電壓功率曲線。在驗證產品的優異效能後，Elcogen 公司於愛沙尼亞擴廠，占地 10,000 m^2，預定 2023/2024 達到 年產 50 MW(SOFC)/200 MW(SOEC)的規模，現有的場地將專注於 R&D 開發。此外，德國精密陶瓷公司 Kerafol 為電池單元的供應者之一。

   (2) 目前，歐洲地區投入 SOC 開發的廠家，主要包含: Hexis(瑞士)、SOLIDpower(瑞士、義大利、德國)、CeresPower(英國)、Bosch(德國)、AVL(德國、跨國)、Sunfire(德國)等，各業者各擅其長，除原先既有之 SOFC 研發外，著眼於再生能源之迅速增長，對儲能的

*:https://energy.economictimes.indiatimes.com/news/renewable/south-korea-saudi-arabia-agree-to- jointly-develop-hydrogen-economy/88996235

需求日殷，以 SOE 具有高效能源轉換的特性，自然成為研發及應用重點項目，包含**電轉氣**(Power to Gas, PtG)、**電轉液態燃料**(Power to Liquid, PtL)，**電轉化學品**(Power to X, PtX)。由於能源屬全球普遍需面臨的共通議題，歐洲相關業者，以歐洲為基地，從**資金流**、**物料資源**、**技術互補**、**市場規模**及**通路**等面向，尋求國際間之**異業結盟**、連結與合作，以擴大其**市場占有率**及**規模**放大。

(3) 瑞士 **Hexis** 上一代產品 **Galileo 1000 N** 1 kW SOFC 發電系統，具有高的熱能效益，在微熱電(micro-Combined Heat and Power, μCHP)系統的應用上具有利基，現已與德國熱水器業者菲斯曼(Viessmann)結盟合作。目前開發的 **Loenardo**，電力輸出 1.5 kW，電效率提高至 40%，整體效率 95%，除瑞士、德國市場外，並與義大利、美國、南韓等相關業者結合，開拓**微熱電共生**(micro-Combined Heat and Power, μCHP)系統的市場。

(4) 英國 **Ceres Power** 的核心技術源自英國Imperial College, London，於 2001 年從 Imperial College 分離(spin-off)成立公司，其所開發的**金屬支撐**型燃料電池，屬**中低溫型**(570-610 ℃)的 SOFC 發電系統，具有**高功率密度**、**耐熱震**、**熱循環**的優勢，相較於陶瓷支撐型電池單元，具有較佳的熱傳導性、機械延展性等優勢，其金屬支撐板材質為使用雷射加工製作微孔的肥粒鐵不鏽鋼，系統規格現階段以 10 kW 發電系統為主。著眼於新興能源市場的拓展，Ceres Power 與總部位於德國的跨國際公司 Bosch、AVL 高度的連結，Bosch 規劃至 2024 年累積投資 400 M€於 SOFC 技術開發，安裝 100 套 SOFC 發電示範系統；日本三浦集團(Miura)自 2016 年即與 Ceres Power 合作，2020 年 3 月宣布擴大與 Ceres Power 的合作關係，成立特別部門與 Cere Power 合作拓展日本的 μCHP 市場，燃料電池 FC-5b，使用都市的天然氣為燃料源(0.75Nm^3/h)，額定發電量 4.2 kW， 熱回收 3.4 kW，發電效率 50%，整體效率 90%。2018 年 5 月 16 日，中國濰柴集團規劃投資 4 千萬英鎊，認購持股比例 20%，與 Ceres Power 成立合資公司，在 SOFC 領域展開全面合作；目前雙方規劃開發 30 kW 定置型模組，然後擴大至交通載具之合作。2020 年 10 月，韓國斗山(Doosan)集團下的燃料電池部門與 Ceres Power 簽下合作協議，規劃建置 50 MW SOFC 燃料電池堆的量產工廠，目前設定開發 10 kW 系統，預定今年進行商品化的試運行。此外，Ceres Power 於今年 6 月 28 日，與石油業巨頭殼牌(Shell) 簽訂以 SOEC 方式生產綠氫的合作協議，預定生產地在印度卡納塔克邦(Karnataka)的首府班加羅爾(Bangalore)，綠氫生產規模為 1 MW，預定於 2023 年完成該 SOEC 示範驗證系統。

(5) 義大利專門從事披覆技術開發於渦輪、機械、及生物科技的 Eurocoating-Turbocoating 集團，著眼於 SOFC 技術具有龐大的未來商機，於 2006 年成立 SOFCpower 公司，規劃專注於 SOFC 技術之開發及應用，該公司於 2007 年初，完全併購由 EPFL 於 2000 年分離出來的 **HTCeramix** 燃料電池公司，隨即於 2008 年在義大利梅佐隆巴爾多(Mezzolombardo)建置先導工廠，小規模量產電池單元、電池堆及發電示範驗證系統；2014 年，配合第

二組生產設施的完成，公司進行品牌重塑，更名為 **SOLIDpower**。2015 年澳洲 CFCL 公司資金調度、財務出現瓶頸，SOLIDpower 出手，**買下 CFCL** 在德國的資產及承接相關的技術人員，藉由公司**的資金挹注**結合 CFCL 既有人力的**技術能量**，迅速達成多項顯著的里程碑。在解決財務問題後，原 CFCL 公司位於德國 Heinsberg 的 BlueGEN 產線重啟，並於 2016 年初提供產品至歐洲的使用端。藉由集團的**人脈連結**，與歐盟各主要研究團隊，均有密切的合作及連結。陸續與石油巨頭 Shell、跨國電腦科技公司微軟(Microsoft)、跨國工程和電子集團博世(Bosch) 結盟。於 2020 年，於義大利佩爾吉內(Pergine)建置電池堆全自動化生產製造廠，每日可生產 60 組電池堆，為目前歐洲地區最大的電池堆生產基地，大型電池堆模組，並可用於電解產氫。新近並積極與電信及關鍵基礎設備業者如 Equinix、Vertiv，合作邊緣資料中心(Edge Data Center, EDC)之研究合作，嘗試將技術與 5G 與物聯網之發展做連結。集團評估認為，氫能為達成減排的關鍵之一，綠氫透過 SOE 生產，為最低電力能耗的電解技術(40 kWh/kg)，在 2030 年時，預估容量達 100 GW，綠氫的生產需求，預估以年成長率 7%逐年增加。SOLIDpower 公司表示，其將持續在 Gas to Power、Power to Gas 及 Power to Power 做技術上的精進，掌握相關的關鍵技術，提供電池堆、電解模組到系統整合的解決方案，涵蓋**設計**(Engineering)、**採購**(Procurement)及**施工**(Construction)等 3 個面向(**EPC**)，為此領域合作開發的最佳夥伴之一。

(6) 本次會議，德國 Sunfire 公司原提報大會簡報「Status of Stack & System Development at Sunfire」，因故未出席；由 Shell 公司 Dr.-ing Srikanth Santhanam 簡報「Hydrogen's Role in Shell's Journey to Net-zero」。Dr.-ing Santhanam 表示，雖然 Shell 公司在今年 6 月初的運轉計畫及財報並未將公司達到淨零碳排的企圖具體呈現，但因應全球淨零碳排的發展趨勢，後續會進行修訂。Shell 將目標設定為:配合社會及顧客端的進展狀況達成符合聯合國巴黎協定，在 2050 前成為淨零碳排的能源企業體。Shell 公司評估認為，氫氣為未來能源系統主要的能源載體，對於再生能源的規模放大及拓展、能源分散系統、緩衝及儲能系統，可有效提高能源系統的韌性；在去碳的交通運輸、工業能源使用、建築、氣網基礎建設、農業肥料、精煉、化學工業品等等，均有賴於納入氫能系統，以竟其功。簡報過程中，他指出 Shell 公司具有充分的能力可在**氫經濟**上獲得成功，關鍵在於，其具有(i)強而有力的**合作夥伴**及寬廣的**通路**；(ii)具有豐富的**程序安全**經驗；(iii)計畫**執行力**充足；(iv)具有數十年氫氣的**運轉實務**經驗；(v)從**生產端**到**供應端**可提供完整的**整合**；(vi)公司在氫能的**創新**、**研究發展**持續維持投資；(vii)與各**政府部門**維持**可信賴**的良好**夥伴**關係。在氫經濟的發展上，他指出仍然面臨兩大挑戰，其一為**成本**，就現階段而言，藍氫(Blue Hydrogen)及綠氫(Green Hydrogen)仍不具成本競爭力，需藉由提高工業**生產規模**以利於降低成本單價、政府需提供**獎勵措施**及**政策**以鼓勵投資、**產學研**間之**合作**以創新技術、氫能**基礎建設**及車**輛生產**者需互相配及到位；其二

為**供應端及需求端的供需平衡**，客觀上，只有在需求端建立新的氫能需求時，氫經濟才有可能逐步建立及成功運作，其次供需端需同步配合**基礎建設**逐步發展到位及擴展；氫經濟的規模及發展，不僅涉及公私部門之間的協調作業，其層面擴及區域、國家及國際社會間的彼此連動。據此，Shell 在策略上設定自身為在氫經濟社會中交通載具及工業氫能應用平台，為跨國的氫氣主要供應者，為氫能需求端提供最佳化的**綠氫供應**及分配網絡；除了擴大綠氫的生產規模外，在技術層面上，並持續投入藍氫相關技術之研發以加速能源轉型至綠氫產業鏈。在做法上，將與顧客端及合作廠家緊密合作，開發完整的系統解決方案(end-to-end solutions)，與政府及立法者的對話以尋求**政策**的**支持**，公司內部的**氫能需求**以促進市場的成長，降低**氫成本**單價達到具經濟可行，在相關作業上，並須呈現**氫**能的**安全性**，取得**民眾**的**信心**，以利於氫能的普及應用。著眼於歐洲、北美及亞洲的市場發展趨勢，Shell 積極與各區域的業者結盟及合作，建立各處的連結及基地。2020 年 9 月 Shell 與張家口運輸建設投資集團合資，使用陸域風機提供再生能源，進行 20 MW 電解產氫設施的建置，經過 13 個月的施工及運轉試車，於 2022 年初開始運轉，提供燃料電池車所需之氫氣，後續規劃將規模放大至 50~100 MW，供應北京、天津區域所需的市場需求，期能有效降低汽車的排碳量，達到低碳及碳中和的標的。藉由歐盟計畫的資助，Shell 在德國 RefHyne 地區建立 10 MW 的 PEM 電解槽產氫，以逐步取代殼牌萊茵煉油廠(Shell Rhineland Refinery)所使用的灰氫(源自天然氣蒸氣重組生產的氫氣)，目前並規劃與英國 ITM 能源公司合作的可能性，將規模放大到 100 MW。Shell 與荷蘭能源公司 Eneco 組成的合資財團 Crosswind 開發公司，利用荷蘭 Kust 風場(設置容量 759 MW)提供的再生能源，預計於 2023 年於荷蘭第二大城鹿特丹（Rotterdam）碼頭，建置 200 MW 的電解場，預計每日可提供 50,000~60,000 kg 的綠氫，取代原先煉製廠所使用的灰氫，未來並可用於燃料電池卡車。在 2021 年 1 月 21 日， **Shell**、日本三菱重工集團(Mitsubishi Heavy Industries, **MHI**)與瑞典 **Vattenfall** 電力公司與德國市政公司 **Wärme Hamburg** 四方簽訂**合作**意向書，規劃利用德國 Hamburg-Moorburg 電廠(再生能源:太陽能及風能)產生的電力，於德國漢堡(Hamburg)建置 100 MW 的電解產氫設施，預計每年產氫量 11,500 噸，每年減少的二氧化碳排放量 92,000 噸，該設施預計 2025 年商轉，Hamburg Green Hydrogen Hub 的架構圖，請參考圖七。更進一步，荷蘭氣體聯合中心 Gasubie, Groningen Seaports, 德國 RWE 電力及天然氣公司、挪威 Equinor 國家石油公司及荷蘭 Shell，跨國集資於 2020 年宣布成立 NortH$_2$計畫，利用離岸風力產生的再生能源，在 2030 年達到 3-4 GW，2040 年 10 GW 以上，綠氫在 2040 年的年產量達 1 百萬噸，每年減少的排碳量 8~10 百萬噸。

(7) 2010 年全球新能源燃料及鋼鐵行業巨頭 Neste and SMS Group 投資集團，於德國成立 Sunfire 公司，翌年併購專注於 SOFC 研發及應用的 STAXERA GMBH 公司(2003 年 Bayer 集團旗下的 HC-Starck 及汽車大廠 Webasto AG 集團以 50/50 股份合資成立)，做為拓展

至 SOFC/SOEC 的核心技術源頭。以此為基礎，公司並拓展研發領域至離網電力系統解決方案之建置，可進行遠端調控在惡劣環境下的能源調度。Sunfire 公司為歐洲地區少數一開始設定推出即為 25 kW 以上的 SOFC/SOEC 系統；公司於 2012 年，推出 SOEC 電解示範雛形，並與波音公司進行電解電池之合作；2014 年於德國德累斯頓(Dresden)展示電轉液態燃料(Power to Liquid, PtL)的示範系統，將水及二氧化碳合成為再生燃料，如生質柴油、石腦油(naphtha)及蠟油等。2016 年，在歐盟 FCH-JU 資助框架下，與德國設備製造商 Salzgitter Flachstahl GmbH 合作成立 GrInHy 計畫，其中德國政府並提供第一期計畫 Kopernikus program "Power-to-X" 的 資金挹注。隨著第一期計畫之順利執行，第二期 "Power-to-X" MultiPLHY 計畫於 2020 年開始推行，合作對象增加法國研究機構 CEA、全球工程及技術顧問巨頭盧森堡的保沃思(Paul Wurth)公司、法國 ENGIE 能源集團，與歐盟從事低碳能源的產官研進行結盟合作。2020 年 6 月，Sunfire 與瑞士 Climeworks 公司(專業溫室氣體研究)， Paul Wurth SA (SMS group) and Valinor 電訊公司，合作建置全球第一套工業化電轉液(PtL)，生產再生能源燃料。基於 SOEC 具有優異的能源轉換效率，而再生能源的間歇性供應，及工業廢熱的妥善應用，德國政府及企業體認到因應歐盟 **2050** 年**低碳社會**的標的，將**再生能源轉換**成**潔淨氫能**為**能源轉型成功**的關鍵之一。在 GrInHy 計畫中，將利用綠電及工業廢熱，產生綠氫及氧氣，並應用至煉鋼及工業用途，達到低碳及減碳的效益，參考圖八。2018 年，Sunfire 拓展其燃料電池事業的版圖，承包德國新勃蘭登堡(Neubrandenburg)城的家用微熱電及遠端離網電力系統。2021 年 1 月，Sunfire 為拓展其事業版圖，併購瑞士鹼性電解(alkaline electrolyzers)IHT 公司，**IHT** 為全球鹼性電解的先導者，具有 70 年以上歷史，電解廠容量 240 MW。如此 Sunfire 同時持有**傳統鹼性電解**及高效的 **SOEC 電解**技術，在氫能的運用上更具彈性，可依據場域需求提供最佳的解決方案。2022 年 1 月， Sunfire 併購位於德國索林根(Solingen) MTV NT GmbH 電鍍廠，其為全球大組件表面功能鍍層的領先者，以配合併購 IHT 後所需的配件產能需求。此外，Sunfire 持續擴大其投資，從 Lightrock and Planet First Partners, Carbon Direct Capital Management, HydrogenOne Capital, Copenhagen Infrastructure Partners (CIP) and Blue Earth Capital 等，迄 2022 年，已成功集資超過 210 M US$。客觀上，藉由**企業**間之**合作、結盟、集資**，已形成**卡特爾**(Cartel)**集團**的模式。

(8) 2012 年芬蘭 VNT 投資公司、Wärtsilä 公司及個別投資者，合資成立 Convion 公司，專注於燃料電池系統開發，翌年接收芬蘭 Wärtsilä 燃料電池公司。接續之前提供義大利業者 50 kW 發電系統的示範驗證，本次會議公司聯合創始人 Kim Åström 說明 Convion 目前開發的 C60 系統，可採 SOFC 及 SOEC 模式運行。若以天然氣、生質氣或氫氣為燃料，可產生 60 kW 的電力，若以水蒸氣及功率為輸入(C250e)，則為 250 kW 的電解系統，可產生氫氣及熱供下游端使用。目前使用的電池堆採用 Elcogen 電池單元製作，

示範驗證系統已安置在芬蘭及中國大陸進行。Kim 表示，由於疫情影響，Convion 與中方的工程師透過視訊、電郵等非接觸方式，完成 C60 發電系統於大陸地區的安裝及測試，效能符合預期。2022 年 4 月，Convion 與愛沙尼亞生產生質甲烷的先鋒 Biometaan OÜ 公司達成合作協議，Convion 將提供 C60 發電系統，以 Biometaan OÜ 由農業廢棄物生產的生質甲烷為燃料，進行生質氣體之熱電共生燃料電池發電系統之驗證測試。Kim 並表示，該公司原設計、製作的 C50 發電系統，經過長期的試驗及修正，C60 系統設計已做精簡化及效能提升，操作上極具彈性，其所設計的系統較其他業者減少 67%的功能組件，參考圖九，沒有熱泵、只使用 1 組熱交換器、無須外接水源、電池堆為對稱性架構、熱整合簡單、低熱損、多元燃料之彈性、系統固有的安全性高，其可靠度及效能高，可有效降低整體成本。在 60 kW-AC 電力輸出情況下，電效率 60%(LHV)以上，熱輸出 27 kW(出口端溫度 40 ℃)，整體效率 85%(LHV)；使用 Elcogen E-3000 電池堆，經 20,000 hr 測試，衰減率 0.4~0.6%/kh。在此基礎上，Convion 將使用同樣的組件，製作 C250 SOE 電解系統，以降低資本投資並提高設備之使用效率，預計在 2023 年完成 C250 的先導驗證系統。藉由系統之持續精進及驗證，Convion 在歐盟 FCH 的框架下，積極參與研發計畫，如 DEMOSOFC、INNOSOFC、LEMENE、NESTE 計畫等等，與歐盟相關成員進行密切合作，如:IKTS、Elcogen、Sunfire，在亞洲地區與韓國簽訂合作備忘錄，與中國南方電網集團進行燃料電池之開發及合作。Convion 並規劃將系統放大至 MW 級系統，以拓展燃料電池領域的商機。

(9) 法國為當前全球使用核能占比最高的國家，法國原子能和替代能源委員會(Commissariat à l'énergie atomique et aux énergies alternatives, CEA)所屬 Liten 研究中心，因應全球低碳社會之發展趨勢，從**提高能源效率**及**循環經濟**的視角，積極投入新能源及能源轉型相關領域之研發，主要包括: **太陽能**、**電網管理**、**二次電池**及**氫能**的發展及應用。著眼於技術的整合發展及商機，一批在法國 CEA-Liten 有數十年研發經驗的技術人才，於 2015 年 6 月自該研究中心分離(spin-off)出來，成立 **Sylfen** 公司，持續運用 CEA-Liten 所開發的技術及專利，建置智能能源中心(Smart Energy Hub)，提供或協助顧客端就能源的規劃、使用一套完整的且具彈性的解決方案。 2021 年 3 月，基於低碳社會的挑戰，運用 CEA 開發的 40 項專利及 15 年以上的研發經驗，CEA 研究中心、跨國石油服務公司 Schlumberger 、及法國建築製造業 ARIS、VINCI、VICAT 等 5 家公民營企業體，合資成立 **GENVIA** 創投公司，目前成員約 60 名，針對工業減碳的議題，提出解決方案；其核心乃就 SOE 所需的資金、電池單元、電池堆、系統及製造等，提供整體性的評析及整合。依目前的規劃，位於格勒諾布爾(Grenoble)的 CEA-Liten 仍為研發中心，電池堆及系統於法國南部貝濟耶(Béziers)製造，系統工程由位於克拉馬(Clamart)的 Schlumberger 負責，計畫推展採分工統合方式進行。目前正進行 4 組電池堆的發電級電解測試，並著手先導廠房的設計，規劃在 2024 年完成每天 200 kg 氫能生產的示範驗證

測試，預定在 2026 年建置 GW 級的 SOE 電解廠，成立再生氫能中心，提供綠氫供業界使用。在本次會議中，Sylfen 生產部門主管 Marc Potron 指出，在歐盟建築相關設施所使用的能源消耗約佔 40%，二氧化碳的排放量約占 36%，因此若能善用區域安置再生能源與當地的建築做結合，將可有效降低建築所衍生的二氧化碳排放；在他所列舉的案例中，藉由**智能能源管理**中心，整合**太陽能**、**低耗能建築**及**可逆式 SOFC** 發電系統，可進行電能及熱能的智能調控；其中 4 組各 10 kW 的電池堆，可提供 40 kW 的調度，可在 SOEC/SOFC 或熱機運轉模式下調度，以提供**穩定**的**熱電來源**，預期在 2024 年，所製作的 SOEC 可提供 400 kW 的調度空間，增加智能能源中心的調度空間。

以上僅就歐盟現階段幾個主要投入 SOE 產業團隊做梗概說明，其他如 AVL、Topsoe、IKTS、Julich、CEA、EPFL、PSI、DTU 等等，各有其專長、特色，不一一論述。

9. 本次會議，麥肯錫公司(McKinsey & Company) Dr. Sebastian Mayer 就 2030 氫能的機會(The 2030 Hydrogen Opportunity)進行廣泛而深入的評析。依據 McKinsey 的分析[(2)]，截至 2021 年底前，已有 93 個國家採納淨零的目標，39 個國家採取氫能策略，預估至 **2050** 氫能**累積**的**減碳量**可達 **80 GT**(Giga-tons)，氫能在各能源使用端，累計的減碳量，請參考圖十。2050 年時，氫能所貢獻的減碳量 7 GT，約占 2050 減碳量需求的 20%，對應的乾淨氫氣產量**需求**為 **660 MT**(million metric tons, 百萬噸)，相當於全球能源需求的 22%，參考圖十一、麥肯錫預估氫能在各能源使用端至 2050 年之需求量。以目前氫氣的使用量約 90 MT，氫氣的需求量有 7~8 倍的成長需求量。雖則，全球對氫能的願景滿懷期待，也陸續提出中大型開發及應用計畫；依據 2021 年底 McKinsey 評析顯示，在現有 160 billion US$的投資計畫中，僅有約 13%的計畫通過**最終**的**投資決定**(Final investment decision, **FID**)，其餘的仍處於**可行性研究**、**前端工程設計**(Front-end engineering and design, **FEED**)階段，或者等待法規鬆綁，再做投資規劃。McKinsey 評估， 至 2030 年，在氫氣生產、基礎設施建置及終端使用，所需的投資額度分別需 300、200、200 billion US$，亦即需要 **700 billion US$**的投資，方能達到 2030 年的氫能運用及減碳標的，扣除現有規劃投資的 160 billion US$，仍有 **540 billion US$** 的**資金缺口**。隨著再生能源規模放大及產氫技術的持續精進，綠氫及藍氫(with CCS)的單價成本，至 2050 年約 1~1.5 US$/kg；灰氫的成本單價，由於石化資源日趨減少，再納入減碳成本，至 2050 年約 3~4 US$/kg，預估其成本反而比乾淨氫高。McKinsey 預估，不同氫能供應來源的組合，從 2020 至 2050 的演化圖，參考圖十二；長期而言，**綠氫將成為氫氣供應的主力**。就電解產氫部分，鹼金屬電解(Alkaline Water Electrolysis, **AWE**)具成熟產氫技術的優勢，為現階段產氫的主力；惟隨著技術的持續精進及規模放大，高分子電解膜(Polymer Electrolyte Membrane, **PEM**)電解，及固態氧化電解池(Solide Oxide Electrolysis Cell, **SOEC**)電解產氫，在投資成本上，會逐漸拉近，概估三者之投資成本落在 230~500 US$/kW。其中，SOEC 操作在高溫下，為三者間能源轉換最高者，並可共解水及二氧化碳，產生碳氫合成氣、液化燃料、化學品原料，具有最高的熱電效益，為後勢看好的能源技術。一方

面各方看好氫能的願景發展，但氫能的放大應用，亦有潛在的風險及挑戰。Dr. Sebastian Mayer 於會議中指出，在**氫能規模擴大**應用時，將面臨 **5 項挑戰**，(1) **財務金融上不確定因素高**，目前氫能及技術發展計畫，大多仍屬早期規劃階段，國際對氫能的大規模應用，其效能如何，仍無太多經驗，承購及資金流不確定，財務的運作機制不確定因素高，例如:風險分擔及信用評比機制，尚付闕如。(2)**欠缺完整產業供應鏈**，因應規模的急遽擴大，如何迅速提供高量、可靠的產品，再者原物料的短缺及高漲，與原預期的市場成長會有落差。(3)**法規的鬆綁及協調**，氫經濟為嶄新的能源技術應用，現有的法規、規範不完全適用，須做修正及調整；一方面尋求法規的鬆綁，另一方面法規必須趨於嚴謹，一來一去之間，法規的界定範圍仍存在高度不確定，相關設施取得操作運轉執照，會是冗長的過程；現階段，業者一方面表示看好氫經濟的願景，不會缺席此一領域的投資與商機，但多採取觀望態度，降低投資的風險。(4)**欠缺氫能大規模儲存及運輸的基礎建設**，實務上，現有的天然氣管線、輸油管線，因氫氣與該等碳氫化合物之物理及化學特性迴異，歐盟現有基礎建設規範須做通盤的檢討，包含管線網絡、碼頭接受站、儲存設施等等，建構符合氫氣安全儲存、運輸的基礎設施，期使供應端及需求端皆能在安全無虞條件下，穩定、安全運作。(5) **消弭大型計畫的風險**，目前執行中的大型計畫，主要利用既有的基礎設施進行氫氣的儲存及傳輸，要確保這些大型計畫之順利施行，該等設施的可靠度必須能確保，再者必須有穩定及無間斷的再生能源供應，安全面上民眾及操作人員必須免於暴露於事故發生的潛在風險；這些大型計畫的示範驗證，為後續規模放大的必要作為。

三、心得

(一) 歐盟燃料電池論壇於 1994 年開始舉辦，持續至今已 28 年，本年度(2022)為第十五屆高溫型燃料電池論壇。2020 年初，COVID-19 新冠疫情爆發，因形勢嚴峻，第十四屆論壇首次採用全視訊方式進行。2021 年 7 月 1 日歐盟正式啟用「歐盟數位新冠肺炎證明」，以簡化歐盟成員國入境旅客之通關查驗，惟迄 2022 年初，各方對疫情的可能演化情況，仍存在高度的不確定因素。論壇籌辦單位，為鼓勵各界人士參加，於論壇平台上，說明因應疫情的不確定因素，若報名後無法參加，論壇將全額退費(fully reimbursement)；本屆參加人員，突破過往，除實體參加會議 450 人外，另有 75 名以視訊會議參加，論壇在相關作業上兼顧了各方不同的需求。一方面，EFCF 長期建立的聲譽，已普為各界所認同；其因應不同及特殊情境況，即時採取相對應的**彈性措施**，亦可為舉辦大型國際會議之參考。因主客觀及不確定因素的考量，本屆未能參與實體會議，與國際各領域專家面對面的交流；藉由視訊會議，掌握國際間氫能及燃料領域的發展現狀及趨勢，可做為後續技術發展、研發策略擬定之參考。

(二) 自 2020 年初全球爆發 COVID-19新冠肺炎疫情，迄今已逾兩年半，由於新冠病毒具高的**基本傳播數**(Basic reproductive number, R_o)，且人類對病毒特性仍未掌握，對年長或抵抗力弱者，會衍生較高比例的傷亡及重症。初期各國乃採取邊界隔離、封城封市等等措施，以降低病毒的蔓延，由於疫情嚴峻，各國及不同族群間交相詰責，此起彼落；另一方面，各國之醫療研發團隊，從 5 條不同路徑(**減活**、**基因重組**、**腺病毒**、**減毒流感**、**核酸**(RNA))，尋求可資運用的疫苗，在不到 1 年的時間內，即開發出具有療效或降低病毒感染引發重症風險的疫苗；在經過實驗室、動物實驗後，確認疫苗的安全性及初步成效，各國政府陸續以緊急使用授權(Emergency Use Authorization, **EUA**)機制，加速核准疫苗施打，以維護民眾的健康。台灣曾在 2003 年，面臨嚴重急性呼吸道症候群（Severe Acute Respiratory Syndrome, SARS）的肆虐，所幸處置得宜，很快的將 SARS 疫情所可能引發的衝擊，迅速消弭；藉由 SARS 疫情的演練，累積了處理高傳染疾病的應對方法，並對防疫體系做了革新。面對此次高傳染力的 COVID-19 病毒，由於台灣各都會間交通便捷，屬 1 日來回共同生活圈的範圍，採取封城封市是不切合實際的；若然社會的動能可能瞬時靜滯，需付出極高的社會成本。儘管在疫情之初，對於病毒特性仍未掌握且欠缺疫苗可資運用，藉由處理 SARS 所**累積的經驗**及**防疫體系**革新並善用**電信網絡**普及化的優勢，政府採取一系列的**非藥物介入措施** (Non-pharmaceutical interventions, NPI)，包含:防疫旅館、居家隔離、口罩、維持社交距離、衛生教育、環境消毒、個人防護、自主健康管理、旅遊限制等等，配合精準疫調模式，大幅抑低病毒的**有效傳播數**（Effective reproductive number, R_t），紓緩因疫情對大多數人生活上的影響。在此一波全球疫情中，台灣有效抑低疫情衝擊，成為國際間防疫成功的典範之一[3]。防疫的成效，有賴政府在**政策**上的**設定**、**第一線防疫及醫療人員**

無私及**辛勤**的付出、及**國民**的**高素質配合**，方能達成，是大家共體時艱的成果。防疫歷經**前兩階段(中斷病毒傳染、提升族群免疫力)**，疫苗施打率普遍提高(在 2022 年 6 月下旬，第一劑及第二劑疫苗施打率分別達到 91%及 83%)，考量台灣在相關作業上須與國際接軌，疫情進入防疫**第三階段**，以**減少重症傷亡**為重點，在此階段，疫情朝向流感化，雖染疫人數階段性陡增，但整體上無症狀及輕症占比在 99.5%以上，因疫情死亡者，在全球各國中，屬於最低程度者之一。

1. 在此波疫情中，對於因疫而逝者，我們深表不捨與哀悼。另一方面，全球病毒肆虐，或許也是**大自然**對人類長期漠視及破壞環境的**反撲**。宏觀上，病毒與細菌為地球上生命的主體之一，存在於地球至少已有數億年之久，與地球上不同的生命體相互依存，是維護生物圈正常運行的必要組成。人類在地球上，屬於生物鏈之一環，暫時成為地球的霸主。自 18 世紀工業革命以來，科技、工藝、醫療水平的大幅提升，加速人類文明的進展，平均壽命顯著增長；彼時，人們對於地球**資源**之**有限性**及**環境永續經營**之概念，尚屬啟蒙、未明階段，乃恣意擷取、揮霍地球上的寶貴資源，不斷開拓土地、森林、破壞雨林，擠壓地球上其他物種既有的生存空間，導致物種大滅絕；地球由多樣、多元生物所建構相互依存的**生命之網**有了大破口，其結果為地球上現存的物種可能因生命之網的崩解，無一倖存。再者，工業革命後，人類急遽消耗地球上累積億萬年的化石燃料，擷取部分能量並大量釋出**廢熱**及**溫室氣體**，地球整體的**熱平衡**受到擾動，**全球碳循環**及**全球水循環**失衡，**熱汙染**(Thermal Pollution)的議題未曾稍歇。往者已矣，目前普遍認知地球環境的失衡，主要是**人為因素**造成的。因此，採取與環境友好的因應措施，**節能**、**減碳**並達到**零碳排**的標的，期能在環境尚在可調控的條件下，及時撥亂反正，**道法自然**，以利生命及環境之永續經營，是當下人類必須承擔的責任。畢竟在蒼芎的宇宙星系中，這顆**蔚藍**的**星球**是**人類與各生命體共存共榮的家園**!
2. 當我們評析，全球整體及歐美亞地區各國疫情演化的統計資料，可發現各國 COVID-19 疫情的峰期發生時間雖不盡相同，但疫情演化的**統計模樣**(Statistical Pattern)相似度高，主要差別在**時間延遲**上，有明顯的差異。筆者評析，此一差異與東西方文化上的差異有極大的關聯性；東方以**群體制約**為先，以群體的力量，要求個體須遵循規範而行；西方強調個體，崇尚**個人自由主義**。在 2020 年初疫情爆發之初，各國咸認台灣首當其衝，疫情可能迅速蔓延，但在政府設定相關的 NPI 規範後，疫情的發展受到嚴謹的管控；直至進入防疫第三階段後，改採以與病毒共存的運作模式，縮短潛在病患的隔離期，乃於 2022 年 4-7 月出現疫情的峰期。客觀而言，台灣將疫情爆發的峰值延後了兩年發生，此時，全球對病毒的特性已有所掌握，疫苗覆蓋率高，病毒核酸檢測聚合酶鏈反應(Polymerase Chain Reaction, PCR)被普及採用，已有抗病毒藥物可資運用。此一**延遲效果**，有效**降低疫情**的**衝擊**，為**群眾**的**健康**提供更大的保障。另一方面，在後疫情時代，可針對疫情演進過程中所採取的各項緊急公衛措施與群眾健康做整體效益評析及經驗傳承，做為未來因

應大型傳染疾病作業的參考[4,5]。配合防疫所採取的一系列 NPI 措施，其必要性及有效性，或可再做科學**參數化**的**檢討**(Parametric evaluation)，例如: 疫苗施打後之有效期限為何?不同疫苗施打組合的效用為何?在高疫苗覆蓋率情況下，NPI 各項措施其參數化後的效用占比為何?例如:巨量的口罩消耗亦為整體資源減量之一環(含使用後的廢棄物處理)，或可重新檢視各項 NPI 措施，逐步鬆綁，回歸正常生活。

3. 因應 2020 年初新冠肺炎疫情的爆發，政府除採取一系列的 NPI 措施外，並支持業者開發國產疫苗。2020 年 5 月，高端疫苗生物製劑公司表示，已獲得美國國家衛生研究院（National Institutes of Health, NIH）的授權，技轉基因重組 S-2P 棘蛋白，合作開發新冠肺炎疫苗抗原。2021 年 5 月底，高端宣布國產疫苗 2 期解盲成功，並擬逕予申請緊急使用授權(EUA)，以因應當時國內陡升的疫情。國產疫苗在尚未完成第三期試驗，即直接申請 EUA，自有國內特殊社會、經濟及專業層面上的考量，其利弊得失，見仁見智，不做論述。客觀而言，在 2021 年 5 月國內疫情陡升之際，國際上已有多組通過 3 期試驗過的疫苗(如:AZ、BNT、莫德納等)廣為各國採用，確定其安全性及效力；國產疫苗開發之初由於國內確診案例低，缺乏足夠的案例執行第三期試驗，**時序**上**落於後手**，在推行上有較高的難度；其次，不同貨源疫苗之取得及施打，涉及藥商及代理商及不同利益團體彼此間之**商業利益**，添加相關作業上的難度。無論如何，透過科學上的**實務認證**，確保疫苗的安全性及有效性，仍是必經的歷程。2022 年 6 月，世界衛生組織(World Health Organization, WHO）挑選高端 COVID-19 疫苗為全球疫苗團結第三期試驗的首項指標性個案，並由 WHO 兩組獨立的統計學團隊進行試驗解盲與資料分析程序。2022 年 7 月，巴拉圭亞松森大學醫學院院長 Osmar Manuel Cuenca 表示，高端疫苗臨床實驗及研究數據顯示，疫苗成效良好，為該國第一個完成三期實驗的 COVID-19 疫苗。我們樂見，站在第一線的科研人員，經由一點一滴的經營積累，終能呈現長期努力的亮麗成果。國內之生技、科研人才濟濟，預期**生技產業**應是國內可**長期經營**、**投入**之重點科技項目。

(三) 因應全球暖化，淨零減排成為普世的共識，國際各國在巴黎協定的框架上，設定國家自主減量貢獻(Nationally Determined Contributions, NDC)，先進國家紛紛設定 2050 淨零減排的目標。**固態氧化物電池/電解技術**，具有**能量轉換效能高**、可採用**多元燃料**、可**共電解**選擇性水蒸氣及二氧化碳產生氫氣及合成氣，在**節能減碳**、**能源轉型**及**低碳社會**議題，可做出貢獻，為淨零減排路徑上，可資運用的重點技術之一。

1. 英國皇家學院(The Royal Society)及美國科學院(National Academy of Science, NAS)自 2014 年起，由頂尖的氣候科學家，以最新取得的氣候數據進行科學系統化的評析，掌握氣候變遷的證據及成因，論證顯示目前氣候變遷的主因乃人為造成[6]。評析顯示，在過去 40 年，太陽照射至地球的整體淨能量並無增加，在太陽約 11 年的照射周期中，太陽能量輸出的變化量僅約 0.1%。從氣象球及衛星所取得地球大氣層的龐大溫度量測數據庫，

顯示地球下方的對流層(troposphere)溫度持續增加，對流層上方的平流層(stratosphere)溫度則呈現下降趨勢，隱示由於溫室氣體的持續累積，地球表層上的熱量無法有效散逸至太氣層外，其結果與科學家在之前尚無充分量測數據，所進行的數學模擬分析預測結果相符。基本上，地球對於地表上 CO_2 等溫室氣體急遽上升後的反應及演化情形，現代人類未曾遭遇，無從知曉也無法實驗，從熱力學來看，屬於單向、不可逆的過程；或者說要達到新的平衡，需透過大氣、海洋、礦化之間緩慢的反應，所需的平衡時間可能長達數千年，二氧化碳濃度才有可能回復到工業革命前的水平。科學家依據基本的物理、化學、生物學的基本原理，建立評析大氣、海洋、陸地、冰川及氣候系統間的交互作用的數學模型，進行氣候變遷的評估及演算。自 1960 年代建立氣候評估模型，其預估能力持續強化、精進，針對個別的風暴、氣流渦旋、聖嬰、反聖嬰等等氣候變化，驗證其預估的精準度；其評估結果，已普為國際所認同，為各國氣候決策的重要參考基準。

2. **世界不平等實驗室**(World Inequality Lab)有鑑於全世界所有區域的財務所得不均等現象日趨惡化，嘗試從**總體經濟**、**個體經濟**等面向，以透明且系統化的方式，提供以**科學數據**為基礎的**公共論證**平台，期待全球及區域間財富之重新分配以投資未來，促進實現世界**財富均衡**的**公平正義**。在 2022 年出版的世界不平等報告中[7]，增列**全球碳不平等**(Global carbon inequality)的論述。其依據聯合國組織所設的跨政府組織，政府間氣候變化專門委員(Intergovernmental Panel on Climate Change, IPCC)，彙整 1850-2019 年間全球各主要區塊的年度二氧化碳排放量，參考圖十三； 1850-2019 全球指標年度之排碳量，參見表六；全球各區域 1850-2020 累積的二氧化碳排放量，及因應地球溫度上升限額 1.5 ℃ 及 2 ℃ 情況下，所允許的二氧化碳當量，參考圖十四。綜整各區域頂層 10%、中層 40%及底層 50%三個區間，每個人頭的排碳量，參考圖十五。依據 IPCC 的評估，目前全球平均氣溫比工業化開始前高 1℃(已為 12.5 萬年以來最熱的時期)，若要符合**溫升 1.5 ℃** 的上限，自 2021-2050 年，全世界每一人頭所允許的**年均排碳量**為 **1.1 噸**；若溫升**上限 2 ℃**，每一人頭允許的**年均排放量 3.4 噸**；在該兩情境下，其所允許的排放量遠低於目前全球每人年均排放量 6.6 噸，其是否能順利施行，存在相當大的難度，短期而言，概屬不可能之任務。表六顯示，1850-2019 全球指標年度之排碳量持續增長；2020 年，受 COVID-19 疫情影響，全球排碳量 353 億噸，低於 2019 的水平；2021 年疫情趨緩，排碳量增長，達 500 億噸。圖十四顯示 1850-2020 的累積二氧化碳排放量為 24500 億噸，再加上 2021 年 500 億噸，合計 **25000** 億噸。各區域所排放的二氧化碳，留存在大氣中，則由全人類共同承擔。客觀上，全球直接受到氣候變化影響最大的，通常都不是那些先進主導國家；基於公平正義及使用者付費的原則，那些曾經或正以排碳獲取財富、利益的地區或國家(通常也是財富頂端擁有者)，需要承擔更多碳減排的職責及經費，對於高碳排者，需要適度提高碳稅，並將該等**資金專用**於**低碳社會**的**基礎建設**。再者，以目前溫升 1.5 ℃ 的上限，所允許的二氧化碳當量 3000 億噸，以全球 2021 年二氧化碳排放的水平，不出數

年，若無成效顯著的**低**或**負碳排**技術可普為採用，碳排量超過限值，難以逆轉。當前，**地球**的**暖化**已是**現在進行式**，如何採取適宜的**因應對策**，宜早為之計。

3. 地球繞日而行，「四時行焉，萬物生焉」；在相對座標上，天體處於類穩態(quasi-steady state)的平衡狀態。據估算太陽施加在地球的能量強度約 $1.73*10^{17}$ 瓦(W)，相當於每日 $1.49*10^{22}$ 焦耳(J)，其中大氣層直接反射約 34%的太陽光。以全球目前所需的初級能源約 160,000 TWh ($576*10^{18}$ 焦耳)，參考圖十六、1800-2019 歷年全球不同形式初級能源之消耗量。若能完全收集日照 1.5 小時所提供的能量，即高於全球 1 年所需的初級能源。實務上，太陽提供的能量，滋養大地，為萬物提供能量源；部分能量透過光合作用，成為生質及石化能源；太陽光照射及地球自轉，不同區間的溫差，氣體及海流的流動，形成風能及海洋能(溫差、海流、潮汐)；水循環(蒸發、凝結、降水、逕流)中的能量源來自太陽，為水力發電的根源，太陽能以不同的方式儲存及呈現。在工業革命之前，人類為大自然生物圈循環中的有機體，對於大地環境的破壞及影響有限，**全球碳庫**之間及冰川河流間**水氣**的**交換**維持相對穩定及**平衡**，**全球碳循環**及**全球水循環**雖小有波動，但基本上是維持穩定的。伴隨著工業化進展，累積億萬年的化石能源，加速的被開採，並排放巨量的溫室氣體，大氣間的二氧化碳濃度從工業革命前的 280 ppm 累積至目前超過 415 ppm，導致**地球能量失衡、暖化增溫**。

   A. 就「**時間**」尺度上，地球的氣候變遷在冰河期跟溫暖(間冰)期之間擺盪，地球偏離黃道面的**米蘭科維奇律動**(包含:地球軌道離心力、自轉軸傾角、軸向進動)，其週期至少在數萬年以上；在工業革命前，**深層碳循環**主要仰賴大規模的**火山爆發**將地底下的碳源噴發至地表。在人類數千年文明歷史的演進過程中，亦曾有多次中小規模的火山爆發，例如:公元 **79 年**義大利**維蘇威火山**爆發指數（Volcanic Explosivity Index, VEI）**5 級**(VEI 5 級)掩埋龐貝城；**1600 年**秘魯**瓦伊納普蒂納火山**爆發(VEI**6 級**)造成全球數年異常寒冷及大飢荒；**1815 年**印尼**坦博拉火山**爆發(VEI **7 級**)為北半球帶來災難性後果，形成「**無夏之年**」，伴隨氣候異常，衍生飢荒、傳染病及戰亂。雖然全球各地區發生的火山爆發造成局部區域或全球性暫時性的氣候異常，IPCC 的研究顯示，在過去兩百年，火山爆發所釋出的溫室氣體排放量，**低於人為排放的 1%**。從「**時間**」及「**規模**」尺度上來看，目前造成**全球暖化**的元凶是**人為因素**。

   B. 以全球目前所需的初級能源約 160,000 TWh ($576*10^{18}$ 焦耳)概估，從熱力學的面向來看，其有效的能源效率小於 33%，其餘 67%($3.86*10^{18}$ 焦耳)以上主要以**廢熱**方式釋出；在地球原先既有的平衡體系統上，這些額加的熱源，或可藉由地球**表面溫度提升**，將熱能藉由輻射擴散至大氣或外太空，達到另一平衡狀態；或者熱能將提供**冰川融化**所需之融化熱焓(冰的融化熱 79.71 kcal/kg)。$3.86*10^{18}$ 焦耳的熱能規模及所可能導致的效應為何?以如此的熱能規模估算，全球冰川總面積總計約 1622,7500 平方

公里($1.62275*10^{13}m^2$)，則每年的**平均冰層融化厚度**約 **0.7mm** [$3.86*10^{18}/(1.62275*10^{13}*1000(kg/m^3)*79.71(kcal/kg)*4.18*10^3(J/kcal))$]。以石門水庫有效容量 20,526 萬立方公尺($2.0526*10^8\ m^3$)為例，熱能 $3.86\ *10^{18}$ 焦耳可將相當 56 座石門水庫容量的冰完全融化成水[$3.86*10^{18}/(2.0526*10^8*1000(kg/m^3)*79.71(kcal/kg)*4.18*10^3(J/kcal))$]。地球在天體中原屬均衡類穩態狀況，氣候變遷週期至少數萬年以上，從**擾動理論**(Pertubation Theory)或**蝴蝶效應**(Butterfly Effect)的面向來看，局部的熱擾動即可能導致**系統**的**失衡**，冰川以每年平均 0.7 mm 速率融化，其影響層面是巨大的殆無疑義。客觀上，地球山川百岳並非均質結構，地球各處熱分布及冰川融化速度不一，目前北極冰層融化有加速現象，導致原封存於**永久凍土**動植物殘骸轉化的碳氫**合成氣**(主要為甲烷)等溫室氣體**加速釋出**。在平衡狀態下，**水氣**是地球本體**維持恆溫**最重要的**溫室氣體**，在大氣中含量趨於穩定，無其他溫室氣體之積累現象；冰川融化的結果，不僅加速上述溫室氣體的巨量釋出，原具有反射太陽光的冰山，成為具有高度吸收太陽能的海洋水，在失衡狀況下來去之間，溫室效應增加。**溫室氣體**的累增及**冰川**的**融化**，為全球暖化的**正回饋**因子。**失控**的**溫室效應**，對於人類及地球上物種的是否得以**續存**，是相當嚴酷的考驗。

4. 依據國際能源總署及麥肯錫公司的全球能源願景評估[8,9]，各國面臨日趨嚴峻的暖化議題，紛紛表態加速淨零排放的標的，提高非化石能源的利用占比(氫能、再生能源及電氣化等)。由於俄烏戰爭衝突的不確定因素、**極端氣候**導致嚴重酷熱、乾旱及水澇、天然氣斷供；必須就能源、糧食的穩定性，檢視及調整長程能源轉型及去碳的路徑及步伐，在主客觀條件綜合考量下，各國之能源政策，會因時、因地做出調整；例如，目前歐盟天然氣短缺，必須重啟煤炭電廠及延長核能的使用年限等等。依據麥肯錫的評析，若各國依據巴黎協定的目標，推動相關能源政策，預計在 2050 年時，再生能源(風能及太陽能)的占比將達 80~90%，氫能及再生燃料為主要的能源載體，再生液態燃料占比預估 8-22%。石油峰期(oil peak)出現在 2024-2027 之間，煤炭占比雖下滑，仍占有一定比例，天然氣的供需之不確定因素偏高。即使各國達成預設的淨零排放目標，全球的暖化仍無可避免，預估暖化在 2100 年溫升 1.7 ℃。提高能源效率、電氣化、再生燃料、二氧化碳的捕捉與封存(Carbon Capture, Utilization and Sequestration, CCUS)的進展都需加速，以符合溫升限制在 1.5 ℃ 的路徑上。

5. 為達成淨零減排的目標，各國紛紛宣示將再生能源、再生燃料、氫能納為發展的重點目標；不過，檢視各國因應**巴黎協定**所設定**無約束力**的 **NDC 減碳目標**，在**理想**與**落實**上持續有著明顯**落差**。就氫能而言，**氫氣**的電化學或燃料反應主要的生成物是水，被認定為解決淨零減排的關鍵能源載體，為**次世代能源系統**的主力之一。但在地球上，氫氣屬於**高活性**的元素之一，主要以碳氫氧化合物方式存在，現階段氫氣的主要生產來源(~96%)均源於化石燃料。若再生能源要成為電解產氫的主要來源，必然必須使用**離峰**額外的再

生電力進行，以提高整體的能源效率。實務上，氫氣儲存及運輸所需之基礎建設需要巨額的成本投資，美國加州、日本已建置先導示範站，國際大部分的企業體均做宣示，但大致採取**觀望**及進行**可行性評估**，以靜制動。以現階段，電解產氫的效率 70-80%，若採取液化需耗損約 13%的能量，壓縮、運送等也消耗不等的能量(10)，在應用上需再經後續的能源轉換(50-60%)及能源管理平台，亦即氫氣從生產端到使用端，整體的**能源效率**僅約 **20-30%**；若應用端採取燃燒方式，能源效率還會再打折扣，且排放的 NO_x 溫室氣體明顯增加。考量在諸多過程中所需的能源耗損(Energy Penalty)，須盡量減少不必要的能量轉換程序，因此再生能源之應用以**即發即用**為先；在系統操作穩定且有餘裕時採取**削峰填谷**，或者配合**電力調度**，或是產生的衍生化合物具有**高附加價值**，使用再生能源進行電轉氣、電轉燃料或衍生化合物等，自然是基於綜合**整體效益評估**所進行的作為。

6. 在全球綠色和平組織、聯合國 IPCC 等機構持續的呼籲下，**淨零減排**成為普世的價值，各國在巴黎協定的框架下，設定 NDC，並積極投入再生能源的開發及應用。在十九世紀之初，伴隨工業革命的進展亟需提供蒸氣所需的動力源，煤炭在當時屬於新能源；可使用的動力源從原先的人力、畜力，提升至以石化為能源主力的內燃機、蒸汽機、渦輪機等。迄今，溫室氣體的累積量逐趨臨界，經過深層的反思，人類逐漸體認到**地球資源**之**有限性**及**永續經營**的必要性；各國依據其所可運用的資源，進行能源轉型，陸續切入再生能源的開發及應用。風能、太陽能等再生能源的**可持續性**、**安全性**，與**環境**相對**友好**，火力(包含:燃煤、燃氣、燃油)電廠產生的二氧化碳必須做安全貯存，以利**能源安全**、**環境保護**及**經濟繁榮**等面向達到共贏，普為各界所認同。但是，再生能源**能量密度低**，需要足夠寬廣的容積安裝，產生的功率具**隨機**及**間歇**性的特性，必須配備**蓄電池**做為**緩衝**及**架設電網**以將所產生的電力送入饋線。此外，**風機**葉片轉動引發的**低頻噪音**、**光害**，對當地的居民、區域的地理、氣候、農作物生長周期及收成、漁類的動線及漁獲產量或鳥類的棲息，都會產生不等的影響。事實上，即便是單純的**水壩**開發，需經過嚴謹的**水文**及**人文**調查、**地質**探勘、**水利**規劃、**環境影響評估**等等作業，以利於**水資源**的有效運用；但因涉及在地居民及既有**生態**平衡的**破壞**及改變，即使開發案通過專業的評估，執行上會面臨**鄰避症候群** (Not in my backyard, NIMBY)的困擾，需要持續以客觀、透明的方式進行多方的折衝及溝通，才能獲得當地居民的共識及同意。面對**複雜**而**多元**的**社會新型態**，官僚體制以**迴避風險**、**安全運作**、**依法行政**為圭臬；一旦涉及不同利益團體間的權利與義務時，公共建設普遍有著**工程延宕**及**品質管控**的問題。再者，民主社會**政權更迭頻繁**乃是常態，主政者通常以**政權**之**延續**為第一要務，欠缺**宏觀整體經濟調控**，動輒以**擴張財政赤字預算**，冀求**經濟表象**之復甦及成長，長期累積的結果導致政府債務不斷攀升(11)，以目前**倒金字塔**型的**人口架構**，中長期發展上有著**生產力趨緩**、**社會負擔增加**的趨勢，**債留子孫**之作為有違**世代**間之**公平正義**，若基盤無法承擔時，後續可能引發**經濟**之**泡沫化**及**崩盤**。由於潛在發生的時間點為未來式，主事者概以 "**不在我任**

內”(Not in my term, **NIMT**)發生為推託，後繼者則以決策為前任所為，也可以 NIMT 帶過；後果由全民共同承擔。當前，重大公共建設的投資，必須通過**公眾接受度**(Public Acceptance, PA)的檢驗，紓解 NIMBY 的**鄰避效應**，由於欠缺普為各方認同的**客觀**、**公正機構**及**機制**，**國家機器空轉**，該項建設最終可能因此被擱置、議而不決、或者成為爛尾樓或蚊子館，與原設定的標的，大異其趣。從國家能源願景發展的角度，或許我們必須**跳脫框架**，在**對錯之外思考**，參考如日本 NEDO 行政法人機構執行新能源產業技術綜合開發，及美國國家科學院(National Academies of Sciences, Engineering, and Medicine, **NASEM**)的運作模式，由**跨領域**的**行政法人機構**，以獨立、客觀及嚴謹的論證，為國家的能源政策把脈，維持政策的**延續性**及**願景發展**；在**專業**、**理性**及**科學**論證的基礎上，建立**公信力**，納入**人文素養**及**社會關懷**，以期國家、社會之**和諧**及**永續經營**。

7. 參考國際能源總署及各國採取的淨零排放策略及路淨，國發會暨相關部會依據國內的現狀及可能發展情境，於今年 3 月 30 日，宣示「**台灣 2050 淨零排放路徑及策略**」提出路徑規劃、轉型策略及兩大基礎[(12)]，在 2030 年前規劃編列 9000 億執行**八大計畫**，包含**再生能源及氫能**、**電網及儲能**、**低碳及負碳技術**、**節能**及**鍋爐淘汰**、**運具電動化**、**資源循環**、**森林碳匯**以及**淨零生活**。國發會提出之 2050 淨零排放規劃，參見圖十七。其中電力部分，2050 年**再生能源**占比 **60-70%**，**氫能 9-12%**，**火力+CCUS 20-27%**，抽蓄水力僅占 1%。檢視國內 2019、2020 及 2021 年等 3 年的碳減排係數量[(13)]，每度電分別為 0.509, 0.502 及 0.509 kg-CO_2^e (Carbon dioxide equivalent)，行政院原設定 2020 及 2021 年目標分別為 0.492 及 0.482 kg-CO_2^e，均未達標，排碳量並無顯著減少之趨勢，後續隨著無碳排核電廠的除役，能源需求則持續增長，碳減排係數短期內仍有上升的趨勢。依據能源局的統計資料，參見表七、歷年燃料燃燒二氧化碳排放指標；若以 2005 年的碳排放量為基準年，在過去 15 年，年度的排碳量並無明顯的增減。相較於過往歷年的碳排情況，目前所設定的 2050 淨零排放目標，具有高度的挑戰性。基本上，**再生能源**(太陽能、風能)的**能量密度低**，台灣本島**地狹人稠**，可利用的陸域場址開發殆盡；往**海域發展**，或可舒緩陸域所需的**民眾溝通**議題；近海場域開發後，規劃以強化離岸、深水區大型化、浮動試發展，以補場域之不足，預計 2026~2035 年離岸風電裝置量**年增 1.5GW**，**2050 年**累計達 **40~55GW**。由於全世界上尚**缺乏於類似場域的實務經驗**，國內**海事工程**的經驗不足(**工程費遠遠高於陸域**)，深水區的**海流流場**及**地質狀況**仍待釐清，**颱風侵襲**、**環境區域**的**風險評估**是否完善?將國家未來的能源供給仰賴於**遠距海域**、**效能未明**及易於受**外力侵襲**之**間歇性**再生**能源**技術，場域成為各方之**綠能試驗平台**，相關作為存在**高度**的**不確定**及**風險**，電網的**穩定度**及**韌性**堪憂。目前所宣示之**淨零排放路徑**及**策略**，或可做為政策方向之引導，惟所據以設定的**能源政策**及**路徑**需**務實**做**滾動式檢討**。

8. 無可否認的，各國在巴黎協定的框架上，紛紛設定 NDC 減量貢獻及 2050 淨零減排目標。但在這個以**競爭為基礎**的國際叢林社會，當涉及**國家利益**時，各國會將其自身的利益做

為優先考量；務實而言，國與國之間只有永恆的利益，沒有永久的敵人或朋友。對於強權國家，當採取減碳策略不利於該國的經濟、民生發展時，即會暫時退出協定；當其掌握**關鍵技術**，減碳作為有利於其經濟發展時，即要求其他國家依據其所設定的規則辦理。台灣人才濟濟、辛勤又具韌性，但因腹地有限，內銷市場及通路不足，產品以外銷為主，自然演進成為國際間**代工生產**(Original Equipment Manufacturer, **OEM**）及**委託開發暨製造服務**（Contract Development and Manufacturing Organization, **CDMO**）的重鎮。舉例而言:半導體業為台灣撐起強而有力的護國神山群，在全球疫情期間經濟一片慘澹的狀況下，為國內保有經濟之微幅成長，值得大家由衷的敬佩。不過，將經濟命脈灌注到單一主體，一旦稍有波瀾，即可能連動到社會的穩定性，若上游端逐步採取「**高端擠壓**」、「**低端擠出**」及「**淡出策略**」，將嚴重**壓縮**到國內業者的**利潤**、國民的**就業機會**及國家的**經濟發展**。今年 8 月初，美國簽署晶片和科學法案(Chips and Science Act)，並要求台灣、日本、韓國與其共同成立「**芯片四方聯盟**」(Chip 4 Alliance)，美國設定**研究、生產、製造**一把抓的戰略，內涵是 2+2 的操作模式，由美日主導 2 奈米量產研發計畫；法案的表象是劍指中國，台灣則是直接**無言的受害者**；後續有賴國內具高智慧的半導體業者，維持**創新**，再**開創**及**調整**適宜的**藍海營運模式**。

9. 麥肯錫公司的全球能源願景評估，至 2050 年，化石能源(煤炭、石油、天然氣)的能源占比會逐年降低，相較於 2020 年，總量減少約 40%，其中煤炭及石油，仍為主力之一，參考圖十八、全球能源占比的年度變化圖。化石能源所產生的二氧化碳必須仰賴 CCUS 的技術，進行有效的利用、固化或封存，才能達到淨零排放的標的。台灣缺乏初級能源，開發風能、太陽能及地熱等再生能源為持續的發展重點。無可諱言，化石能源在我國能源的供應面，至 2050 年能源配比至少仍有 20%以上的占比，預期未來還需就再生能源發展的狀況做調升。針對國家之淨煤減排目標，國內在第一期能源國家淨煤主軸專案計畫中，已就台灣二氧化碳地質封存地圖集進行彙整，初估台灣陸海域**二氧化碳地質封存量**達 **459 億噸**，主軸計畫並就地質封存風險評估與管理、管制法規、地質封存及碳捕獲等之技術藍圖暨產業化、產業聚落發展等，進行全面性的探討，彙整第一期能源國家型淨煤主軸專案計畫編製之專書，參見表九。研究成果顯示，台灣具有優異的二氧化碳地質封存條件，若能在策略上整合國內資源，釐清二氧化碳地質封存產業聚落建置之機會及對策，將有助於我國建立 CCUS 相關的產業鏈及聚落之成形，並為我國達成淨零減排目標之必要選項。客觀上，各項減碳相關技術是否得以順利施行，除政策、法規之強制要求外，其主要考量為:必須透過**成本效益分析**(Cost Benefit Analysis, **CBA**)、**生命週期成本**(Life Cyle Cost, **LCC**)及**生命週期永續評估**(Life Cycle Sustanability Assessment, **LCSA**)，確認該技術具有長遠的發展利基，然後挹注資源，取得先機，並逐步擴展應用及發展空間。據評析，二氧化碳之捕獲、利用、及封存的最大瓶頸為如何有效且低成本**"捕獲"**二氧化碳，捕獲成效之良窳，瓶頸之一為二氧化碳在尾氣中的濃度及雜質條件。舉例而言，

美國 DOE 於今年 4 月宣布投入 14 百萬美金，邀請 5 家前端工程設計(FEED)公司，進行二氧化碳空氣直接捕獲(Direct Air Capture, DAC)技術的開發及放大研究，由於空氣中的二氧化碳濃度為數百 ppm，要將之捕獲並匯集成可封存的高濃度二氧化碳(> 90%)，其需大型的設施規模且成本偏高。DAC 或為負碳排的可資運用的技術之一，但不會是我國的主要選項。若要有效降低二氧化碳的捕獲成本，最佳的選項為具高二氧化碳濃度及低雜質的尾氣，若尾氣無需再做濃度提升，可直接進行壓縮及封存，會是最佳的選項。顯然的，結合氣化及燃料系統的**複合氣化燃料電池**(Integrated Gasification Fuel Cell, **IGFC**)及**天然氣燃料電池**(Natural Gas Fuel Cell, **NGFC**) 等**次世代高效率發電系統**，經整合後，除具高效率外(發電效率>60%)，排放的尾氣含高濃度的二氧化碳，具有最佳的減碳迴避成本(Cost of CO_2 emissions avoided, **CCA**)。Thomas A. Adams II 比較不同類型的碳基發電系統的 CCA，分析顯示[14]，整合氣化複合系統(Integrated Gasification Combined Cycle, IGCC)的減碳成本 US$ 60-70/tCO_{2}^{e}(2016 年幣值)，**IGFC** 的 CCA 在 US$ **10/tCO_{2}^{e}** 以下，在 7 種類型的碳基發電系統中，具有最佳的減碳成本，請參考圖十九。簡言之，**IGFC** 可做為我國**淨零減排**發展的**重點項目**。

10. 固態氧化物電池/電解為**高效率、高技術門檻**之**低碳能源**技術，具有能量轉換效能高、可採用多元燃料、可共電解選擇性水蒸氣及二氧化碳產生氫氣及合成氣，在節能減碳、能源轉型及低碳社會議題，可做出貢獻，為淨零減排路徑上，可資運用的重點技術之一。各國著眼於 SOFC/SOEC 在能源轉型、減碳社會所具的潛在龐大商機，目前國際各大企業彼此結盟，**卡特爾**(Cartel)集團的**閉鎖模式**(Lock-in model)已逐漸成形，若無積極作為，後續台灣只能繼續扮演 OEM 的角色，難以建置完整產業鏈。SOFC 及其相關技術，兼具高效率、環境友好、模組化、分散式及減碳的效益，符合能源轉型所必須的三要素，在穩定**安全**(Safety)的前提下，確保**能源安全**(Energy Security)、繁榮**經濟發展** (Economy Development)及友好**環境保護**(Environment Protection)等維持 3E 共贏。SOFC/SOEC 之推廣應用，與推動低碳社會所需的四項驅動力，**去碳**(Decarbonization)、**分散**(Decentralization)、**數位**及**互聯網**(Digitalization)及**法規**調整(Deregulation)是相互呼應的。本項技術之推廣及應用，與國家所設定 2050 淨零排放路徑及策略八大計畫中，**再生能源及氫能、電網及儲能、低碳及負碳技術、節能**等計畫，息息相關。再者，國際間，燃料電池系統已運用於船舶及燃料電池車等載具之開發，**燃料電池電動車**可補足電動車續航力及充電不足之處；再者，運用工業廢氫或有機廢棄物生產的沼氣或生質氣，都可為 SOFC 的燃料源，為**資源循環**之體現；國際上，燃料電池已陸續安裝於家庭、數據中心、中小型社區，為實現**淨零**減排**生活**之一環。亦即，**SOFC/SOEC 技術**之推廣及應用，與國家**淨零排放路徑**及**策略，高度契合**。建議**強化**此項領域之**研發投資**，以利於國家**節能減碳**及**淨零排放**目標之實現。

(四) 瑞士在 2000 年設定 CO_2 Act(二氧化碳法)做為政府氣候政策的中心支柱，規劃在 2020 年時的溫室氣體排放量至少降低 1990 時的 20%。因應後續的碳減排需求，瑞士聯邦政府積極提出 revised CO_2 Act 二氧化碳法修正案，包含機票稅(air ticket levy)、碳稅、補償金、氣候基金等等，並於 2021 年 6 月 13 日進行公投，基於汙染使用者付費原則設定碳稅、獎勵措施等等，可惜該修正案未能說服民眾，法案未獲通過(反對者占 51.6%)；反對方認為，該法案所設定的碳稅、逐步禁用油及天然氣於家庭之加熱系統及機票碳稅等之措施，會增加瑞士家庭過高的**碳稅負擔**。雖則瑞士聯邦政府宣稱，瑞士仍然符合國際氣候協議所設定的巴黎協定(Paris Agreement)；不過，此一法案未能順利通過，意味著瑞士原先設定 2030 年是否能達成巴黎協定的減排要求，碳排量較 1990 減半，存有疑義。瑞士碳排 1990 年為 5420 萬公噸，若減半為 2710 萬公噸，目前瑞士聯邦政府持續就二氧化碳法修正案進行調整，期待能得到大部分民眾的支持，預期 2030 年減少至 3460 萬公噸(主要為家庭及車輛之碳排放減少)，目標 2050 年達到淨零排放。回顧 2017 年 5 月 21 日瑞士曾透過全民公投，58.2%贊成通過**新能源政策**(New Energy Policy)，主要 3 個重點是:(1)逐步降低核能的占比(目前～38%)(2)提高再生能源的上網電價補助從 1.5c $/kW 提高到 2.3c $/kW，期間至 2022 年止(3)提昇能源效率。新能源政策主要是**政策上**的**宣示**，**未**直接**涉及人民額外的支出**，大致能順利獲得通過。在二氧化碳法修正案中，民眾則須負擔外加且必要的碳稅支出，公投不過關。再者，該法案的挫敗，適逢歐盟積極推動、引進**碳減排**及**環保稅**等措施之際，例如**碳邊境調整機制**(Carbon Border Adjustment Mechanism, **CBAM**)，其後續效應值得關注。

(五) 歐美各國之學、研與業界維持緊密之合作關係，當學界、研究中心所開發的技術，具有未來發展潛力時，會以 spin-off 方式，與業界做連結，成立新創公司，加速技術的進展並拓展利基，相關作為以**興利大於防弊**之思維出發，乃能源源不斷開創新的事業體。以 SOFC 技術之拓展為例，Ceres Power 技術源於 Imperial College, London；HTCeramix 源於 EPFL；InDEC 源於荷蘭能源研究中心（Energy research Centre of the Netherlands, ECN），法國 Sylfen 公司及 GENVIA 創投公司自法國 CEA-Liten spin-off，美國 Bloom Energy 技術源於 NASA 火星計畫。在各新創**公司發展**的過程中，需要集結**領航者**、**人才**、**技術**、**資金**、潛在**通路**等等。由於各方咸認 SOFC/SOEC 的**高效率能源轉換**效率，在全球**節能減碳**的發展願景，必然扮演關鍵的角色，各大企業體前仆後繼，投入該項領域之開發及應用。實質上，新創公司在拓展過程中，所面臨的最主要臨界問題，為**資金調度**及**通路**拓展之不確定。Ceres Power 曾一度面臨破產的危機，後續藉由策略的調整，尋找國際的合作夥伴，陸續與歐盟地區及亞洲地區中日韓業者建立同盟夥伴關係，取得資金挹注的來源；SOLIDpower 集團併購瑞士 HTCeramix、澳大利亞 CFCL；德國 Sunfire 併購 Staxera，其母公司的投資集團並持續擴大投資範疇及連結；德國 H.C. Starck 曾投入電池單元的開發，併購 InDEC，計畫於 Selb 設廠，但因效能未達預期，終止資金持續投入，2019 年 2 月由日本 Kyocera 集團 100%收購 H.C. Starck Ceramics GmbH 的所有權，Kyocera 集團在歐盟地區取得拓展業務的基地。就現狀而

言，各大**企業體**採取**合縱連橫**的策略，藉由企業間之**合作**、**結盟**、**集資**，逐漸形成**卡特爾**(Cartel)集團的**閉鎖模式**(Lock-in model)；若無足夠的技術及資金支撐，不利於同領域新創公司之續存。

(六) 台灣經濟之成長，仰賴國人**兢兢業業**勤奮工作，產**業界靈活**且具**彈性**的運作模式，從**勞力密集**逐漸累積至**技術密集**的量能，成為國際間代工生產(Original Equipment Manufacturer, **OEM**）的重鎮。在 OEM 的過程中，雖然 know-how 的技術能量持續增長，但受限於國外上位**專利智財權**的**箝制**，OEM 之 **CP 產值**(Cost-performance ratio)**偏低**，並須支付高額的**智財權利金**。長期以來，**霸權**國家挾其在**軍事**、**金融**、**科技**、**文化**等之優勢，壓制他國服膺其所制定的規則及價值觀，確實有值得商榷之處。大國博弈，以其自身**利益為先**，正義為名，**台灣為棋**，處境維艱。試觀中東百年戰火瀰漫，日本經濟之起飛及泡沫，大國之影舞，不言可喻。若**產業結構**未調整，**能源密集度**未有效降低，隨著**經濟**之成長、**生活**及**電力化水平**提升，**電力需求**勢必持續增長。國發會預估國內用電量年均成長 2±0.5%，2050 年電力需求電量 4,275 至 5,731 億度，(c.f. 2021 年度**用電量**為 **2834 億度**，較前年增加約 123 億度，漲幅 4.5%)，整體成長幅度相較 2021 年增加 50%~102%。以 2021 年，台灣能源的配比[(15)]，進口初級能源佔 97.7%，自產的能源合計 2.3%(其中配比，生質廢棄物(51.4%)、太陽及風能(29.8%)、水力(10.1%)、廢油回收(6%)、地熱及太陽熱能(2.7%))；**風光**的**能源占比**約 **0.69%**。2021 年**發電量 2909 億度**(較前一年度成長約 3.9%)，再生能源發電占比 6%，其中**風光**發電占比合計 **3.5%**(太陽能 2.7%, 風能 0.8%)。實務上，風光再生能源的進展未如預期，以過往數年緩慢的成長速度(6 年約 1.9%)，外推 2025 年風光發電占比要達到 20%(目前調降至 15.1%)，能否達標，須面臨諸多挑戰。延伸至 **2050** 的**淨零減排**目標，後續的推展作業存在**高度**的**不確定**及**風險**，建議須**務實**就不同的能源**情節**及**路徑**，提出可資運用的**因應策略**及**措施**。

(七) 台灣初級能源仰賴進口，**能源**的**多元化**及**技術自主化**，為**避免單一事件衝擊**國家的**能源穩定供給**的必要作為。基準上，電力為現代化國家正常運行的動脈，提供**穩定**的**電力**來源為**政府責無旁貸**的職責。不同類型的初級能源及再生能源，其採用與否，各有其利弊得失，宜做**綜合**性**評估**，俟相關技術**驗證**成熟**可行**，以**穩健**方式進行能源轉型，期能順利達到淨零減排的標的。從**國家能源**及**產業發展**的**戰略高度**，參酌各先進國家所設定的氫能及燃料電池發展路徑，**SOFC/SOEC** 在本質上固有的**高效能源轉換**效率，為**橋接化石能源**世代**至次世代能源**架構的**低碳能源**技術。在主客觀情勢上，國內具有**能源轉型**及**能源市場**的需求、具有**完整自主技術**能量、且國內業者具有充分的**零組件製作能量**；若能結合**技術**、**需求**、**供應**、及**通路**的優勢，**聚焦**此一具有龐大產業效益之能源技術，在本土即可有很好的發展機會。**建議政府投入資源**支持**自主技術**之**整合驗證**測試系統及推展，將有助於國家**節能**、**低碳社會**及**淨零減排**標的之達成，並可開創一**新興能源產業**。

四、建議事項

(一) 每兩年於瑞士琉森舉辦之歐盟 SOFC&SOE 國際論壇及燃料電池展，為此領域的指標性國際會議；第十六屆論壇預定 2024 年 7/2-7/5 於瑞士琉森 KKL 會議中心舉行，會議主席預定為 Prof. Albert Tarancón，為掌握國際之發展現況及未來趨勢，使研發可與國際接軌，建議派員參加。

(二) 面臨此次 COVID-19 全球疫情，台灣有效抑低疫情衝擊，為國際間防疫成功的典範之一；預期生技產業是國內可長期經營、投入之重點科技項目。本所即將改制為行政法人，具有跨領域整合、分析及應用科學的人才，除了核醫藥物的開發外，未來可結合人工智慧、藥學資料庫，促進我國生技及醫療產業之發展。

(三) 固態氧化物電池/電解，具有能量轉換效能高、可採用多元燃料、可共電解選擇性水蒸氣及二氧化碳產生氫氣及合成氣，在節能減碳、低碳社會及能源轉型議題，具有最低的減碳迴避成本，為淨零減排路徑上，可資運用的重點技術之一。SOFC/SOEC 之推廣及應用，與國家設定之淨零排放路徑及策略，高度契合；IGFC 並可為淨零減排發展的重點項目。建議強化該領域之研發投資，以利於節能減碳及淨零排放目標之實現。

(四) 國內具有能源轉型及能源市場的需求、具有完整自主技術能量、且國內業者具有充分的零組件製作能量；若能結合技術、需求、供應、及通路的優勢，聚焦此一具有龐大產業效益之能源技術，在本土即可有很好的發展機會。建議投入資源支持**自主技術**之**整合驗證**測試系統及推展，將有助於**國家節能**、**低碳社會**及**淨零減排**整體目標之達成，並可開創一新興**能源產業**。

五、参考文獻

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12. *台灣 2050 淨零排放路徑及策略總說明*，國發會，3 月 30 日，2022
13. *109 年度我國燃料燃燒二氧化碳排放統計與分析*，經濟部能源局，2021 年 10 月。
14. Thomas A. Adams II *, Leila Hoseinzade, Pranav Bhaswanth Madabhushi and Ikenna J. Okeke, *Comparison of CO_2 Capture Approaches for Fossil-Based Power Generation: Review and Meta-Study*, Processes, MDPI, 2017
15. BOE (2022), *Monthly Energy Statistics*, 經濟部能源局，June 2022

表一、大會提供之燃料電池暨氫能(FCH)課程之議程

The Tutorial lecture topics are fuel cell operating principles, thermodynamics, kinetics, efficiencies, central notions such as electrolyte ionic conductivity, electrode overpotential, triple phase boundary, Nernst equation, fuel reforming, cell and stack architectures and design, fuels (both fossil and renewable) for different fuel cells including their treatment, all fuel cell families (SOFC, MCFC, PAFC, PEFC/DMFC, AFC).

Tutorial Schedule:

09:30 Registration & Get-Together
10:00 Welcome & Introduction (EFCF)
10:15 Lecture 1: Fundamentals of electrochemical energy Conversion (GGS)
11.00 Lecture 2: Characteristics of the important Fuel Cell technologies (GGS)
11:45 Coffee break
12.00 Lecture 3: Fuels for Fuel Cells, Fuel Processing (JVh)
12:45 Lunch break
14:00 Lecture 4: Applications of Polymer electrolyte Fuel Cells PeFC (GGS)
14:45 Lecture 5: system Aspects, Applications of High temp. Fuel Cells sOFC (JVh)
15.30 Coffee break
15:45 Lecture 6: state-of-the-Art, Challenges, summary (JVh)
17:00 End of Tutorial, Opportunity to visit the Exhibition

表二、大會提供之電化學阻抗頻譜儀(EIS)課程之議程

Tutorial Schedule:

09:30 Registration, welcome refreshments
10:00 Welcome & Introduction (EFCF)
10:15 Lecture 1: Fundamentals of Electrochemical Impedance Spectroscopy
11.00 Lecture 2: Applications I – Analysis of SOC - Materials and (Model-) Electrodes
11:45 Coffee break
12.00 Lecture 3: Applications II – – Analysis of SOC - Single Cells and Stacks
12:45 Lunch Break
14:00 Lecture 4: Evaluation of Impedance Spectra – Kramers-Kronig Test, DRT-Analysis & CNLS Fit
14:45 Lecture 5: Impedance Modelling and Simulation
15.30 Coffee break
15:45 Lecture 6: „EIS challenge" – Summary
17:00 End of EIS Tutorial, Opportunity to Visit the exhibition

表三、第十五屆歐盟燃料電池論壇國際諮議委員會人員名單

International Board of Advisors	www.EFCF.com/IBoA
Prof. Joongmyeon Bae, KAIST, Daejeon, Korea	
Prof. Frano Barbir, University of Split, Croatia	
Dr. Ulf Bossel, ALMUS AG, Switzerland	
Prof. Karel Bouzek, UCT Prague, Czech Republic	
Dr. Annabelle Brisse, Eu Inst. for Energy Research, Germany	
Dr. Isotta Cerri,Toyota Motor Europe, Belgium-Japan	
Dr. Niels Christiansen, NCCI innovation, Denmark	
Prof. Paulo Emílio V. de Miranda, Coppe - Federal Uni of Rio de Janeiro, Brazil	
Prof. Michael Eikerling, Forschungszentrum Jülich, Germany	
Dr. Karl Föger, formerly Ceramic Fuel Cells, Australia	
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Dr. Nancy L. Garland, Department of Energy, USA	
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Prof. John Irvine, University of St. Andrews, United Kingdom	
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Dr. Florence Lefebrve-Joud, CEA, France	
Niels Luchters, HySa Cathalysis, University of Cape Town, South Africa	
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Prof. Vladislav A. Sadykov, Boreskov Institute of Catalysis, Russia	
Prof. Massimo Santarelli, Politecnico di Torino, Italy	
Prof. Kazunari Sasaki, Kyushu University, Japan	
Dr. Günther G. Scherer, formerly Paul Scherrer Institute, Switzerland	
Dr. Subhash Singhal, Pacific Northwest National Laboratory, USA	
Prof. Robert Steinberger-Wilckens, University of Birmingham, United Kingdom	
Prof. Constantinos Vayenas, University of Patras, Greece	
Prof. Wei Guo Wang NIMTE, PR China	
Prof. Jianbo Zhang, Tsinghua University, China	
Assoc. Prof. Zhichuan Jason Xu, NTU, Singapore	

表四、EFCF-2022 SOFC &SOE 論壇之議程

Schedule of Events — **Motto 2022:** From materials to systems including modeling and advanced characterisation — **www.EFCF.com/Events**

Monday, 4 July 2022		**Tuesday, 5 July 2022**	
11:00 – 12:00	Registration for **GSM 2022 – Grid Service Markets** symposium	08:30 – 09:30	Registration for 2nd GSM day
12:00 – 18:00	**GSM Sessions** 19:30 **GSM Network Dinner**	09:30 – 16:30	**GSM Sessions** 16:30 **GSM Goodbye coffee & travel refreshment**
Tuesday, 5 July 2022			
09:30 – 10:00	Registration for **Tutorials** – 2nd floor Club Rooms above Auditorium	11:00 – 16:00	**Exhibition set-up**
10:00 – 17:00	…/FCH: **Fuel Cell, Electrolyser & H_2** Tutorial, Dr. G. G. Scherer/Dr. J. Van herle	16:00 – 18:00	**Poster pin-up / Opening** of the exhibition
10:00 – 17:00	…/EIS: **Electroch.Impedance Spectroscopy** Tutorial, Dr. A. Weber/Dr. D. Klotz		On-site **Registration** open (continued on the following days)
09:00 – 17:00	**Group & Project Workshops:** IEA AFC Annex 32, AdAstra/RUBY, Nautilus (p. 9)	18:00 – 19:00	**Welcome gathering** in the splendid KKL exhibition hall
Wednesday, 6 July 2022			
08:00 – 16:00	On-site **Registration**, Speakers Warmup Coffee till 09:00, info at main desk	09:00 – 18:00	**Exhibition** & Poster area open 12:30 Press Conference by invitation only
09:00 – 18:00	**Conference Sessions 1 – 6, Keynotes K1 – 4:**	13:15 – 15:00	**Poster Session I:** All Session Topics + Co-Electrolysis & CO_2-Electrolysis
	Presentations on programs & activities in various countries, status of industry,	12:00 – 14:00	Registration for **MEEP 2022** symposium – **14:00 – 18:00 MEEP Sessions**
	technical highlights on electrodes & cell lifetime; Networking & exhibition	18:30 – 23:00	**MEEP Network Evening; Swiss Surprise Night** – separate registration
Thursday, 7 July 2022			
08:00 – 16:00	On-site **Registration**, Warmup Coffee till 09:00, info at main desk	09:00 – 18:00	**Exhibition** & Poster area open 13:15 – 15:00 **Poster Session II**
09:00 – 18:00	**Conference Sessions 7 – 13, Keynote K5 – 6:**	09:00 – 16:15	**MEEP Sessions** 16:30 **MEEP Apéro in the exhibition**
	Power to X, advanced characterisation; Networking & exhibition	19:20 – 23:25	Great **Dinner on the Lake** – The unique networking event
Friday, 8 July 2022			
08:00 – 10:00	On-site **Registration**, Speakers Warmup Coffee till 09:00, info at main desk	15:00 – 16:15	**Closing & Award Ceremony:**
09:00 – 16:15	**Conference Sessions 14 – 17, Keynotes K7 – 8:** H_2 production + mix;		Best poster, best scientific contribution & outstanding lifetime work:
	individual poster presentation, exhibition & networking		K8 EFCF Gold Medal of Honour Winner Prof. Dr. Juergen Fleig TU Wien/AT
09:00 – 12:00	**Exhibition** & Poster area open 12:00 – 14:00 Poster removal	16:15 – 17:00	**Goodbye** coffee and travel refreshment in front of the Luzerner Saal

表五、 論壇會議平行進行技術發展(Session A)及科技成就(Session B)兩主軸

Session Program 15th European SOFC & SOE Forum — KKL Lucerne, Switzerland, 4 - 8 July **EFCF 2022**

OVERVIEW — incl. GSM & MEEP symposium, Project Meetings, Tutorials

Mo 4 July / Tu 5 July: www.GridServiceMarket.com — **GSM 2022 - 6th Grid Service Market symposium** — G Auditorium | Partner Meeting Montana: IEA AFC Annex 32 | PM: Uni LU H5: AdAstra/RUBY | PM: Terrassensaal: Nautilus | Tutorials: Club Rooms: FCH, EIS

We - Fr	A Luzerner Saal	Page	B Auditorium	Page	M Club Rooms
We 9:00	A01: P1: Opening Session	14			**6 - 7 July MEEP 2022** 4th international **symposium** on Microbial, Enzymatic & Bio-Photovoltaic Electrochemical Reactors, Cells & Systems
9:30	A02: K1 - 4: EU, USA, JP & Korean Programs/Partnerships	15	B02: Fuel Electrodes	15	
11:00	A03: Technology status at industry I	16	B03: Fuel & Oxygen Electrodes	16	
6 July 13:15	Auditorium Foyer		A04: Poster Session I covering All Session Topics + B09s: Co-Electrolysis & CO_2-Electrolysis	17, 29-39	
14:30	A05: Technology status at industry II	17	B05: Oxygen electrodes	17	
333316:30	A06: Technology status at industry III & Projects Overview	18	B06: Lifetime Cells I	18	
Th 9:00	A07: K5: Power to optimised X by Haldor Topsøe A/S	20	B07: K6: Advanced characterization tools by AIST	20	
9:30	A08: Lifetime Stacks	20	B08: Stack & System Modelling	20	
11:00	A09: Performance Cell/Stack	21	B09: Proton Conducting Materials, Cells & Stacks	21	
7 July 13:15	Auditorium Foyer		A10: Poster Session II covering All Session Topics + B09s: Co-Electrolysis & CO_2-Electrolysis	22, 29-39	PM: Club Rooms CH2P
14:30	A11: System Design, Performance & BoP	22	B11: Lifetime Cells II	22	
16:30	A12: Cells Design & Manufacturing I	23	B12: Interconnects, Coatings, Contact Layers & Sealants	23	
Fr 9:00	A13: K7: H_2 production paths and the future H_2 mix	24	B13: Cells Design & Manufacturing II	24	
9:30	A14: Other Fuels	24	B14: Lifetime Assessment & Advanced Characterisation	24	
8 July 11:00	A15: SOC Integration & Energy System Perspectives	25	B15: Advanced Characterisations	25	
13:30	A16: Products, Demonstration & Novel Concepts	27	B16: Material Modelling	27	
15:05	A17: P2: Closing Ceremony K8 by the EFCF Gold Medal of Honour Winner 2022	28	**Legend:** Px: = Plenary, Kx: = Keynote, PM: = Project Meetings All times are given in UTC/GMT +2 hours		

表六、不同燃料電池型態高效長期運轉之劣化機制及劣化率*

Table 1. Summary of long-term and high-efficient operations of advanced stacks

Stacks	Degradation factors	Observed mechanism	Time dependence	Degradation rates, %/kh
Flat tube(Kyocera) 	·IR-loss ·Cathode polarization Max. operation Uf=80% 20,000h Uf=85% 15,000h	■IR-loss: Zirconia phase transformation Contact metal oxidation SrZrO3 insulating layer formation ■Cathode polarization: SrSO4, SeCrO4 formation/Sr-depletion in LSCF	Linear, square root, exponential	0.32%/kh at Uf=80% 0.45%/kh at Uf=85%
Planar type (MORIMURA SOFC TECHNOLOGY) 	·IR-loss ·Cathode polarization Uf=80% 7,000 h Uf=85% 5,000 h	■IR-loss: Zirconia phase transformation IC metal oxidation SrZrO3 insulating layer formation Temp. distribution ■Cathode polarization: SrSO4, SeCrO4 formation/Sr-depletion in LSCF	Linear, square root, exponential	0.30% at Uf=80% 0.35% at Uf=85%
Planar type (DENSO) 	·IR-loss ·Anode polarization Uf=80% several 1,000 h Uf=85% several 1,000 h	■IR-loss: Zirconia phase transformation IC metal oxidation ■Anode polarization: microstructure change ■Cathode polarization: SrSO4, SeCrO4 formation/Sr-depletion in LSCF	Linear, square root, exponential	0.72%/kh-some%/kh at U=80%

*: Teruhisa Horita, AIST, 15th European SOFC and SOE Forum, A0203, Switzerland 5-8 July, 2022

表七、全球指標年度之排碳量**

Table 6.1 *Global carbon emissions, 1850-2019*

	Global emissions (billion tonnes)	Emissions per capita (tonnes per person)
1850	1.0	0.8
1880	2.5	1.8
1900	4.2	2.7
1920	6.6	3.5
1950	10.9	4.3
1980	30.2	6.8
2000	35.3	5.8
2019	50.1	6.6

Interpretation: *Emissions of carbon dioxyde equivalent (including all gases) from human activites (including deforestation and land-use change).* ***Sources and series:*** *wir2022.wid.world/methodology and Chancel (2021).*

**: *World Inequality Report 2022*, World Inequality Lab, 2021.

表八、歷年燃料燃燒二氧化碳排放指標

年度	CO_2 排放量		碳排放密集度		人均排放	
	萬公噸	成長率(%)	公斤 CO_2/元	成長率(%)	公噸 CO_2/人	成長率(%)
1990	10,947	-	0.02121	-	5.41	-
1991	11,844	8.20	0.02118	-0.16	5.79	7.01
1992	12,606	6.43	0.02081	-1.74	6.10	5.41
1993	13,521	7.26	0.02090	0.41	6.49	6.26
1994	14,310	5.84	0.02057	-1.55	6.80	4.90
1995	15,081	5.39	0.02036	-1.04	7.11	4.49
1996	15,858	5.15	0.02016	-0.97	7.41	4.30
1997	17,084	7.73	0.02048	1.58	7.92	6.78
1998	18,152	6.25	0.02088	1.97	8.34	5.28
1999	19,045	4.92	0.02053	-1.70	8.68	4.08
2000	20,912	9.81	0.02120	3.28	9.45	8.95
2001	21,296	1.83	0.02190	3.28	9.56	1.13
2002	22,055	3.56	0.02150	-1.82	9.83	2.86
2003	23,061	4.56	0.02157	0.32	10.22	3.95
2004	23,993	4.04	0.02098	-2.72	10.59	3.66
2005	24,796	3.35	0.02058	-1.93	10.91	2.97
2006	25,533	2.97	0.02003	-2.64	11.19	2.55
2007	25,921	1.52	0.01903	-4.99	11.31	1.10
2008	24,754	-4.50	0.01803	-5.26	10.76	-4.84
2009	23,587	-4.71	0.01746	-3.15	10.22	-5.05
2010	25,171	6.72	0.01690	-3.20	10.88	6.43
2011	25,710	2.14	0.01665	-1.48	11.08	1.91
2012	25,317	-1.53	0.01604	-3.67	10.88	-1.85
2013	25,407	0.36	0.01571	-2.08	10.88	0.04
2014	25,848	1.74	0.01526	-2.85	11.04	1.48
2015	25,848	0.00	0.01504	-1.45	11.02	-0.25
2016	26,298	1.74	0.01498	-0.41	11.18	1.51
2017	26,946	2.46	0.01486	-1.23	11.44	3.84
2018	26,721	-0.84	0.01433	-3.52	11.33	-0.94
2019	25,882	-3.14	0.01348	-9.24	10.97	-4.11
2020	**25,743**	**-0.54**	**0.01301**	**-3.55**	**10.92**	**-0.48**
年均成長率(%)						
2020 相較 2005	**0.25**		**-3.01**		**0.01**	
2020 相較 2016	**-0.53**		**-3.47**		**-0.60**	

註：本表排放指標係依據燃料燃燒二氧化碳排放量計算，未包括其他溫室氣體。

資料來源：經濟部能源局，2021 年 10 月。

表九、第一期能源國家型淨煤主軸專案計畫編製之專書

項次	編　號	書　名	作　者　群
1	CCMP-A-S-001	台灣高效率分散型能源技術藍圖暨產業化策略之研究	●財團法人台灣經濟研究院 左峻德、鄭俊才、張行直、江婉宜 ●行政院原子能委員會核能研究所 葛復光、柴蕙質、熊惟甲 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光、林孫美、劉文惠
2	CCMP-A-T-001	台灣碳捕獲與封存技術經濟評估之現況與展望	●行政院原子能委員會核能研究所 葛復光、卓金和、劉家豪、陳中舜 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光
3	CCMP-B-T-001	台灣二氧化碳地質封存潛能評估	●財團法人中興工程顧問社 冀樹勇、邵國士、李易叡、譚志豪、俞旗文 ●財團法人台灣經濟研究院 左峻德、陳彥豪 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光、林孫美、劉文惠
4	CCMP-A-T-002	台灣二氧化碳捕獲與地質封存管制法規之芻議	●財團法人中興工程顧問社 冀樹勇、林志英、高銘志、俞旗文 ●國立清華大學 科技法律研究所 高銘志、李明珊、吳妍儂、黃筱蘋、林致毅 ●國立中正大學 法律系 廖宗聖、林韋仲、許宏吉、吳柏諭、屈覺維、林婉蓉、邱美蘅、張嘉珉 ●財團法人台灣經濟研究院 左峻德、陳彥豪 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光、林孫美、劉文惠
5	CCMP-B-S-001	台灣發展二氧化碳地質封存技術藍圖暨產業化策略之芻議	●財團法人中興工程顧問社 冀樹勇、譚志豪、劉浙仁、俞旗文、林志英 ●財團法人台灣經濟研究院 左峻德、陳彥豪 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光、林孫美、劉文惠
6	CCMP-A-S-002	台灣發展碳捕獲與封存技術藍圖與產業聚落發展策略芻議	●財團法人台灣經濟研究院 左峻德、陳彥豪、張懷文、馬雲亭 ●淨煤主軸計畫作業室 林立夫、陳慶馨、江烈光、劉文惠
7	CCMP-B-T-002	二氧化碳地質封存地風險評估與管理	●財團法人中興工程顧問社 譚志豪、鍾明劍、陳嬿璇、劉浙仁、俞旗文、冀樹勇 ●財團法人台灣經濟研究院 左峻德、鄭俊才、陳彥豪、鄭貞怡、馬雲亭 ●淨煤主軸計畫作業室 林立夫、陳慶馨、丁桓展、劉文惠

項次	編　號	書　名	作　者　群
8	CCMP-B-T-003	台灣二氧化碳地質封存地圖集	●中央大學 林殿順、楊健男、李科豎 ●財團法人中興工程顧問社 譚志豪、劉浙仁、邵國士、王順民、李易叡、俞旗文、冀樹勇 ●財團法人台灣經濟研究院 左峻德、鄭俊才、陳彥豪、鄭貞怡、馬雲亭 ●淨煤主軸計畫作業室 林立夫、陳慶馨、丁桓展、劉文惠
9	CCMP-A-S-003	台灣固態氧化物燃料電池系統技術藍圖暨產業化策略之研究	●淨煤主軸計畫作業室 林立夫、陳慶馨、丁桓展、劉文惠 ●中央大學/聯合大學/元智大學團隊 林景崎、鄭憲清、鄭志雄、曾重仁、李　泉、李勝偉、張仍奎、洪逸明、周正堂、林錕松 ●交通大學/成功大學團隊 陳宗麟、李積琛、吳宗信、王啟川、劉耀先、方冠榮 ●台北科技大學團隊 姚立德、王錫福、涂世達、李達生、李文興、鄭鴻斌、楊重光、邱德威、柯明村、簡良翰、徐永富、楊永欽、吳玉娟
10	CCMP-A-S-004	台灣發展煤製油暨碳捕獲與封存之成本評估分析	●作者 張懷文 ●淨煤主軸計畫作業室 林立夫、陳慶馨、丁桓展、劉文惠

15th European SOFC & SOE Forum

EFCF 2022

Chaired by:

Dr-Ing. Julie Mougin is Head of the Hydrogen Technologies Department at CEA, French Atomic and Alternative Energies Commission, in Grenoble, France.

After graduating from Grenoble Institute of Technology (INPG) in Electrochemistry, she obtained a PhD in Materials Science, and gained industrial experience in the field of materials for energy and automotive markets before joining CEA/Liten in 2005 as the head of the SOFC/SOEC testing and characterization research group. From January 2010 to now, she has led the Hydrogen Technologies Laboratory, focused on hydrogen production, storage and fuel cells. She also supervised a team over a 4 year period in charge of techno-economical and life cycle assessment for new energy technologies.

In her current position, she supervises a team of 50 people in charge of the development and characterization of SOEC and SOFC technologies, from cells to systems. She has extensive management experience as coordinator of various past and on-going EU projects related to hydrogen and fuel cells (RAMSES, INSIGHT, REFLEX, MULTIPLHY). She is recognised as an international expert in the field of hydrogen, involved in several missions such as contributing to EU roadmaps, review of national hydrogen programs for several countries, and standards.

Julie Mougin is author/co-author of more than 50 publications in reviewed scientific journals (100 in total), five book chapters and four patents.

Dr. Hab. Jerome Laurencin is a senior scientist at the French Atomic and Alternative Energies Commission (CEA), where he leads a research group on the modeling and characterization of Solid Oxide Cells (SOC). After a Masters degree in material science and engineering, he obtained his Ph.D. from Grenoble Institute of Technology (INPG) with a dissertation on the performance and durability of solid oxide fuel cells. He received his habilitation in 2013 on the modeling of high temperature electrochemical devices.

Jérôme Laurencin has been working in the field of SOC for more than 15 years at CEA. His research activities are related to modelling, coupled with advanced material and mechanical characterizations. With his research group, he has adapted methods based on synchrotron X-ray radiation for the microstructural and physico-chemical characterizations. He has developed a multi-scale and multi-physic modeling framework that accounts for electrochemical and mechanical cell behavior. His current research interests aim at understanding the complex relationships between the electrode microstructure and the fundamental properties of materials, to optimize the cell durability and robustness in electrolysis and fuel cell modes.

Jérôme Laurencin has participated in several National and European projects as work-package leader. He is author/co-author of 90 articles in peer-reviewed scientific journals (more than 130 in total), three book chapters and holds 5 patents in the field of SOC.

圖一、EFCF-2022 SOFC &SOE 論壇及本次會議主席之簡歷

圖二、EFCF-2023 低溫燃料電池會議預定 2023 年 7 月 4-7 日舉辦

圖三、EFCF-2024 SOFC &SOE 論壇預告 2024 年 7 月 2-5 日舉辦

EFCF 2024

Lucerne, Switzerland, 2 – 5 July

Scope of the Forum

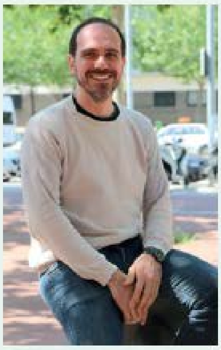
The 16th EUROPEAN SOFC & SOE FORUM 2024 will address issues of science, engineering, materials, systems, applications and markets for all types of Solid Oxide Fuel Cell and Electrolysis technologies, as well as for any electrochemical Reactors based on Solid Oxide Membranes. The Forum continues the strong tradition as one of the leading international meetings on Solid Oxide science, technology and implementation.

Technical Status and Achievements: The following companies have presented in the previous EFCF editions:

AVL, Boeing, Bosal, Bosch, Ceramatec, Ceres Power, Convion, EBZ, Elcogen, Fuel Cell Energy/Versa Power, Halder Topsoe, Hexis/Viessmann, Microsoft, Plansee, SOLIDpower, Sunfire, Sylfen.

Chair of the Conference

ICREA and head of the Nanoionics and Fuel Cells group at IREC



ICREA Prof. Albert Tarancón is Head of the Fuel Cells Group at the Catalonia Institute for Energy Research (IREC). Albert holds M.Sc. and PhD in Physics from the University of Barcelona (2001, 2007) and an M. Eng. in Materials Science from the Polytechnic University of Catalonia (2007). He has worked as a research associate at CSIC (ES) and as a visiting researcher at the University of Oslo (NO), Imperial College London (UK) and Caltech (USA). In 2010, Albert joined the Catalonia Institute for Energy Research (IREC) as Head of Group. Since 2018, he is ICREA Research Professor at IREC and leads a group of 25+ people dedicated to hydrogen technologies and alternative energy sources.

Albert has devoted more than 20 years to the field of Solid Oxide Cells developing innovative materials, cells and stacks close together with the major industrial players in Europe. In recent times, Albert's team is pioneering the introduction of revolutionary 3D printing technologies in the SOC community exploring unprecedented shapes and interfaces to improve performance and efficiency. In his active career, Albert has been Principal Investigator of 10 European projects, including two ERC grants, coordinating four of them on hydrogen technologies. Moreover, he has been actively involved in the definition of national and international research programmes in the field of power generation and energy storage.

Albert has authored more than 150 scientific articles in peer-reviewed journals collecting more than 5000 citations and 200+ oral presentations in international congresses (60+ invited and keynotes). Albert has been recently included in the 1% top-cited scientists in the field of "Energy". Moreover, he is currently editor of the emerging Journal of Physics Energy (IoP publishing) and the well-reputed Journal of the European Ceramic Society (Elsevier).

Exhibition

Why exhibit at EFCF?

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Contact with the right people, who understand and benefit from your added values and participate in the purchasing decision.
Valuable Contacts

Complete & Convenient
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In the core of the Fuel Cell, Electrolyser & Hydrogen community boosts
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圖四、EFCF-2024 SOFC &SOE 論壇會議主席 Prof. Albert Tarancón 之簡歷

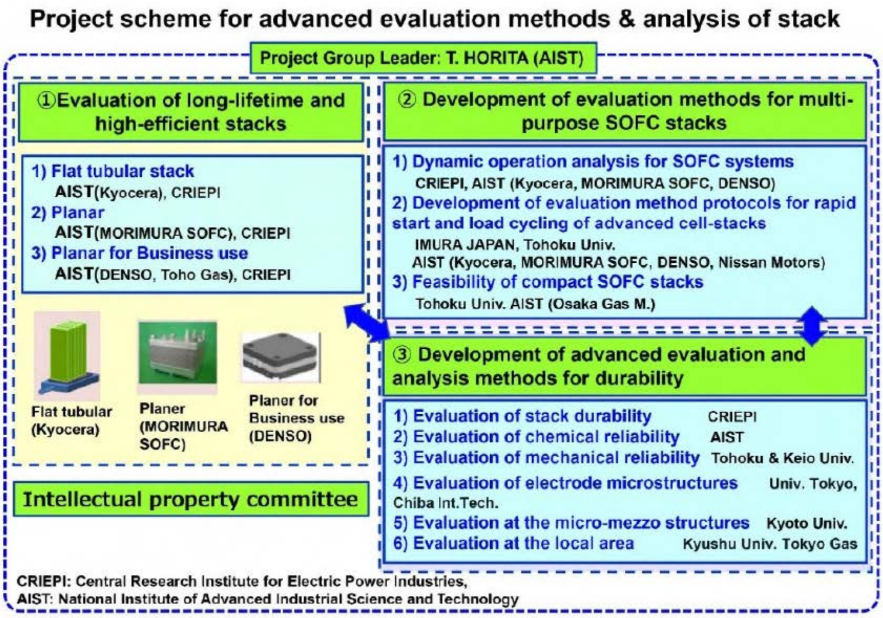
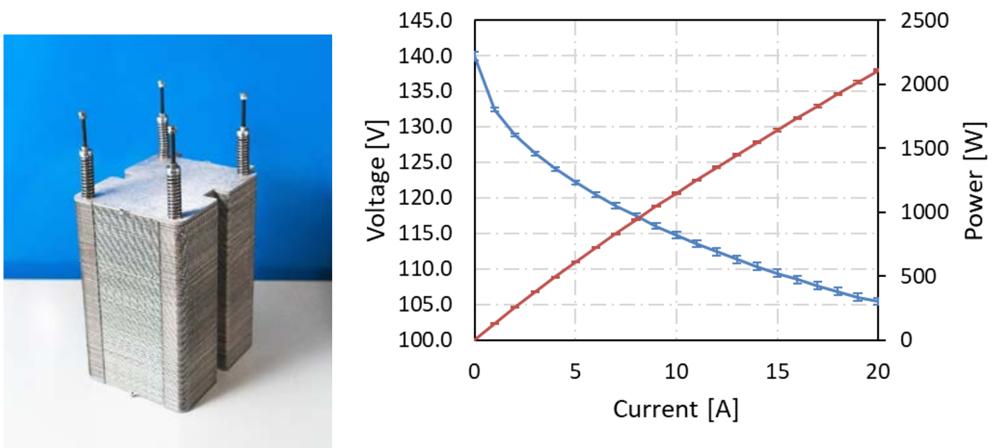


Figure 1. Project scheme for the current NEDO project, “Development of advanced evaluation and analysis technologies for the durability of Solid Oxide Fuel Cells stacks (2020-2024)”.

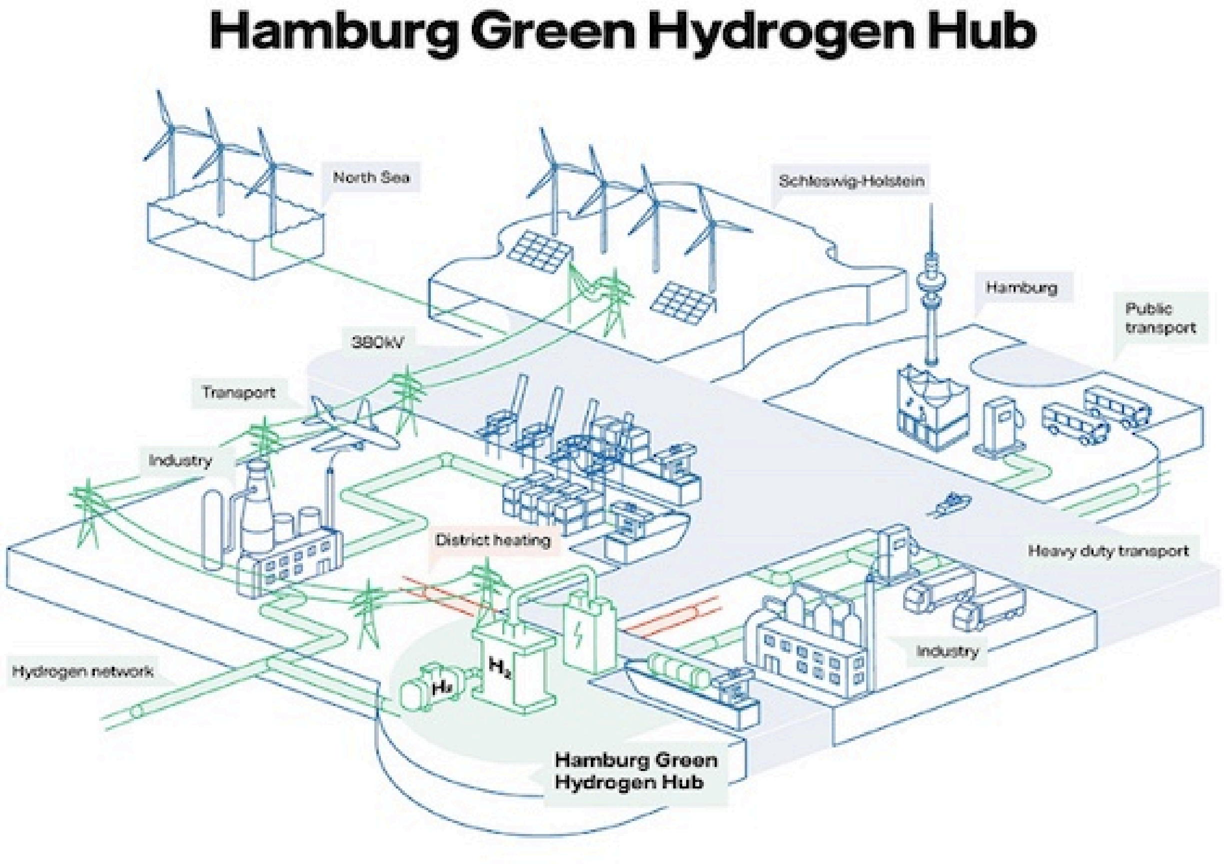
圖五、電池堆耐久性先進評析技術發展*



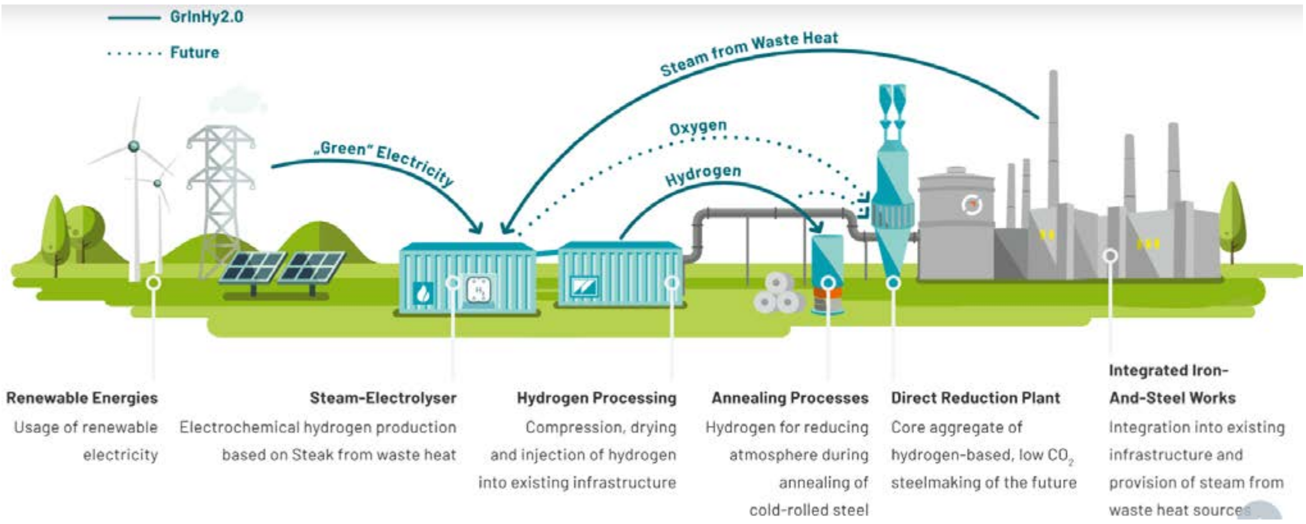
圖六、Elcogen 製作的 elcoStack® E3000 (119 片電池單元，空氣通道)及電流、電壓功率曲線**

*: Teruhisa Horita, AIST, 15th European SOFC and SOE Forum, A0203, Switzerland 5-8 July, 2022

**: Matti Noponen et. al, Elcogen, 15th European SOFC and SOE Forum, A0503, Switzerland 5-8 July, 2022



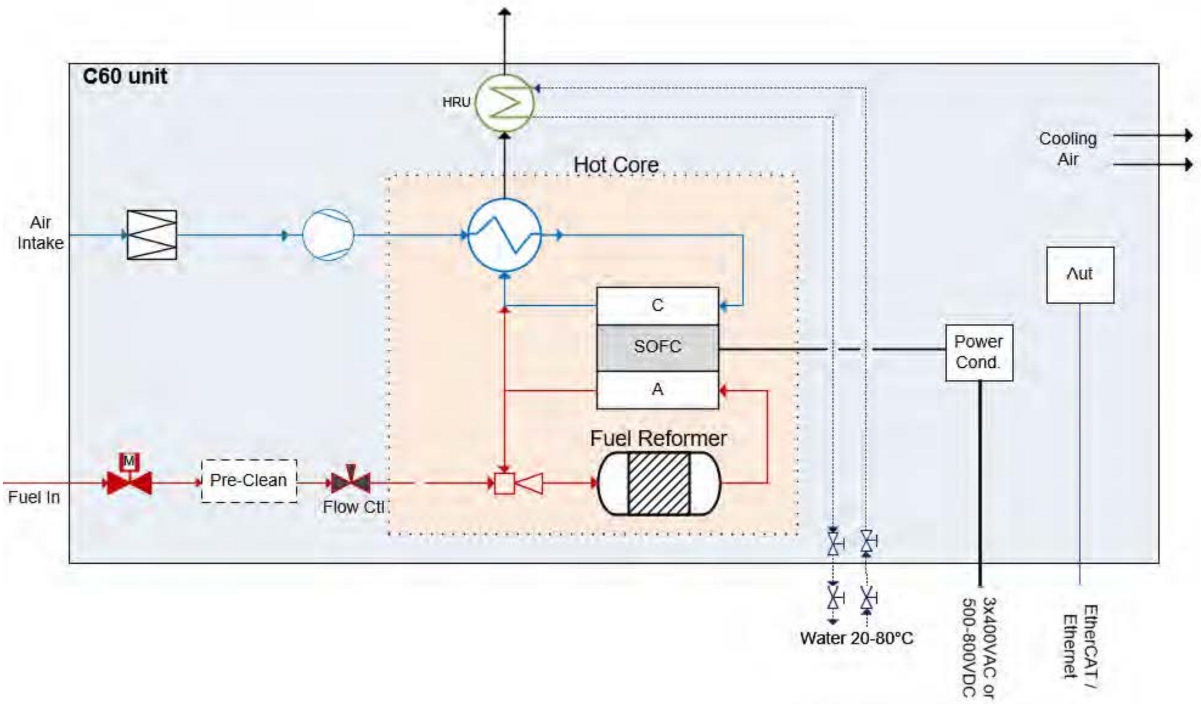
圖七、Hamburg Green Hydrogen Hub 的架構圖*



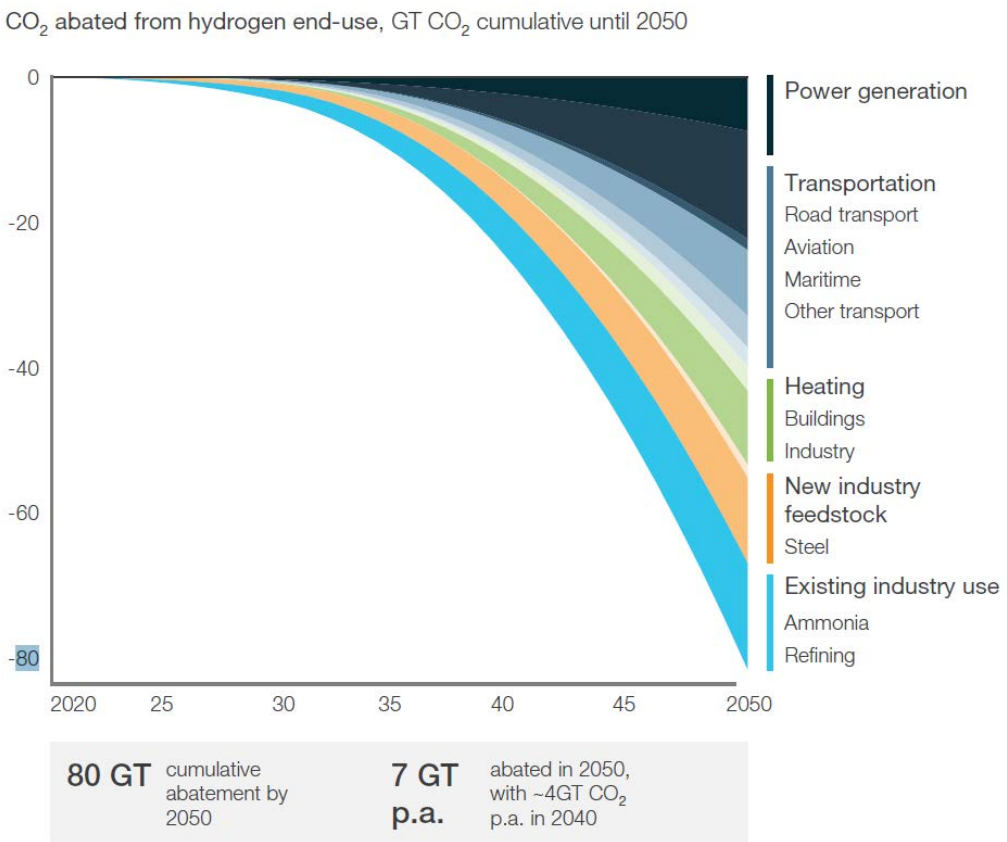
圖八、GrInHy 計畫，與再生能源結合綠氫之生產及應用情節**

* source: https://group.vattenfall.com/

** source: https://salcos.salzgitter-ag.com/en/grinhy-20.html



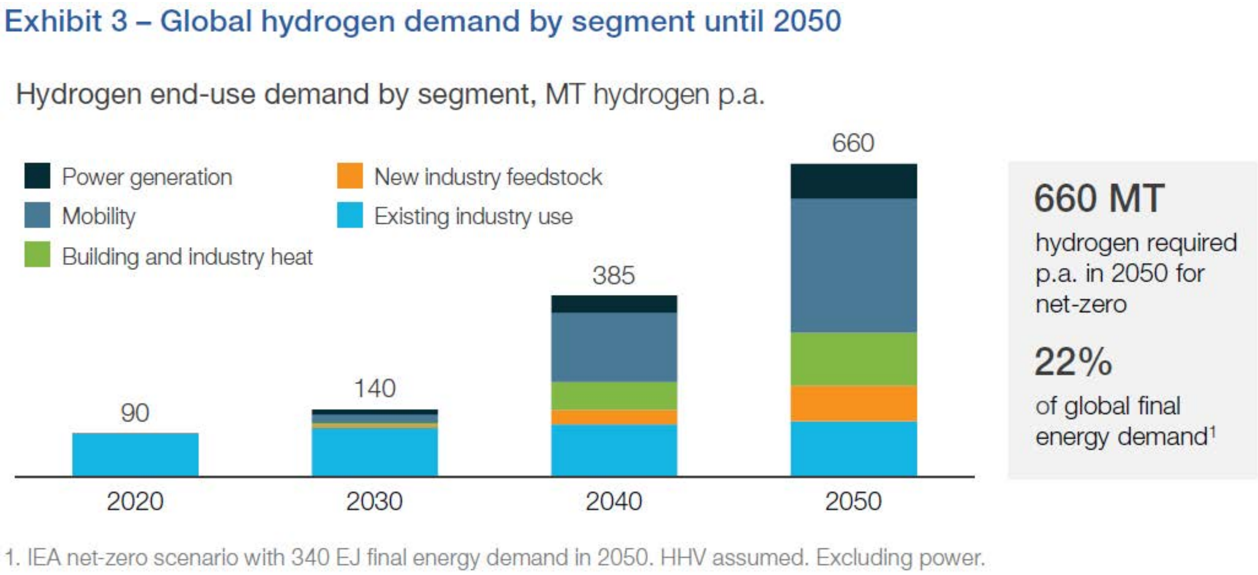
圖九、Convion 公司開發 C60 發電系統之架構*



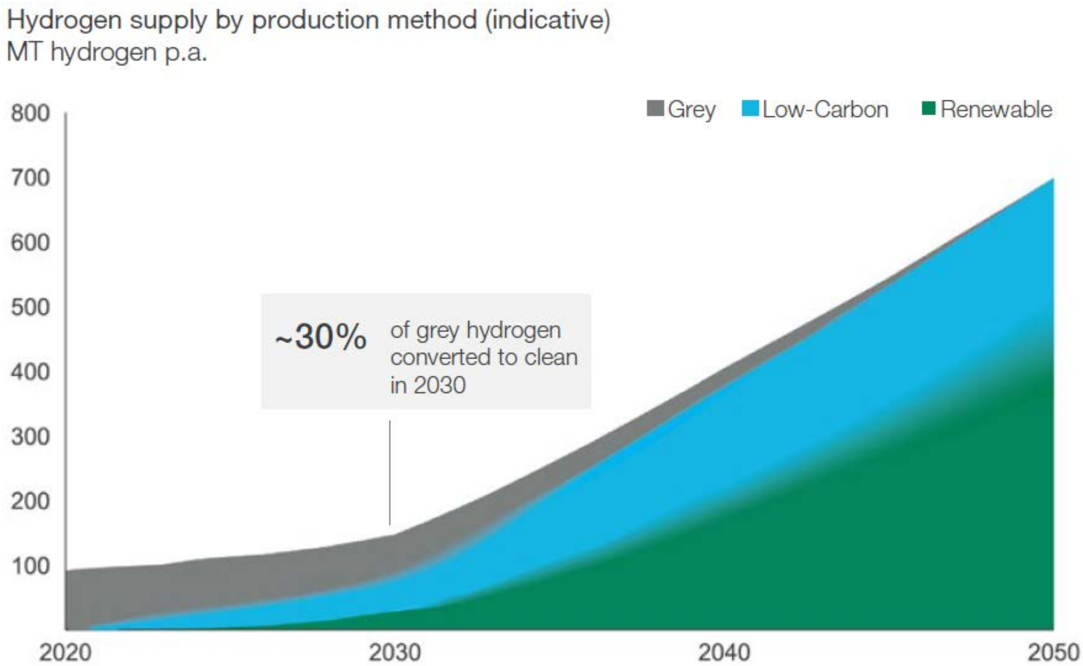
圖十、預估氫能在各能源使用端至 2050 年累積的減碳量**

*: Kim Åström et. al, Convion, 15th European SOFC and SOE Forum, A0302, Switzerland 5-8 July, 2022

**:*Hrdrogen for Net-Zero*-A critical cost-competitive energy vector, McKinsey & Co., Hydrogen Council, Nov., 2021.



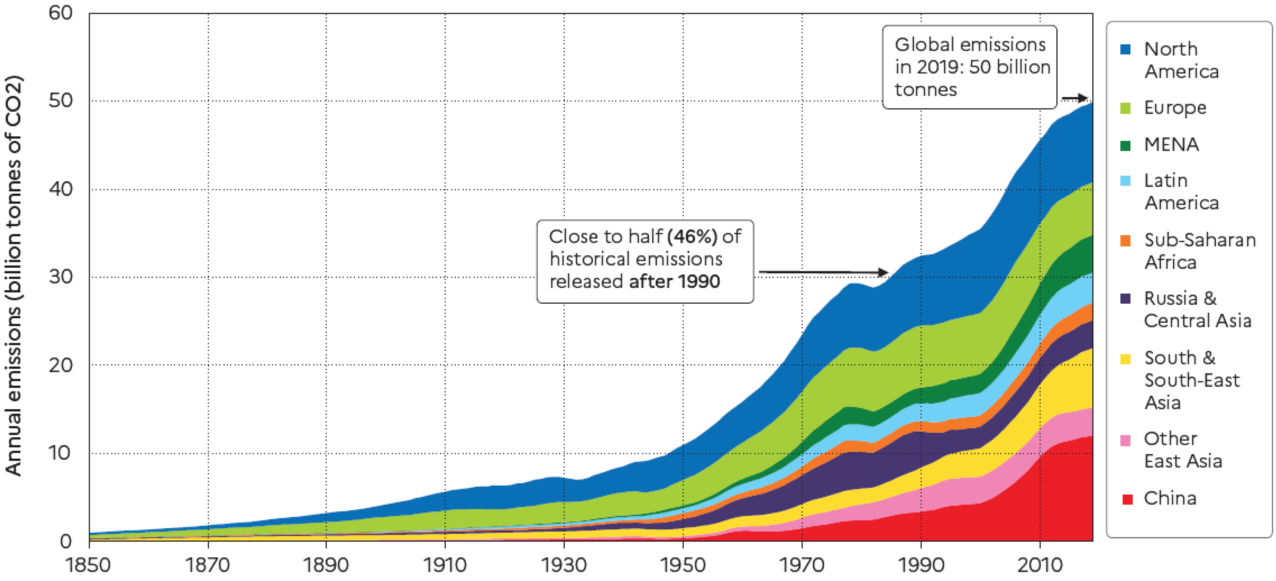
圖十一、預估氫能在各能源使用端至 2050 年之需求量*



圖十二、McKinsey 評估不同氫能供應來源的組合，從 2020 至 2050 的演化圖*

* ref:*Hrdrogen for Net-Zero*-A critical cost-competitive energy vector, McKinsey & Company, Hydrogen Council, Nov., 2021.

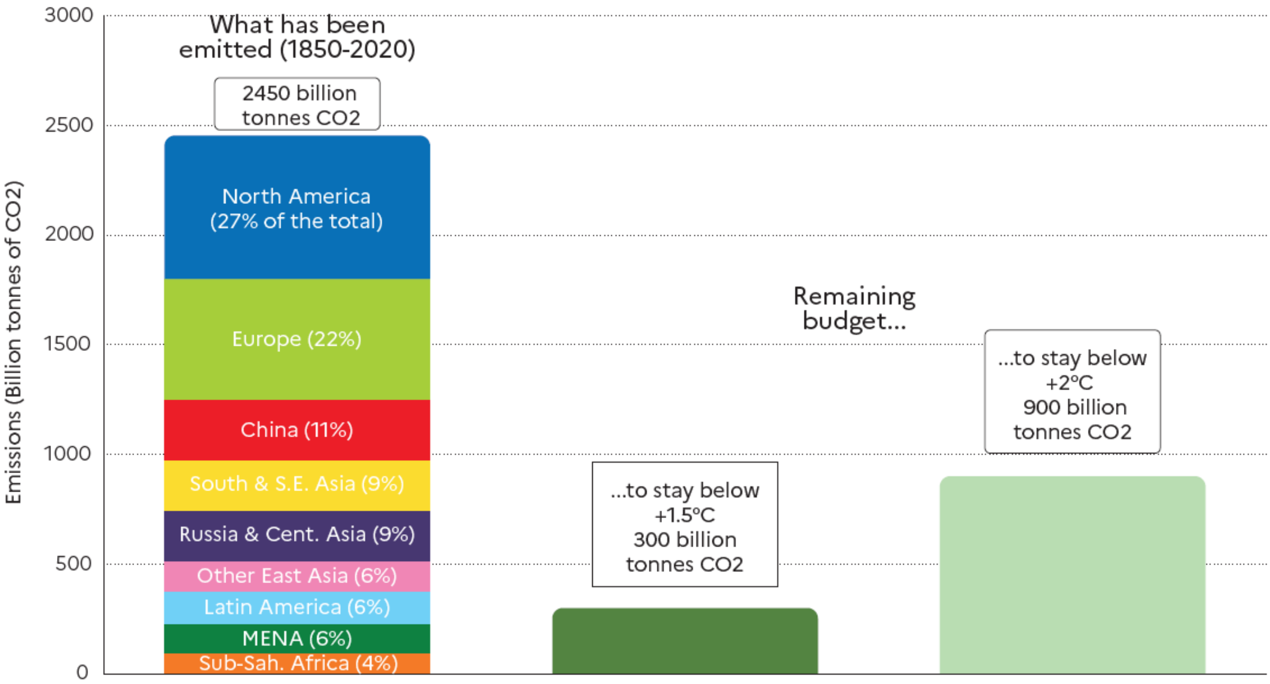
Figure 6.1 *Global annual CO2 emissions by world region, 1850-2019*



Interpretation: *The graph shows annual global emissions by world regions. After 1990, emissions include carbon and other greenhouse gases embedded in imports/exports of goods and services from/to other regions.* ***Sources and series:*** *wir2022.wid.world/methodology and Chancel (2021). Historical data from the PRIMAP-hist dataset. Post-1990 data from Global Carbon Budget.*

圖十三、1850-2019 年間全球各主要區塊的年度二氧化碳排放量*

Figure 6.2 *Historical emissions vs. remaining carbon budget*

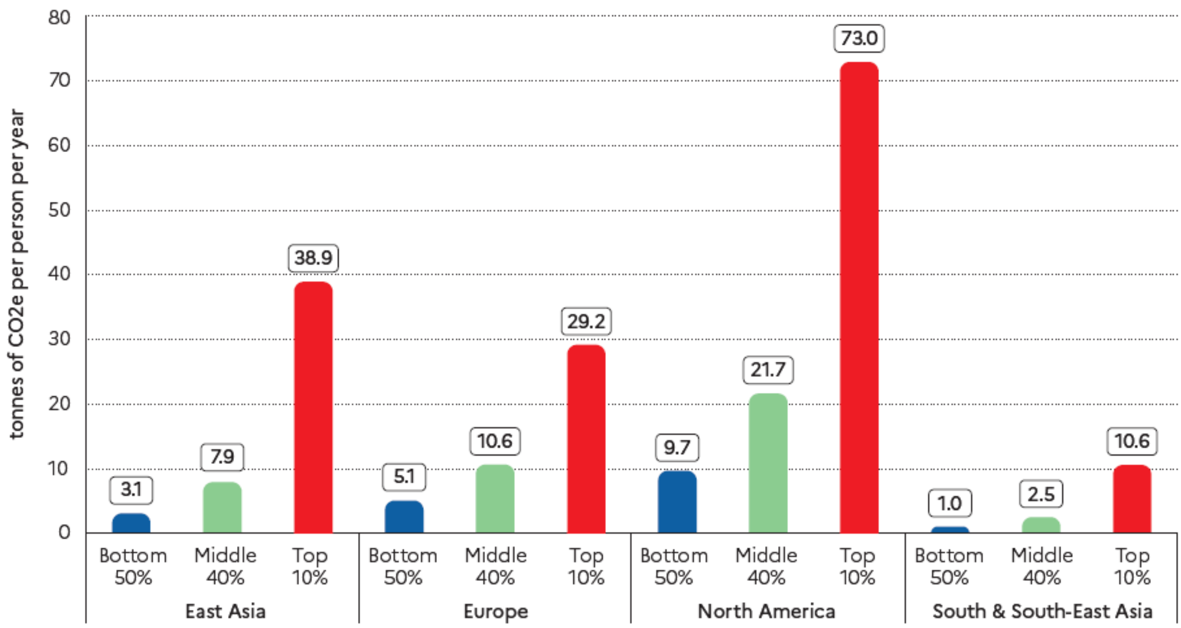


Interpretation: *The graph shows historical emissions by region (left bar) and the remaining global carbon budget (center and right bars) to have 83% chances to stay under 1.5°C and 2°C, according to IPCC AR6 (2021). Regional emissions are net of carbon embedded in imports of goods and services from other regions.* ***Sources and series:*** *wir2022.wid.world/methodology and Chancel (2021). Historical data from the PRIMAP-hist dataset.*

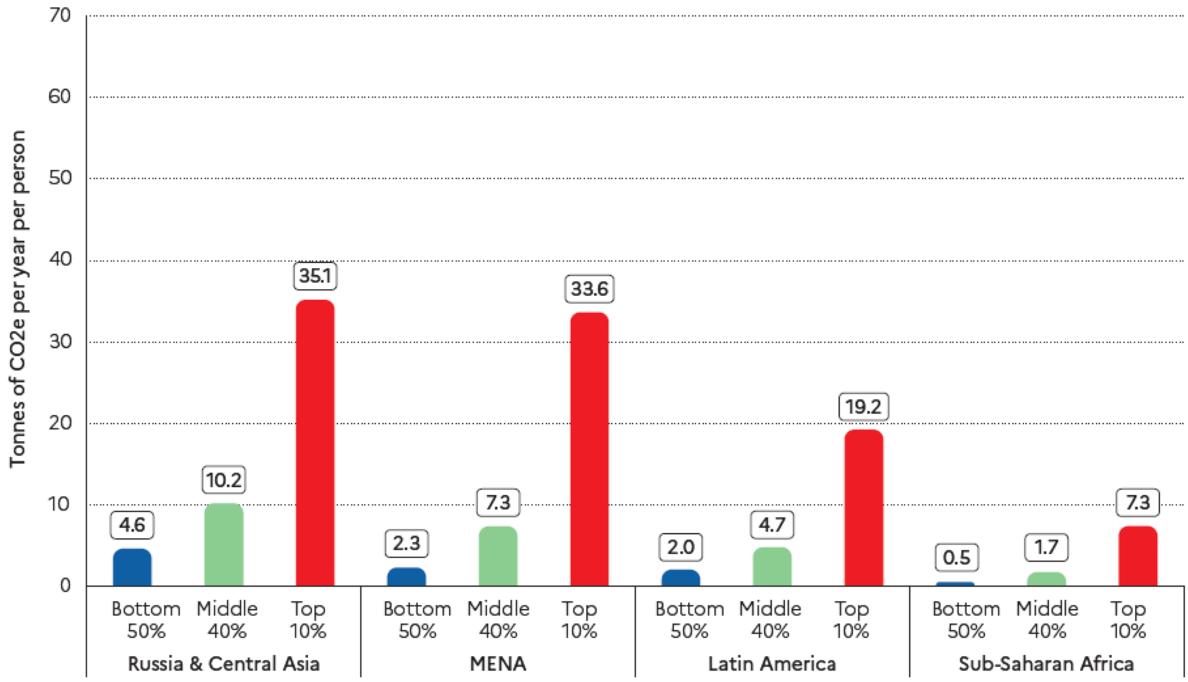
圖十四、1850-2020 全球累積之二碳化碳排放量及 1.5℃/2℃ 上限的二氧化碳排放當量*

*: *World Inequality Report 2022*, World Inequality Lab, 2021.

Figure 15 *Per capita emissions across the world, 2019*



Interpretation: *Personal carbon footprints include emissions from domestic consumption, public and private investments as well as imports and exports of carbon embedded in goods and services traded with the rest of the world. Modeled estimates based on the systematic combination of tax data, household surveys and input-output tables. Emissions split equally within households.* ***Sources and series:*** *wir2022.wid.world/methodology and Chancel (2021).*



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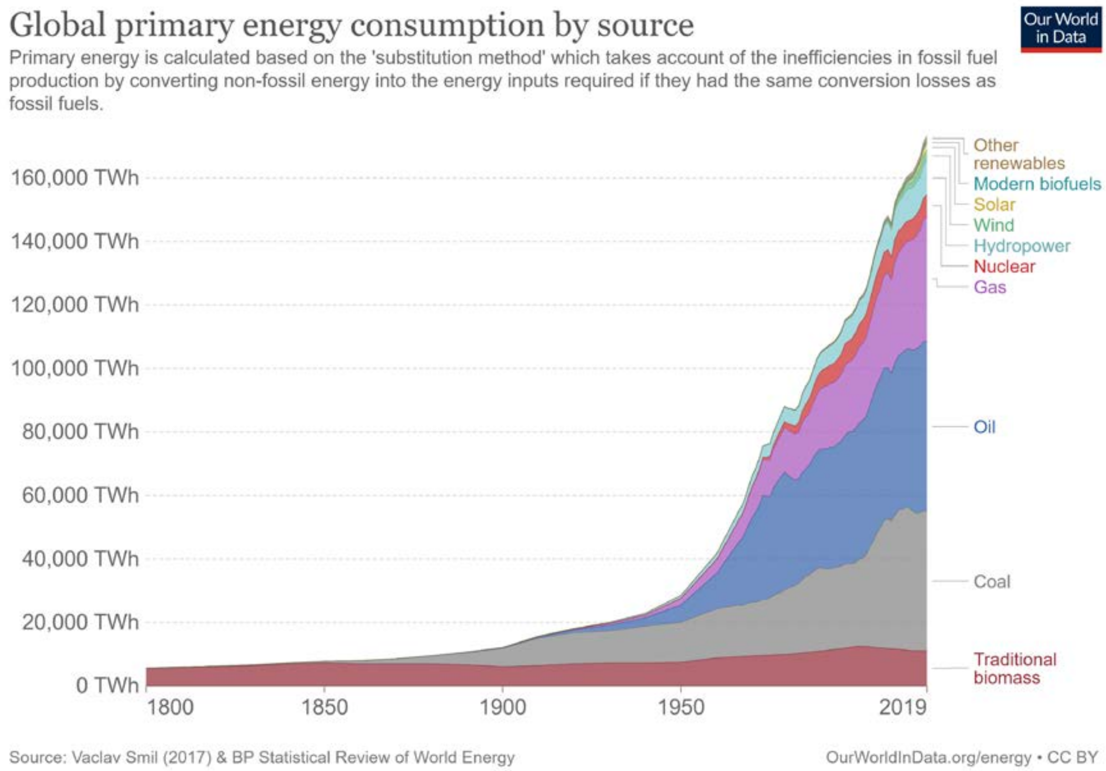
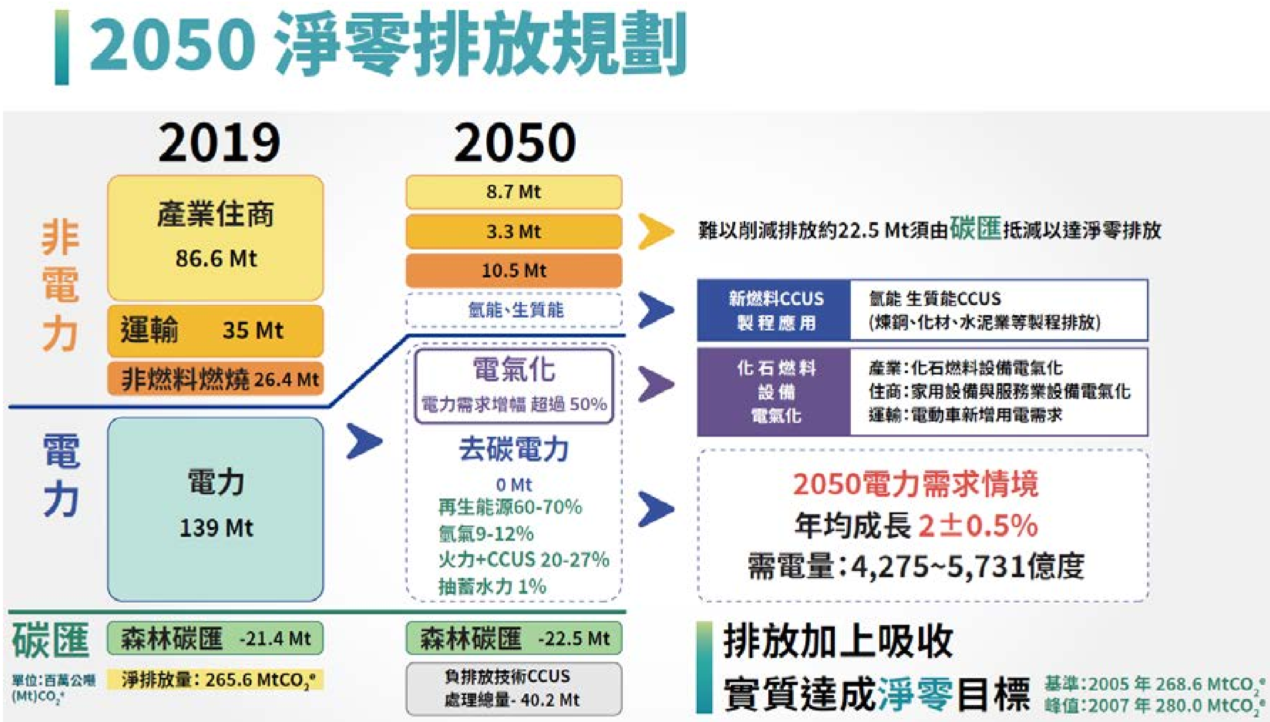
圖十五、全球不同區域頂層、中層及底層之人均碳排放值*

*: *World Inequality Report 2022*, World Inequality Lab, 2021.

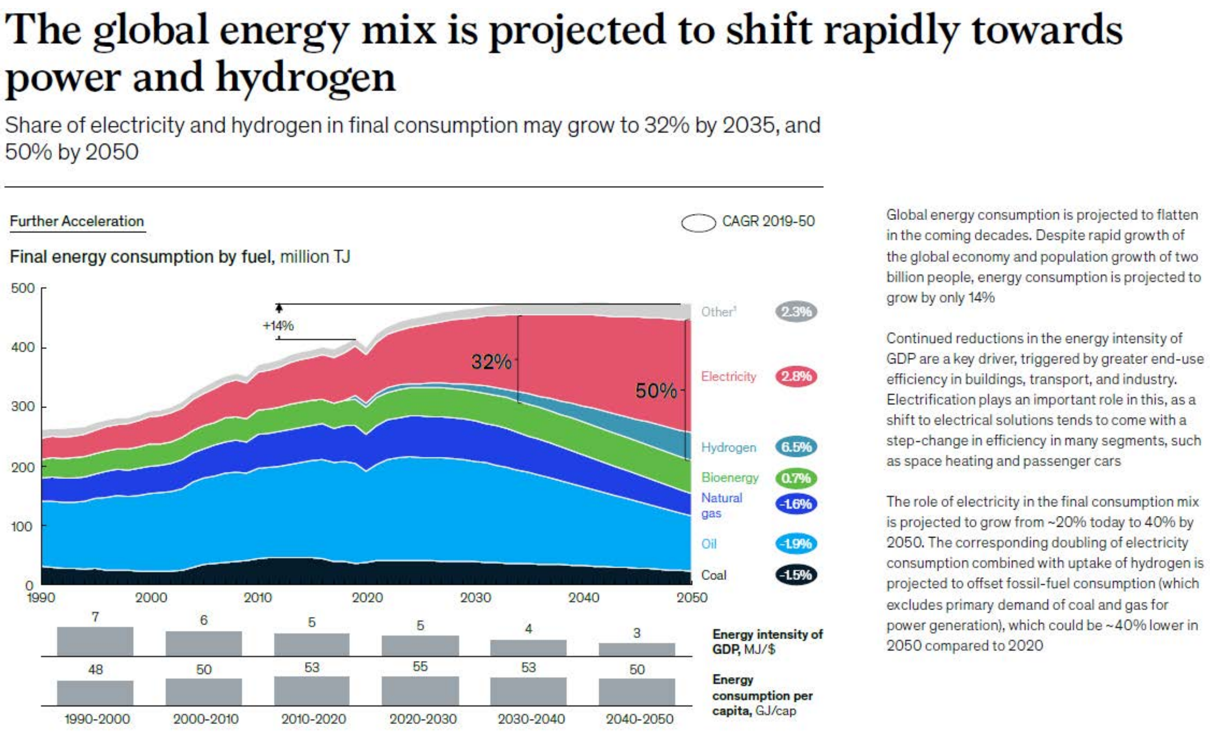


圖十六、1800-2019 歷年全球不同形式初級能源之消耗量



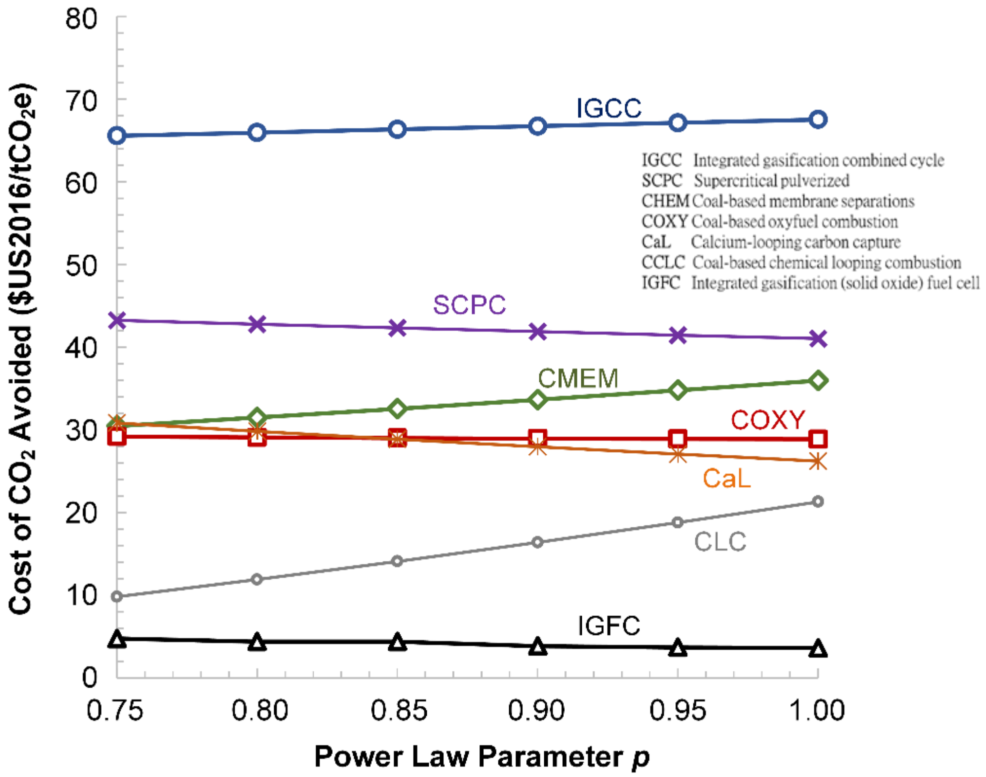
圖十七、國發會提出之 2050 淨零排放規劃*

* ref:台灣 2050 淨零排放路徑及策略總說明，國發會，3 月 30 日，2022.



圖十八、麥肯錫評估全球能源占比的年度變化圖**

**: *Global Energy Perspective 2022*, McKinsey & Company, Hydrogen Council, Aptil, 2022



圖十九、不同類型碳基發電系統的迴避減碳成本比較**

**ref.:Thomas A. Adams II et. al, MDPI, Processes 5, 44, 2017

附件一、 EFCF-2022 論壇口頭簡報之議程

EFCF 2022, 4 - 8 July
Session Program

Morning - Luzerner Saal — Wednesday, 6 July 2022

09:00 A01 - P1: Opening Session

09:00	**Welcome by the Organizers (A0101)** Olivier Bucheli, Michael Spirig European Electrolyser & Fuel Cell Forum, Luzern/Switzerland
09:05	**Welcome by the Chairs (A0102)** Julie Mougin, Jérôme Laurencin CEA-Liten, Grenoble/France
09:15	**Welcome to Switzerland (A0103)** Stefan Oberholzer, Rolf Schmitz, Benoît Revaz Swiss Federal Office of Energy, Bern/Switzerland

09:30

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Mihails Kuznesoff, IKTS, DE	Ligang Wang, NCEPU, CN
Jérome Laurencin, CEA, FR	André Weber, KIT, DE
Florence Lefebvre-Joud, CEA, FR	We thank the SAC for the evaluation and contribution to structure the technical program.

Scientific Advisory Committee (SOC) — www.EFCF.com/SOC

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Bertrand Morel, CEA, FR	Manon Prioux, CEA, FR
Jérôme Aicart, CEA, FR	Cintia Hartmann, CEA, FR
Marie Petitjean, CEA, FR	We thank the SOC for the content and quality contribution of the technical contributions.

Morning - Luzerner Saal — Wednesday, 6 July 2022 — Auditorium - Morning

09:30	**A02: Keynotes: EU, USA, JP & Korean Programs/Partnerships**	**B02: Fuel Electrodes**
09:30 09:35	**K1: The Status of SOFC & SOEC R&D in the Clean Hydrogen Partnership (A0201v)** A. Aguilo-Rullan, M. Atanasiu, B. Biebuyck, D. Dirmiki, D. Tsimis Clean Hydrogen Partnership, Brussels/Belgium;	Change to Auditorium **LSM based fuel electrode materials for SOECs operating under steam, co-electrolysis and CO_2-electrolysis modes (B0201)** Vaibhav Vibhu (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1) (1) Institute of Energy and Climate Research, Fundamental Electrochemistry (IEK-9), Forschungszentrum Jülich GmbH, Jülich/Germany; (2) Institute of Physical Chemistry, RWTH Aachen University, Aachen/Germany;
09:50	**K2: U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office Opening Remarks (A0202)** William T. Gibbons, U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office, Washington/USA	**Sulfur-Activated SFM-Based Fully Ceramic Fuel Electrodes for Solid Oxide Cells (B0202)** Matthias Riegral, Noriko Sata, Rémi Costa German Aerospace Center (DLR), Institute of Engineering Thermodynamics, Stuttgart/Germany;
10:05 10:10	**K3: Recent achievements of advanced evaluation and analysis technologies for the durability of Solid Oxide Fuel Cells stacks in Japan (A0203)** Teruhisa Horita; National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba/Japan	**Electrode Materials for Robust Solid Oxide Electrolysis Stacks (B0203)** S. Elango Elangovan, Tyler Hafen, Taylor Rane, Dennis Larsen, Joseph Hartvigsen, Jenna Pike OxEon Energy, LLC.; North Salt Lake/USA;
10:20		**Generalization and optimization of Ni exsolution with diffusion-determined model to achieve highly active and stable anode for solid oxide fuel cells (B0204)** Yo Han Kim and Jae-ha Myung; Department of Materials Science and Engineering, Incheon National University; Incheon/Republic of Korea;
10:30 10:35	**K4: Overview o the Korean Hydrogen and Fuel Cell Program (A0204v)** Kisuk Chung Korean Energy Technology Evaluation and Planning (KETEP), Korea	**Reversibility limitations of metal exsolution catalysts at low dopant concentrations (B0205)** Moritz L. Weber (1,2,3), Regina Dittmann (1), Rainer Waser (1,4), Norbert H. Menzler (2), Felix Gunkel (1), Christian Lenser (2), Olivier Guillon (2,3); (1) Peter Gruenberg Institute (PGI-7) and JARA-FIT; (2) Institute of Energy and Climate Research (IEK-1), Forschungszentrum Juelich GmbH, Juelich/Germany; (3) Institute of Mineral Engineering (GHI); (4) Institute for Electronic Materials (IWE 2), RWTH Aachen University, Aachen/Germany;
10:50	**Break - Ground Floor in the Exhibition**	

11:15 A03: Technology status at industry I

11:15 **Gas_to_Power and Power_to_Gas solutions from SOLIDpower (A0301)**
Massimo Bertoldi (1), Antonello Nesci (2), Zacharie Wuillemin (2), Stefano Modena (1), Dario Montinaro (1), Daniele Penchini (1).
(1) SOLIDpower SpA. Mezzolombardo/Italy;
(2) SOLIDpower SA, Yverdon-les-Bains/Switzerland;

11:30 **Field Experiences and Development of C60 Platform for Premium Efficiency SOFC and SOEC (A0302)**
Kim Åström, Tuomas Hakala, Erkko Fontell
Convion Oy, Espoo/Finland;

11:45 **Commercialization of the Ceres SteelCell® Technology for Power Generation and Electrolysis (A0303)**
Robert Leah, Adam Bone, Per Hjalmarsson, Ahmet Selcuk, Mike Lankin, Mahfujur Rahman, Florence Felix, Jeffrey De Vero, Xin Wang, Laura Rios, Subhasish Mukerjee,Mark Selby
Ceres Power Ltd; Viking House, Horsham/U.K.;

12:00 **Power-to-X and green hydrogen at Haldor Topsoe: status and plans (A0304)**
Peter Blennow, Thomas Heiredal-Clausen, Jeppe Rass-Hansen, Michael Hultqvist, John Bøgild Hansen, Poul Georg Moses
Haldor Topsoe A/S; Lyngby/Denmark;

12:15 **Status of Hexis and mPower' SOFC and SOEC Activities (A0305)**
Andreas Mai (1,2), Jan G. Grolig (1), Venkatesh Sarda (1), Holger Bausinger (1), Alexander Schuler (1, 2), Amarnath Chakradeo (3), Siddharth R. Mayur (3)
(1) Hexis AG; Winterthur/Switzerland;
(2) Hexis GmbH; Konstanz/Germany;
(3) mPower GmbH; Dresden/Germany;

B03: Fuel & Oxygen Electrodes

Influence of A-Site modifications on the properties of $(La_{0.2}Sr_{0.7-x}Ca_x)_yTi_{0.95}Fe_{0.05}O_{3-\delta}$ based fuel electrode for solid oxide cell (B0301)
S. Paydar (1), O. Volobujeva (2), E. Lust (1), G. Nurk (1)
(1) Institute of Chemistry, University of Tartu; Tartu/Estonia;
(2) Department of Materials Science, Tallinn University of Technology, Tallinn/Estonia

The role of noble metal current collectors in electrochemical SOC studies of MIEC catalysts (B0302)
Mykhailo Pidburtnyi, Haris Ansari, Viola Birss
Department of Chemistry, University of Calgary, Calgary/Canada;

LSM/GDC as electrodes material for symmetrical IT – SOFC fueled by methane (B0303)
Enrico Squizzato (1), Caterina Sanna (2), Marie Lund Traulsen (3), Paola Costamagna (2), Peter Holtappels (3), Antonella Glisenti (1,4)
(1) Department of Chemical Sciences, University of Padova, Padova/Italy;
(2) Department of Chemistry and Industrial Chemistry, University of Genoa, Genoa/Italy;
(3) Department of Energy Conversion and Storage, Tech. Uni. of Denmark, Lyngby/Denmark;
(4) CNR-ICMATE, Padova/Italy;

Degradation behavior of $Ln_2Ni_{1-x}Co_xO_{4+\delta}$ (Ln = La, Pr or Nd) and $La_{1.5}Pr_{0.5}Ni_{1-x}Co_xO_{4+\delta}$ (x= 0, 0.1, 0.2) oxygen electrodes under steam electrolysis conditions (B0304)
Vaibhav Vibhu (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
(1) Institute of Energy and Climate Research, Fundamental Electrochemistry (IEK-9); Forschungszentrum Jülich GmbH, Jülich/Germany;
(2) Institute of Physical Chemistry, RWTH Aachen University, Aachen/Germany;

Cobalt-free air electrode for the next generation of Solid Oxide Cells based on $(La,Sr)FeO_3$ materials (B0305)
Claire Ferchaud, Frans van Berkel, Loek Berkeveld, Miranda Heijink-Smith, Jakobert Veldhuis, Hans van Wees
ECN part of TNO, Petten/The Netherlands;

12:30 Lunch - 2nd Floor on the Terrace / Coffee - Ground Floor in the Exhibition & 1st Floor in the Poster Area

13:15 A04: Poster Session I covering All Session Topics + B09s: Co-Electrolysis & CO_2-Electrolysis — Auditorium Foyer

15:00 A05: Technology status at industry II

15:00 **Status of Stack & System Development at Sunfire (A0501)**
Christian Walter, Oliver Posdziech, Matthias Boltze
Sunfire GmbH; Dresden/Germany;

15:15 **AVL's SOC Portfolio for a Hydrogen Based Energy System (A0502)**
Martin Hauth, Bernd Reiter, Raphael Neubauer, Manuel Tandl
AVL List GmbH; Graz/Austria;

15:30 **SOC development at Elcogen (A0503)**
Matti Noponen (1), Hanna Granö-Fabritius (1), Sergii Pylypko (2), Enn Õunpuu (2)
(1) Elcogen; Vantaa/Finland;
(2) Elcogen; Tallinn/Estonia;

15:45 **Reversible SOEC/ SOFC System Development and Demonstration (A0504)**
Jenna Pike, S. Elango Elangovan, Joseph Hartvigsen, Dennis Larsen, Tyler Hafen, Michele Hollist, Abel Gomez, Ainsley Yarosh, Jessica Elwell
OxEon Energy; North Salt Lake/USA;

B05: Oxygen electrodes

Influence of the B-site Dopant (M = Ti, Nb) Content on the Electrochemical Performance of $(La_{0.6}Sr_{0.4})_{0.99}Co_{1-x}M_xO_{3-\delta}$ Oxygen Electrode (B0501)
Alar Heinsaar (1), Indrek Kivi (1), Jaan Aruväli (2), Kuno Kooser (3), T. Käämbre (3), Gunnar Nurk (1), Enn Lust (1); (1) Institute of Chemistry, University of Tartu, Tartu/Estonia; (2) Institute of Ecology and Earth Sciences, University of Tartu, Tartu/Estonia; (3) Institute of Physics, University of Tartu, Tartu/Estonia

Route to achieving high power densities using nanostructured cathodes on anode-supported SOFCs (B0502)
Katherine Develos-Bagarinao (1), Tomohiro Ishiyama (2), Hiroyuki Shimada (3)
Haruo Kishimoto (1), Katsuhiko Yamaji (2)
(1) Global Zero Emission Research Center, AIST West;
(2) Research Institute for Energy Conservation, AIST Central 5;
(3) Innovative Functional Materials Research Institute, AIST Chubu; National Institute of Advanced Industrial Science and Technology (AIST), Japan;

Significantly reduced area specific resistance of $Pr_4Ni_3O_{10\pm\delta}$ – $Ce_{0.75}Gd_{0.1}Pr_{0.15}O_2$ composite cathode by optimizing microstructures for IT-SOFCs (B0503)
Zheng Xie, Stephen J. Skinner
Department of Materials; Imperial College London, London/UK;

Oxygen isotope exchange in $SrFe_{1-x}Si_xO_{3-\delta}$. (B0504)
Artur J. Majewski (1), Natalia Porotnikova (2), Anna Khodimchuk (2), Maxim Ananyev (3), Peter R. Slater (4), Dmitriy Zakharov (2), Robert Steinberger-Wilckens (1)
(1) School of Chemical Engineering, University of Birmingham, Birmingham/UK;
(2) Institute of High Temperature Electrochemistry, Yekaterinburg/Russia;
(3) Federal State Research and Design Institute of Rare Metal Industry, ul., Moscow/Russia;
(4) School of Chemistry, University of Birmingham, Birmingham/UK

16:00 Break - Ground Floor in the Exhibition & 1st Floor in the Poster Area

16:30 A06: Technology status at industry III + Projects Overview

16:30 **The highly efficient power source – the stationary fuel cell system by Bosch (A0601)**
Sven Steib
Robert Bosch GmbH; Stuttgart/Germany;

16:45 **Status of Electroyser Development at GENVIA (A0602)**
Patrice Tochon, Capella Festa, Najet Agrane, Gilles Iafrate
GENVIA SAS; PLAINE SAINT PIERRE, BEZIER;

17:00 **Development of a rSOC modular product for a sustainable local energy supply (A0603)**
Nicolas Bardi, Caroline Rozain, Marc Potron, Guillaume Préaux
Sylfen; Le Cheylas;

17:15 **Progress on Reversible Solid Oxide Cell, Stack, and System Technologies (A0604)**
Emir Dogdibegovic* (1), Robert Braun (2), Scott Barnett (3), Samuel Horlick (1), Anila Wallace (1), David Kopechek (1), Gene Arkenberg (1), Judy Garzanich (1), John Funk (1), Sergio Ibanez (1), Aadarsh Parashar (2), Yubo Zhang (3), Scott Swartz (1), Chad Sellers (1), Bradley Glenn (1), Mark Evans (1)
(1) Nexceris; Ohio/USA;
(2) Colorado School of Mines; Colarado/USA;
(3) Northwestern University; Illinois/USA;

17:30 **Large Area Solid Oxide Electrolysis Stack (A0605)**
Kerry Meinhardt, Nathanael Royer, John Zaengle, Lorraine Seymour, Joelle Reiser, Jie Bao, Naveen Karri, Olga A. Marina
Pacific Northwest National Laboratory; Washington/USA;

17:45 **Mn(II)-doped scandia stabilized zirconia electrolyte: materials, cells and stack performance (A0606)**
Marie-Laure Fontaine (1), Einar Vøllestad (1), Vegar Øygarden (1), John Pietras (2), Julian Dailly (3), Karine Couturier (4)
(1) SINTEF AS.; Oslo/Norway;
(2) Saint-Gobain Research North America; Northborough/USA;
(3) EIFER; Karlsruhe/Germany;
(4) CEA; Univ. Grenoble Alpes – CEA/LITEN, Grenoble/France;

B06: Lifetime Cells I

Accelerated Failure of Standard Solid-Oxide Electrolysis Cells from Multiscale Modeling (B0601)
Brandon C. Wood (1), Joel Berry (1), Namhoon Kim (1), Richard D. Boardman (2), Gregory A. Hackett (3), Harry W. Abernathy (3), William K. Epting (3, 4), Olga Marina (5), Jamie Holladay (5), David Peterson (6), William T. Gibbons (6)
(1) Lawrence Livermore National Laboratory; Livermore/USA;
(2) Idaho National Laboratory; Idaho/USA;
(3) National Energy Technology Laboratory; Morgantown/USA;
(4) NETL Support Contractor, Pittsburgh, PA / Morgantown, WV / Albany, OR;
(5) Pacific Northwest National Laboratory, Washington/USA, ;
(6) Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy- EERE; Colarado/USA;
(7) Hydrogen and Fuel Cell Technologies Office, U.S. Department of Energy- EERE; Washington/USA;

Accelerated testing of microstructural degradation in nickel/ceria fuel electrodes (B0602)
Yanting Liu (1), Florian Wankmüller (2), Martin Juckel (3), André Weber (1)
(1) Institute for Applied Materials (IAM-WET); Karlsruhe Institute of Technology (KIT), Karlsruhe/Germany;
(2) Laboratory for Electron Microscopy, Karlsruhe Institute of Technology, Karlsruhe/Germany
(3) IEK-1, Forschungszentrum Jülich GmbH, Jülich/Germany

Effect of Operating Conditions on Durability of Solid Oxide Electrolysis Cells (B0603)
Olga A. Marina, Long Le, Christopher Coyle, Dan Edwards, Jie Bao, Dewei Wang, Kerry Meinhardt, Jamie Holladay
Pacific Northwest National Laboratory; Washington/USA;

30,000 Hours Steam Electrolysis with a 3YSZ-Electrolyte Supported Cell at Elevated Current Density (B0604)
Josef Schefold (1), Aline Leon (1), Christian Walter (2)
(1) European Institute for Energy Research (EIFER); Karlsruhe/Germany;
(2) Sunfire GmbH; Dresden/Germany;

Ni migration in Solid Oxide Cells: a coupled modeling and experimental study (B0605)
Léa Rorato (1), Yijing Shang (2), Shenglan Yang (2,3), Maxime Hubert (1), Karine Couturier (1), Lijun Zhang (3), Julien Vulliet (4), Ming Chen (2), Jérôme Laurencin (1)
(1) Univ. Grenoble Alpes - CEA/LITEN; Grenoble/France;
(2) Department of Energy Conversion and Storage, Technical University of Denmark; Kgs. Lyngby/Denmark
(3) State Key Laboratory of Powder Metallurgy, Central South University; Changsha/China;
(4) CEA, DAM, Le Ripault, Monts/France;

Effect of Current Density on Performance Degradation and Microstructural Evolution in Ni/CGO Fuel Electrode for Steam Electrolysis Operation (B0606)
Morten Phan Klitkou, Henrik Lund Frandsen, Peter Vang Hendriksen
Technical University of Denmark, Department of Energy Conversion and Storage; Lyngby/Denmark;

18:00 End of Sessions

18:30 Swiss Surprise Night Registered participants meet between KKL and railway station

09:00 A07: Keynote - Power to optimised X by Haldor Topsøe A/S

09:00 **K5: Power to X: What is the optimum X from a SOEC perspective? (A0701)**
John Bøgild Hansen; Haldor Topsøe A/S, Lyngby/Denmark

B07: Keynote - Advanced characterization tools by AIST

K6: Cutting-edge technologies for probing degradation phenomena in solid oxide cells (B0701)
Katherine Develos-Bagarinao; Global Zero Emission Research Center (GZR), National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba/Japan

09:30 A08: Lifetime Stacks

09:30 **Utilizing the full power of electrochemical impedance spectroscopy to identify stack degradation mechanisms in commercial SOEC stacks (A0801)**
Daniel B. Drasbæk, Peter Blennow, Thomas Heiredal-Clausen, Jeppe Rass-Hansen, Giovanni Perin, Jens V. T. Høgh, Anne Hauch
Topsoe A/S Haldor Denmark, Lyngby/Denmark;

09:45 **15000 hours test of a SOE short stack in co-electrolysis mode (A0802)**
Stefan Diethelm (1), Audrey Wesoly (1), Samaneh Daviran (1), Hamza Moussaoui (1), Dario Montinaro (2), Jan Van herle (1)
(1) Group of Energy Materials; École Polytechnique Fédérale de Lausanne/Switzerland;
(2) SOLIDpower SpA, Mezzolombardo/Italy;

10:00 **Combining SOEC and biomass gasification for synthesis of methanol; use of purge gases on the oxygen electrode and their impact on cell durability (A0803)**
Peter V. Hendriksen (1), Belma Talic (1,2), Jens V. T. Høgh (1,3), P. Blennow (3), R. Küngas (3), M. Chen (1) X. Sun (1), J. Ahrenfeldt (4), U. B. Henriksen (4), W.-R. Kiebach (1)
(1) Department of Energy Conversion and Storage, Technical University of Denmark;
(2) Sintef, Department of Sustainable Energy Technology, Norway;
(3) Haldor Topsøe A/S, Denmark; (4) DTU Chemical Engineering, TU of Denmark;

10:15 **Benchmark Study of Performances and Durability between Different Stack Technologies for High Temperature Electrolysis (A0804)**
Jerome Aicart (1), Alexander Surrey (2), Lucas Champelovier (1), Kilian Henault (1), Chistian Geipel (2), Oliver Posdziech (2), Julie Mougin (1)
(1) Univ. Grenoble Alpes, CEA, Liten, Grenoble/France; (2) Sunfire GmbH, Dresden/Germany;

B08: Stack & System Modelling

Operation & modelling of ammonia fuelled solid oxide fuel cell, stack & systems (B0801)
Henrik Lund Frandsen, Hossein Nami, Omid Babie Rizvandi, Francesco Mondi, Claudia Goebel, Xiufu Sun, Anke Hagen, Peter Vang Hendriksen;
Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;

A high-throughput design of a multifunctional tubular hydrogen reactor (B0802)
Santos-Blasco Joaquin (1), Catalá-Martínez David (1), Escolástico Sonia (1), Veenstra Peter (2), Vøllestad Einar (3), Fontaine Marie-Laure (3), Kiebach Wolff-Ragnar (4), Strandbakke Ragnar (5), Serra José Manuel (1);(1) Instituto de Tecnologia Quimica (CSIC-UPV); Valencia/Spain; (2) Shell Global Solutions International B.V., The Hague/Netherlands; (3) SINTEF Industry; (4) Technical University of Denmark, Roskilde/Denmark; (5) University of Oslo, Oslo/Norway;

Comparative assessment of gas channel flow models for detailed multi-physics planar solid oxide cell and stack simulations (B0803)
Oscar Furst, Lukas Wehrle, Olaf Deutschmann
Karlsruhe Institute of Technology, Institute for Chemical Technology and Polymer Chemistry; Karlsruhe/Germany;

Transient simulation and experimental validation of a solid oxide cell module in electrolysis and polygeneration mode (B0804)
Santiago Salas Ventura, Matthias Metten, Marius Tomberg, Dirk Ullmer, Marc P. Heddrich, S. Asif Ansar
German Aerospace Center (DLR), Institute of Engineering Thermodynamics; Stuttgart/Germany;

10:30 Break - Ground Floor in the Exhibition

11:00 A09: Performance Cell/Stack

11:00 **Impact of GDC interlayer microstructure on strontium zirconate interphase formation and cell performance (A0901):** Sadhana Golani (1), André Weber (1), Florian Wankmüller (2), Werner Herzhof (3), Christian Dellen (3), Norbert H. Menzler (3); (1) Inst. for Applied Materials - Electrochemical Technologies (IAM-ET); (2) Lab. for Electron Microscopy (LEM); Karlsruhe Institute of Technology (KIT), Karlsruhe/Germany; (3) Forschungszentrum Jülich GmbH, Inst. of Energy & Climate Research (IEK), Jülich/Germany;

11:15 **Development and Full System Testing of Novel Co-Impregnated La0.20Sr0.25Ca0.45TiO3 Anodes for Commercial Combined Heat and Power Units (A0902)**
Robert Price (1), Holger Bausinger (2), Gino Longo (2), Ueli Weissen (2), Mark Cassidy (1), Jan G. Grolig (2) Andreas Mai (2), John T. S. Irvine (1); (1) University of St Andrews.; School of Chemistry, St Andrews, Fife/UK.; (2) HEXIS AG; Winterthur/Switzerland;

11:30 **Performance and Endurance Characterization of a Commercial Prototypical SOEC Stack (A0903)**
Micah Casteel (1), Cliff Loughmiller (1), Randy Petri (1), Tyler Westover (1), Jeremy Hartvigsen (1), Peter Blennow (2), John Bøgild Hansen (2), Richard Boardman (1)
(1) Idaho National Laboratory; Idaho/USA; (2) Haldor Topsoe A/S; Lyngby/Denmark;

11:45 **Solid Oxide Electrolysis Stack development and upscaling (A0904)**
Stephane Di Iorio, Thibault Monnet, Géraldine Palcoux, Livia Ceruti, Julie Mougin
Univ. Grenoble Alpes – CEA/LITEN, Grenoble/France;

12:00 **Evaluation of temperature gradients during stack operation with internal reforming (A0905)**
Stefan Megel, Stefan Rothe, Jens, Schnetter, Sebastian Hielscher, Jakob Schöne, Nikolai Trofimenko, Jochen Schilm, Mihails Kusnezoff
Fraunhofer IKTS; Dresden/Germany;

12:15 **Performance enhancement in SOFC stacks (A0906)**
Ute de Haart, Qingping Fang, Norbert H. Menzler, Ralf Peters
Forschungszentrum Jülich GmbH; Institute of Energy and Climate Research; Jülich/Germany;

B09: Proton Conducting Materials, Cells & Stacks

Proton conducting ceramic based components, cells and modules development for high pressurized electrolysis (B0901)
Marie-Laure Fontaine
SINTEF AS Oslo/Norway;

Performance of protonic ceramic cells and systems for hydrogen production (B0902)
A. A. Thatte (1), M. Pastula (2), R. J. Braun (1)
(1) Colorado School of Mines, Department of Mechanical Engineering; Colorado/USA;
(2) Versa Power Systems; Calgary/Canada;

NH_3-fed IT-Proton Conducting Ceramic Cells: a $BaCe_{0.7}Y_{0.2}Zr_{0.1}$-based efficient nanocomposite anode. (B0903)
Pietro Trainotti (1), Fabrice Mauvy (2), Antonella Glisenti (1,3);
(1) University of Padova Dept. of Chemical Sciences; Padova/Italy
(2) Université de Bordeaux – CNRS – PESSAC/FRANCE; (3) CNR-ICMATE, Padova/Italy;

Proton conducting ceramic cells with $Ba_{1-x}Gd_{0.8}La_{0.2+x}CO_2O_{6-\delta}$ oxygen electrode for steam electrolysis application (B0904)
Haoyu Zheng (1), Noriko Sata (1), Matthias Riegraf (1), Amir Masoud Dayaghi (2), Truls Norby (2), Rémi Costa (1); (1) Institute of Engineering Thermodynamics, German Aerospace Center (DLR); Stuttgart/Germany; (2) Department of Chemistry, Centre for Materials Science and Nanotechnology (SMN); University of Oslo, Oslo/Norway;

Towards the development of large scale proton conducting ceramic cells (B0905)
Mariya E. Ivanova (1), Wendelin Deibert (1), Norbert H. Menzler (1), Olivier Guillon (1,2); (1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, Materials Synthesis and Processing (IEK-1); Jülich/Germany; (2) RWTH Aachen University, Institute of Mineral Engineering (GHI), Department of Ceramics & Refractory Materials; Aachen/Germany;

B0907 is requested to be presented here

12:30 Lunch - 2[nd] Floor on the Terrace / Coffee - Ground Floor in the Exhibition & 1[st] Floor in the Poster Area

Afternoon - Luzerner Saal | Thursday, 7 July 2022 | Auditorium - Afternoon

13:15 A10: Poster Session II covering All Session Topics + B09s: Co-Electrolysis & CO_2-Electrolysis — Auditorium Foyer

15:00 A11: System Design, Performance & BoP

15:00 **Ammonia SOFC System Development (A1101)**
Bernd Reiter, Martin Hauth, Raphael Neubauer, Clemens Mair, Markus Reinbacher
AVL List GmbH; Graz/Austria;

15:15 **Progress in the development of LNG and Diesel-fueled SOFC systems for maritime applications (A1102)**
Jan Hollmann (1), Marco Fuchs (1), Elmar Pohl (2), Melanie Grote (2), Carsten Spieker (3), Ulrich Gardemann (3), Michael Steffen (3), Stephan Kabelac (1)
(1) Institute of Thermodynamics, Leibniz University Hannover; Hannover/Germany
(2) OWI Science for Fuels gGmbH; Herzogenrath; (3) Zentrum für BrennstoffzellenTechnik (ZBT GmbH); Duisburg;

15:30 **Experimental results of a 10/40 kW rSOC lab system (A1103)**
Roland Peters, Nicolas Kruse, Wilfried Tiedemann, Ingo Hoven, Robert Deja, Qingping Fang, Ralf Peters
Forschungszentrum Jülich GmbH; Institute of Energy and Climate Research; Jülich/Germany;

15:45 **Highly efficient SOFC system with CFY-stack module operated with gasified biomass - HiEff-BioPower - (A1104)**
Martin Hauth (1), Ortwin Dumböck (1), Christopher Sallai (1),Stefan Megel (2), Jens Schnetter (2), Mihails Kusnezoff (2), Klaus Supancic (3), Thomas Brunner (3), Ingwald Obernberger (3)
(1) AVL List GmbH; Graz/Austria; (2) Fraunhofer IKTS; Dresden/Germany; (3) BIOS BIOENERGIESYSTEME GmbH; Graz/Austria;

B11: Lifetime Cells II

Electrochemical and degradation behaviour of Ni-GDC electrode under steam-, co- and CO_2-electrolysis (B1101)
Ifeanyichukwu D. Unachukwu (1,2), Vaibhav Vibhu (1), Jan Uecker (1,2), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
(1) Institute of Energy and Climate Research, Fundamental Electrochemistry (IEK-9); Forschungszentrum Jülich GmbH, Jülich/Germany
(2) Institute of Physical Chemistry, RWTH Aachen University; Aachen/Germany;

A systematic analysis of the durability behavior of Ni/CGO-based electrolyte-supported cells in co-electrolysis (B1102 previewed to be shifted to Poster B1107)
Matthias Riegraf (1), Noriko Sata (1), Chen-Yu Tsai (2), Mariana Heringer Boucas (2), Christian Geipel (2), Rémi Costa (1)
(1) German Aerospace Center (DLR), Institute of Engineering Thermodynamics; Stuttgart/Germany
(2) Sunfire GmbH, Dresden/Germany;

Modeling of Ni Migration in Ni-YSZ Electrodes During Solid Oxide Electrolysis (B1103)
Qian Zhang, Peter W Voorhees, Scott A Barnett
Northwestern University; Evanston/USA;

Microstructures of Ni-GDC electrodes with carbon deposition (B1104)
Anna Sciazko (1), Yosuke Komatsu (1), Akiko Nakamura (2), Yusuke Sunada (1), Zhufeng Ouyang (1), Toru Hara (2), Naoki Shikazono (1)
(1) Institute of Industrial Science, The University of Tokyo; Tokyo/JAPAN;
(2) National Institute for Material Science, Tsukuba/JAPAN;

16:00 Break - Ground Floor in the Exhibition & 1[st] Floor in the Poster Area

16:30 A12: Cells Design & Manufacturing I

16:30 **Metal-Supported Solid Oxide Cells for Chemical Conversion, Electrolysis, and Power Production (A1201)**
Michael Tucker, Boxun Hu, Martha Welander, Fengyu Shen, Grace Lau
Lawrence Berkeley National Laboratory; CA/USA;

16:45 **Influence of substrate nature on electrochemical performance of electrolyte supported cells for operation as SOFC/SOEC (A1202)**
Nikolai Trofimenko, Sindy Mosch, Mihails Kusnezoff; Fraunhofer IKTS, Dresden/Germany

17:00 **Innovative architectural oxygen electrodes for solid oxide cells using electrostatic spray deposition (A1203)**
Elisabeth Djurado (1), Rakesh Sharma (1), Özden Çelikbilek (1), Nur I. Khamidy (1,2), Lydia Yefsah (1,2), Jérôme Laurencin (2); (1) Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, Grenoble/France; (2) Univ. Grenoble Alpes, CEA, LITEN, DTCH, Grenoble/France;

17:15 **Progress in the development of metal-supported-cell architecture with proton conducting ceramics (A1204)** Rémi Costa, Haoyu Zheng, Feng Han, Matthias Riegraf, Noriko Sata; German Aerospace Center, Institute of Engineering Thermodynamics Electrochemical Energy Technology; Stuttgart/Germany;

17:30 **Development of high-flexible SOFCs via phase-controlled YSZ for high performance and mechanical durability (A1205)**
Bo-Ram Won, Jae-ha Myung
Department of Materials Science and Engineering, Incheon National University; Incheon/Republic of Korea;

17:45 **Status of Solid Oxide Cell development at TNO (A1206)**
Frans van Berkel, Manoj Shinde, Michiel Langerman, Claire Ferchaud
TNO, Petten/The Netherlands;

B12: Interconnects, Coatings, Contact Layers & Sealants

$(Co,Cu,Mn)_3O_4$ contact layers: their mechanical, electrical and Cr retention properties (B1201)
Claudia Goebel (1), Yousef Alizad Farzin (1), Ilaria Ritucci (1), Belma Talic (1), Mareddy Reddy (2), Jan Froitzheim (2), Ragnar Kiebach (1), Henrik Lund Frandsen (1);
(1) DTU Energy, Technical University of Denmark; Kongens Lyngby/ Denmark;
(2) Energy and Materials, Chalmers University of Technology; Gothenburg/Sweden

Stability of glass ceramic sealants in atmospheres with increased water contents (B1202 is presented in B1206) Axel Rost (1), Jochen Schilm (1), Hassan Javed (2), Kai Herbrig (2)
(1) Fraunhofer IKTS, Dresden/Germany; (2) sunfire GmbH; Dresden/Germany;

Sintering of cobalt free coatings for prevention of chromium poisoning in Solid Oxide Fuel Cells (B1203) Justyna Ignaczak (1), Sebastian Molin (1), Ming Chen (2) Piotr Jasiński (1); (1) Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology; Gdańsk/Poland; (2) Department of Energy Conversion and Storage, Technical University of Denmark; Fysikvej, Lyngby/Denmark;

Diffusion barrier coatings against the dual atmosphere effect on IT-SOFCs (B1204)
Matthieu Tomas, Alberto Visibile, Jan-Erik Svensson, Jan Froitzheim
Energy and Materials, Chalmers University of Technology; Gothenburg/Sweden;

Design and characterization of improved glass sealant-interconnect interfaces in reversible solid oxide cells (B1205) Federico Smeacetto (1), Hassan Javed (2), Elisa Zanchi (1), Chiara Bert (3), Domenico Ferrero (3), Christian Walter (2), Massimo Santarelli (3); (1) Department of Applied Science and Technology (DISAT), Turin/Italy; (2) Sunfire GmbH; Dresden/Germany; (3) Department of Energy (DENERG), Turin/Italy;

Co-Sintering of Spinel-Based Coating/Contact Dual-Layer Structure for SOFC Cathode-Side Application (B1206 is presented in B1202) Yutian Yu (1), Fupeng Cheng (1), Yue Lu (1), Chengzhi Guan (1,2), Jianqiang Wang (1,2); (1) Shanghai Institute of Applied Physics, Chinese Academy of Sciences.; Shanghai/PR China; (2) Dalian National Laboratory for Clean Energy, Chinese Academy of Sciences.; Liaoning Province/PR China;

18:00 End of Sessions

19:15 Dinner on the Lake

Boarding 19.20 - Lake side of KKL pier 5/6 - Departure 19.30
Back 23.00 (short stop in Brunnen 22.30 for return by train)

09:00 A13: Keynote - H_2 production paths and the future H_2 mix

09:00 K7: **The various H_2 production paths and their expected importance in the future mix (A1301)**
Sebastian Mayer McKinsey & Company, Inc. München/Germany

B13: Cells Design & Manufacturing II

09:00 **Analysis of ceramic nanocomposite fuel cell fabricated through a hybrid of 3D printing and laser scribing (B1301)**
Muhammad Imran Asghar (1,2), Peter Lund (1)
(1) New Energy Technologies Group, Department of Applied Physics, Aalto University School of Science; Espoo/Finland;
(2) Faculty of Physics and Electronic Science, Hubei University; Hubei/China;

09:15 **Metal exsolved electrode infiltrated in 8YSZ electrolyte with porous scaffold produced by hybrid 3D printing (B1302)**
Maritta Lira (1), Natalia Kostretsova (1), Simone Anelli (1), Alex Morata (1), Marc Torrell (1), Albert Tarancon (1,2)
(1) IREC, Catalonia Institute for Energy Research; Barcelona/Spain;
(2) ICREA; Barcelona/Spain;

09:30 A14: Other Fuels

09:30 **Ammonia as a fuel for SOFCs - Cracking kinetics of ammonia over Ni/YSZ (A1401)**
Claudia Goebel (1), Omid Babaie Rizvandi (1), John Bøgild Hansen (2), Henrik Lund Frandsen (1), Anke Hagen (1), Peter Vang Hendriksen (1)
(1) DTU Energy, Technical University of Denmark; Kongens Lyngby;
(2) Haldor Topsoe A/S, Kongens/Lyngby;

09:45 **Ammonia fueled SOFC for shipping – The Aegir project (A1402)**
Anke Hagen, Riccardo Caldogno, Xiufu Sun
Technical University of Denmark, DTU Energy; Lyngby/Denmark;

10:00 **Effect of metal dopants (Sn, Ag, Cu) on the electrochemical performance and carbon resistance of the biogas operated IT-SOFC anodes (A1403)**
Zeyu Jiang, Kun Zhang, Abigail Snowdon, Bernardo Sarruf, Ahmad El-kharouf, Robert Steinberger-Wilckens
Centre for Fuel Cell and Hydrogen Research, School of Chemical Engineering; University of Birmingham, Birmingham/UK;

10:15 **Impedance analysis of chlorine poisoning on nickel-ceria anode of solid oxide fuel cell operated in H_2 and biogas (A1404)**
M.J. Escudero, J.L. Serrano, T. González-Ayuso
Energy Department, CIEMAT; Madrid/Spain;

B14: Lifetime Assessment & Advanced Characterisation

09:30 **Local investigation of a segmented reversible-SOC: Performance mapping and durability analysis supported by electrochemical modelling and post-mortem characterization (B1401)**
Hamza Moussaoui (1), Audrey Wesoly (1), Stefan Diethelm (1,2), Gerald Hammerschmid (1), Zacharie Wuillemin (2), Dario Montinaro (3), Jan Van herle (1)
(1) Group of Energy Materials, École Polytechnique Fédérale de Lausanne/Switzerland;
(2) SOLIDpower SA, Yverdon-les-Bains/Switzerland;
(3) SOLIDpower S.p.A., Mezzolombardo/Italy;

09:45 **X-Ray synchrotron nanoprobe characterization of diffusion barrier layers for avoiding degradation in SOFCs aged for 14000h (B1402)**
Lucile Bernadet (1), Jaime Segura (2), Dario Montinaro (3) Marc Torrell (1), Alex Morata (1), Albert Tarancón (1,4)
(1) IREC, Catalonia Institute for Energy Research, Dept of Advanced Materials for Energy Applications; Barcelona/Spain;
(2) ID16B, European Synchrotron (ESRF); Grenoble/France;
(3) SOLIDPower SpA, Mezzolombardo/Italy;
(4) ICREA, Barcelona/Spain;

10:00 **Nanoscale X-ray absorption spectroscopy at the Ni K-edge on solid oxide electrolysis cell (B1403)**
Aline Léon (1), Julie Villanova (2), Sabine Schlabach (3)
(1) European Institute for Energy Research; Karlsruhe/Germany;
(2) ESRF –The European Synchrotron; Grenoble/France;
(3) Karlsruhe Institute for Technology, Institute for Applied Materials, Karlsruhe Nano Micro Facility and Institute of Nanotechnology, Eggenstein-Leopoldshafen/Germany

10:15 **Modelling and experimental investigation of a reversible SOC using Total Harmonic Distortion Analysis as an advanced online monitoring tool (B1404)**
Gerald Hammerschmid (1, 2), Hamza Moussaoui (1), Vanja Subotić (2), Jan Van herle (1)
(1) Group of Energy Materials, École Polytechnique Fédérale de Lausanne/Switzerland;
(2) Institute of Thermal Engineering, Graz University of Technology, Graz/Austria;

10:30 Break - Ground Floor in the Exhibition

11:00 A15: SOC Integration & Energy System Perspectives

11:00 **Comprehensive electrochemical analysis of a 150 kW reversible SOC system installed at a power plant Mellach in Austria (A1501)**
Vanja Subotić (1), Benjamin Königshofer (1), Michael Höber (1), Christoph Hochenauer (1), Markus Koroschetz (2), Martin Hochfellner (2), Jörg Brabandt (3), Jens Baumgartner (3)
(1) Institute of Thermal Engineering, Graz University of Technology; Graz/Austria;
(2) VERBUND Thermal Power GmbH; Wildon/Austria;
(3) Sunfire GmbH, Dresden/Germany;

11:15 **Wind2Hydrogen via solid oxide electrolysis (A1502)**
Ming Chen (1), Jens Høgh (1,2), Peter Blennow (2), Xiufu Sun (1), Yi Zong (3), Christopher Graves (1,4)
(1) Department of Energy Conversion and Storage, Technical University of Denmark;
(2) Topsoe A/S, Haldor Topsøe, Lyngby/Denmark; (3) Department of Electrical Engineering, Technical Univ of Denmark; Lyngby/Denmark;(4) Noon Energy Inc., Palo Alto, California, USA

11:30 **Demonstration and Scale-Up of High-Temperature Electrolysis Systems (A1503)**
Konstantin Schwarze, Thomas Geißler, Robert Blumentritt
Sunfire GmbH, 2 Gasanstaltstraße, D-01237 Dresden/Germany

11:45 **Operation strategy of the four-type energy supply system with SOFC: Focusing on CO_2 enrichment for smart-farm application (A1504)**
Gwangwoo Han (1), Kyoung-Ho Lee (1), Wang-Je Lee (1), Young-Sub Ahn (1), Hong-Jin Joo (1), Jong-Eun Hong (2), Dong Woo Joh (2), Hye-Sung Kim (2), Seung-Bok Lee (2), Tak-Hyoung Lim (2), Seok Joo Park (2), Rak-Hyun Song (2)
(1) Renewable Heat Integration Laboratory, Korea Institute of Energy Research;
(2) High Temperature Energy Conversion Laboratory, Korea Institute of Energy Research, Daejeon/South Korea

12:00 **Process Development of Synthetic Liquid Fuel Production with Solid Oxide Electrolysis Cell and FT synthesis (A1505)**
Yohei Tanaka (1), Tomohiro Ishiyama (2), Katsuhiko Yamaji (2)
National Institute of Advanced Industrial Science and Technology (AIST):
(1) AIST East, Ibaraki/Japan;
(2) AIST Central 5, Ibaraki/Japan;

12:15 **Optimal design of SOFC-based cogeneration systems for the building sector (A1506)**
Paolo Marocco, Marta Gandiglio, Massimo Santarelli
Department of Energy, Politecnico di Torino; Torino/Italy;

B15: Advanced Characterisations

11:00 **A SOFC working in an Environmental Transmission Electron Microscope (B1501)**
Q. Jeangros (1), M. Bugnet (2), T. Epicier (2,3) C. Frantz (4) S. Diethelm (4), D. Montinaro (5), E. Tyukalova (6), Y. Pivak (7), J. Van herle (4),A. Hessler-Wyser (1), M. Duchamp (6,8)
(1) Photovoltaics and Thin-Film Electronics Laboratory (PVLab), École Polytechnique Fédérale de Lausanne (EPFL); Neuchâtel/Switzerland;
(2) Univ Lyon, CNRS, INSA-Lyon, UCBL, MATEIS, Villeurbanne/France;
(3) Univ Lyon, UCBL, IRCELYON, Villeurbanne/France;
(4) Group of Energy Materials (GEM), École Polytechnique Fédérale de Lausanne (EPFL), Sion/Switzerland;
(5) SOLIDpower S.p.A., Mezzolombardo/Italy;
(6) Lab. for in situ & operando Electron Nanoscopy, School of Mater. Sci. and Engineer., Nanyang Technological University (NTU), Singapore;
(7) DENSsolutions, Delft/The Netherlands;
(8) MajuLab, International Joint Research Unit UMI 3654, CNRS, Université Côte d'Azur, Sorbonne Université, National University of Singapore, NTU, Singapore;

11:15 **Study of the oxygen diffusion behaviour of $(La_{0.8}Sr_{0.2})_{0.95}Cr_{0.5}Fe_{0.5}O_{3-\delta}$ A-site deficient perovskite oxides in humid conditions (B1502)**
Zijie Sha, Eleonora Cali, Zonghao Shen, Ecaterina Ware, Gwilherm Kerherve, Stephen J. Skinner
Department of Materials; Imperial College London, London/UK;

11:30 **Oxygen diffusion and surface exchange coefficients determined under high pressure: Comparisons between oxygen deficient vs. oxygen over-stoichiometric air electrode materials (B1503)**
Jérôme Laurencin (1), Aurélien Flura (2), Giuseppe Sdanghi (1,2), Sébastien Fourcade (2), Vaibhav Vibhu (3), Jean-Paul Salvetat and Jean-Marc Bassat (4)
(1) CEA Grenoble, DRT/LITEN/DTBH/SCSH, Grenoble/France;
(2) CNRS, Univ. Bordeaux, Pessac/France;
(3) Institute of Energy / Climate Research, IEK-9, FZJ GmbH, Jülich/Germany;
(4) CNRS, Placamat, UMS 3626, 33600 Pessac/France;

11:45 **Investigation of a solid oxide electrolysis cell poisoned by sulfur using lock-in thermography (B1504)**
Guillaume Jeanmonod (1), Jan Van herle (2)
(1) Hydro-Québec Research Institute (IREQ); Varennes/Canada;
(2) Group of Energy Materials, Faculty of Engineering Science; Sion/Switzerland;

12:00 **Development of $La_{0.35}Sr_{0.55}Ti_{0.95}Ni_{0.05}O_{3-\delta}$ model electrodes and characterization with EIS and NAP-XPS (B1505)**
Mait Ainsar (1), Kuno Kooser (2), Margus Kodu (2), Glen Kelp (2), Taivo Romann (1), Priit Möller (1), Tanel Käämbre (2), Michael Hävecker (3), Enn Lust (1), Gunnar Nurk (1)
(1) Institute of Chemistry, University of Tartu.; Tartu/Estonia; (2) Institute of Physics, University of Tartu.; Tartu/Estonia; (3) Helmholtz-Zentrum Berlin, Berlin/Germany

12:15 **Current interruption technique for the investigation of solid electrolyte electrolysis cells (B1506)**
Marina Bockelmann; CUTEC Clausthal Research Center for Environmental Technologies, TU Clausthal; Clausthal-Zellerfeld/Germany;

12:30 Lunch & Coffee - 2nd Floor on the Terrace & still open the Poster Area on the 1st Floor

13:30 A16: Products, Demonstration & Novel Concepts

13:30 **Large Stack Module and System Development for SOFC, SOE and Reversible Operation in Industrial Processes (A1601)**
Zacharie Wuillemin (1), Florian Waeber (1), Cédric Beetschen (1), Yannik Antonetti (1), Fabrice Schärer (1), Florian Denève (1), Thierry Cornu (1), Gabriele Prosperi (1), Antonello Nesci (1), Massimo Bertoldi (2); (1) SOLIDpower SA, Yverdon-les-Bains/Switzerland; (2) SOLIDpower SpA; Mezzolombardo/Italy;

13:45 **Evaluation of a hybrid SOFC & battery genset for cruise ship applications (A1602)**
Matthias Metten (1), Santiago Salas Ventura (1), Dirk Ullmer (1), Marc P. Heddrich (1), Cem Ünlübayır (2), Stefan Diethelm (3), S. Asif Ansar (1); (1) German Aerospace Center (DLR), Institute of Engineering Thermodynamics, Stuttgart; (2) RWTH Aachen University, Institute for Power Electronics and Electrical Drives (ISEA), Chair for Electrochemical Energy Conversion and Storage Systems; Aachen; (3) SOLIDpower SA; Yverdon-les-Bains;

14:00 **C2FUEL Solid Oxide Electrolyser Demonstration System (A1603)**
Timo Lehtinen, Matti Noponen
Elcogen; Vantaa/Finland;

14:15 **Electrothermal balanced operation - A new operation method for improved SOEC performance (A1604)**
Søren Højgaard Jensen (1,2), Anne Lyck Smitshuysen (1), Samuel Simon Araya (2), Simon Lehnart Sahlin (2), Xiaoti Cui (2), Chris Graves (3), Theis Løye Skafte (3), Henrik Lund Frandsen (4), Omid Babaie Rizvandi (4), Anne Hauch (4), Mogens Mogensen (4), John Bøgild Hansen (5)
(1) DynElectro ApS; Sjælland; (2) AAU, Department of Energy. Aalborg/Denmark; (3) Noon Energy Inc. CA/USA; (4) DTU, Department of Energy; (5) Haldor Topsoe A/S. Lyngby/Denmark;

14:30 **Results of 200kw SOFC power generation using biomethane gas from wastewater treatment process (A1605)**
Kimito Kawamura (1,2), Toshihiro Oshima (2), Tsutomu Kawabata (2), Shunsuke Taniguchi (2), Tomomasa Kanda (1), Kazunari Sasaki (2); (1) Asahi Quality and Innovations ltd.; (2) Kyushu University Next-Generation Fuel Cell Research Center; Fukuoka-shi/Fukuoka/JAPAN;

14:45 **Commercial-scale SOFC systems (ComSos) (A1606)**
Jari Kiviaho (1), Aki Nieminen (1), Markus Münch (2), Florian Waeber (3), Stefano Modena (4) Massimo Santarelli (5), Marta Gandiglio (5), Jeroen Buunk (6), Arjen de Jong (6),Tuomas Hakala (7)
(1) VTT Technical Research Centre of Finland Ltd, Espoo/Finland;
(2) Sunfire GMBH, (3) SolidPower SA, (4) SolidPower SpA;

B16: Material Modelling

13:30 **Reaction mechanisms of mixed ionic and electronic conductors used as oxygen electrodes in Solid Oxide Cell: focus on $La_{1-x}Sr_xCo_{y-1}Fe_yO_{3-\delta}$ and $La_2NiO_{4+\delta}$ (B1601)**
Lydia Yefsah (1,2), Giuseppe Sdanghi (2,3), Giuseppe Sassone (2), Jean-Marc Bassat (3), Maxime Hubert (2), Elisabeth Djurado (1), Jérôme Laurencin (2)
(1) Univ. Grenoble Alpes, CNRS, LEPMI, Grenoble/France; (2) Univ. Grenoble Alpes, CEA-Liten, DTCH, Grenoble/France; (3) CNRS, Univ. Bordeaux, ICMCB, Pessac/France;

13:45 **Microstructural optimization of the hydrogen electrode for solid oxide cells by a multiscale modelling approach (B1602)**
Manon PRIOUX (1), Eduardo DA ROSA SILVA (1), Maxime HUBERT (1), Julien VULLIET (2), Jérôme LAURENCIN (1)
(1) Univ. Grenoble Alpes – CEA/LITEN, Grenoble/France;
(2) CEA, DAM, Le Ripault, Monts/France;

14:00 **Development of a Fluid-Electrochemo-Stress Coupled Simulation Method for SOFC Degradation Prediction (B1603)**
Mayu Muramatsu (1), Masami Sato (2), Reika Nomura (3), Kenjiro Terada (3), Keiji Yashiro (4), Tatsuya Kawada (4), Harumi Yokokawa (5); (1) Department of Mechanical Engineering, Keio University; Yokohama/Japan; (2) Graduate School of Engineering, Tohoku University, Sendai/Japan; (3) International Research Institute of Disaster Science, Tohoku University; Sendai/Japan; (4) Graduate School of Environmental Studies, Tohoku University; Sendai/Japan; (5) Institute of Industrial Science, the University of Tokyo; Tokyo/Japan;

14:15 **Advanced linkage of multi-physics modelling towards experimental impedance spectroscopy (B1604)**
Julian Taubmann, Xiufu Sun, Omid Babaie Rizvandi, Henrik Lund Frandsen
Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;

14:30 **DFT study on elementary reaction pathways for $La_{1-x}Sr_xCo_{1-y}Fe_yO_3$ electrode material (B1605)**
Cintia Hartmann (1,2,3), Grégory Geneste (1,2), Jérôme Laurencin (3)
(1) CEA, Arpajon/France;
(2) Université Paris-Saclay, CEA, Laboratoire Matière en Conditions Extrêmes, Bruyères-le-Châtel/France; (3) Univ. Grenoble Alpes - CEA/LITEN; Grenoble/France;

14:45 **Modelling of an RSOC with Open Source Tools (B1606)**
Maximilian Hauck (1), Maximilian Schmid (1), Stephan Herrmann (1), Burak Polat (1), Benjamin Steinrücken (1), Luis Poblotzki (1), Felix Fischer (1), Jeremias Weinrich (2), M. Gaderer (2), Hartmut Spliethoff (1)
(1) Technical University of Munich, Chair of Energy Systems; Garching/Deutschland;
(2) Technical University of Munich, Regenerative Energy Systems; Straubing/Deutschland;

15:00 5 Min to change from Session B16 to Luzerner Saal for Plenary Session A17

Afternoon - Luzerner Saal | Friday, 8 July 2022

15:05 A17 - P2: Closing Ceremony
Keynote by the EFCF Gold Medal of Honour Winner 2022

15:05 **Summary by the Chairs (A1701)**
Julie Mougin, Jérôme Laurencin
CEA-Liten, Grenoble/France

15:20 **Information on Next EFCF:**
EFCF 2024 16th European SOFC & SOE Forum
EFCF 2023 10th FC, Electrolyser & H_2 Processing Forum (A1702)
Michael Spirig (1), Albert Tarancón Chair 2024 (2), Olivier Bucheli (1)
(1) European Electrolyser & Fuel Cell Forum, Lucerne/Switzerland;
(2) IREC Catalonia Institute for Energy Research, Sant Adrià de Besòs/Spanien

15:30 **Christian Friedrich Schönbein Award for the Best Poster, Best Science Contribution, Medal of Honour (A1703)**
Jérôme Laurencin, Julie Mougin
CEA-Liten, Grenoble/France

15:40 **K8: Advanced tools and concepts for investigating electrode kinetics in SOCs (A1704)**
Jürgen Fleig, EFCF Gold Medal of Honour Winner 2022
Institute of Chemical Technologies and Analytics, TU Wien, Vienna/Austria

16:05 **Thank you and Closing by the Organizers (A1705)**
Olivier Bucheli, Michael Spirig
European Electrolyser & Fuel Cell Forum, Luzern/Switzerland

16:15 End of Sessions - End of Conference
Good bye coffee and travel refreshment in front of the Luzerner Saal

附件二、 EFCF-2022 論壇海報名稱及議程

Poster List

Auditorum Foyer

A04: Poster Session I — Wednesday, 6 July 2022 — Afternoon 13.15 - 15:00

A10: Poster Session II — Thursday, 7 July 2022 — Afternoon 13.15 - 15:00

covering All Session Topics + **B09s: Co-Electrolysis & CO_2-Electrolysis**

A03: Technology status at industry I

Test beds, Tools and Instruments for Advanced SOFC Research and Development (A0307)
Vikrant Venkataraman
Instrumentation & Test Systems Department, Fuel Cell Business Unit, AVL List GmbH; Graz/Austria

Fuel Cell Innovations: An example of strategic industrial cooperation between Asia and the MENA region for the industrialization of hydrogen and fuel cells. (A0308)
Tae-Won Lee
Fuel Cell Innovations; Daejeon/South Korea;

Current status of Ceres electrolysis programme (A0309)
Per Hjalmarsson, Jon Harman, Amin Zerfa, Chandra Mackuley, Ian Methley, Hacib Benaissa, Caroline Hargrove
Ceres Power, Horsham/United Kingdom

A06: Technology status at industry III + Projects Overview

Performance and durability of 3YSZ electrolyte supported cell and stack operated in steam electrolysis and co-electrolysis (A0607)
Aline Léon, Cahit Benel, Alexandria Dritschler
European Institute for Energy Research; Karlsruhe/Germany;

SOFC stack development at INER (A0608)
Hung-Hsiang Lin (1), Szu-Han Wu (1), Yi-Jing Wu (1), Chun-Liang Chang (1), Yung-Neng Cheng (1), Chien-Kuo Liu (1), Ruey-yi Lee (1), Wei-Hsun Hsu (2), Huei-Long Lee (2)
(1) Institute of Nuclear Energy Research; Taoyuan City/Taiwan (R.O.C.);
(2) Porite Taiwan Co., Ltd.; Miaoli County/Taiwan (R.O.C.);

A08: Lifetime Stacks

Combining SOEC and biomass gasification for synthesis of methanol; use of purge gases on the oxygen electrode and their impact on cell durability (A0807 = A0803)
Peter V. Hendriksen (1), Belma Talic (1,2), Jens V. T. Høgh (1,3), P. Blennow (3), R. Küngas (3), M. Chen (1) X. Sun (1), J. Ahrenfeldt (4), U. B. Henriksen (4), W.-R. Kiebach (1)
(1) Department of Energy Conversion and Storage, Technical University of Denmark;
(2) Sintef, Department of Sustainable Energy Technology, Norway ;
(3) Haldor Topsøe A/S, Denmark; (4) DTU Chemical Engineering, Technical University of Denmark;

Experimental Report on Galvanostatic Operation of Electrolyte-Supported Stacks for High Temperature Electrolysis (A0808)
Jerome Aicart (1), Lionel Tallobre (1), Alexander Surrey (2), Denis Reynaud (1), Julie Mougin (2)
(1) Univ. Grenoble Alpes, CEA, Liten, Grenoble/France; (2) Sunfire GmbH, Dresden/Germany;

PVD Gd-doped Ceria Layers for Electrolyte Supported SOCs: Stack Test (A0809)
Feng Han (1), Michael Lang (1), Patric Szabo (1), Christian Geipel (2), Christian Walter (2), Rémi Costa (1)
(1) Institute of Engineering Thermodynamics, German Aerospace Center (DLR); Stuttgart/Germany, (2) Sunfire GmbH; Dresden/Germany;

Long-term Degradation Analysis of SOFC Performance (2) (A0810)
Koichi Asano, Takumi Imabayashi, Akifumi Ido, Hiroshi Morita, Tohru Yamamoto, Yoshihiro Mugikura; Central Research Institute of Electric Power Industry (CRIEPI); Kanagawa/Japan;

A09: Performance Cell/Stack

The influence of LSCF sintering atmosphere on the formation of impurity phases and stack performance (A0907)
Christian Dellen (1), Qingping Fang (1), Nikolaos Margaritis (2), Michael Müller (1), Norbert H. Menzler (1)
(1) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK); Jülich/Germany; (2) Forschungszentrum Jülich GmbH, Central Institute of Engineering, Electronics and Analytics; JülichGermany;

A11: System Design, Performance & BoP

Pre-reforming of liquid fuels for utilization in commercial SOFC systems (A1107)
Tobias Schiekel, Elmar Pohl
OWI Science for Fuels gGmbH; Herzogenrath/Germany;

B02: Fuel Electrodes

Influence of La-Sr balance and A-site deficiency on surface chemistry of $(La_{1-y}Sr_y)_xCr_{0.5}Mn_{0.45}Ni_{0.05}O_{3-d}$ solid oxide cell electrode (B0207)
Indrek Kivi (1), Ove Korjus (1), Jaan Aruväli (2), Priit Möller (1) Gunnar Nurk (1)
(1) Institute of Chemistry, University of Tartu.; Tartu/Estonia;
(2) Institute of Ecology and Earth Sciences, University of Tartu.; Tartu/Estonia;

Physical and Electrochemical Characterization of $La_{0.25}Sr_{0.25}Ca_xTi_{0.55}Ni_{0.05-y}Sn_yO_{3-\delta}$ (x =0.40,0.45; y=0...0.05) Solid Oxide Cell Fuel Electrodes (B0208)
Martin Maide (1), Jaan Aruväli (2), Marian Külavir (2), Enn Lust (1), Gunnar Nurk (1)
(1) Institute of Chemistry, University of Tartu.; Tartu/Estonia;
(2) Institute of Ecology and Earth Sciences, University of Tartu.; Tartu/Estonia;

Synergistically improved in-situ exsolution catalyst via NiFe alloy nano particles on perovskite electrode scaffold (B0209)
Hyeongwon Jeong, Jae-ha Myung
Dept. Materials science and engineering, Incheon national university; Incheon/South Korea;

Influence of dopants on contact resistance in AS-SOFCs between doped ceria & YSZ (B0210)
Alexander Schwiers, Christian Lenser, Olivier Guillon, Norbert H. Menzler
Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research (IEK), IEK-1: Materials Synthesis and Processing; Juelich/Germany;

Ammonia fuelled-Solid Oxide Fuel Cells: Architecture for suitable anode based on Ni exsolution in titanate (B0211)
Jonathan Cavazzani (1), Enrico Squizzato (1), Elena Brusamarello (1), Antonella Glisenti (1,2)
(1) Department of Chemical Sciences, University of Padova; Padova/Italy;
(2) CNR-ICMATE, Padova/Italy;

Exsolution of Ni-Ru bimetallic nanoparticles from A-site deficient lanthanum nickel ruthenium double perovskites (B0212)
Jia Guo (1), Rongsheng Cai (2), Stephen J Skinner(1)
(1) Department of Materials; Imperial College London, London/UK;
(2) Department of Materials; University of Manchester, Manchester/UK;

Nickel free fuel electrodes for CO_2 electrolysis (B0213)
Veronika Rečková (1,2), Ivar Wærnhus (1), Nelson Thambiraj (1), Maria-Eleftheria Farmaki (3), Kalliopi-Maria Papazisi (3), Dimitrios Tsiplakides (3), Stella Balomenou (3) Brandon Buergler (4)
(1) Clara Venture Labs, Bergen/Norway;
(2) Department of Inorganic technology, UCT Prague, Prague 6/Czech Republic; (3) Chemical Process and Energy Resources Institute, Centre for Research and Technology Hellas (CPERI-CERTH), Thessaloniki/Greece; (4) European Space Agency (ESA), Noordwijk/The Netherlands;

Finding the optimum loading of Au & Mo in NiO/GDC and the influence of Fe for the reversible operation of solid oxide cells (B0214)
Fotios Zaravelis (1,2), Stylianos G. Neophytides (1), Dimitrios K. Niakolas (1)
(1) Foundation for Research and Technology, Institute of Chemical Engineering Sciences (FORTH/ICE-HT); Patras/Greece; (2) Dep. of Chemical Engineering, University of Patras, Greece;

Exsolution of palladium nanoparticles from A-site layered double perovskite $PrBaMn_2O_{5+\delta}$ (B0215)
Ritika Vastani (1), Inyoung Jang (2), Eleonora Calì (1), Geoffry H. Kelsall (2), Stephen J. Skinner (1), Sivaprakash Sengodan (1) (1) Department of Materials, Imperial College London, London/UK
(2) Department of Chemical Engineering, Imperial College London, London/UK

B03: Fuel & Oxygen Electrodes

The European project NewSOC Next Generation Solid Oxide Fuel Cell and Electrolysis Technology at midterm (B0307)
Anke Hagen (1), Jerome Laurencin (2), Julien Vulliet (3), Nunzia Coppola (4), Luigi Maritato (4), Pierpaolo Polverino (4), Giovanni Carapella (5), Fotios Zaravelis (6), Charalampos Neofytidis (6), Evangelia Ioannidou (6), Stylianos Neophytides (6), Dimitrios K. Niakolas (6), Stella Balomenou (7), Dimitrios Tsiplakides (7), Kalliopi-Maria Papazisi (7), Claire Ferchaud (8), Frans van Berkel (8);
(1) Fysikvej B., Lyngby/Denmark; (2) Univ. Grenoble Alpes, CEA/LITEN, Grenoble/France; (3) CEA/DAM, Monts/France; (4) Dipartimento di Ingegneria Industriale DIIN, Università degli Studi di Salerno, Fisciano(SA)/Italy; (5) Dipartimento di Fisica "E.R. Caianiello", Università degli Studi di Salerno, Fisciano(SA)/Italy; (6) Institute of Chemical Engineering Sciences, Foundation for Research and Technology-Hellas (FORTH-ICEHT), Patras/Greece; (7) Chemical Process and Energy Resources Institute/CERTH, Thessaloniki/Greece; (8) TNO, Netherlands Organization for Applied Scientific Research, Petten/The Netherlands;

Investigation on Additive Manufactured High Temperature Alloys for SOFC Components (A1108)
Dagmar Kuckelberg, Elmar Pohl; OWI Science for Fuels GmbH; Herzogenrath/Germany;

Solid oxide fuel cell – internal combustion engine hybrid system fueled by ammonia (A1109)
Minkyoung Park, Wonjae Choi
Division of Mechanical and Biomedical Engineering, Ewha Womans University; Seoul/South Korea;

Solid Oxide Fuel Cell Systems for decentralized, hydrogen based power generation (A1110)
Raphael Neubauer, Bernd Reiter, Martin Hauth; AVL List GmbH, Graz/Austria;

Operation of Co-SOEC reactors for syngas production utilizing CO_2 from air (A1111)
Marius Tomberg (1), Marc P. Heddrich (1), Dirk Ullmer (1), S. Asif Ansar (1), K. Andreas Friedrich (1,2)
(1) German Aerospace Center (DLR), Institute of Engineering Thermodynamics; Stuttgart;
(2) University of Stuttgart, Institute for Building Energetics, Thermotechnology and Energy Storage; Stuttgart;

Advanced Sorbents for Desulfurization and Purification of Natural Gas, LPG and Biogas Feedstocks (A1112)
Gokhan Alptekin; SulfaTrap LLC; Colorado/United States;

From prototype, prove of concepts, towards reliable serial design and robust production processes for SOFC and SOEC Hot Balance of Plant systems. (A1113)
Jean-Paul Janssens (1), Michel Dubuisson (2)
(1) R&D BOSAL Energy; Lummen/Belgium;
(2) BOSAL Energy Conversion Industries; Vianen/The Netherlands;

Techno-economic evaluation of hydrogen production via solid oxide electrolyser powered by solar energy (A1114)
Yumeng Zhang (1), Ligang Wang (1), Jan Van herle (2)
(1) Innovation Research Institute of Energy and Power, North China Electric Power University; Beijing/China;
(2) Group of Energy Materials, Swiss Federal Institute of Technology in Lausanne; Sion/Switzerland;

Development and validation of a reversible prototype system to test 1.5 kW SOC stacks (A1115)
Lucile Bernadet (1), Lilia Sutac (1), James Zapata (2), Maria Serra (3), Jaume Roqueta (2), Marc Torrell (1), Albert Tarancón (1,3)
(1) IREC, Catalonia Institute for Energy Research, Dept of Advanced Materials for Energy Applications, Sant Adrià del Besós;
(2) AESA; (3) IRI, CSIC-UPCC, (4) ICREA, 08010 Barcelona/Spain

Investigation of LSF as an anode material for SOFC (B0308)
Buse Bilbey (1,2), M. Imran Asghar (2), Leyla Colakerol Arslan (3), Peter D. Lund (2), Aligul Büyükaksoy (1)
(1) Department of Materials Science and Engineering; Gebze Technical University, Gebze, Kocaeli/Turkey;
(2) New Energy Technologies Group, Aalto University School of Science, Aalto, Espoo/Finland;
(3) Department of Physics; Gebze Technical University, Gebze, Kocaeli/Turkey;

Pr- and Co-substitution in rare earth nickelates – application as SOEC air electrodes (B0309)
Andreas Egger, Sarah Eisbacher-Lubensky, Kathrin Sampl, Edith Bucher, Werner Sitte
Montanuniversitaet Leoben, Chair of Physical Chemistry; Leoben/Austria;

Innovative RF-sputtering technique for the realization of the cathode/electrolyte barrier layer on high performance large area industrial SOFCs (B0310)
Nunzia Coppola (1), Hafiz Sami Ur Rehman (1), Pierpaolo Polverino (1), Giovanni Carapella (2), Dario Moninaro (3), Francesca Martinelli (3), Alice Galdi (1), Cesare Pianese (1), Luigi Maritato (1)
(1) Dipartimento di Ingegneria Industriale DIIN, Universitá degli Studi di Salerno; Fisciano(SA)/Italy;
(2) Dipartimento di Fisica "E.R. Caianiello", Universitá degli Studi di Salerno; Fisciano(SA)/Italy;
(3) SOLIDpower S.p.A.; Mezzolombardo (TN)/Italy;

Investigation of infiltrated YSZ backbone electrodes at intermediate temperature range (B0311)
Bartosz Kamecki (1,2), Yun Xie (2), Xiaofeng Tong (2,3), Piotr Jasiński (1), Sebastian Molin (1), Ming Chen (2)
(1) Laboratory of Functional Materials, Gdańsk University of Technology; Gdańsk/Polska;
(2) Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;
(3) Innovation Research Institute of Energy and Power, North China Electric Power University, Beijing/China;

$La_2NiO_{4+\delta}$ Thin Films with Columnar Nanostructure for Enhanced Oxygen Exchange Kinetics (B0312)
Adeel Riaz (1,2), Alexander Stangl (1), Laetitia Rapenne (1), Carmen Jiménez (1), Michel Mermoux (2), Mónica Burriel (1)
(1) Univ. Grenoble Alpes, CNRS, Grenoble/France;
(2) Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, 38000 Grenoble/France;

Investigation of the effect of modulated structure on ion transport in Mo doped LaNbO4 (B0313)
Yidong Han, Stephen Skinner;
Department of Materials; Exhibition Road, Imperial College London, London/UK;

A12: Cells Design & Manufacturing I

Monolithic Solid Oxide Cells by 3D printing (A1207)
Natalia Kostretsova (1), Simone Anelli (1), Marc Nuñez (1), Alex Morata (1), Marc Torrell (1), Albert Tarancón (1,2)
(1) Catalonia Institute for Energy Research; Barcelona/Spain;
(2) ICREA; Barcelona/Spain;

ReScale: Large scale manufacturing of Solid Oxide Cells (A1208)
Anne Lyck Smitshuysen (1,2), Søren Højgaard Jensen (1,3), Karsten Klemens Hansen (1), Bhaskar Reddy Sudireddy (2), Henrik Lund Frandsen (2)
(1) DynElectro ApS; Viby Sjælland;
(2) DTU, Department of Energy Conversion and Storage; Lyngby; (3) AAU, Department of Energy; Aalborg;

Hybrid additive manufacturing fabrication of symmetric solid oxide cells (A1209)
Simone Anelli (1), Massimo Rosa (2), Federico Baiutti (1), Marc Torrell (1), Vincenzo Esposito (3), Albert Tarancón (1,4)
(1) Catalonia Institute for Energy Research (IREC), Department of Advanced Materials for Energy; Barcelona/Spain;
(2) GBU Performance, Brembo S.p.A., Curno/Italy;
(3) Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark; (4) ICREA, 08010 Barcelona/Spain;

Cu-doped lanthanum strontium titanate: copper exsolution to realize an efficient anode for direct methane-Solid Oxide Fuel Cells (A1211)
Jonathan Cavazzani (1), Victor Longo (1,2), Enrico Squizzato (1), Antonella Glisenti (1,3)
(1) Department of Chemical Sciences, University of Padova; Padova/Italy;
(2) Department ChiBioFarAm, ERIC aisbl and CASPE/INSTM, University of Messina; Messina/Italy;
(3) CNR-ICMATE, Padova/Italy;

Fabrication of Sc and Y co-doped ZrO_2 solid electrolyte thin film on a porous electrode substrate via simple drop-coating method for IT-SOFCs (A1212)
Dale Mhar Alfeche, Rinlee Butch M. Cervera
Energy Storage and Conversion Materials Research Laboratory, Department of Mining, Metallurgical, & Materials Engineering; University of the Philippines Diliman, Quezon City/Philippines;

Electrochemical characterization of the high entropy perovskite $La_{0.2}Pr_{0.2}Nd_{0.2}Sm_{0.2}Sr_{0.2}CoO_{3-\delta}$ for solid oxide cell air electrodes (B0314)
Patrick Pretschuh (1*), Edith Bucher (1), Andreas Egger (1), Fereshteh Falah Chamasemani (2), Roland Brunner (2), Werner Sitte (1); (1) Montanuniversitaet Leoben, Chair of Physical Chemistry, Leoben/Austria; (2) Materials Center Leoben Forschung GmbH, A-8700 Leoben

High entropy oxides as novel electrode materials for SOCs (B0315)
Antonio Maria Asensio (1), Lucile Bernadet (2), Simon Schweidler (3), Miriam Botros (3), Marc Torrell (2), Antonio Barbucci (1), Albert Tarancón (2,4)
(1) UNIGE, Universitá degli Studi di Genova, Dept Chemical, Civil and Environemental Engineering, Genova/Italy; (2) IREC, Catalonia Institute for Energy Research, Dept of Ad. Materials for Energy App., Barcelona/Spain; (3) KIT, Karlsruhe Institue of Technology Institute of Nanotechnology, Eggenstein-Leopoldshafen/Germany; (4) ICREA, Barcelona/Spain

Nanofiber-based composite electrodes for application in intermediate temperature solid oxide cell (B0316)
Caterina Sanna (1), Enrico Squizzato (2), Peter Holtappels (3), Antonella Glisenti (2), Paola Costamagna (1)
(1) Department of Chemistry and Industrial Chemistry, University of Genoa; Genoa/Italy;
(2) Department of Chemical Sciences, University of Padua; Padua/Italy;
(3) Department of Energy Conversion and Storage, Technical Uni of Denmark; Lyngby/Denmark;

B08: Stack & System Modelling

Comparative thermodynamic analysis of marine SOFC system for alternative fuels (B0807)
Berend van Veldhuizen (1), Lindert van Biert (1), Klaas Visser (1), Aravind Purushothaman Vellayani (2), Hans Hopman (1); (1) Delft University of Technology; Delft; (2) Uni of Groningen; Groningen;

A Fast Open Source Solid Oxide Cell Stack Model in Python (B0808)
Nicolas Kruse, Roland Peters
Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research; Jülich/Germany;

Solid Oxide Electrolysis Cell Reliability Analysis Using Modeling (B0809)
Jie Bao, Naveen Karri, Brian Koeppel, Olga A. Marina
Pacific Northwest National Laboratory; Washington/USA;

Hot Stand-by Operation Effect of a SOFC Hybrid System for Decentralized Power Generation in Single-Family Homes (B0810)
Laura Nousch, Mathias Hartmann
Fraunhofer Institute of Ceramic Technologies and Systems IKTS; Dresden/Germany;

Fabrication and CFD modelling of a graded porous scaffold for Reversible Solid Oxide Cells (rSOCs) (A1213)
Davide Cademartori (1), Elisa Mercadelli (2), Angela Gondolini (2), Alessandra Sanson (2), Ahmad El-Kharouf (3), Robert Steinberger-Wilckens (3), Davide Clematis (1), Antonio Maria Asensio (1), Maria Paola Carpanese (1)
(1) Department of Civil, Chemical and Environmental Engineering, University of Genoa (UNIGE-DICCA); Genoa/Italy;
(2) Institute of Science and Technology for Ceramics, national research council (CNR-ISTEC); Faenza/Italy;
(3) School of Chemical Engineering, University of Birmingham; Birmingham/United Kingdom;

Planar metal supported SOFC fabricated by sequential aqueous tape casting, constrained cosintering and screen-printing. (A1214)
Laura Parvaix, Pascal Lenormand, Patrick Rozier, Damien Quéré
CIRIMAT,; Université Toulouse 3 – Paul Sabatier, Toulouse cedex 9/France;

Effect of anode thickness on thin-film solid oxide fuel cells deposited on nanoporous substrates (A1215)
Myung Seok Lee, Suk Won Cha
Seoul National University; Seoul/Republic of Korea;

Direct Methane Low Temperature Solid Oxide Fuel Cells (DM-LT-SOFC): a dream come true (A1216)
Enrico Squizzato (1), Giovanni Carollo (1), Daniele Rossi (2), Antonella Glisenti (1,3)
(1) Department of Chemical Sciences, University of Padova; Padova/Italy;
(2) Pietro Fiorentini S.p.A, Arcugnano/Italy; (3) CNR-ICMATE, Padova/Italy;

A hybrid synthesis-fabrication method for SOFCs using carboxylic composite as a novel self-pore forming and sintering agent (A1217)
Mohammadmehdi Choolaei, Qiong Cai, Bahman Amini Horri
University of Surrey Stag Hill, Department of Chemical and Process Engineering, Faculty of Physical Sciences and Engineering; Guildford/UK;

Production and Characterisation of Tubular NiO-ScCeSZ Solid Oxide Fuel Cells Produced by Hot Extrusion (A1218)
Recep Akdeniz (1), Ahmad El-Kharouf (1), Robert Steinberger-Wilckens (1), Ali Murat Soydan (2)
(1) School of Chemical Engineering, University of Birmingham; Edgbaston, Birmingham/UK;
(2) Gebze Technical University, Institute of Energy Technologies; Kocaeli/Turkey;

SFE and SFS, spray processes: chemical new routes to produce disruptive materials (A1219)
Denis Spitzer
NS3E Laboratory; SAINT-LOUIS/France;

A14: Other Fuels

Ammonia decomposition and utilization as fuel in solid oxide fuel cells (A1407)
Belma Talic, Per Martin Rørvik, Vegar Øygarden
SINTEF Industry, Department of Sustainable Energy Technology; Oslo/Norway;

Operating an SOFC single cell on reformed biogas with periodic sulfide poisonings (A1408)
Cédric Frantz, Jan Van herle
Group of Energy Materials, Faculty of Engineering Sciences (STI);
Ecole Polytechnique Fédérale de Lausanne (EPFL), Sion/Switzerland;

Coupling a SOFC Short Stack with an Entrained Flow Gasifier (A1409)
Benjamin Steinrücken (1), Stephan Herrmann (1), Maximilian Hauck (1), Philipp Johne (1), Philipp Leuter (1), Andreas Ewald (1), Lukas Pusterhofer (1), Alexander Schwiers (2,3), Christian Lenser (2), Norbert H. Menzler (2,3), Hartmut Spliethoff (1)
(1) Technical University of Munich, Chair of Energy Systems; Garching/Germany;
(2) Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research - Materials Synthesis and Processing (IEK-1), 52425 Jülich/Germany
(3) RWTH Aachen University, Institute of Mineral Engineering; Aachen/Germany;

Deep biogas cleaning for exploitation in Solid Oxide Fuel Cells: experimental and techno-economic evaluation (A1410)
Gandiglio Marta, Elena Rozzi, Andrea Lanzini, Massimo Santarelli
Department of Energy, Politecnico di Torino, Torino/Italy;

SOFC-Stack coupled with wood gasification: Influence on the Performance and Degradation (A1411)
Fabian Grimm, Federica Torrigino, Jürgen Karl
FAU Erlangen-Nürnberg; Lehrstuhl für Energieverfahrenstechnik; Nürnberg/Germany;

Effect of ammonia fuel on single cell degradation (A1412)
Maryam Asghari (1,2), Suhas Nuggehalli Sampathkumar (1), Jack Brouwer (2), Jan Van herle (1)
(1) École Polytechnique Fédérale de Lausanne (EPFL); Sion/Switzerland;
(2) University of California, Advanced Power and Energy Program; Engineering Laboratory Facility, California/USA;

The biogas-oxyfuel process as a carbon source for high-temperature co-electrolysis and degradation by oxidized trace contaminants (A1413)
Dominik Schäfer, Felix Schorn, Remzi Can Samsun, Qingping Fang, Ralf Peters
Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research Jülich/Germany

Multiphysics modeling of high-temperature electrolysis for SOCs on lab-scale level (B0811)
Markus Nohl (1,2), Stephanie E. Wolf (1,2), Lucy Dittrich, (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
(1) Institute of Energy and Climate Research, Fundamental Electrochemistry (IEK-9); Forschungszentrum Jülich GmbH, Jülich/Germany;
(2) Institute of Physical Chemistry, RWTH Aachen University; Aachen/Germany;

Development of SOEC Stack Dynamic Model and Validation (B0812)
Dongkeun Lee (1), Young Sang Kim (1,2), Kook Young Ahn (1,2)
(1) Korea Institute of Machinery & Materials (KIMM); Daejeon/South Korea;
(2) University of Science and Technology (UST);

Off-design operation of proton conducting Solid oxide Fuel Cell (H+SOFC) (B0813)
Jarosław Milewski, Arkadiusz Szczęśniak; Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, Institute of Heat Engineering; Warsaw/Poland;

(B0814)

SOE stack prototyping through modeling and integration of advanced materials (B0815)
Gonzalo Jiménez Martín, Xabier Judez, Paula Ciaurriz, Mónica Aguado Alonso, Iñigo Garbayo
Hydrogen Area, Grid Integration, National Renewable Energy Center of Spain (CENER); Sangüesa (Navarra)/Spain

Numerical Investigation of a Hybrid Micro-Grid with Photovoltaic Energy Production and Hydrogen Storage (B0816)
Mario Iamarino (1), Antonello Damato (1), Antonio Ferraro (1), Antonio D'Angola (1), Marco Borgarello (2), Lorenzo Croci (2); (1) Scuola di Ingegneria, Università della Basilicata, Potenza/Italy
(2) RSE SpA - Ricerca sul Sistema Energetico, Milano/Italy

B09: Proton Conducting Materials, Cells & Stacks

Cold Sintering Process contribution to $BaZrCe_YO_{3-\delta}$ electrolyte densification (B0907 is requested to be presented orally in B0906)
Pablo Castellani, Clément Nicollet, Eric Quarez, Olivier Joubert, Annie Le Gal La Salle
Institut des Matériaux Jean-Rouxel de Nantes (IMN-CNRS); Nantes/France;

Fabrication and testing of thin-film based metal-supported proton ceramic electrochemical cells (B0908)
M. Stange (1), C. Denonville (1), E. Stefan (1), A.M. Dayaghi (2), Y. Larring1, P.M Rørvik (1), R. Haugsrud (2), T. Norby (2)
(1) SINTEF Industry; Oslo/Norway; (2) Uni of Oslo, Department of Chemistry, SMN, Oslo/Norway;

Proton World class Innovative Novel Nanoscale optimized electrodes and electrolytes for Electrochemical Reactions: WINNER (B0909)
Marie-Laure Fontaine
SINTEF AS Oslo; Oslo/Norway;

Characterization of metal-supported BZCY721 protonic conducting ceramic membranes for pressurized hydrogen separation (B0910)
Luca Mastropasqua, Jack Brouwer
National Fuel Cell Research Center, University of California, California/USA;

Direct measurements of hydrogen exchange and diffusion kinetics at elevated temperatures in proton-conducting solid oxide materials (B0911)
Mudasir A Yatoo, Stephen J Skinner
Department of Materials, Faculty of Engineering, Imperial College London; Royal School of Mines, London/U.K.;

Self-assembly $SrCo_{0.8}Fe_{0.2}O_{3-\delta}/Fe_3O_4$ heterostructure proton membrane for advanced semiconductor ionic fuel cell (B0912)
Nabeel Akbar (1), Sara Paydar (1), Wu Yan (1), Bin Zhu (1,2)
(1) Engineering Research Center of Nano-Geo Materials of Ministry of Education, Faculty of Materials Science and Chemistry, China University of Geosciences; Wuhan/China;
(2) Jiangsu Provincial Key Laboratory of Solar Energy Science and Technology/ Energy Storage Joint Research Center, School of Energy and Environment; Southeast University, Nanjing/China;

Molten salt synthesis of perovskite as electrolyte material for proton-conducting cell (B0913)
Linjuan Zhang, Ze Liu, Yuxuan Zhang, Jian-Qiang Wang
Shanghai Institute of Applied Physics; Chinese Academy of Sciences, Shanghai/China;

Characterization of Mechanical Properties of Half-Cells for Proton-Conducting Ceramic Cells and Effect of Ageing and Operating Conditions (B0914)
Federico Palmerini (1), Peyman Khajavi (1), Henrik Lund Frandsen (1), Peter Vang Hendriksen (1), Dustin Beeaff (2), Ragnar Kiebach (1)
(1) DTU Energy, Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;
(2) CoorsTek Membrane Sciences; Oslo/Norway;

Synthesis & characterization of BSCF air electrode material for protonic conducting cells (B0915)
Castellani Pablo (1), Schmider Daniel (2), Notar Catherine (2), Nicollet Clément (1), Quarez Eric (1), Dailly Julian (2), Joubert Olivier (1), Le Gal La Salle Annie (1)
(1) Institut des Matériaux Jean-Rouxel de Nantes (IMN-CNRS); Nantes/France;
(2) European Institute for Energy Research (EIFER); Karlsruhe/Deutschland;

A15: SOC Integration & Energy System Perspectives

Solid Oxide Fuel Cells Operated on Hydrogen and Natural Gas Blends and the Impact on Waste Heat Recovery (A1507)
Alejandro C. Lavernia, Maryam Asghari, Luca Mastropasqua, Jack Brouwer
National Fuel Cell Research Center, University of California, CA/USA;

Development of a Highly Efficient Co-SOEC-Based Power-to-Liquid Plant (A1508)
Martin Hauth (1), Bernd Reiter (1), Manuel Tandl (1), Fabian Zapf (2), Stefan Megel (3)
AVL List GmbH; Graz/Austria;
(1) AVL List GmbH, Graz/Austria;
(2) Prozess Optimal CAP GmbH, Vorau/Austria;
(3) Fraunhofer-Institut für Keramische Technologien und Systeme IKTS, Dresden/Germany

Assessing reversible solid oxide cell systems for grid-energy storage based on H_2/H_2O and CH_4/H_2O-CO_2 chemistries (A1509)
A. Parashar, J, Hosseinpour, E. Reznicek, R.J. Braun
Colorado School of Mines, Department of Mechanical Engineering; Golden, Colorado/U.S.A.;

~~(A1510)~~

Green hydrogen production with concentrating solar tower system coupled with SOE (A1511)
Luca Mastropasqua (1), Jun Yong Kim (1), Andrea Giostri (2), Marco Binotti (2), Paolo Silva (2), Jack Brouwer (1)
(1) National Fuel Cell Research Center, University of California, CA/USA;
(2) Department of Energy, Politecnico di Milano; Milano/Italy;

Hydrogen and syngas production by solid oxide electrolysis with solar heat integration (A1512)
Michael Lang (1), Patric Szabo (1), Bruno Lachmann (2), Vamshi Krishna Thanda (2), Nathalie Monnerie (2), Remi Costa (1)
(1) German Aerospace Center (DLR), Institute for Engineering Thermodynamics; Stuttgart/Germany;
(2) German Aerospace Center (DLR), Institute for Future Fuels; Köln-Porz;

Waste2Watts: Techno-economic evaluation of biogas-fed SOFC power system integrated with CCS and CCU (A1513)
Hangyu Yu (1), Ligang Wang (2), Jan Van herle (1)
(1) Group of Energy Materials, Faculty of Engineering Sciences (STI), École Polytechnique Fédérale de Lausanne (EPFL); Sion/Switzerland;
(2) Innovation Research Institute of Energy and Power, North China Electric Power University (NCEPU); Beijing/China;

The analysis of the status of industrial ecology system and technical level in Korea's fuel cell technology sector (A1514)
Ran Yoo, Seongkon Lee
Energy Policy Research Center, Korea Institute of Energy Research, Daejeon/Republic of Korea

A16: Products, Demonstration & Novel Concepts

Robust remote power supply (RoRePower) (A1607)
Jari Kiviaho (1), Jyrki Mikkola (1), Markus Münch (2), Daniele Penchini (3) Matthias Boltze (4), Michael Spirig (5), Mari Tuomaala (6)
(1) VTT Technical Research Centre of Finland Ltd, Espoo/Finland;
(2) Sunfire GMBH, (3) SolidPower SpA ; (4) Sunfire Fuel Cells GmbH,
(5) European Fuel Cell Forum AG (6) 3E Energy Oy;

Development status of a 70% efficient hybrid SOFC system for 100 kW-class distributed generation applications (A1608)
R.J. Braun, G. Floerchinger, N. Sullivan, T. Vincent (1), R. Danforth (2), I. Frampton (2), T. Bandhauer, D. Olsen, B. Windom (3)
(1) Colorado School of Mines, Golden; Colorado/U.S.A.;
(2) Kohler Power Systems, Kohler, Wisconsin/U.S.A.;
(3) Colorado State University, Ft. Collins, Colorado/U.S.A.;

ShipFC project: NH3-SOFC to decarbonise commercial shipping application (A1609)
Colin Bettini (1), Ivar Wærnhus (2), Tjalve Magnusson Svendsen (3), Laurence Grand-Clément (1), Valentina Ruiz (1)
(1) Pers-ee; Smarter Energy; Lyon/France;
(2) Clara Venture Labs; Bergen/Norway;
(3) Alma Clean Power, Bergen/Norway

Electrochemical processes and energy systems towards step-wise emission reduction of marine transport (A1610)
S. Asif Ansar, Matthias Metten, Santiago Salas Ventura, Dirk Ullmer, Christian Schnegelberger
German Aerospace Center (DLR), Institute of Engineering Thermodynamics; Stuttgart/Germany;

Techno-economic analysis of maritime fuel cell hybrid power system in commercial operations (A1611)
Colin Bettini, Laurence Grand-Clément, Valentina Ruiz
Pers-ee, Smarter Energy; Lyon/France;

Design, development, and characterization of BCZY(Yb)-based proton-conducting ceramic cells and stacks for H_2 extraction (B0916)
Stéven Pirou (1), Federico Palmerini (1), Peyman Khajavi (1), Xanthi Georgolamprou (1), Qingjie Wang (1), Ming Chen (1), Sandrine Ricote (2), Ragnar Kiebach (1)
(1) Technical University of Denmark, Department of Energy Conversion and Storage; Lyngby/Denmark;
(2) Colorado School of Mines, Department of Mechanical Engineering; Golden/USA;

B09s: Co-Electrolysis & CO_2 Electrolysis

Flexible solid oxide cells for low carbon fuel utilisation and syngas production by co-electrolysis (B09s07)
Bernardo Jordão Moreira Sarruf, Robert Steinberger-Wilckens
Centre for Fuel Cells and Hydrogen Research, School of Chemical Engineering; University of Birmingham, Edgbaston, Birmingham/UK;

(B09s08)

3D microstructural characterization of Ni/YSZ electrodes in long-term CO_2 electrolysis (B09s09)
Yijing Shang (1), Anne Lyck Smitshuysen (1), Miao Yu (1), Yuliang Liu (1,2), Peter Stanley Jørgensen (1), Ming Chen (1)
(1) Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;
(2) School of Materials Science and Engineering, Henan University of Science & Technology; Luoyang/China;

~~(B09s10~~

Effect of PH2 and of the PH_2O/PCO_2 ratio on the CO origin and the occurring electro-catalytic interactions on Ni/GDC during H_2O/CO_2 co-electrolysis (B09s11)
Evangelia Ioannidou (1,2), Mara Chavani (1,2), Stylianos G. Neophytides (1), Dimitrios K. Niakolas (1)
(1) Foundation for Research and Technology, Institute of Chemical Engineering Sciences (FORTH/ICE-HT); Patras/Greece;
(2) Department of Chemical Engineering, University of Patras, Greece;

Electrochemical performance and microstructure analysis of solid oxide cells operated in CO_2 electrolysis (B09s12)
Miao Yu (1), Xiufu Sun (1), Yuliang Liu (1,2), Yijing Shang (1), Ming Chen (1)
(1) Department of Energy Conversion and Storage, Technical University of Denmark; Lyngby/Denmark;
(2) School of Materials Science and Engineering, Henan University of Science & Technology; Luoyang/China;

Analysis of the hysteresis in current-voltage characteristic curves during solid oxide electrolysis (B09s13)
Lucy Dittrich (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
(1) Institute of Energy and Climate Research, Fundamental Electrochemistry (IEK-9); Forschungszentrum Jülich GmbH, Jülich/Germany;
(2) Institute of Physical Chemistry, RWTH Aachen University; Aachen/Germany;

Development of SOEC performance evaluation method (B09s14)
Takumi Imabayashi, Koichi Asano, Yoshihiro Mugikura
Central Research Institute of Electric Power Industry (CRIEPI); Kanagawa/Japan;

B11: Lifetime Cells II

Degradation studies of 1000 h aged SOECs: From lab analysis to local level simulation
(B1107 is requested to be presented orally in B1106)
Aiswarya Krishnakumar Padinjarethil (1), Fiammetta Rita Bianchi (2), Anke Hagen (1), Barbara Bosio (2)
(1) Department of Energy Conversion and Storage, Technical University of Denmark (DTU), Lyngby/Denmark;
(2) Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa;

Lightweight tubular solid oxide fuel cell for aeronautical application (A1612)
Vignesh Ahilan (1), Pedro Nehter (1), Helge Geisler (1), Oliver Rohr (2), Hugo Vulin (2), Maximilian Kolb (3), Aurelie Walter (4), Stéphane Suel (4);
(1) Electrification Technologies (1XRE), Airbus Operations GmbH, Hamburg/Germany; (2) Materials (1XRM1), Airbus Defense and Space, Ottobrunn/Germany; (3) X-Labs (1RXP) Airbus Defense and Space, Ottobrunn/Germany; (4) Materials (1XRM1), Airbus SAS, Nantes/France;

High Pressure Water Electrolyser Development for Space Exploration Surface Missions (A1613)
Nelson Thambiraj (1), Ivar Waernhus (1), Crina Ilea (1), Arild Vik (1), Maria-Eleftheria Farmaki (2), Kalliopi-Maria Papazisi (2), Dimitrios Tsiplakides (2), Stella Balomenou (2), Brandon Buergler (3), Brigitte Lamaze (3); (1) Clara Venture Labs; Bergen/Norway; (2) Chemical Process and Energy Resources Institute, Centre for Research and Technology Hellas (CPERI-CERTH), Thessaloniki/Greece; (3) European Space Agency (ESA), Noordwijk/The Netherlands;

Solid Oxide Fuel Cell Technology developments for Space Applications (A1615)
Brandon Buergler, Brigitte Lamaze, Geraldine Palissat; ESTEC; Noordwijk/The Netherlands;

Reducing green hydrogen production costs by improving the SOEC cell technology (A1616)
Hua Liu(1), Lasse Røngaard Clausen(2), Ligang Wang(3), Ming Chen(1)
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Recycling possibilities and strategies for solid oxide cell stacks (A1617)
Stephan Sarner (1,2), Norbert H. Menzler (1,2), Andreas Mai (3), Venkatesh Sarda (3), Dmitry Sergeev (1), Nikolaos Margaritis (4), Olivier Guillon (1,2,5)
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Training Staff in Fuel Cell and Hydrogen Technologies – Continuous Professional Development and Blended Learning (A1618)
Robert Steinberger-Wilckens, Naser Al-Mufachi, Ahmad El-kharouf, Yousif Al-Sagheer, Kun Zhang, Artur Majewski, John Hooper; University of Birmingham, Birmingham/UK;

CO_2 methanation over Ni/YSZ catalysts: Effect of operating conditions (A1619)
Osaze Omoregbe, Ahmad El-kharouf, Robert Steinberger-Wilckens; Centre for Fuel Cell and Hydrogen Research, School of Chemical Engineering, University of Birmingham; Birmingham/U.K;

Table-Top SOFC Demonstration in Five Minutes (A1620)
Ulf Bossel; ALMUS AG, Oberrohrdorf/Switzerland;

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Accelerated Stress Testing of Standard Solid-Oxide Electrolysis Cells (B1108)
Cameron Priest (1,8), Josh Gomez (1), Jeremy Hartvigsen (1), Lucun Wang (1), Micah Casteel (1), Richard Boardman (1), Dong Ding (1), Scott Swartz (2) Gene Arkenberg (2), Olga Marina (3), David Ginley (4), Mike Tucker (5), David Peterson (6), William T. Gibbons (7), Gang Wu (8)
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Regeneration of Co-Fe nano-catalysts on $Sr_2Fe_{1.5-x}Co_xMo_{0.5}O_{6-\delta}$ electrodes for symmetrical RSOCs (B1109)
Hye-jin Jeon, Jae-ha Myung
Department of Materials Science and Engineering; Incheon National Univ. Incheon/Korea;

Sulfur poisoning of Ni/CGO fuel electrodes at low operating temperature (B1110)
Felix Kullmann (1), Martin Juckel (2), André Weber (1)
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Effect of inlet gas composition on the durability of solid oxide electrolysis cells (B1111)
Xiufu Sun (1), Anders Kring Clausen (1), Peter Vang Hendriksen (1), Anne Hauch (1), Timo Lehtinen (2), Matti Noponen (2)
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(2) Elcogen; Vantaa/Finland;

Time-Dependent Degradation Process Identification of Solid Oxide Electrolysis Cells (B1112)
Stephanie E. Wolf (1,2), Eric Tröster (1), Vaibhav Vibhu (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
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Felix Kullmann (1), Cedric Grosselindemann (1), Luis Salamon (1), Franz-Martin Fuchs (2), André Weber (1)
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Grey-Box Data-Driven Model for the prediction of the impedance response of an IT-SOFC for fast cell and batch characterization (B1508)
Andrea Monforti Ferrario (1,2), Davide Pumiglia (1), Massimiliano Della Pietra (1), Stephen McPhail (1), NN (3)
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FIB-SEM 3D reconstruction of SOC electrodes for determining microstructure modeling data (B1509)
Markus Nohl (1,2), Roland Schierholz (1), Krzysztof Dzieciol (1), Vaibhav Vibhu (1), Izaak C. Vinke (1), Rüdiger-A. Eichel (1,2), L.G.J. (Bert) de Haart (1)
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Numerical model of Steam Electrolysis in Solid Oxide Cells with Ni/Gd-Doped Ceria (CGO) fuel Electrode (B1607)
Andrey Koksharov, Matthias Riegraff, Rémi Costa, Arnulf Latz, Thomas Jahnke
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Composite conductivity of MIEC-based SOFC anodes: Implications for microstructure optimization (B1608)
Philip Marmet (1), Thomas Hocker (1), Jan G. Grolig (2), Holger Bausinger (2), Andreas Mai (2), Joseph M. Brader (3), Lorenz Holzer (1)
(1) Zurich University of Applied Sciences, Institute of Computational Physics;
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LT-SOFCs: Effect of Molybdenum Doping on Carbon Deposition and Anode Performance of $La_{0.6}Sr_{0.4}(Co_{0.8}Fe_{0.2})_{1-x}Mo_xO_{3-\delta}$ (B1113)
Kimia Y. Javan, Vincenzo M. Sglavo
University of Trento, Department of Industrial Engineering; Trento/Italy;

Comparative study on solid oxide fuel cell anode microstructure evolution after long-term operation (B1114)
Dong Yan (1), JiaQi Geng (1), ZhenJun Jiao(2), LiChao Jia (1), Jian Li (1)
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Investigation protocols on SOFC anodes after accelerated aging: microstructural and electrochemical characterization (B1115)
Paolo Piccardo (1,2), Daria Vladikova (3), Blagoy Burdin (3), Roberto Spotorno (1)
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Deconvolution of the electrochemical impedance spectra of solid oxide electrolysis cells: A quantitative and time-dependent analysis (B1116)
Vasileios Bilalis, Xiufu Sun, Henrik Lund Frandsen, Ming Chen
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Development of strategies to mitigate degradation of solid oxide electrolysis cells (B1117)
Benjamin Königshofer (1), Michael Höber (1), Pavle Boškoski (2), Đani Juričić (2), Gjorgij Nusev (3), Christoph Hochenauer (1), Vanja Subotić (1)
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Online Monitoring and Experimental Investigation of Methane Utilization Along Anode Supported SOFCs (B1118)
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B12: Interconnects, Coatings, Contact Layers & Sealants

Influence of steel composition and alloying elements on the oxidation mechanism and electrical properties in single and dual atmosphere (B1207)
Jouni Puranen, Antonio Alfano, Matti Noponen; Elcogen Oy; Vantaa/Finland;

Comparison of an SOC with Ni/CGO Fuel Electrode during Operation with H_2/H_2O and CO/CO_2 (B1609)
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Numerical analysis of the effects of tar components on single planar SOFC under high fuel utilization (B1610)
Yixing Li, Fabian Grimm, Jürgen Karl
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Homogenized three-dimensional modeling on the chemical reactions coupled transport phenomena in solid oxide cell (SOC) stacks with an open-source library (B1611)
Shidong Zhang, Roland Peters, Nicolas Kruse, Robert Deja, Ralf Peters
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1D Modeling of an Electrolyte Supported Planar SOFC with 8YSZ and 10Sc1CeSZ based on Non-Equilibrium Thermodynamics (B1612)
Aydan Gedik (1), Gerardo Valadez Huerta (2), Nico Lubos (1), Stephan Kabelac (1)
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Computational design for tailoring the distortion of surface octahedra in La1-xSrxFeO3-δ (LSF) as a cathode for H-SOFC (B1613)
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Transient study of heat & mass transfer phenomena in solid oxide fuel cells - SOFCs (B1614)
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An Integrated Modeling Approach to Link Structural Degradation with the Performance of Solid Oxide Cells (B1615)
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Accelerating ageing test on solid oxide cell interconnects (B1208)
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Comparison of uncoated and Ce/Co coated FeCr steels for SOFC interconnects (B1209)
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Molten Salt Synthesis Activities for Solid Oxide Convertors (B1210)
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Study and improvement of sealing solutions for solid oxide cells (B1211)
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Microstructural and compositional changes in AISI 441 induced by diffusion of nickel (B1212)
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Effects of thermal aging on the joint strength of an SOFC braze seal with metallic interconnect (B1213)
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附件三、投稿論文

A0608
SOFC stack development at INER

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Abstract

The Institute of Nuclear Energy Research (INER) has committed to developing the SOFC technology for years. Substantial efforts are paid to cells, sealants, stacks, catalysts, components of balance of plant as well as system integration. Of which, the stack, composed of cells, sealants, interconnects, contact and coating layers, is considered as the core element for a SOFC power system. A series of short-stack tests under different test conditions are carried out to get a comprehensive understanding on the characteristics and performance of SOFC stacks. Accordingly, operating procedures are progressively adjusted to enhance the stack performance. Consistent and reproducible stack performance can then be achieved through quality control procedures. To facilitate the progress of stack technology, versatile configurations are designed and tested for different types of cells. In the study, we employ the anode-supported cells (Elcogen) and Crofer-22H (VDM) ferritic steel for interconnects to assemble successively 5 sets of 30-cell stacks. Performance results, under an elevated temperature of 700 °C, indicate consistent and minor variations of current-voltage and power (I-V-P) curves for 5 sets of stacks. The OCV of a stack is around 33.6 V (1.12 V/cell), while stack voltage at 28.2 V (0.94 V/cell) the power output is ~1.2 kW (330 mW/cm^2). Additionally, the metal-supported-cells (MSC, INER) and Fe-Cr alloy interconnects (Porite Taiwan) are utilized to assemble 5 sets of 36-MSC stacks. The Fe-Cr interconnects are formulated in accordance with designated shapes through a patented powder metallurgy process to minimize extra machining work. For the 36-MSC stack, the OCV is 37.8 V (1.05V) under an elevated temperature of 750 °C. As the power output around 1.2 kW (420 mW/cm^2), the stack voltage is ~ 30.6 V (0.85 V/cell). Consistent I-V-P curves are observed for the 36-MSC stacks as well.

1. Introduction

The solid oxide fuel cell is an inherently high efficient energy conversion device, which converts the chemical energy of hydrogen, ammonia, syngas or hydro-carbon rich fuels into electricity and thermal power. Contemporarily, the SOFC is considered as an essential bridge from the fossil fuels to next generation power systems. As a national energy research laboratory, INER has committed and devoted substantial efforts to developing the SOFC technology. From a holistic point of view, the stack, composed of cells, sealants, interconnects, contact and coating layers, involved with materials, thermal and mechanical designs as well as characteristic of electro-chemistry, is the most important key element for a SOFC power system. In the past decade, we have made progressive progress in related technological development. Both ceramic anode supported cells (ASC) by convectional tape casting, spin coating, screening printing and metal supported cells (MSC) by the atmospheric plasma spraying (APS) have been well developed(1-4). A series of tests for both types of cells under specific test procedures are carried out for prolonged periods. The electrochemical impedance spectroscopy (EIS) analyses and microstructural examinations are vital to provide insight information to modify the receipts and manufacture techniques. A barium-aluminum-borosilicate glass associated with its paste formulation, designated as GC9, is employed as a high-temperature seals in SOFC applications. Extensive testing and evaluation regarding its mechanical properties, interfacial fracture resistance, joint strength, creep under elevated temperatures are intensively investigated to validate its stability and compatibility with adjacent components in a stack (5-6). To increase the oxidation resistance and mitigate the Cr evaporation from interconnects, thin protective films are deposited onto the interconnect surfaces by pulsed-DC magnetron sputtering technique (PDCMS) and/or atmospheric plasma spraying method (APS). Evolution of area specific resistance (ASR) as well as microstructural and electrical properties of protective films are evaluated for specimens undergone thousands of hours testing so as to meet the functional requirements for interconnects(7,8). While the cells, sealants, interconnects and protective coated films manifested satisfactory performance, it is beneficial to produce a robust SOFC stack. Thermo-electrochemical and thermal stress analysis provides the foundation to optimize the flow patterns in the gas manifolds and acceptable stress distribution for a stack(9). Taguchi method is utilized to optimize the operating parameters, performance maps of a cell and a short stack are obtained under different flow rates, fuel utilizations, current densities and temperatures. Standard operation procedures for assembly, curing and reduction processes are subsequently established through a series of short-stack validation tests(10).

In this study, on the basis of aforementioned progress, we employ two schemes to assemble SOFC stacks with designated power output of 1.2 kW. Firstly, we take advantage of commercial available products, the anode-supported cells (Elcogen) and Crofer-22H (VDM) ferritic steels as interconnects, to assemble successively 5 sets of 30-cell stacks. The other approach, we utilize thin metal-supported cells fabricated at INER(11,12) and patented Cr-Fe alloy interconnects(13) (Porite Taiwan) with innovative stack design(14,15) to assemble 5 sets of 36-cell stacks. The innovative design is particularly invented for compact size, high efficiency, easy packing and assembly, and modular arrangement for flat type stacks.

2. Experimental

I. Metal-Supported Cells

In this study, thin Ni-Mo substrates, developed at INER, by tape casting and sintering processes are employed for SOFC stacks. The green Ni-Mo slurries mixed with solvent, binder, dispersant and plasticizer are casted to form green sheets. The sheets are then sintered at temperature 1200 °C for 4 h in a reducing atmosphere to form a porous Ni-Mo substrate. The thickness, permeability and average thermal expansion coefficient of the porous Ni-Mo substrate are around 0.2 mm, 0.2 Darcy and 14.8 ppm/°C, respectively. Powders such as YSZ(8 mol % yttrium doped zirconia)-NiO, GDC ($Ce_{0.8}Gd_{0.2}O_{2-\delta}$)-NiO, LDC ($Ce_{0.55}La_{0.45}O_{2-\delta}$), LSGM ($La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_{3-\delta}$), SDC ($Sm_{0.15}Ce_{0.85}O_{3-\delta}$) and SSC ($Sm_{0.5}Sr_{0.5}CoO_{3-\delta}$) available in the commodity, are sequentially sprayed by the APS processes onto the porous Ni-Mo substrate to form anode layer, anode functional layer, electrolyte, composite cathode layer and cathode current collector. A schematic configuration for the MSC is illustrated as Figure 1. Prior to the APS, around 1% additive Li_2O powder is mixed with the LSGM to lower the sintering temperature and improve the tightness of the electrolyte. An annealed process with a constant load of 500 g/cm^2 at elevated temperature is applied to minimize the residual thermal stresses of the MSC cell after the APS processes.

II. Fe-Cr alloy interconnect

Instead of conventional powder metallurgy (PM) method to formulate interconnect by chrome (Cr) powder and iron (Fe) powder, we employ an innovative formulation process with Cr powder and Cr-Fe alloy powder. The invented interconnect possesses an easier heating procedure and stabilized properties after heating. Different compositions of Cr-Fe alloys are formulated and evaluated their material properties and compatibility with adjacent components of a SOFC stack. The evaluation items include mass density, thermal conductivity, coefficient of thermal expansion, mechanical strength, surface morphology, oxidation resistance, adhesion test with sealant (GC9), leakage rate test and ASR measurement. The bulk density is obtained by the balance measurement of the mass for a specific size of alloy specimen. Thermal conductivity is measured by HotDisk TPS2500S and the coefficient of thermal expansion by a high temperature dilatometer (Diamond TMA, PerkinElmer, USA) for temperature ranging from 50~800 °C. The weight-gain rate, oxidation test, is executed to examine the oxidation resistance of the alloy for a test period of 1200 hours. Adhesion test with sealant (GC9) is observed to check the adhesive behavior and suitability for the alloy with the sealant. Additionally, leakage rate test for the alloy with the GC9 sealant is performed at a temperature of 800 °C for a period of 700 hours. Evolution of area specific resistance (ASR) of the PM alloy (LSM coated) aging at 800 °C is evaluated for a period of 1000 hours in air. Test results indicate that the 78Fe-Cr alloy suffices the functional requirements of a SOFC stack in this study. Examination of cross-sectional micro-structure and elemental profile of the adhesion test for the PM alloy and GC9 seals is shown as Figure 2 after aging at 800 °C for 500 hours. The measured data for the 78Fe-Cr alloy are summarized as Table 1.

III. SOFC stack

In this study, we employ two schemes to assemble SOFC stacks with designated power output of 1.2 kW. Planar stack design, which generally offers a higher performance than tubular one and commercially viable for further applications, is developed. In the first scheme, planar configuration with internal manifold, counter flow for fuel/oxidant gases, and inlet/outlet gas channels in parallel is adopted. A schematic diagram for the planar type design for a stack is illustrated as Figure 3. Where a stack is assembled with repeated units jointed by sealant from lower to upper end plates. Of which, a unit is formed by an interconnect, a cell, current collectors and a frame to separate the oxidant and fuel gases in the cathode and anode sides. A protective layer (LSM) is deposited onto the interconnect surface to improve the oxidation resistance and mitigate Cr evaporation through the interconnect surface. In the practice, commercial available product, Elcogen ASC-400B,

anode-supported cells with a size of 12cm*12 cm (effective area 11cm*11cm) and total thickness of 415 µm are utilized to assemble the stacks. A more detail technical data of the ASC-400B can be found in Elcogon's official website. Planar Crofer-22H (VDM), a ferritic high-temperature stainless steel, specially designed for use in high-temperature fuel cells (SOFC), is selected as interconnect in this study. Once the stack was assembled, it is transferred into a furnace to go through the curing and reduction proposes. In order to minimize the temperature variation inside the stack, a benign heating rate of 1 °C/min is used. Two temperature plateaus at 350 °C and 600 °C for 1 hour, respectively, are set to remove the organic/binder and flatten the temperature profile of the stack. In compliance with the transition and soften temperatures of the sealant, the stack is curing at a temperature of 850 °C for 4 hours. During the curing process, a small amount of nitrogen/air gases at a flow rate of 400 ml/min/cell are flowing into the anode and cathode sides of the stack, respectively. After the curing process, the furnace temperature gradually decreases to the elevated temperature of 700 °C for the reduction process with a constant current around 130 mA/cm^2 for 4 hours. Hydrogen at a flow rate of 9.8 ml/min/cm^2 with 20% of nitrogen and air inlet at a flow rate of 24.7 ml/min/cm^2 (lamda~1) are used in the reduction and Tafel power performance measurement. Standard operation procedures (SOP) are established and applied to assemble and test for 5 successive sets of 30-cell stacks.
For the other scheme, planar configuration with internal manifold, radially distributed flow for fuel gas, and a parallel flow pattern for oxidant gas is applied. To increase the flatness of sealant on the stack components, glass-ceramic tape sealant is produced via tape casting and shaped in accordance with the designated geometry[(16)]. In this study, thin metal-supported cells fabricated at INER, as mentioned above, are utilized to assemble the stacks. To integrate the capabilities of Taiwan SOFC Industry Alliance (TSIA), a collaborative framework for the stack is conducted by INER. In the framework, Cr-Fe alloy interconnects are provided by Porite Taiwan Co., glass-ceramic tapes and LSM coating (via APS) on the interconnects are commissioned to domestic companies of TSIA. Subsequently, under the guidelines of standard operation procedures, stacking, curing, reduction, performance testing are carried out at INER. Consistent results of power performance are achieved for 5 successive sets of 36-cell MSC stacks.

3. Results and Discussion

Figure 4 indicates the current-voltage-power (I-V-P) curves for two types of planar MS-SOFC cells (10×10 cm^2). The power densities for a MSC cell with pure LSGM electrolyte reach to 380, 630 and 890 mW/cm^2 at a cell voltage of 0.6 V and operating temperatures of 650, 700 and 750 °C, respectively. As a MSC cell with Li_2O-doped LSGM electrolyte, the power densities increase to 540, 855 and 1060 mW/cm^2, under the same cell voltage and operating temperatures as above. Observations reveal that the gas tightness, density and OCV for Li_2O-doped LSGM electrolyte are superior to that of the pure LSGM ones. Thus, the Li_2O-doped LSGM electrolyte is adopted. To validate the reliability of SOP for stacking processes, a series of short stack tests for 1-cell and 3-cell stack are conducted. Typically, hydrogen at a flow rate of 9.8 ml/min/cm^2 with 20% of nitrogen and air inlet at a flow rate of 24.7 ml/min/cm^2 are used in this study. Figure 5 shows the Nyquist plot and I-V-P curves for a single-cell MSC stack at elevated temperatures of 700 and 750 °C. The Nyquist plot reveals the ohmic resistance and polarization resistance are 0.198 and 3.22 Ω cm^2 and 0.148 and 2.68 Ω cm^2, respectively. The power outputs reach to 44.3 and 54.7 W at 0.7 V and 700 and 750 °C, respectively. A durability test of the MS-SOFC single-cell stack for 3,500 hours at a constant current density of 400 mA/cm^2 and 700°C, where the cell voltage drops from 780 to 754 mV, indicates its degradation rate less than 1 %/1000hr.

Table 1 shows the measured material properties for the 78Fe-Cr alloy formed by the powder metallurgy (PM) method. The measured density is 7.31 g/cm^3, around 95% of theoretical density under the specific weight fraction of Fe/Cr alloy. The thermal conductivity of 10.47 W/m·K is lower than that of alloy for SOFC application, such as: ZMG232 or Crofer-22 (both in the range of 20-30 W/m·K). The tensile strength is 334 MPa at room temperature and around 25 MPa at 800 °C, respectively. These lower values of material properties imply a weaker metallic bond between atoms for the alloy formed by the PM method. The coefficient of thermal expansion, 12.4 ppm/°C, is compatible to the sealant. The weight gain rate of 3.60/cm^2-h, leak rate 3.47 3.47*10^{-6} mbar·ℓ/s/cm, and area specific resistance 7.04 mΩ-cm^2 are all within acceptance criteria for current SOFC applications. Examination of cross-sectional micro-structure and elemental profile of the PM alloy adhered to GC9 seals after aging at 800 °C for 500 hours, as shown in Figure 2, indicates the wettability and adherence properties are satisfactory. In overall, the 78Fe-Cr alloy fulfills the functional requirements in this study.

Figure 6 illustrates two type of SOFC stacks. The sizes of stack-E (Elcogen cells inside) and stack-M (MSC cells) are 210 x 140 x175 mm^3 and 138 x 110 x 142 mm^3, respectively. The weight of stack-E is 23 kg and stack-M 10.3 kg. The volume and mass ratios for the stack-M to stack-E are around 42% and 45%, respectively. The active area per cell in the stack-M is approximately 65% of the stack-E. Figure 7 shows the I-V-P curves for 5 successive stack performance for these two types of stacks. The excellent consistence of the I-V-P curves of stack-E, as shown in Figure 7(a), indicates the high quality of the cells, good compatibility and stability among stack components, and well-established stacking and testing SOPs. The OCV of a stack-E is around 33.6 V (1.12 V/cell) at nominal fuel/oxidant gas flow rates and elevated temperature of 700 °C. As stack voltage at 28.2 V (0.94 V/cell), the power output is ~1.2 kW (40 W/cell, or 330 mW/cm^2) and the fuel utilization about 28.9%. As the flow rate reduced to 53% of origin, the fuel utilization reaches to 51.9% for the power output at 1.1 kW. Figure 8 shows the voltage variations of clusters for five sets of stack-E at power output of 1.2 kW. There are 6 clusters in a stack (5 cells/cluster) for temperature monitoring and voltage measurement. The voltage variations of clusters for the 5 sets of stack-E reveal only a small deviation (~0.6%) from a 5-cell voltage of 4.71 V (0.94/cell). The I-V-P curves for 5 successive sets of stack-M, as shown in Figure 7 (b), indicate consistent performance is achieved for the stack-M. The OCV of a stack-M is around 37.8 V (1.05 V/cell) at nominal fuel/oxidant gas flow rates and elevated temperature of 750 °C, while stack voltage at 30.6 V (0.85 V/cell) with a power output of 1.2 kW (33.3 W/cell, or 420 mW/cm^2). The fuel utilization is about 39.2%. As the flow rate reduced to 53% of origin, the fuel utilization is about 47.5% for the power output at 800 W. For the 36-cell stack-M, each cluster consists of 6 cells. Figure 9 shows the voltage variations of clusters for the 5 sets of stack-M at power output of 1.2 kW. The results indicate small variations (~2%) exist among clusters of a stack-M. A lower cell OCV of stack-M than that of stack-E indicates the tightness of MSC cells remains rooms for improvement. Methods for a thinner thickness and lower permeability (sub-micron or nano-powders) of the electrolyte for MSC cells are being undertaken. Meanwhile, skills to minimize the curvature of the cells attributed to the thermal residual stresses in the high temperature plasma spraying processes are evaluated for a new version of MSC cells. Findings and observations in the stack-M stacking and testing serve as the technical foundation for further improvements. Essentially, it indicates that the innovative planar configuration of modular stack design, which possesses a symmetric geometry configuration and a shorter uniformly-distributed travelling length of fuel gas, consequently lower thermal and stress gradients for stack components, is viable for commercial applications in the near future.

4. Conclusions

In this study, we successfully assemble 5 successive SOFC stacks with two different planar stack configurations and demonstrate the power output of each stack reach to 1.2 kW. Some remarks are listed as follows:

- MSC cell: thin flexible MSC-cell with porous nickel-molybdenum substrate formed by conventional tape casting and sintering processes is developed. Multi-layers including anode, anode function, electrolyte, composite cathode and current collector layers are sequentially sprayed onto the substrate. The thin flexible MSC cells with stable and consistent quality are utilized for the innovative planar stack.
- Fe-Cr interconnect: interconnect formulated by an innovative powder metallurgy (PM) process with Cr powder and Cr-Fe alloy powder is employed. Measurement of the material properties indicates the 78Fe-Cr alloy fulfills the functional requirements for the designated stack.
- Stack-E: planar configuration with internal manifold, counter flow for fuel/oxidant gases, and inlet/outlet gas channels in parallel is adopted. Commercial available products, Elcogen ASC-400B and Crofer-22 H (VDM), are used in the stack. Excellent agreement of I-V-P curves and insignificant voltage variations for 5 successive stacks indicate high quality and high performance of cells and stacks as well as establishment of sophisticated SOP for SOFC stacks.
- Stack-M: planar configuration with internal manifold, radially distributed flow for fuel gas, and a parallel flow pattern for oxidant gas is applied. Thin flexible MSC cells made at INER and 78Fe-Cr interconnects provided by Taiwan Porite Co., are used. The 78Fe-Cr interconnect is produced in accordance with the designated shape to minimize extra machining work afterwards. With a significant volume and mass reduction of the innovative stack design, consistent performance and high performance of stack-M is observed, while there exists rooms for further improvements.

Acknowledgment
The authors would like to express our gratitude to the team members of the SOFC project for their persistent efforts. Constructive discussions and technical supports through the collaborative framework of Taiwan SOFC Industry Alliance are highly appreciated.

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Keywords: Anode Supported Cell, *Metal Supported Cell, Atmospheric Plasma Spraying, Sealant, Fe-Cr alloy Interconnect, SOFC Stack*

Table 1. Material properties for bulk density, thermal conductivity (K), coefficient of thermal expansion (CTE), tensile strength (TS), weight gain rate (WGR), leakage rate (L_r) and area specific resistance (ASR) of the 78Fe-Cr alloy by powder metallurgy method

Parameter	Density	κ	CTE	TS	WGR	L_r	ASR
unit	g/cm³	w/m·K	ppm/°C	MPa	mg/cm²·h	mbar·ℓ/s/cm	mΩ-cm²
Measured	7.31	10.47	12.4	334	3.60*10⁻⁴	3.47×10⁻⁶	7.04

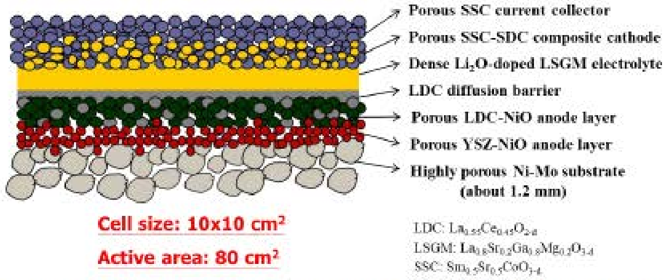

Figure 1. Schematic configuration of a MSC cell with multiple layers by APS.

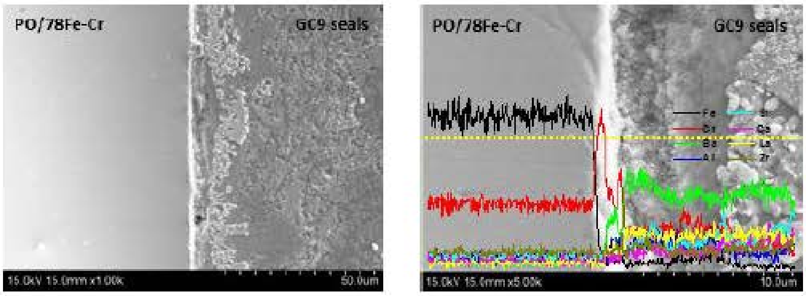

Figure 2. Cross-sectional micro-structure and elemental profiles of 78 Fe-Cr alloy adhered to GC9 seals after aging at 800 °C for 500 hours.

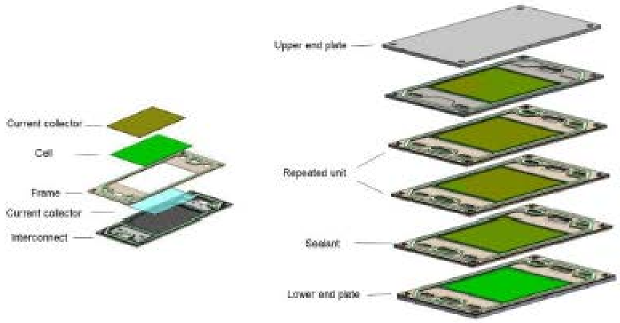

Figure 3. A schematic diagram for the planar type design for a stack.

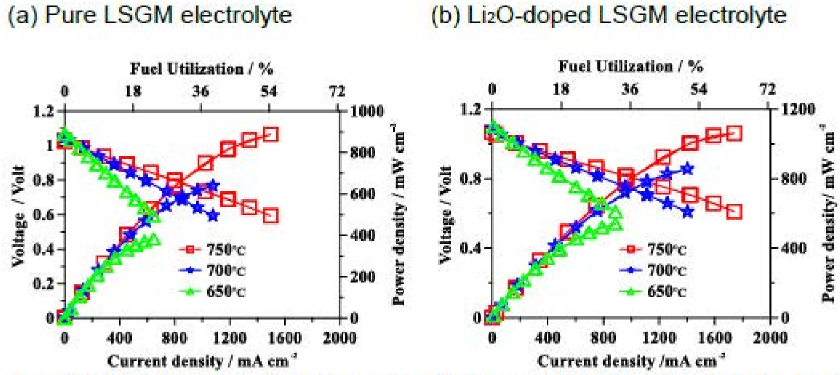

Figure 4. Current density-voltage-power curves for (a) pure LSGM cell and (b) Li_2O-doped LSGM cell at temperatures of 650, 700 and 750°C.

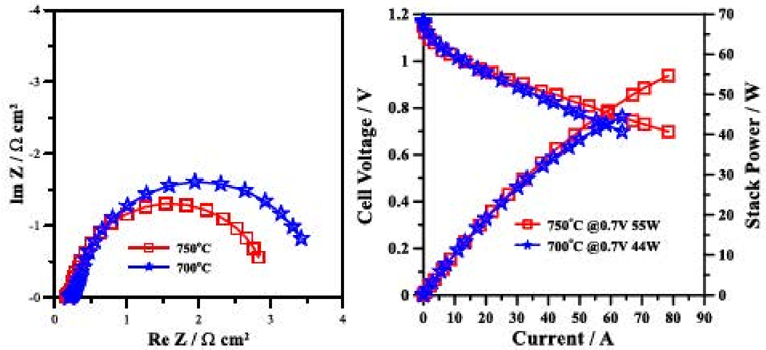

Figure 5. Nyquist plot and current-voltage-power curves for a single-cell MSC stack at temperatures of 700 and 750°C.

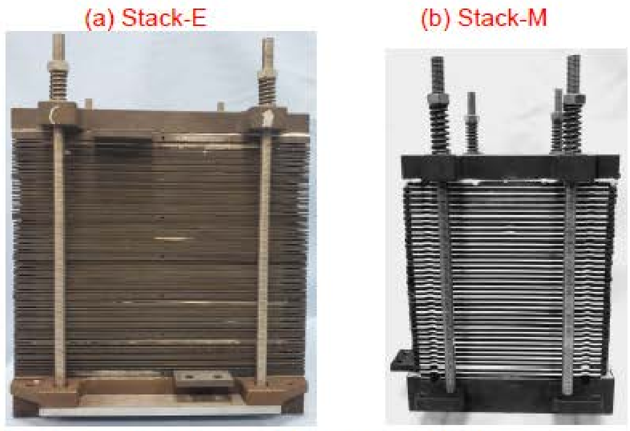

Figure 6. Two types of stacks, stack-E and stack-M, after performance testing (stack-E 210x140x175 mm³, stack-M138x110x142 mm³, not to scale).

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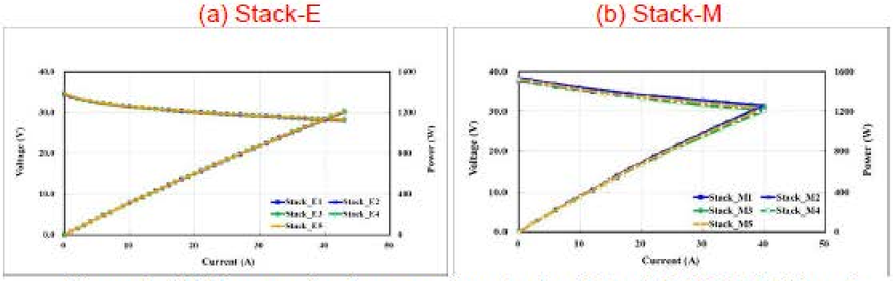

Figure 7. I-V-P curves for 5 successive stacks of stack-E (@ 700 °C) and Stake-M (@750°C) for a designated power output of 1.2 kW.

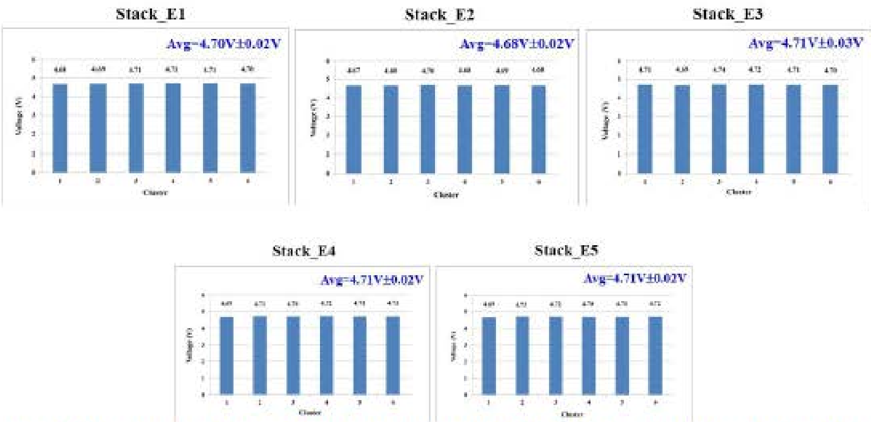

Figure 8. Voltage variations of clusters for five sets of stack-E at power output 1.2 kW.

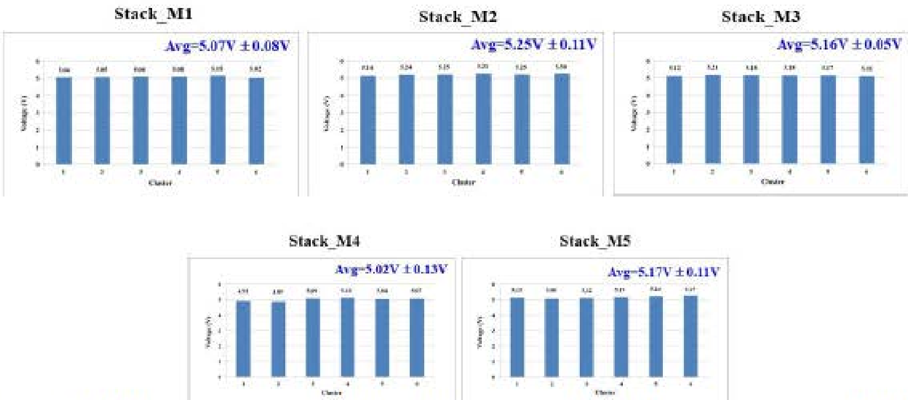

Figure 9. Voltage variations of clusters for five sets of stack-M at power output 1.2 kW.

附件四、論文簡報

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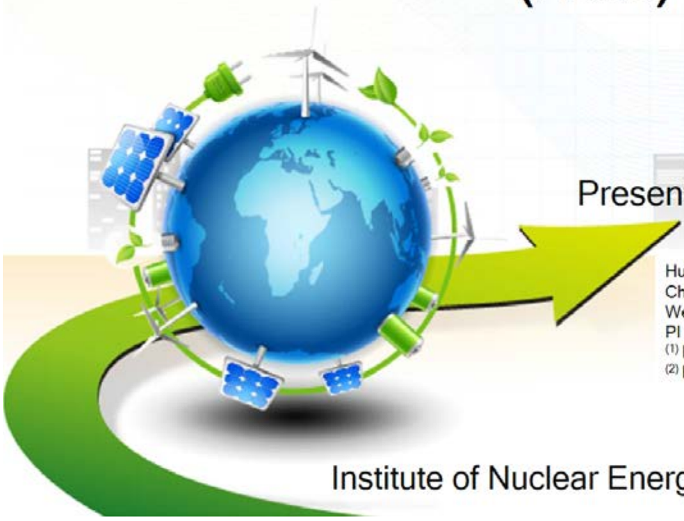
SOFC Stack Development at INER (A608)



Present by Yi-Jing Wu

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[(1)] Institute of Nuclear Energy Research

[(2)] Porite Taiwan Co.

Institute of Nuclear Energy Research

Institute of Nuclear Energy Research
Atomic Energy Council, R. O. C.

Outline

- Introduction
- Experimental
  - Metal-supported Cells(MSC)
  - Fe-Cr alloy interconnect
  - SOFC stacks (stack E and stack M)
- Results and Discussion
  - MSC single cell and single stack
  - Stack E
  - Stack M
- Conclusions

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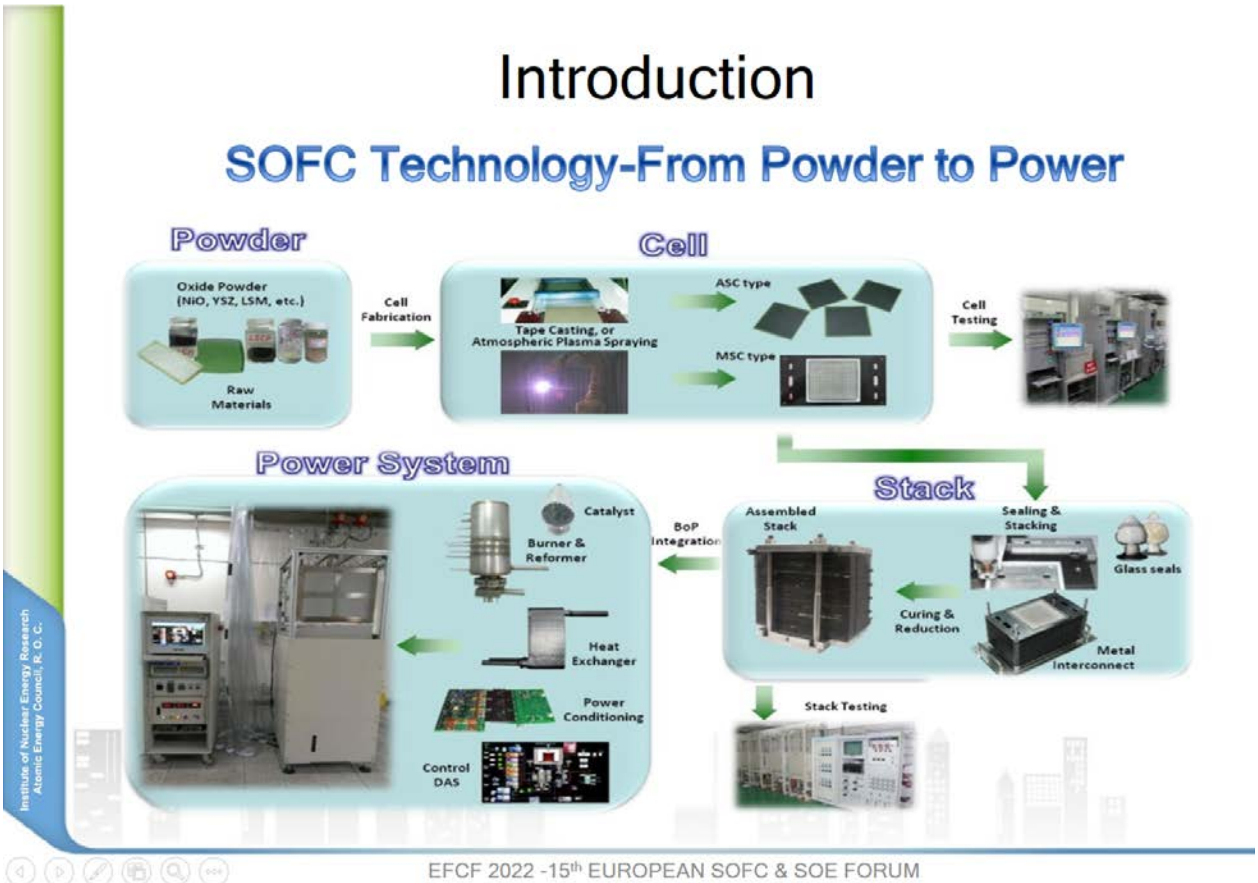
Introduction
SOFC Technology-From Powder to Power
Powder
Oxide Powder (NiO, YSZ, LSM, etc.)
Raw Materials
Cell Fabrication
Cell
Tape Casting, or Atmospheric Plasma Spraying
ASC type
MSC type
Cell Testing
Power System
Catalyst
Burner & Reformer
BoP Integration
Heat Exchanger
Power Conditioning
Control DAS
Stack
Assembled Stack
Sealing & Stacking
Glass seals
Curing & Reduction
Metal Interconnect
Stack Testing
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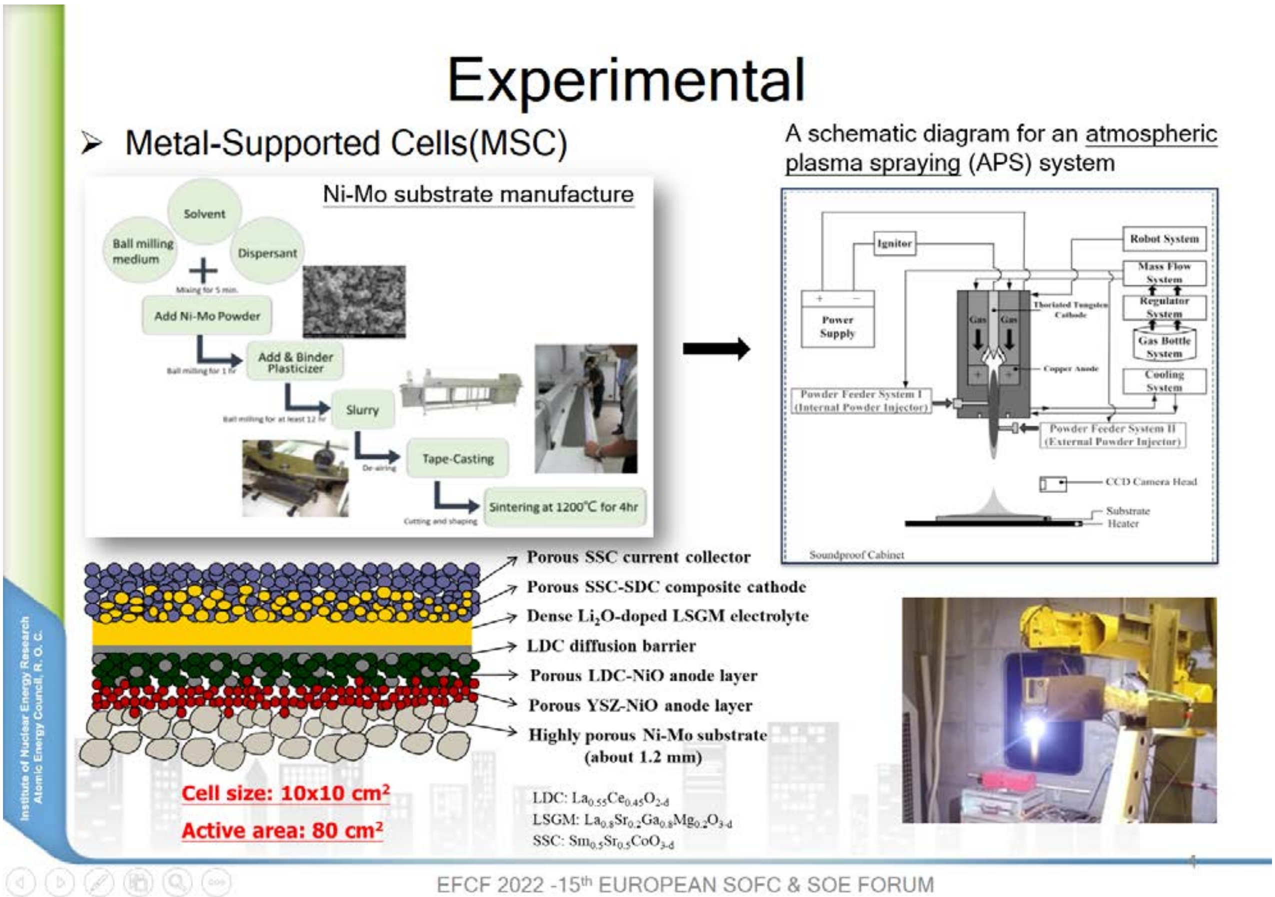
Experimental
Metal-Supported Cells(MSC)
Ni-Mo substrate manufacture
Solvent
Ball milling medium
Dispersant
Add Ni-Mo Powder
Add & Binder Plasticizer
Slurry
Tape-Casting
Sintering at 1200°C for 4hr
A schematic diagram for an atmospheric plasma spraying (APS) system
Ignitor
Robot System
Mass Flow System
Regulator System
Gas Bottle System
Cooling System
Power Supply
Thoriated Tungsten Cathode
Copper Anode
Powder Feeder System I (Internal Powder Injector)
Powder Feeder System II (External Powder Injector)
CCD Camera Head
Substrate Heater
Soundproof Cabinet
Porous SSC current collector
Porous SSC-SDC composite cathode
Dense Li2O-doped LSGM electrolyte
LDC diffusion barrier
Porous LDC-NiO anode layer
Porous YSZ-NiO anode layer
Highly porous Ni-Mo substrate (about 1.2 mm)
Cell size: 10x10 cm2
Active area: 80 cm2
LDC: La0.55Ce0.45O2-δ
LSGM: La0.8Sr0.2Ga0.8Mg0.2O3-δ
SSC: Sm0.5Sr0.5CoO3-δ
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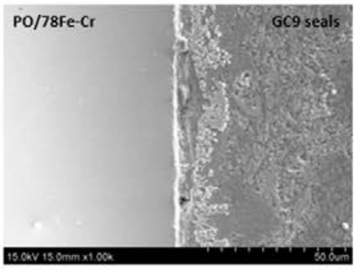
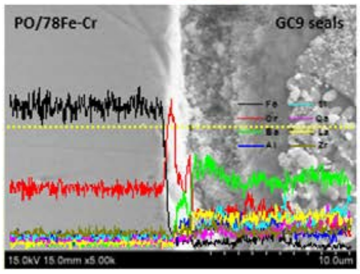
Experimental(cont'd)

➢ Fe-Cr alloy interconnect

Cr powder + Cr-Fe powder → powder metallurgy (PM) → Fe-Cr interconnect



aging at 800 °C for 500 hours →

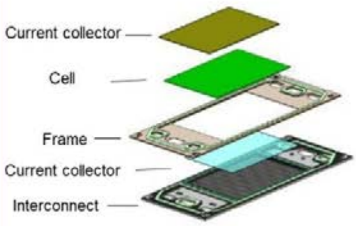


Parameters	bulk density	thermal conductivity	coefficient of thermal expansion	tensile strength	weight gain rate	leakage rate	area specific resistance
unit	g/cm^3	w/m·K	ppm/°C	MPa	$mg/cm^2 \cdot h$	mbar·ℓ/s/cm	$m\Omega\text{-}cm^2$
Measured	7.31	10.47	12.4	334	$3.60*10^{-4}$	3.47×10^{-6}	7.04

Experimental(cont'd)

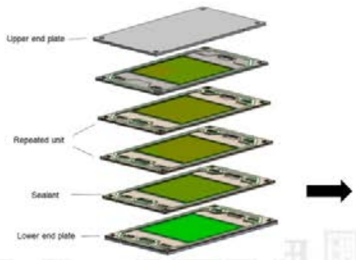
➢ SOFC stacks

Repeat unit



⬇

Repeated units stacking



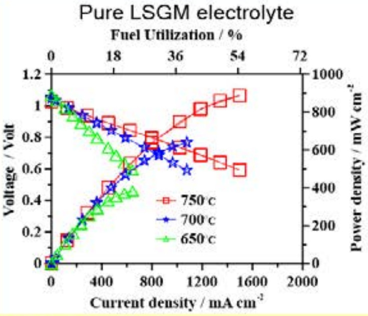
Characteristics		Stack E	Stack M
Cell		Elcogen cells	Metal-supported cells (MSC)
Size		$210 \times 140 \times 175\ mm^2$	$138 \times 110 \times 142\ mm^2$
Weight		23 kg	10.3 kg
Active area per cell		$121\ cm^2$	$80\ cm^2$
Interconnect		Crofer 22H (VDM)	Fe-Cr alloy
Number of cells per stack / cluster		30 / 5	36 / 6
Flow rate	H_2	$9.8\ ml/min/cm^2$	
	N_2	20% of H_2	
	Air	$24.7\ ml/min/cm^2$	
Stack			

Results and Discussion

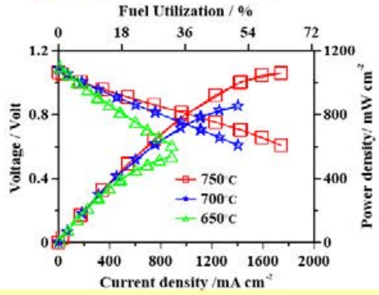
➢ MSC single cell and single stack

MSC single cell

Pure LSGM electrolyte

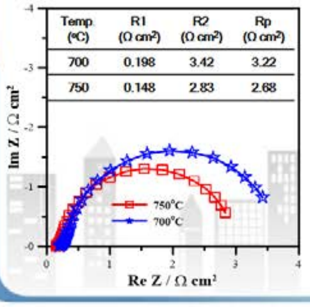


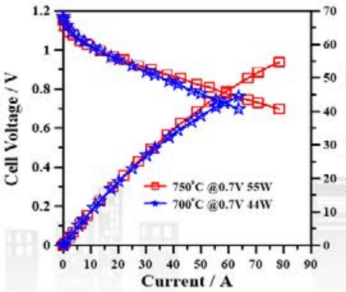
Li_2O-doped LSGM electrolyte



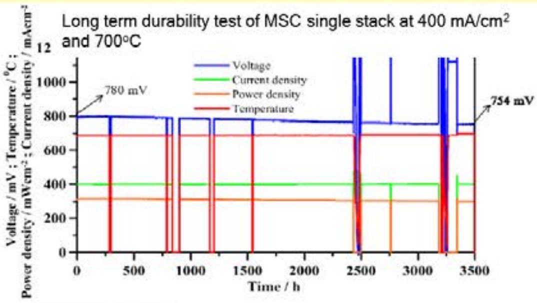
Temp.	Power density at 0.6 V (mW/cm^2)	
	Pure LSGM electrolyte	Li_2O-doped LSGM electrolyte
650 °C	380	540
700 °C	630	855
750 °C	890	1060

MSC single stack





Long term durability test of MSC single stack at 400 mA/cm² and 700°C

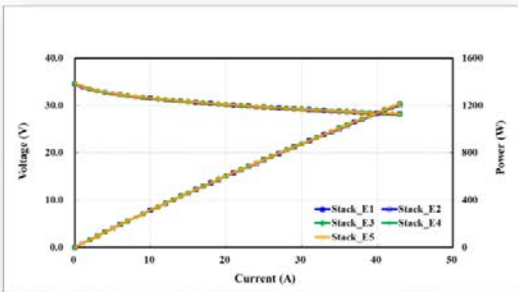


Degradation < 1%/khr

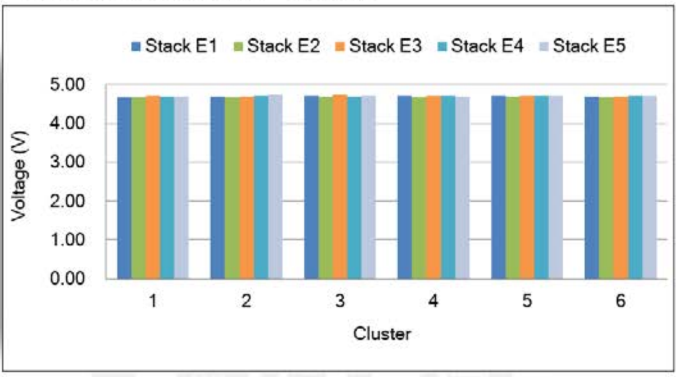
Results and Discussion(cont'd)

➢ Stack E (at 700 °C)

- Consistent IVP curves
- OCV~33.6 V for 30 cells (1.12 V/cell)
- Power output~1.2 kW (40 W/cell or 330 mW/cm^2) while stack voltage ~28.2 V(4.71 V/cluster or 0.94 V/cell)
- Small voltage variations ~0.6% for 5 successive stacks



Performances of Stack E1~E5 at 700 °C

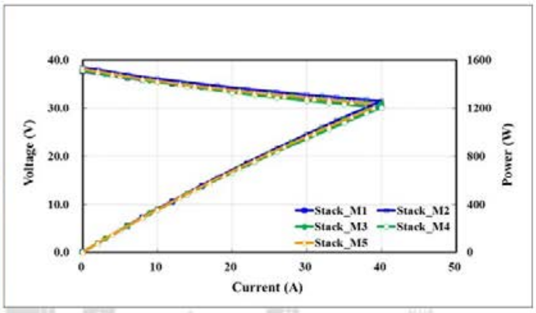


Voltage distributions of power output at 1.2 kW for stack E1~E5 at 700 °C

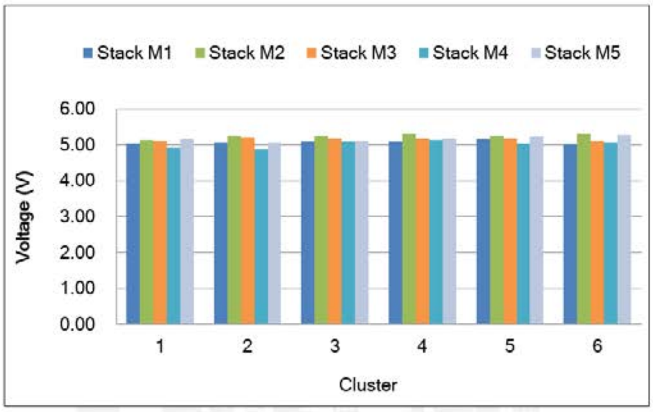
Results and Discussion(cont'd)

➢ Stack M (at 750 °C)

- Consistent IVP curves
- OCV~37.8 V for 36 cells(1.05 V/cell)
- Power output~1.2 kW (33.3 W/cell, or 420 mW/cm^2) while stack voltage ~30.6 V (5.10 V/cluster or 0.85 V/cell)
- Voltage variations ~2% for 5 successive stacks



Performances of Stack M1~M5 at 750 °C



Voltage distributions of power output at 1.2 kW for stack M1~M5 at 750 °C

Conclusions

➢ MSC cell

- Thin flexible MSC cells with stable and consistent quality

➢ Fe-Cr interconnect

- Measurement of the material properties indicates the 78Fe-Cr alloy fulfills the functional requirements for the designated stack.

➢ Stack-E

- Counter flow for fuel/oxidant gases, and inlet/outlet gas channels in parallel
- Consistent I-V-P curves
- Small voltage variations ~0.6% for 5 successive stacks

➢ Stack-M

- Radially distributed flow for fuel gas, and a parallel flow pattern for oxidant gas.
- Consistent IVP curves
- Voltage variations ~2% for 5 successive stacks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Thank You for Your Attention