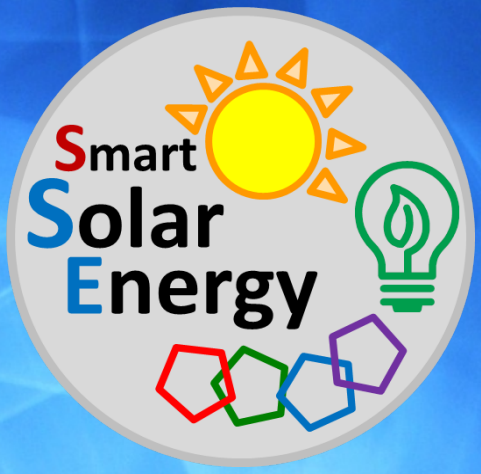
The Chinese University of Hong Kong



Smart Solar Energy

Harvesting, Storage, and Utilization

UNITE and EMPOWER
Energy Technology Leaders

CONVENE

COLLABORATE

CATALYSE

CONVERT

… and BEYOND

Partner Institutions:

- The Hong Kong Polytechnic University
- The Hong Kong University of Science and Technology
- The University of Hong Kong

Funded by:
Theme-based Research Scheme (TRS), Research Grants Council (RGC),
University Grant Committee (UGC), HKSAR (T23-407/13-N)

前言

香港中文大學 (中大) 是香港以至國際上首屈一指的大學。我們的未來發展與本港、珠江三角洲、中國以至全球的可持續發展息息相關。過去數十年以來，能源科技獲得國際上不少關注，化石燃料所衍生的各種環境問題，也令各界竭力尋求更高效可靠的可再生能源解決方案。

有見及此，中大工程學院致力尋求科技上的研究突破。2013 年，我們成立了一個由超過二十位專家學者組成的跨學科團隊，進行是次研究項目**「智能化太陽能技術 - 採集、存儲及應用」**。是項研究與香港特區政府於 2005 年擬定的《可持續發展綱要》密切相關，我們很榮幸獲得香港政府研究資助局（RGC）主題研究計劃 （TRS）資助六千萬港元，進行這個項目。加上院校資助後，**項目總撥款高達七千六百萬港元**。本項目在太陽能科技研究上已取得多項優秀成果，令香港在再生能源技術上領先全球。

本項目旨在於人類對能源需求的快速增長以及使用傳統化石燃料所導致的全球氣候惡化情況之下，開發和利用潔淨可再生能源以代替化石燃料的使用。是項研究計劃的設計十分整全，目標包括三方面：

- **採集**（提升太陽光採集技術的效能）
- **儲存**（研發高效能電力儲存系統）
- **應用**（研發高效能及安全的智能太陽能配電系統，以切合在不同運作模式下之各種用戶需求）

這個大型合作項目與 2016 年11月公布、並適用於香港的全球《巴黎協定》、以至香港於2017年1月公布、目標把本港的碳強度由2005 年的水平降低 65%至70%的《香港氣候行動藍圖2030+》息息相關。事實上，本港現已推行不同的能源方針應對氣候變化，如香港政府於 2017 年1月在石壁水塘成立的首個浮動太陽能系統，產能一百千瓦，供應水塘抽水站四分一用電量；香港政府亦自1994年起豁免電動車首次登記稅，吸引市民轉用電動車。截至2017年6月底，全港由2010年不足一百輛電動車，急增至2017年6月底的11,018輛，升幅逾一百倍。身為創新科技領導者之一，中大亦於 2016 年初公布的「香港中文大學策略計劃 2016–2020」中，把「環境與持續發展」定為四大「策略性研究領域和主題」領域之一。以上各種措施，均可見政府及大學持份者對能源科技的重視。

此外，本項目團隊發展的 CIGS 電池和組件科技，除了在香港中文大學組建了CIGS光伏系統，更成功於2015 年在中國浙江省嘉興市秀洲區國家高新技術產業開發區成立了啟動公司，估計產能達每年 2 MW。2017年，我們將不同隊伍的研究成果成功整合為實際應用方案，於中大《和聲書院》設置太陽能微電網發電示範基地，以驗證再生能源電力系統的效益。未來我們將繼續發掘更出色的研究突破，以結合各種不同系統及高效智能電網應用為最終目標。

汪正平教授
項目統籌
香港中文大學工程學院院長

Smart Solar Energy

FOREWORD

The Chinese University of Hong Kong (CUHK) has been taking pride as a leading university in both the global and the regional context. Our future development is intertwined with the sustainability of Hong Kong, the Pearl River Delta, China and the world. For decades, energy has been a leading global issue , and the underlying adverse consequences of fossil fuels usage exerted more and more urges for us to explore the renewable alternatives.

In this regards, the Faculty of Engineering has been aspiring excellence in research efforts. Since 2013, we established a multi-disciplinary team consisted of more than 20 enthusiastic scholars to start this 5-year research project **"Smart Solar Energy Harvesting, Storage and Utilization"**. The project is honored to obtain a support of HK$ 60 million from the Hong Kong Research Grants Council, under the Theme-based Research Scheme (TRS) which is in line with the strategic objectives on sustainable development outlined by the Hong Kong Government in 2005. Together with the institutional support, the **total project fund is as high as HK$ 76 million**. The project is actively progressing and has achieved a good deal of world records, putting Hong Kong on the map. This project aimed at addressing the urgency of developing clean and renewable energy resources to replace fossil fuels, given the fast-growing demand for energy and the recognition of man-made global climate change. The approach adopted in this project is **harvesting** energy directly from sunlight by using photovoltaics (PV), photocatalysis and artificial photosynthesis, which in turn developing efficient and smart energy **storage** systems to ensure reliable energy supply, and increasing the penetration of solar energy **utilization**.

This collaborative research is in line with the "Paris Agreement" which came into force in Nov 2016, and applicable to Hong Kong, as well as "Hong Kong's Climate Action Plan 2030+" in Jan 2017, which targeted to reduce its carbon intensity by 65% to 70%. Various measures have been implementing regionally to combat climate change, e.g., Hong Kong's first floating solar PV system in Shek Pik Reservoir launched by the Hong Kong SAR Government in Jan 2017, with output power of 100kW and saved electricity expenses of the pumping station by 25%; and the waiving of the first registration tax for electric vehicles (EV) to encourage the shift from diesel-powered vehicles to EVs since 1994, leading to a more than hundredfold increase of less than 100 EVs in Hong Kong in 2010 to 11,020 in late July 2017. In addition, being one of the innovative pioneers in technology advancement to benefit the society, CUHK is committed to and advocates the university research activities in "Environment and Sustainability" by including it as one of the four major research areas in the CUHK Strategic Plan 2016 – 2020. These measures showed the recognition on energy technology by various stakeholders of Hong Kong Government and university.

In our project, a high-efficiency CIGS solar energy generation system was successfully launched, as well as a start-up company in the Xiuzhou National High-tech Zone, Jiaxing, Zhejiang of China since 2015, with estimated capacity 2MW/year. In 2017, the various achievements of the team were integrated into field application strategies, based at the CUHK Lee Woo Sing College, for validating the performance of the renewable energy system. In the future we are going to further explore even more breakthroughs, with the ultimate goal of integrating diversified systems for high-performing smart microgrids.

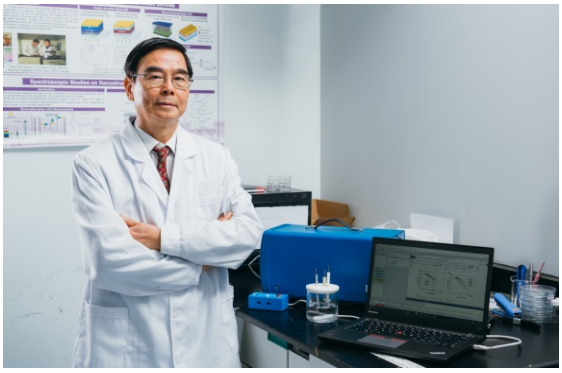
Prof. Ching-ping Wong
Project Coordinator
Dean of Engineering, The Chinese University of Hong Kong

目錄

Contents

關於本項目統籌 About the Project Coordinator

汪正平教授現為香港中文大學工程學院院長及卓敏電子工程學講座教授。汪教授在美國普渡大學取得科學學士學位，並在賓夕法尼亞州州立大學取得哲學博士學位。其後，他獲獎學金，赴史丹福大學師從諾貝爾獎得主Henry Taube教授從事博士後研究。汪教授在研究上取得豐碩的成果，已經發表了逾1,000篇專業論文，撰寫及編輯12本書籍，並持有超過65項美國專利。汪教授通過開拓新的材料，從根本上改變了半導體封裝技術，為業界作出重要貢獻。汪教授於2000獲選為美國工程院院士，及於2013年獲選為中國工程院外籍院士。



汪正平教授
項目統籌
香港中文大學工程學院院長
Prof. Ching-Ping Wong
Project Coordinator
Dean of Engineering,
The Chinese University of Hong Kong

Professor C.P. Wong is currently Dean of Engineering of The Chinese University of Hong Kong and Choh-ming Li Professor of Electronic Engineering. He received his BS degree from Purdue University, and MS and PhD degree from Pennsylvania State University. After doctoral study, he was awarded postdoctoral fellowship under Nobel Laureate Prof. Henry Taube at Stanford University. Prior to joining Georgia Tech, he was with AT&T Bell Laboratories for many years and became an AT&T Bell Laboratories Fellow (the highest technical award bestowed by AT&T Bell Labs) in 1992.

Published extensively over 1,000 technical papers and 12 books, he yielded fruitful research results and holds over 65 US patents. He made significant contributions to the industry by pioneering new materials, which fundamentally changed the semiconductor packaging technology. He is a Member of US National Academy of Engineering (elected in 2000), and Foreign Academician member of Chinese Academy of Engineering (elected in 2013).

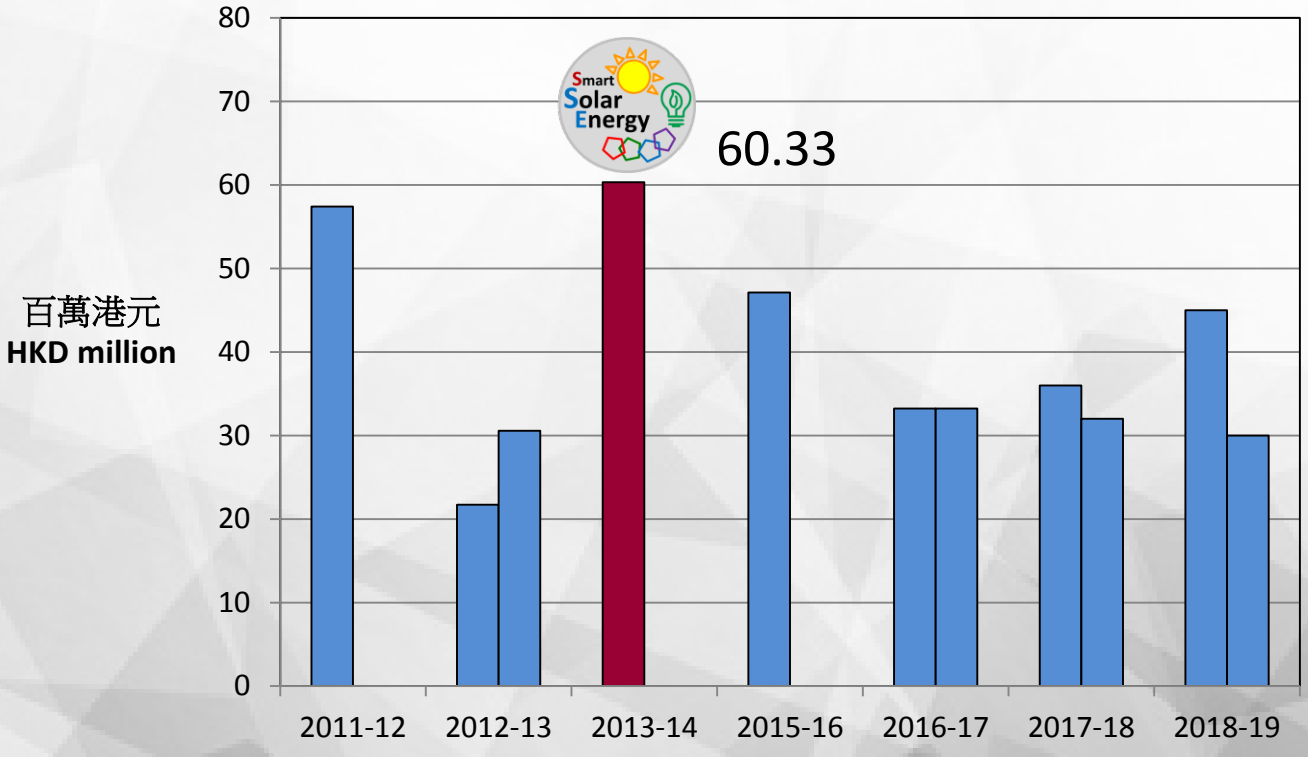
關於本項目 About the Project

關於主題研究計劃 About TRS

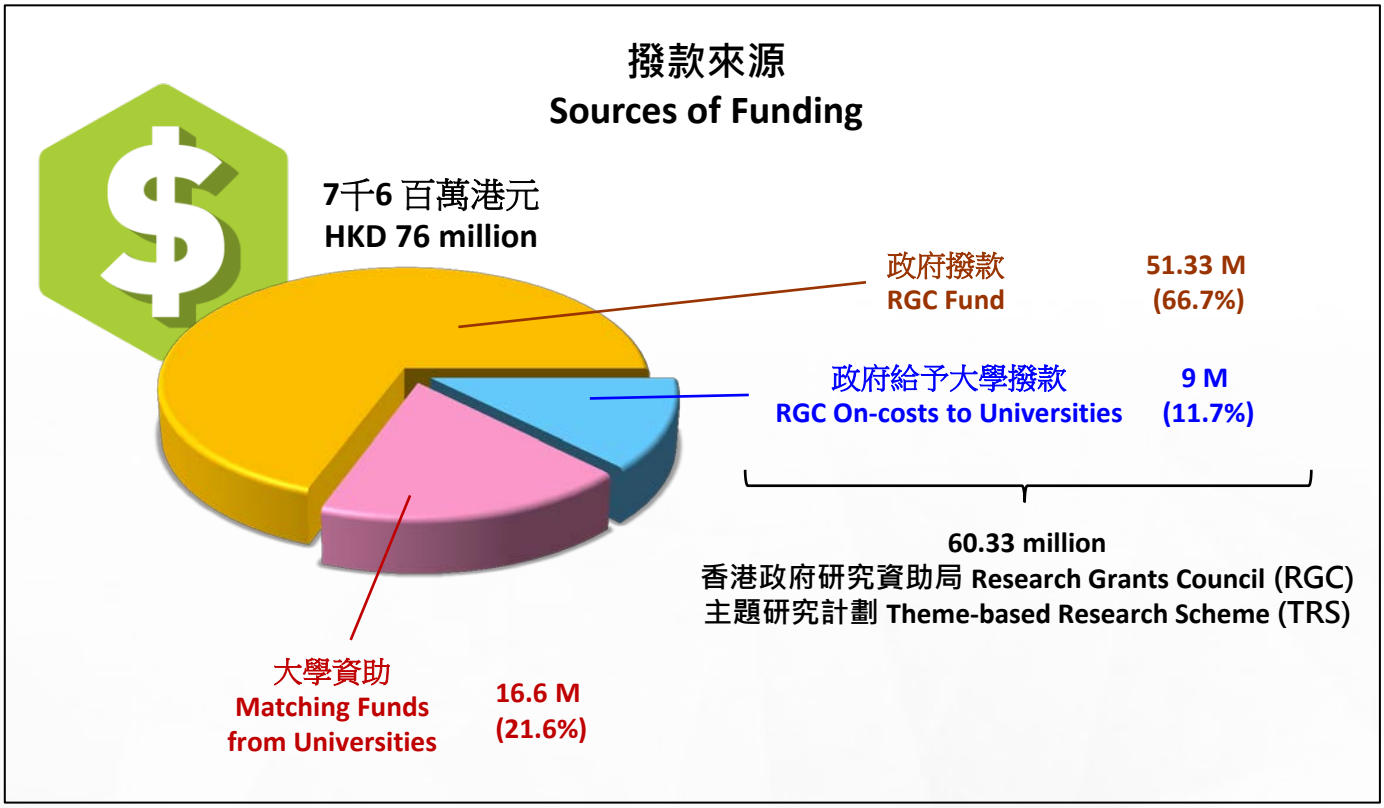
2011年，香港政府設立了「主題研究計劃」(Theme-based Research Scheme, TRS)，以支持本港八所資助院校進行較長期及策略上有利於香港發展的主題研究。「智能化太陽能技術：採集、存儲和應用」為其四大範疇之一「建設可持續發展的環境」中，至今獲撥款最高的項目。該項目涵蓋太陽光的有效採集、存儲及應用，有策略地全面提升太陽能發電的效能，促進電能的使用效率，克服推行再生能源的各種障礙，積極回應香港政府以至全球《巴黎協定》的減碳目標。本計劃旗下的各項研究已漸見成果，並獲刊登於國際頂尖的科技期刊，令香港在再生能源技術上領先全球。

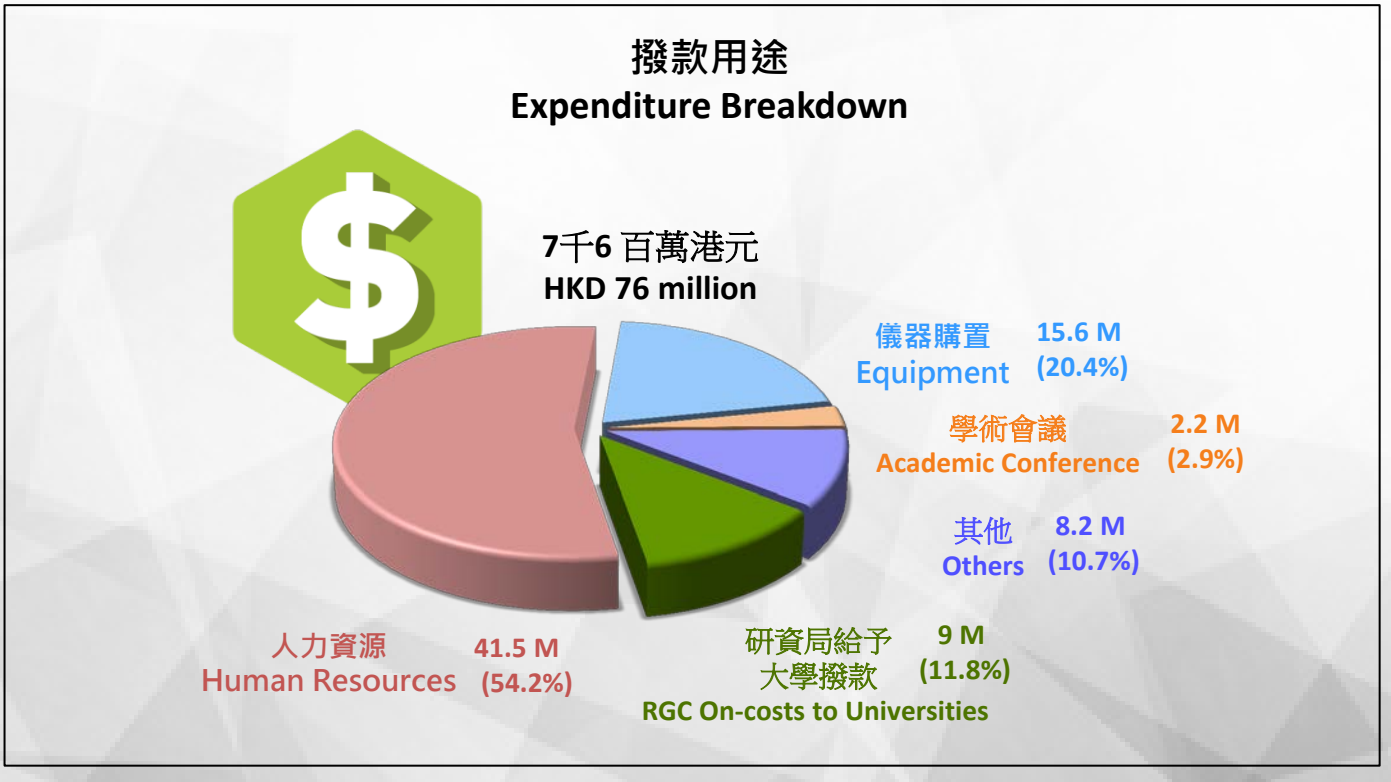
In 2011, the Hong Kong government established the Theme-based Research Scheme (TRS) to support research at the eight UGC-funded institutions which is more long-term and strategically beneficial to the development of Hong Kong. The Research Project "Smart Solar Energy Harvesting, Storage and Utilization" is the most highly funded under the grand challenge topic "Developing a Sustainable Environment". The project adopted a holistic approach, ranging from efficient harvesting of solar energy and storage to utilization. Its aim was to substantially boost the efficiency of solar energy generation, effectively elevate the utilization of electricity, and tackle various obstacles in renewable energy technology, thereby fostering the widespread commercialization of relevant technology. This collaborative research is in line with Hong Kong government policy as well as the "Paris Agreement". Various results from the project achieved remarkable world records and were published in various renowned international scientific journals papers , putting Hong Kong on the map.

主題研究計劃「建設可持續發展的環境」範疇歷年獲撥款項目 (2011年至今)
TRS Funding Results under the theme "Developing a Sustainable Environment" (2011 to Present)



項目撥款 Project Fund





由於四捨五入關係，個別項目的數字加起來可能與總數略有出入。
There may be a slight discrepancy between the sum of individual items and the total as shown owing to rounding.

背景 Background

項目時期 Project Period: 5 年 years (2014 – 18)

隨着人類對能源需求的快速增長以及使用傳統化石燃料所導致的全球氣候惡化，人類急需開發和利用潔淨可再生能源以代替化石燃料的使用。從太陽光獲取能源是一種非常有前景的方式來滿足這些需求，具體的實現途徑有光電轉換、光催化、人工光合作用和其他太陽能收集技術。

為了發展薄膜太陽能電池和組件以提升香港在太陽能技術方面的競爭力及市場滲透，是項研究計劃的設計十分整全，目標包括三方面：

- **採集**：提升太陽光採集技術的效能。
- **儲存**：研發高效能電力儲存系統。
- **應用**：研發高效能及安全的智能太陽能配電系統，以切合在不同運作模式下之各種用戶需求。

The fast-growing demand for energy and the recognition of man-made global climate change underscore the urgency of developing clean and renewable energy resources to replace fossil fuels. Harvesting energy directly from sunlight by photovoltaics (PV), photocatalysis, artificial photosynthesis, and other enabling technologies is a promising way to meet such requirements.

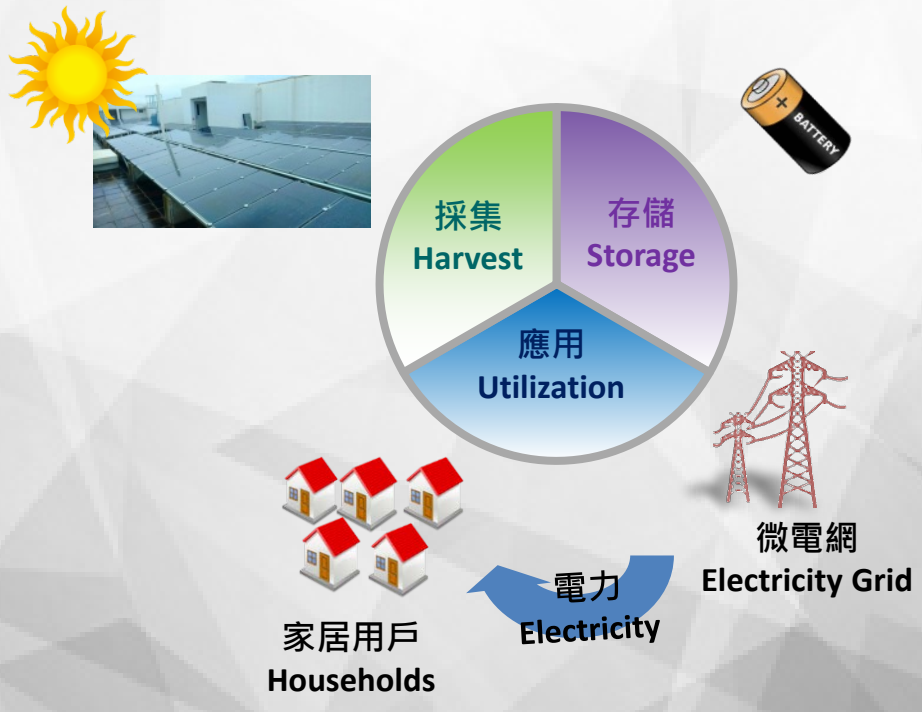
The project aims to strengthen the competitive edge of Hong Kong in solar energy technologies and their market penetration by combining the newly developed PV modules with the intelligent system integration. The holistic approach covers:

- **Harvesting:** The development of thin film PV devices and modules to enhance the performance of solar harvesting;
- **Storage:** The design of highly performed electricity storage;
- **Utilization:** To enhance the performance and security of solar smart grid systems to better meet the electricity demand under various operating modes.

我們的整全策略 Our Holistic Approach

系統效能 System efficiency =

f (採集Harvesting，存儲Storage，應用Utilization)



研究團隊 Project Team

科學委員會 Scientific Board

- 共包括六個子項目，各由一位資深教授領導
- 20 多位來自中大、香港理工大學、香港科技大學及香港大學跨學科、跨院校學者共同合作
- 項目自開始以來，已有超過 150 位研究人員及研究生參與

- Six sub-topics, each led by one senior professor
- More than 20 expert scholars from CUHK, HK PolyU, HKUST and HKU
- More than 150 research staff and students since project commenced in 2014.

採集 Harvesting

存儲 Storage

應用 Utilization

1 2 3 4 5 6

Smart Solar Energy

高性能真空沉積薄膜太陽能電池結構和組件
High Performance Vacuum Deposited Thin Film PV Cells and Modules

研究領導 Leader：肖旭東教授 Prof. Xudong Xiao
（中大物理系 Dept of Physics, CUHK）

太陽能電池和組件之溶液工藝製作
Solution Processed Excitonic Solar Cells

研究領導 Leader：許建斌教授 Prof. Jianbin Xu
（中大電子工程系
Dept of Electronic Engineering, CUHK）

新型光能採集之開發
Alternative Solar Technologies

研究領導 Leader：余濟美教授 Prof. Jimmy Yu
（中大化學系, Dept of Chem, CUHK）

能源儲存
Energy Storage

研究領導 Leader：汪正平教授 Prof. Ching-ping Wong
（中大工程學院院長，電子工程系
Dean of Engineering, Dept of Electronic Engineering, CUHK）

微電網監控、管理及全面保安
Microgrid Monitoring, Management, and Comprehensive Security

研究領導 Leader：陳名華教授 Prof. Minghua Chen
（中大信息工程學系 Dept of Information Engineering, CUHK）

太陽能電池組件及智能能源儲存之實驗室及實地應用
Laboratory and Field Demonstration of MGs with PV Modules and Smart Storage

研究領導 Leader：許昭教授 Prof. Zhao Xu
（香港理工大學，電機工程學系 Dept of Electrical Engineering, The Hong Kong Polytechnic University）

專家顧問團 Advisory Board

我們的專家顧問團由 17 位本地以至國際專家組成，他們來自智慧化新能源上學術界及業界不同界別，為本項目提供專業顧問意見。顧問團會議每兩年進行一次（2015 及 2017 年）。

Our Advisory Board consists of 17 experts from local and overseas academics and industry in smart solar energy to lead the macro-level direction of the project. Board meetings was held once per two years (2015 and 2017).

Prof. Zhong Lin WANG
Regents Professor, Materials Science & Engineering, Georgia Inst of Tech

Prof. Peidong YANG
Distinguished Professor of Energy, Chemistry, U of California, Berkeley

Dr Michael CHANG
Chairman, Amperex Technology Limited (ATL)

Prof. Jun-hao CHU
Professor/CAS Member, Shanghai Institute of Technical Physics, CAS

Dr Fuqiu ZHOU
Director, Energy System Analysis Center of Energy Research Institute, National Development and Reform Commission

Prof Qirong JIANG
Professor, Department of Electrical Engineering, Tsinghua University

Prof Yusheng XUE
Honorary President, SGEPRI (State Grid Electric Power Research Institute)

Dr. Henry SNAITH
Co-Director, Prog on Solar Energy: Organic Photovoltaics, U of Oxford

Mr. Siu Hung CHAN
Managing Director – China CLP Holdings Limited

Prof. Fanny M.C. CHEUNG
Pro-Vice-Chancellor (Research), CUHK

Prof. FUNG Tung
Asso Dir (Admin), Inst of Env, Energy and Sust, CUHK

Prof Joseph Hun Wei LEE
VP for Research & Grad Studies, Chair Professor of Civil & Env Erg, HKUST

Prof Norman C. TIEN
Dean of Engineering, HKU

Prof. Alexander Ping-kong WAI
Ir Professor & VP (Research Devt), PolyU

Prof. Henry NC WONG
Dean of Science, CUHK

Prof. Subodh MHAISALKAR
Professor & Executive Dir, Sch of Materials Sci & Engineering, Energy Research Inst, Nanyang Tech U

Prof. Hongjin FAN
Associate Professor
School of Physical & Mathematical Sciences, Nanyang Technological University

統計數字 Facts and Figures

「智能化太陽能技術：採集、存儲和應用」研究項目
The Research Project "Smart Solar Energy Harvesting, Storage and Utilization"

為香港政府「主題研究計劃」(Theme-based Research Scheme, TRS) 於 2011 年成立以來，四大範疇之一「建設可持續發展的環境」中，**至今獲撥款最高的項目**。
Is the **most highly funded project** under the grand challenge topic "Developing a Sustainable Environment" in the Hong Kong government Theme-based Research Scheme (TRS) since its establishment in 2011.

在太陽能科技研究上研發**七項全球最佳效能科技**，令香港在再生能源技術上領先全球。
Obtained **7 world-record performance technologies** achieved by the team, putting Hong Kong on the map.

項目自開始以來，已有**超過 150 位研究人員**參與。
More than **150 students and research staffs** trained / involved.

在多份國際期刊上發表了**超過 210 篇論文**。
More than **210 international journal papers** published.

已取得或正在申請**十項技術專利**。
10 patents obtained and / or application in progress.

獎項及嘉許 Awards and Recognitions

在本研究進行期間，研究團隊的出色研究成果獲得了多個專業機構的獎項及嘉許。
During the implementation of the project, the project team members have been obtaining awards from various professional bodies, as recognitions to their outstanding research accomplishments.

採集 Harvest

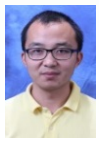
Prof. Jianbin XU
- IEEE Fellow on Nanotechnology, 2017
- Best Presentation Award at the China PV Technology International Conference (CPVTIC 2017), 31 Mar 2017, Xi'an, China.
- Cheung Kong Visiting Chair Professorship 2014 at Nanjing University, Ministry of Education, China.
- Outstanding Fellows (Faculty-level) Awards of CUHK, 2014

Prof. Ni ZHAO
- Best Poster Award, Perovskite Solar Cells session, *2015 MRS Spring Meeting*.

Prof. Jimmy YU
- Highly Cited Researcher 2016, Chemistry and Materials Science, *Web of Science*

Prof. Wei-Hsin LIAO
- Outstanding Fellows (Faculty-level) Awards of CUHK, 2014

Prof. Jianfang WANG
- Khwarizmi International Award (KIA) Laureate, 31st Session 2018



Prof. Keyou YAN
- 1,000 Youth Talents Program, 2018

儲存 Storage

Prof. Ching-ping WONG
- Choh-Ming Li Professor of Electronic Engineering 2013-17

Prof Yi-Chun LU
- CUHK Young Researcher Award 2016

應用 Utilization

Prof. Dah Ming CHIU
- The detailed analysis of current energy usage with CUHK Lee Woo Sing College led to the Silver Award in the *GREENPLUS Recognition Award 2014* of China Light Power (CLP) HK Ltd.

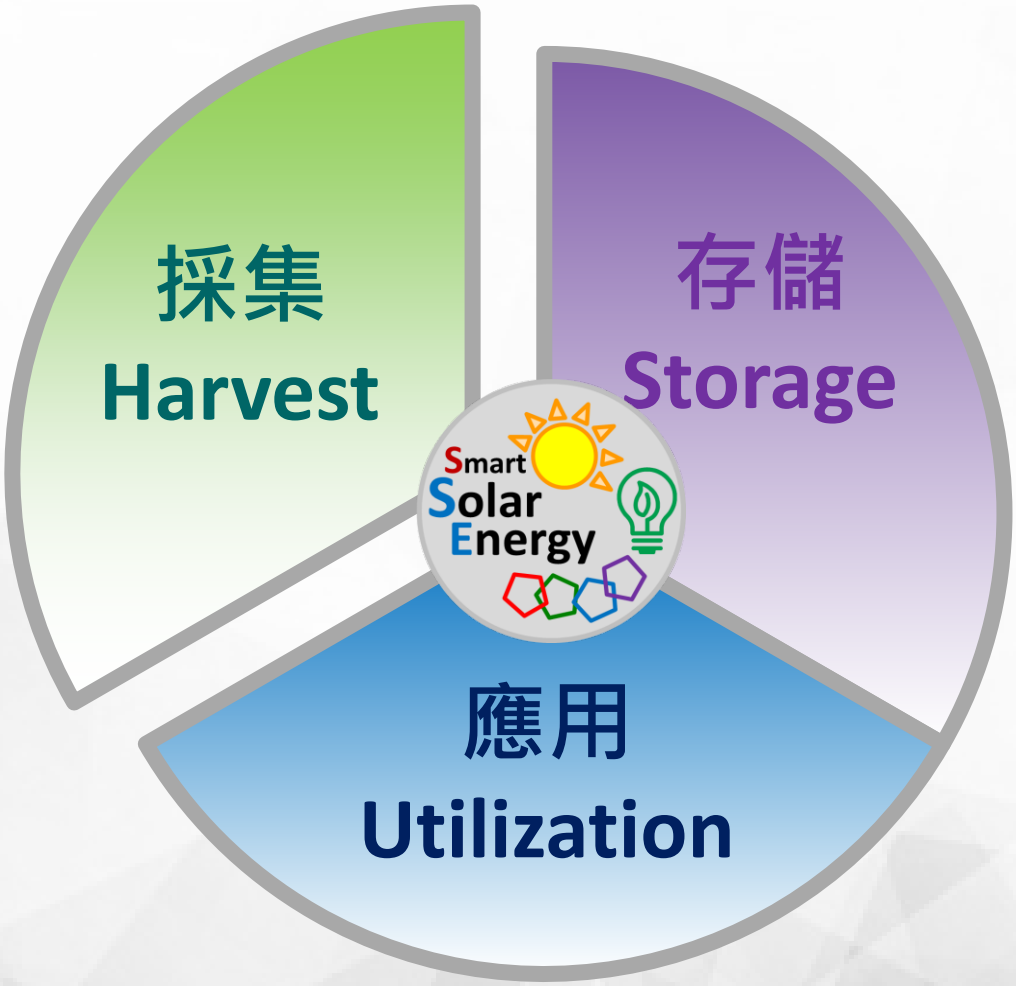
Prof. Zhao XU
- 2017年度高等學校科學研究優秀成果獎(科學技術) 一等獎
- Best Conference Paper, 2016 Power & Energy Society General Meeting, *IEEE Power and Energy Society General Meeting (PES)*, 2016.
- Best algorithms for solving the complicated optimal power flow problem in power system operation, *IEEE Power & Energy Society General Meeting,* 2014.

Prof. Minghua CHEN
- ACM Recognition of Service Award, 2017, for contribution to research community, in particular for serving as General Chair of *ACM e-Energy 2017*.
- Best Paper Award Candidate on *ACM e-Energy 2016* (3 in total).
- Best Paper Award Candidate on *ACM e-Energy 2016* (3 in total).
- CUHK Young Researcher Award, 2013

Prof. Jianwei HUANG
- IEEE Communications Society Distinguished Lecturer, 2015 – 2018
- Best Paper Award Finalist, *IEEE ICC 2017*.
- IEEE Communications Society Distinguished Lecturer, 2015-2016.
- Thomson Reuters Highly Cited Researcher in Computer Science, 2016.

Prof. Angela Yingjun ZHANG
- IEEE Communications Society Distinguished Lecturer 2018-19
- Fellow, Institution of Engineering and Technology (IET), 2016

我們的整全策略
Our Holistic Approach



子項目一：高性能真空沉積薄膜太陽能電池結構和組件
Subtopic 1: High Performance Vacuum Deposited Thin Film PV Cells and Modules

01. CIGS 太陽能電池的性能優化
Device Optimization of CIGS Solar Cells

香港中文大學物理系 Department of Physics, CUHK

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路新慧教授
Professor Xinhui Lu
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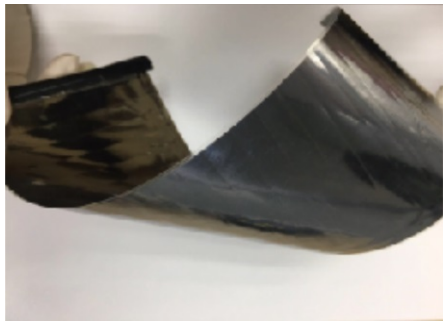
產品：柔性 CIGS 薄膜太陽能電池
Product: Flexible CIGS Thin Film Solar Panels

傳統的矽基太陽能電池容量大，對太陽光的轉換率可以達到20%，技術成熟，但是它的最大問題，是必須加工成堅硬的板塊狀電池板，這就限制了它的許多日常用途。柔性太陽能電池重量輕，而且可以折疊、捲曲，甚至黏貼在其它物體的表面，例如汽車玻璃，衣服等。團隊採用自行研發的技術，生產了柔性 CIGS（銅銦鎵硒）薄膜太陽能電池。

The traditional silicon-based solar cells is a mature technology. It has a good capacity and solar power conversion efficiency as high as 20%. However, its shortcoming is that it has to be mounded onto thick substrate modules, significantly limited its widespread applications. By contrast, the flexible kind of solar cells is light, foldable and bendable, and even can be struck onto the surface of different objects e.g. vehicle windows or clothes. The research team invented their own technology and developed their flexible CIGS (Copper Indium Gallium Selenium) thin film solar cells .



團隊研發的柔性 CIGS 薄膜太陽能電池。
Flexible CIGS Thin Film Solar panel developed by the team.

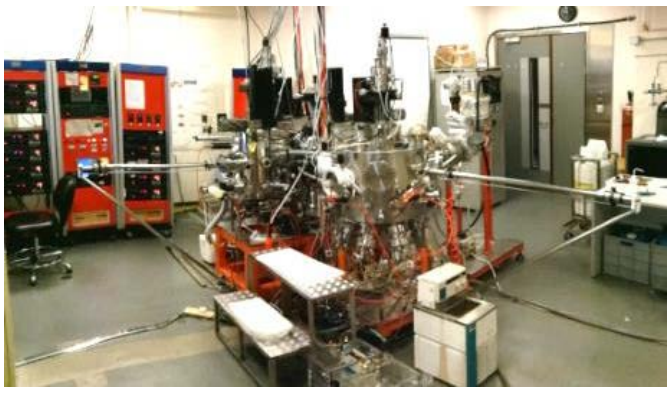
團隊設於香港中文大學物理系實驗室內之大型實驗儀器：CIGS Evaporation Chamber System (主題研究計劃資助了此儀器的部份零件，約六十萬港元)。

The large equipment CIGS Evaporation Chamber System established by the research team at Department of Physics in The Chinese University of Hong Kong (The TRS scheme sponsored around **HK$ 600,000** for some parts of this equipment).

CZTS 太陽能電池 CZTS Solar Cells

此外，團隊也正在研發另一種新型的 CZTS 太陽能電池。

In addition, the team is also doing research work on another new type of CZTS solar cells.



團隊的另一大型實驗設施：Multi-chamber Co-evaporation System for CZTS (主題研究計劃提供了約 150 萬港元資助).

Another large equipment “Multi-chamber co-evaporation system for CZTS” established by the team (The TRS scheme sponsored around **HK$ 1.5 million** for this equipment).

旭科新能源股份有限公司 Shinetech Co., Ltd.

2015年成立
註冊資本：
5,200 萬元人民幣
估計產能：每年 2 MW
地址：浙江嘉興秀洲高新區

Established in: 2015
Registered capital: RMB 52 million
Estimated capacity: 2MW/year
Location: Xiuzhou National High-tech Zone, Jiaxing, Zhejiang province, China

團隊發展的 CIGS 電池和組件科技，除了在香港中文大學組建了 CIGS 光伏系統，更於 2015 年在中國浙江省嘉興市秀洲區國家高新技術產業開發區成立了啟動公司**「旭科新能源股份有限公司」**，估計產能達每年 2 MW。公司現時擁有之以聚酰亞胺為基底的柔性 CIGS 薄膜太陽能電池生產線，是全中國第一、全球第二家，並擁有佔地 3,000 平方米的無塵室及 82 位員工（當中 20 位具碩博資歷）。此外，公司又獲得了嘉興市政府批准興建「省級企業研究院」及嘉興市「高新研究中心」。在 CIGS 太陽能電池研究上，團隊研發的科技取得了全球第三高的轉換效率。

The full-set technology of fabricating efficient CIGS cells and modules by the team leads to a high-efficiency CIGS PV system in CUHK, as well as a start-up company **"Shinetech Co Ltd"** in the Xiuzhou National High-tech Zone, Jiaxing, Zhejiang province of China since 2015, with estimated capacity 2MW/year. The company currently has the first in China, the second in world production line of flexible CIGS thin film solar panels based on polyimide substrate. The company currently has 3,000m² clean room, 82 employees (20 of them have Master of Science or PhD degrees), and has been approved to build "Provincial Enterprise Research Institute" of Zhejing province and "High-tech R&D Center" of Jiaxing. In the field of CIGS solar cells, the R&D team achieved the third conversion efficiency in the world.

公司員工 Company staff	82人 people
研發人員 Research staff	62
博士 PhD	12
碩士 Masters	8

關於公司創辦人：肖旭東教授
About Prof. Xudong Xiao, Company Founder

- 博士畢業於美國加利福尼亞大學柏克萊分校 PhD degree obtained from University of California, Berkeley, USA
- 現職香港中文大學物理系教授及旭科新能源股份有限公司董事長 Currently holds the positions of Professor, Department of Physics, The Chinese University of Hong Kong and Chairman of Shinetech Co., Ltd.
- 中國國家科學技術部「海外高層次人才引進計劃」（簡稱「千人計劃」）獲獎人 One of the awardees of the "Recruitment Program of Global Experts" (Known as the "Thousand Talents Plan"), Ministry of Science and Technology, China
- 中國國家重點基礎研究發展計畫（973計劃）首席科学家 Principle Scientist of "Major State Basic Research Development Program of China" (Known as "973 Program")
- 主領超過 40 項科研計劃，總撥款達人民幣 1 億元 Presided more than 40 scientific research projects (Funding over CNY 100 million)
- 於《*科學*》及其他國際知名學術期刊發表了超過150篇論文，被引用超過4,500 次，H 指數達35. More than 150 papers published in *Science* and other international well-known journals, cited more than 4,500 times; H factor 35.
- 申請了約 50 項技術專利，獲批達 47 項 Applied for about 50 patents, authorized 47.

可授權專利 Available Patents

Novel design of barrier layers for deposition of CIGS thin film solar cells on metallic substrates
(Patent: CN201410203029.X)

System and Method for Laser Scribing a Solar Panel and the Solar Panel
(Patents: US 15/455376 • CN 201710141357.5)

產品特長 Product Advantages

高效率 High efficiency (12 – 18%)

其他柔性產品的效率約為 8-11%. The efficiency of other company's flexible products is 8 – 11%.

輕便 Light weight

高功率：重量比（重量約為矽基太陽能電池的20分之一）
High power/weight ratio (> 0.2W/g)
(Weight is 1/20 of silicon solar cells)

可卷曲 Rollable and bendable

聚酰亞胺基底層厚度只有 0.05mm.
Polyimide substrates is as thin as 0.05mm.

穩定性極佳 Excellent stability

20年內的能量損耗只有10%. Decreased by 10% of the power in 20 years.

低損耗 Low loss

內部連接了高電壓、低電流的電池.
Battery internal series connected (high voltage, low current)

用途廣泛 Wide application range

外型時尚美觀，而且不受溫度影響。
Fashionable and with attractive appearance, excellent temperature resistance.

卷軸式薄膜太陽能充電寶
Rollable Thin Film Solar Power Bank

顏色 Color：

重量 Weight：218g

尺寸 Size：直徑 Diameter 30mm x 長 Length 190mm
輸出電壓 Output Voltage：5.0V
輸出電流 Output Current：2.0 A
電池容量 Battery Capacity：4,800 mAh

關於「秀洲高新區」
About the "Xiuzhou National High-tech Zone"

嘉興秀洲高新技術產業開發區（簡稱秀洲高新區）位於嘉興市西側，2006年被批准為省級開發區。2015年9月，國務院正式同意秀洲高新區升級為**國家高新技術產業開發區**。經過十多年的發展，秀洲高新區已成為嘉興市經濟轉型升級的重要基地。2017 年 8 月，首次參與國家高新區排名的秀洲高新區，綜合排名進入全國前二分之一佇列，排名居**全國所有新升級的國家高新區首位**。

The "Xiuzhou National High-tech Zone" (the Zone) is located at the west of the Jiaxing prefecture of Zhejiang province, China, which was approved to be a province-level development zone in 2006. In Sep 2015, the State Council approved the Zone to be upgraded to a **National High-tech Industrial Development Zone**. After the developing for more than 10 years, the Zone now becomes an important base for economic transformation and upgrade in Jiaxing. In Aug 2017, the Zone joined the National high-tech zone ranking in China for the first time, and its overall ranking entered the first half nationally, and is the **highest rank among all newly upgraded national high-tech zones**.

2017年12月19日，嘉興市政府五位嘉賓(嘉興市政協副主席柴永強、嘉興學院院長盛頌恩、秀洲區委書記吳炳芳、嘉興學院社會處長袁志明、秀洲國家高新區主任嚴加友) 蒞臨訪問肖教授設於中大的研究設施，並到訪香港科技園。
Five guests from the Jiaxing government visited R&D facilities of Prof. XD Xiao at CUHK as well as The Hong Kong Science Park on 19 Dec 2017.

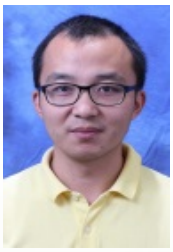
更多項目資訊
More information

子項目二：太陽能電池和組件之溶液工藝製作
Subtopic 2: Solution Processed Excitonic Solar Cells

02. 具良好穩定性及高結晶性大尺寸晶粒鈣鈦礦薄膜之研發
Highly Crystalline Large-grain Size Perovskite Thin Film Crystals with Good Stability

香港中文大學電子工程系 Department of Electronic Engineering, CUHK

許建斌教授
Professor Jianbin Xu
Email: jbxu@ee.cuhk.edu.hk



嚴克友教授
Professor Keyou Yan
Email: kyyan@ee.cuhk.edu.hk

針對問題 Problem to be Solved

鈣鈦礦太陽能電池（Perovskite Solar Cell，PSC）是國際前沿研究課題，於2013年更被《科學》期刊（*Science*）納入該年《十大科學突破》之列。可是，這種太陽能電池主要由一類相當不穩定的鈣鈦礦所製成，阻礙了它的商業化。

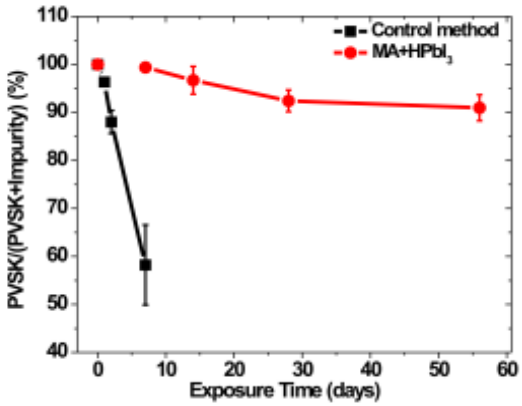
Perovskite solar cell (PSC) is one of the leading frontier research topics worldwide. In 2013, PSC was selected by the *Science* journal as one of the "Top 10 Breakthroughs of 2013". The raw material of this kind of solar cells is a particular kind of instable perovskite, which hampered its device fabrication for commercialization.

大幅度提高鈣鈦礦物料穩定性
Significant Improvement of Perovskite Stability

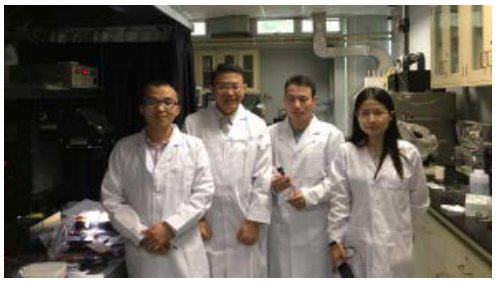
團隊成功優化有機無機雜合鈣鈦礦的合成路徑，研發出名為「非化學計量比的酸鹼反應」（NABR）之合成方法，有效提高了 $MAPbI_3$ 鈣鈦礦的穩定性。這項突破性的成果近日在國際知名學術期刊《自然通訊》（*Nature Communications*）發表。

他們系統化地研究了鈣鈦礦的形成、降解和恢復原理，並在此基礎上提出了NABR。用 NABR 所製成的鈣鈦礦薄膜，**在空氣濕度 65% 的環境下，能夠保持穩定兩個月，比以傳統方法製造的鈣鈦礦薄膜，只能保持約一星期大大提升。**這項研究結果，有望研發出高效率、低成本、高穩定的鈣鈦礦太陽能電池；團隊成員並希望未來此技術能應用於另一類鈣鈦礦太陽能電池。

The team successfully established a technique named "non-stoichiometric acid-base reaction (NABR)" to significantly improve the stability of $MAPbI_3$ perovskite thin films through reaction route optimization in organic and inorganic hybrid perovskite. The breakthrough has been published recently in the latest issue of the renowned journal *Nature Communications*.



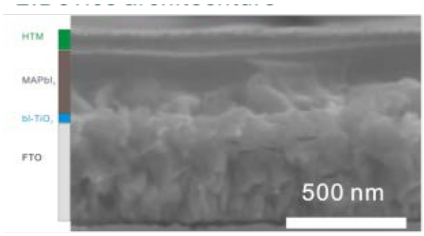
由NABR合成的$MAPbI_3$鈣鈦礦材料，材料穩定性由一星期大大提升至兩個月。
The stability of perovskite material prepared through the NABR methodology is significantly boosted from one week into two months.



（左起）中大電子工程學系研究團隊 - 嚴克友教授、許建斌教授、博士研究生張天愷及龍明珠。
(From left) Prof. Keyou Yan, Prof. Jian-Bin Xu, PhD students Tiankai Zhang and Mingzhu Long of the Department of Electronic Engineering, CUHK.

They systematically investigated the perovskite formation, degradation and recovery and proposed the NABR based on the mechanism investigation. Being an ion crystal, perovskite is subject to instability under environments of high air humidity. **The research team discovered that perovskite material prepared through their NABR methodology is stable for two months under a humidity of approximately 65%, whereas perovskites prepared by traditional methods degraded distinctly after one week.** The study sheds light on the development of highly efficient PSC with low cost and high stability, which is promising to be applied in the stability enhancement work of another type of perovskite.

$MAPbI_3$鈣鈦礦太陽能電池的材料結構。
Structure of the $MAPbI_3$ perovskites solar cell.



進一步提升晶粒結構及電池面積
Enhancement of Crystal Structure and Surface Area

另一方面，雖然目前小面積鈣鈦礦電池（1平方厘米或以下）達到不俗的光電轉換效率，它們如需達到市場應用要求，必須製作成大面積模組（10 x 10cm²或以上）才行。可是由於基板上導電膜的電阻較大，它們一旦做成大面積模組後，效率往往大為降低。針對此問題，**中大團隊亦設計出氣固反應過程和反應器，能夠製備出緻密的大面積鈣鈦礦薄膜（5 × 5 cm²）**，大大增加了鈣鈦礦電池的面積，向商業化生產所需要求大大邁進一步。同時，此種新的氣固生產技術不但快捷（數秒便可完成），而且能大規模生產出具良好穩定性的鈣鈦礦物料，進一步促進了產品的生產及商業化潛力。本研究成果已分別發表在 Wiley 旗下期刊《先進能源材料》（*Advanced Energy Materials*）及著名國際雜誌《納米能源》(*Nano Energy*) 上。

商業化潛力 Commercialization Potential

	以傳統方法生產的鈣鈦礦 PSC by Traditional Method	中大團隊研發 的鈣鈦礦 PSC by CUHK Team
電池面積 Cell Area	⊗ 小面積 Small（1 × 1 cm² 或以下 or less）	✓ 大面積 Large（5 × 5 cm²）
濕度及熱穩定性 Humidity and thermal Stability	⊗ 只能維持一星期 One week only	✓ 能維持兩個月 Two months
晶粒 Crystallinity	⊗ 晶粒較小、結晶性較低 Small crystals, low crystallinity	✓ 大尺寸晶粒、高結晶性 Large crystals, high crystallinity
製備過程 Process	⊗ 需使用抗溶劑 Involves anti-solvents ⊗ 製備較複雜 More complicated	✓ 免除了抗溶劑的使用 No anti-solvents ✓ 簡化了製備過程 Simplified process

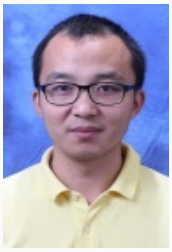
On the other hand, although small area PSC (1 x 1cm^2) achieved a modest power conversion efficiency (PCE) currently, fabricating into large area modules (10 x 10 cm^2 or more) is mandatory for market applications. However, owing to the limitation of substrate resistance , PCE is substantially lowered. Hence, the team designed a reactor process and device which are able to fabricate compact and large-area PSCs, significantly improved commercial requirements. In addition, this approach is fast (within a few seconds) and applies to mass production. The related results were published recently in *"Advanced Energy Materials"* of the Wiley series and the renowned international journal *"Nano Energy"*.

關於許建斌教授 About Prof. Jian-Bin Xu

許教授為納米技術和電子材料領域的資深專家，已發表的技術論文超過350篇。他積極參加各種專業活動，並曾擔任多個重要國際電子材料會議的主席。他是香港工程師學會(HKIE)會員，美國電機及電子工程師學會（IEEE）高級會員、香港材料研究學會秘書長和理事等。許教授現時是中大材料科學技術研究中心主任。他也是國家教育部長江學者講座教授及工程學國際權威組織電機及電子工程師學會（IEEE）2018年度院士 (納米科技)。

Professor Xu is a respected expert in nanotechnology and electronic materials. He has published over 350 technical papers, and actively taken part in a myriad of professional activities. He is a Fellow of the Hong Kong Institute of Engineers (HKIE), Senior Member of the Institute of Electrical and Electronics Engineers (IEEE), the Secretary and Council Member of the Hong Kong Materials Research Society. He is currently the Director of Materials Science and Technology Research Centre, CUHK. He is a recipient of several prestige awards including Chang Jiang Scholar Chair Professor by the Ministry of Education, China and Fellow on Nanotechnology of the prestigious Institute of Electrical and Electronics Engineers (IEEE), 2018.

關於嚴克友教授 About Prof. Keyou Yan



嚴教授具有材料物理化學跨學科背景，是材料化學領域的青年專家，他已發表了超過50篇期刊論文，其中多篇在國際化學頂級期刊如 *Journal of the American Chemistry Society* (JACS)、納米權威期刊如 *ACS Nano*，能源環境期刊如 *Energy & Environmental Science* 發表，文章被個人引用多達 2,000 餘次，其中 2015 年發表的兩篇關於鈣鈦礦太陽能電池的文章被 *Web of Science* 選為高引用論文。嚴教授為美國化學學會 (ACS) 會員，並擔任 JACS、*Nature Communications* 等權威期刊的審稿人。

Professor Yan has a multidisciplinary background in materials physics and chemistry as well as comprehensive expertise in material chemistry. He has published over 50 papers in top and authoritative journals including Journal of the American Chemistry Society (JACS), ACS Nano and Energy & Environmental Science and others, with more than 2,000 citations. Particularly, his two papers related to perovskite solar cells in 2015 were selected by Web of Science as highly-cited papers. Professor Yan is a Member of the American Chemistry Society (ACS), and also a regular reviewer of submissions to JACS and Nature Communication etc.

相關文獻 Related Papers:

- Mingzhu Long, Tiankai Zhang, Yang Chai, Chun-Fai Ng, Thomas C. W. Mak, Jianbin Xu & Keyou Yan. (2016). Nonstoichiometric acid-base reaction as reliable synthetic route to highly stable CH3NH3PbI3 perovskite film. *Nature Communications, 7*: 13503. [Link]
- Mingzhu Long*, Tiankai Zhang*, Wangying Xu, Xiaoliang Zeng, Fangyan Xie, Qiang Li, Zefeng Chen, Fengrui Zhou, Kam Sing Wong, Keyou* Yan & Jianbin Xu*. (2017). Large-grain formamidinium PbI3-xBrx for high-performance perovskite solar cells via intermediate halide exchange. *Advanced Energy Materials, 7*(12): 1601882. [Link]
- Mingzhu Long, Tiankai Zhang, Houyu Zhu, Guixia Li, Feng Wang, Wenyue Guo, Yang Chai, Wei Chen, Qiang Li, Kam Sing Wong, Jianbin Xu* & Keyou Yan*. (2017). Textured CH3NH3PbI3 thin film with enhanced stability for high performance perovskite solar cells. *Nano Energy, 33*: 485 - 96. [Link]

更多項目資訊 More information

03. 新型有機太陽能電池材料之設計及合成

Design and Synthesis of New Organic Photovoltaic (OPV) Materials

顏河教授 Professor Henry Yan
香港科技大學化學系
Dept of Chemistry, Hong Kong University of Science & Technology
Email: hyan@ust.hk

公司說明 Company Description

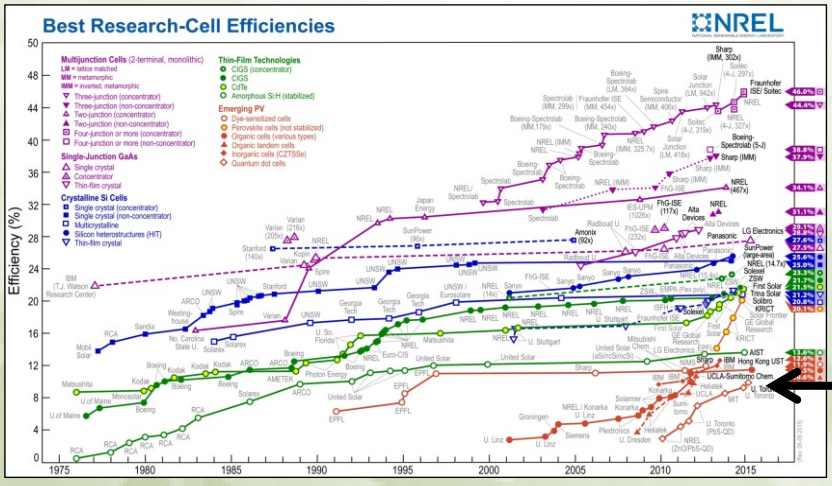
「**香港易柔光伏科技有限公司**」是一家位於香港的高科技能源企業，公司技術基於香港科技大學在有機光伏領域的重大突破，打破有機光伏能量轉換效率的世界記錄，並載入著名的 NREL 太陽能電池世界記錄表。公司致力於新型有機光伏的技術研發，產業化及市場銷售，持續提升有機光伏科技之性能，致力成為全球領先的有機薄膜發電太陽能裝備與光伏應用解決方案供應商。

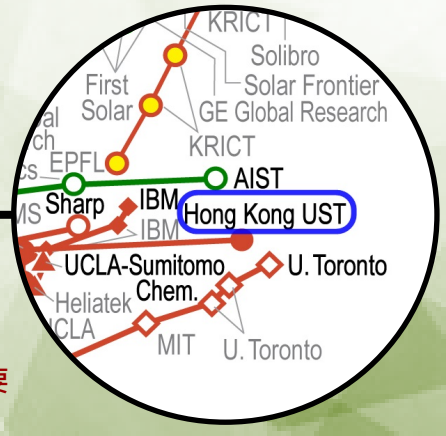
"***eFlexPV***" is an advanced energy technology enterprise based in Hong Kong. Their technology is based on a major breakthrough in organic photovoltaic (OPV) energy conversion world record, which was officially certified in the renowned NREL solar cell record. The company aspires to develop new type OPV technology, commercialization, sales and marketing, consistently elevating its performance, aiming at becoming the world-leading supplier of organic thin film PV devices and applications.

eflexPV

香港易柔光伏科技有限公司
https://eflexpv.com

聯繫電郵 Contact email:
info@eflexpv.com



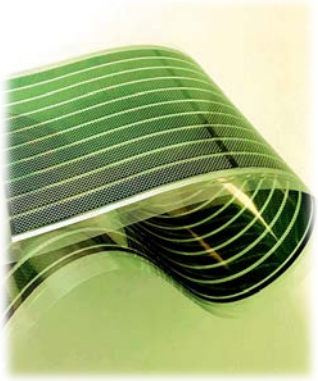


早於 2015年，**團隊已把單結有機太陽能電池 效能提升至世界最高的 11.5%，並獲美國能源部國家再生能源實驗室 (NREL) 正式確認為主要科技突破**，並刊登於 國際知名的「最佳效能研究電池圖表」上。

Earlier in 2015, the team achieved single-junction organic solar cells with a record efficiency of 11.5%, which has been officially certified. This achievement is noted as a major technological breakthrough in the renowned National Renewable Energy Laboratory (NREL) (US Dept of Energy) chart of "best research-cell efficiencies".
Reference: https://energy.gov/sites/prod/files/2016/04/f30/efficiency_chart_0.jpg

產品特色 Product Advantages

- ❑ 色彩美觀（可曲面安裝） Attractive appearance (Bendable)
- ❑ 顏色可訂制（綠/藍/灰） Customized colors (Green/blue/gray)
- ❑ 半透明（透明度可調節）
  Semi-transparent (Adjustable degree of transparency)
- ❑ 輕薄（重量為晶矽光伏1/50）
  Light weight (1/50 of regular silicon type)
- ❑ 柔性（可捲曲，可彎折） Flexible (Bendable, rollable)
- ❑ 安全（塑料薄膜） Safe (plastic thin film)
- ❑ 穩定可靠（壽命 15年以上）
  Reliable and stable (lifetime more than 15 years)



團隊研發的有機太陽能電池產品實物圖。
Organic PV product developed by the team.

安裝例子 Installation Examples

發電遮陽棚
OPV in curved cover

示意圖
Schematic Diagram

夾層有色發電玻璃
OPV installed in between colored glass layers

示意圖
Schematic Diagram

可選透明度 Customized degree of transparency*:

20%-40%

*透明度會影響發電效率，因而影響安裝面積和成本回收週期
Degree pf transparency would influence generation efficiency and in turn, installation area and length of pay-back period.

關於顏河教授 About Prof. Henry Yan

顏教授本科畢業於北京大學，2004年於西北大學獲得博士學位。2012年加入香港科技大學之前，曾於著名有機電子公司 Polyera 帶領科研團隊進行研究。過去兩年，顏教授於科大的團隊在有機太陽能電池上取得重要進展，有關研究於該領域處於領先地位。

Prof Yan graduated from Peking University and obtained his PhD at Northwestern University in 2004. Before joining HKUST in 2012, he led a research group at Polyera Corporation – a leading company in the organic electronics industry. During the past two years, Prof Yan's team has had major advances in emerging organic solar cells and is considered a leading group in the field.

更多項目資訊
More information

相關文獻 Related Paper:

- Yuhang Liu, Cheng Mu, Kui Jiang, Jingbo Zhao, Yunke Li, Lu Zhang, Zhengke Li, Joshua Yuk Lin Lai, Huawei Hu, Tingxuan Ma; Rongrong Hu, Demei Yu, Xuhui Huang, Ben Zhong Tang & He Yan*. (2015). A tetraphenylethylene core-based 3D structure small molecular acceptor enabling efficient non-fullerene organic solar cells. *Advanced Materials, 27*(6): 1015-20. [Link]

04. 基於柔性機構的卷對卷多層印刷系統的精密設計及控制

Precision Design and Control of a Flexure-based Multi-layer Roll-to-roll Printing System

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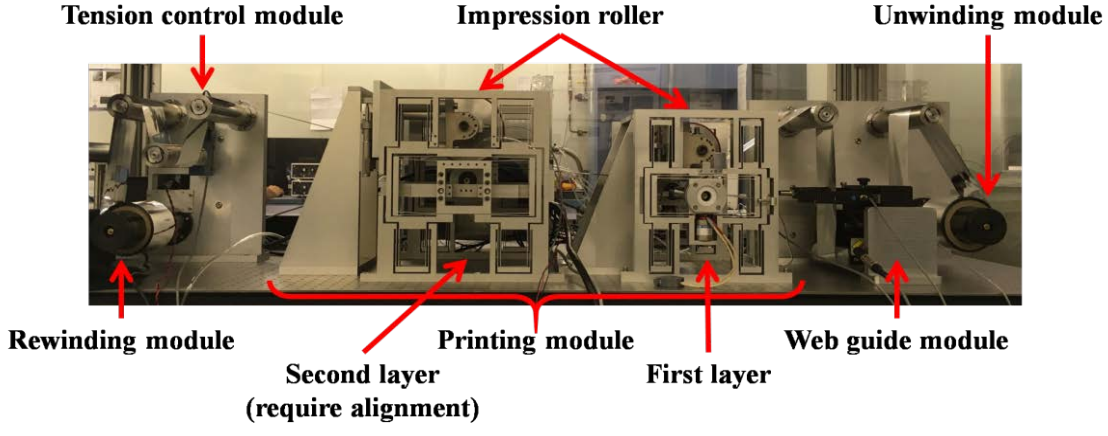
項目說明 Project Description

卷對卷（Roll-to-Roll, R2R）製造技術在許多產業中早已被廣泛應用，例如造紙業、紡織業或是鋼鐵業，其主要特性為連續式、大量生產等，具有簡單、綠色、低成本等優點，故一致被業界認為是未來製造的發展方向。

團隊開發了一個以微接觸印刷（MCP）技術為基礎的精密多層卷對卷印刷（R2R）系統，以低成本量化生產高解像度高對準精度的光電器件。微接觸印刷是一種軟光刻技術，實驗證實其印刷精度不受光學衍射極限的限制，可達到納米量級的解像度。目前微接觸印刷僅應用於學術研究，並未應用於實際生產。本項目將開發微接觸印刷的關鍵技術，並將自行研發的高精度微接觸多層卷對卷印刷系統用於量化生產以下兩種柔性光電器件:（1）有機場效應電晶體（2）基於超穎材料的太赫茲吸收體。為開發關鍵技術，團隊將設計並製造以柔性機構為主體，（1）具有納米量級準確度及多軸校準功能，及（2）亞微米量級多層對準精度的高精度滾筒印刷系統。柔性機構已被廣泛的應用於高精度光刻定位設備，此技術將大幅提高多層滾筒印刷系統的可重複性，精度和解像度，並可廣泛應用於製造低成本光電器件。

Roll-to-Roll (R2R) printing technology has been widely adopted in various industrial applications, e.g. paper, textile and steel industries. Its characteristics include continuous printing and high throughput, simplified process, environment-friendly and low cost, hence considered promising in future applications.

The team developed a scalable precision multi-layer roll-to-roll (R2R) printing system that achieves continuous printing on a 4” web with 100 nm print resolution. The R2R platform is compatible with various high precision contact printing techniques. For example, Microcontact Printing (MCP) technique has been implemented on the R2R system to fabricate nanoscale photonic devices and optical components, e.g., optical gratings. To demonstrate the practicality, this project will deliver R2R fabricated (1) optical gratings of various pitches, (2) organic field-effect transistors, and (3) terahertz metamaterial perfect absorber. To illustrate the capabilities of the

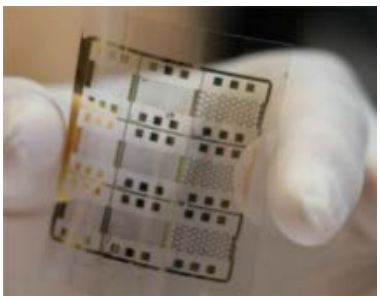


基於柔性機構的多層卷對卷印刷系統原型
Prototype of the flexure-based multi-layer R2R printing system

high- throughput high-resolution multi-layer R2R . The high printing precision of the R2R platform is realized via the application of compliant mechanisms which generate highly repeatable mechanical motion via the compliance of the material. In the R2R system, the print roller is supported by a four-axis flexure positioner; in combination with a cascade feed-forward controller, nanometer level positioning precision is achieved. Multi-layer submicron registration accuracy is achieved via a five-axis flexure positioner with novel optical alignment algorithms. The developed technology could be widely adapted to manufacture low cost photoelectronic devices.

針對問題 Problem to be solved

1：設計並構造一個多軸柔性機構導向的卷對卷印刷系統
2：開發基於柔性機構的多層卷對卷印刷系統
3：開發基於微接觸印刷的亞微米解像度樣本的生產工藝
4：設計和優化生產光柵和金屬網格的工藝參數
5：設計並實現亞微米精確度的多層對準方法
6：將微接觸印刷金屬網格應用於柔性有機光伏電池
1：Design and construct a multi-axis flexure guided R2R system
2：Develop a multi-layer flexure-based R2R printing system
3：Develop process to fabricate submicron resolution samples using MCP
4: Design and optimize fabrication parameters for printable optical gratings and metal grids
5: Design and implement a submicron accuracy multi-layer registration method
6: Incorporation of MCP metal grids into flexible organic photovoltaic cells

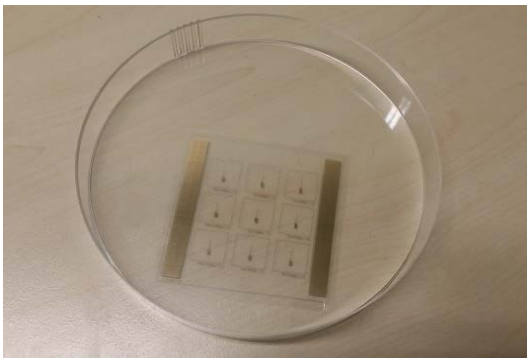


在柔性基底上卷對卷印刷金電極
R2R printed gold electrodes on flexible substrate (PET web)

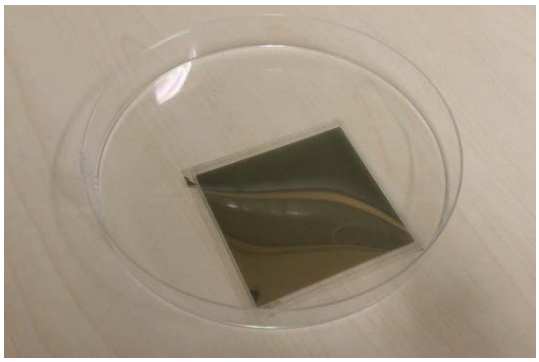
特點及優勢 Uniqueness and Competitive Advantages

團隊成功研發**全球精確度紀錄最高之卷對卷多印刷技術，準確度達 100 nm**，並具有以下特長：
1：高解像度及可重複性
2：高產量
3：多自由度誤差校正
4：實時接觸壓力監控
5：層與層之間的高對準精度

The team successfully developed a **world record technology in precision R2R printing, realizing continuous printing on 4" web with 100 nm resolution** with the following merits:
1: high resolution and repeatability
2: high throughput
3: multiple DOFs misalignment correction capability
4: real time contact pressure monitoring
5: Submicron layer-to-layer registration accuracy



(Left) First Layer of FET (Field-effect Transistor) Fabricated by Roll-to-roll Printing System (卷對卷印刷系統所製造之晶體管的第一層)；



(Right) Metal Grids Fabricated by Roll-to-roll Printing System (卷對卷印刷系統所製造的金屬網格)

Sample printed products: Flexure-based Precision Roll-to-roll Machine for Fabrication of Flexible Electronics

應用 Applications

此技術已獲兩項美國專利。同時，由於此技術的高精確度，它非常適合應用於製造精密細小及厚度超薄的可彎曲光電器件。如應用此技術，將令體積更細小及厚度超薄的可彎曲光電器件。如應用此技術，將令體積更細小及可穿戴式的各種器件設計變得可能，大大促進新型便携產品的發展生產。現時，技術已能印製 4 英吋寬度的產品，亦能升級至 1 – 2 米寬度。

其他應用包括：

1：衍射光柵
2：高解像度 ~85%透明的金屬網格
3：以金屬網格為電極的柔性有機光伏電池
4：有機薄膜場效應電晶體
5：光學超穎材料 如太赫茲吸收體
6：多層柔性印刷電路

This technology already obtained two US patents. Owing to its high precision, the technology is very suitable for manufacturing high-resolution and ultrathin flexible electronics and photoelectronic devices. By adopting this technology, the design of more tiny size and wearable devices would become possible, substantially fostering the manufacturing of portable products. Currently, the web width is 4 inch and it is able to be upgraded to 1 – 2 m.

Other applications include:

1: diffraction gratings
2: high resolution ~85% transparent metal grids
3: flexible organic photovoltaic cells that utilize the metal grids as electrodes
4: organic thin-film field-effect transistor
5: photonic metamaterial, e.g. terahertz perfect absorber
6: multi-layer flexible printed circuit

目標用戶 Target Users

柔性電子/光電子器件產品生產商

Manufacturers of flexible electronics/ photoelectronic devices

可授權專利
Available Patents

Precision design and control of a flexure-based roll-to-roll printing system
(Patent: **US**14/057,320)

Advantages

- High throughput, high resolution and repeatability
- Multiple degrees of freedom misalignment correction
- Real time contact pressure monitor
- High layer-to-layer overlay accuracy

Positive Microcontact Printing

土豆網短片介紹
Tudou Video

更多項目資訊
More information

相關文獻 Related Paper:

- Xi Zhou, Dien Wang, Ji Wang, and Shih-Chi Chen*. (2016). Precision design and control of a flexure-based roll-to-roll printing system. *Precision Engineering, 45*: 332 – 41. [Link]

子項目三：新型光能採集之開發
Subtopic 3: Alternative Solar Technologies

05. 研發微纖維紅磷從水中高效製造新型潔淨能源（氫氣）
Using micro-fibrous Red Phosphorus to Produce Clean Fuel (Hydrogen) from Water with High Efficiency

余濟美教授 Professor Jimmy Yu
香港中文大學化學系 Department of Chemistry, CUHK
Email: jimyu@cuhk.edu.hk

簡介Abstract

余濟美教授最近的研究發現，只要在水中加入一種「神秘成分」，一起暴露在陽光下，就能製造潔淨燃料。關鍵成分就是紅磷。在陽光下，紅磷可把水分解，產生氣泡狀的氫 —— 一種潔淨燃料。研究發現，一種特別類型的「微纖維紅磷」比其他種類的紅磷、甚至比其他光催化劑，能更有效從水中生產氫氣，同時成本也更低。

The research team of Prof. Jimmy Yu found a way to create clean fuel by simply exposing water (laced with a secret ingredient) to sunlight. The key ingredient is red phosphorus. Their research discovered that the hydrogen yield by a particular type of red phosphorus (micro-fibrous phosphorus) is much higher than that of other types, and is the highest among elemental photocatalysts at a much lower cost.

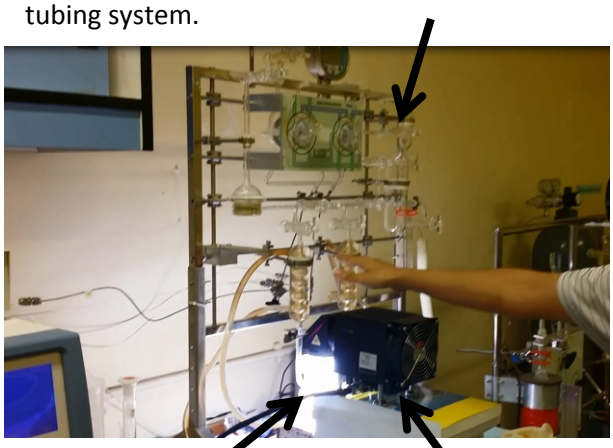
針對問題 Problem to be Solved

隨着人類對能源需求的快速增長以及使用傳統化石燃料所導致的全球氣候惡化，全球正為尋求潔淨能源而努力。光催化劑的運作，就如葉綠素之於植物，它吸收光的能源，產生化學反應並轉化為能源，過程就是一種人工的光合作用。可用作光催化劑的材料，沒有數千也有數百種，但大都是重金屬氧化合物，昂貴且製造過程複雜，常要用上稀有元素來提高效能。因此化學家一直尋求有相同功能的單一元素。紅磷蘊藏量豐富，取之不竭。它藏在地殼中，開採也容易。氫這種潔淨能源的容量很高，能比其他化學燃料產生更大能量。生產過程完結後，餘下的副產品只有水，並無有毒氣體。

The fast-growing demand for energy and the recognition of man-made global climate change underscore the urgency of developing clean and renewable energy resources to replace fossil fuels. A photocatalyst operates much as chlorophyll does in a plant, absorbing energy from light and causing a chemical reaction. The process of photocatalysis is simply a form of artificial photosynthesis. There are hundreds, if not thousands, of materials that can be used as photocatalysts. But most of them are heavy-metal oxide compounds that are expensive and complicated to produce. Very rare elements are often used to enhance their efficiency. So chemists have been searching for a single element that can perform the same function. Red phosphorous is abundant in the earth's crust and can be extracted fairly easily. At the same time, hydrogen has a high fuel capacity and creates more energy than other chemical fuels. The process of conversion leaves only water as a by-product, not toxic gas.

傳統光催化劑 Traditional Photocatalysts	微纖維紅磷 Micro-fibrous Red Phosphorus
× 大都是重金屬氧化合物 Most are heavy-metal oxide compounds × 昂貴且製造過程複雜 Expensive and complicated production process × 要用上稀有元素來提高效能 Need rare elements to enhance efficiency	✓地殼蘊藏量豐富，取之不竭，而且開採容易 Abundant in the earth's crust and can be extracted fairly easily ✓氫的能源容量很高，比其他化學燃料產生更大能量 High fuel capacity and creates more energy than other chemical fuels ✓生產過程完結後，餘下的副產品只有水，並無有毒氣體 The process of conversion leaves only water as a by-product, not toxic gas

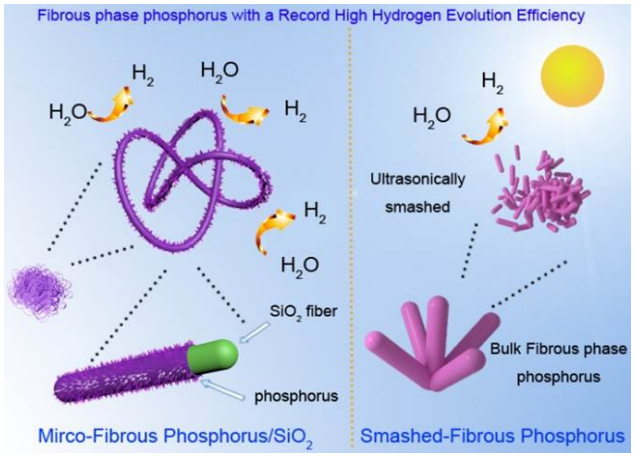
氫氣由玻璃管收集
Hydrogen gas produced is collected by glass tubing system.



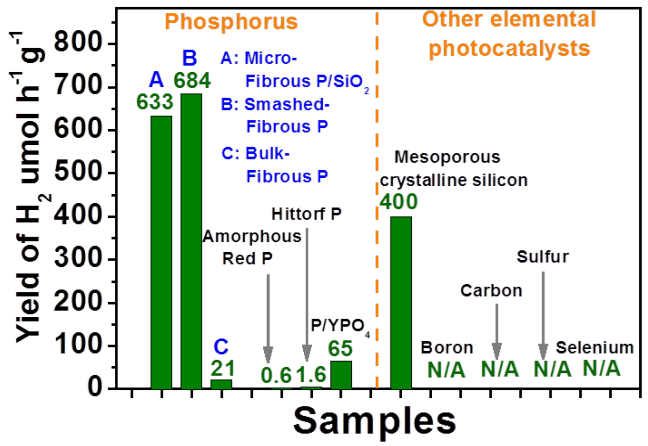
微纖維紅磷及水的混合物
Mixture of micro-fibrous red phosphorus and water

模擬太陽光之光源
Simulated solar light

團隊設計的實驗設備。
Experiment designed by the team.



以微纖維紅磷從水中製造新潔淨能源 (氫氣) 示意圖。
Diagram showing the production of hydrogen from water via micro-fibrous phosphorus/SiO_2.



微纖維紅磷比其他種類的紅磷、甚至比其他光催化劑，能更有效從水中生產氫氣。
The hydrogen yield by micro-fibrous phosphorus/SiO2 is much higher than that of other red phosphorus, and is the highest among elemental photocatalysts.

可授權專利
Available Patent

Photocatalytic Co-Ps-loaded Red Phosphorus for H2 Formation from Water
(Patent: **US**8,940,656)

Advantages

- Performance for CoP2 : 6 times > Platinum
- Price for CoP2 : 200 times < Platinum

關於余濟美教授 About Prof. Jimmy Yu

余教授是光催化研究領域中的領先專家。2016 年，他獲 *Web of Science* 選為化學及材料科學領域最高被引學者 (最高被引的定義是過去 11 年中，取得引用次數最高的 1%)。余教授發明的光催化淨水及空氣淨化系統技術均已在市場上應用。他擁有多項發明專利，並獲湯森路透 (Thomson Reuters) 譽為「2014 世界最具影響力科學家」之一。

Professor Yu is a leading scientist in the field of photocatalysis. He is selected by *Web of Science* as a most cited researcher in both chemistry and materials science in 2016 (Highly Cited Papers are defined as those that rank in the top 1% by citations for field during the previous 11 years in Web of Science.). Photocatalytic water treatment and air purification systems based on Prof. Yu's inventions have been commercialized. He holds several patents for his inventions, and was named as the "World's Most Influential Scientific Minds" in 2014 by Thomson Reuters.

Story / video featuring the invention in the "Brand Hong Kong" Series by the Hong Kong Government:
http://goo.gl/JS0zUh

土豆網短片介紹
Tudou Video:

更多項目資訊
More information:

相關文獻 Related Paper:

- Zhuofeng Hu, Luyan Yuan, Zhifeng Liu, Zhurui Shen,* & Jimmy C. Yu*. (2016). An elemental phosphorus photocatalyst with a record high hydrogen evolution efficiency. *Angewandte Chemie, 55*: 9580-5. [Link]

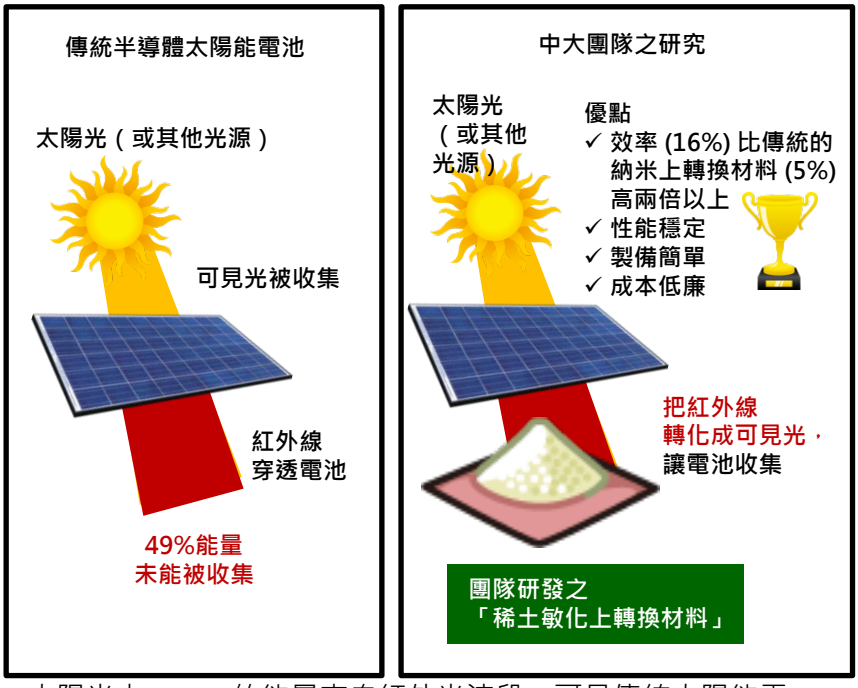
06. 上轉換及表面等離子體共振納米材料
Upconversion and Plasmonic Nanomaterials

王建方教授 Professor Jianfang Wang
香港中文大學物理系 Department of Physics, CUHK
Email: jfwang@phy.cuhk.edu.hk

針對問題 Problem to be Solved

太陽光中，49%的能量來自紅外光波段，但傳統半導體太陽能電池由於本身的禁帶寬度所限，絕大部分紅外光是無法被吸收並轉化為電能。在不改變太陽能電池材料本身的前提下，要有效利用紅外光是一個很艱鉅的挑戰。

49% of sunlight energy falls in infrared region. Due to the limitation of bandgap in semiconductor solar cells, majority of infrared energy was not absorbed and converted into electricity. Given no change to the materials of solar cells, efficient use of infrared energy is a challenging task.



太陽光中，49% 的能量來自紅外光波段，可是傳統太陽能電池來未能收集紅外光能量。研究團隊研發的新型稀土敏化轉換料，能夠把紅外光直接轉化為可見光，讓太陽能電池收集。它的能量轉換效率達 16%，比傳統的納米上轉換材料 (5%) 高兩倍以上。

特點及優勢 Uniqueness and Competitive Advantages

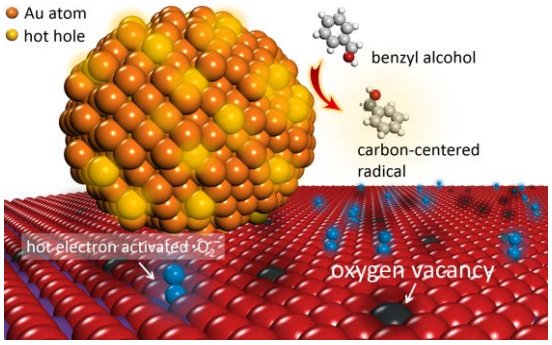
團隊研發了一種新型的稀土敏化轉換材料，能夠把紅外光直接轉化為可見光，能量轉換效率達到16%，相比傳統的納米上轉換材料效率提升一倍以上。這種材料性能穩定，製備簡單，成本低廉，並且成功將聚焦太陽光中的紅外光轉變成可見光。團隊也設計出了將太陽能電池和新材料相結合的模型。這項新科技還有很多潛在的商業應用價值，例如照明系統和顯示器等等。這項成果已發表於《*自然*》雜誌旗下子刊《*自然通訊*》上。

The research team invented an innovative lanthanide-sensitized oxide, reaching a maximal power upconversion efficiency of 16% for infrared light, which is at least double the efficiency of traditional nano-upconversion materials. This material is stable, with simple fabrication and low cost, and able to successfully convert infrared light into visible light. The team also designed solar cell models of this new material. The technology also has the commercialization potential of in lighting and computer monitors. This work has been published in *Nature Communications* in 2014.

在紅外光照射下，團隊研發的新型稀土敏化轉換材料能發出強烈的可見光。
Under the excitation of a near-infrared, the lanthanide-sensitized oxide powder developed by the team emitted strong visible light to the eye.

應用 Applications

應用於太陽能電池時，能把低於半導體禁帶寬度的光能轉化為高能量的光子。
Assist solar cells to convert subsemiconductor band-gap light energy into solar cell absorbable high energy photons.



等離激元產生的電荷載流子。激發局域表面等離激元產生熱電子和熱空穴，它們的協同作用驅動化學反應。
Plasmonically Generated Charge Carriers. The excitation of localized surface plasmon generates hot electrons and hot holes. The hot charge carriers interact synergistically to drive chemical transformations.

可授權專利
Available Patent

Converting infrared light into visible light using lanthanide-sensitized oxides
(Patent: US 14/279,128)

Advantages

- Conversion efficiency (infrared to visible light): >4% (max 0.1% for existing materials)

土豆網短片介紹
Tudou Video

更多項目資訊
More information

相關文獻 Related Paper:

- Junxin Wang*, Tian Ming*, Zhao Jin, Jianfang Wang, Ling-Dong Sun & Chun-Hua Yan. (2014). Photon energy upconversion through thermal radiation with the power efficiency reaching 16%. *Nature Communications, 5*: 5669. [Link]

07. 熱電發電機之研發
Development of Thermoelectric Generators (TEGs)

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簡介Abstract

熱電發電機 (TEG) 是運用熱電效應將熱（溫度差）直接轉換成電能的一種裝置。在生活中，有許多被廢棄的熱能，如：

- 工業熱能（如工業高 / 低階廢棄熱能）
- 交通工具排放熱能（如汽車尾氣）
- 環境熱（如太陽熱能 / 溫泉地熱）
- 其他熱能（如熱水管、住宅器具熱能）

如果能將這些熱能善加利用，即可成為再次使用的能源。

TEG 具有可靠性高、壽命長及環保等優點，而且，相比傳統的熱力發電機，它的體積小、可擴展，能在較小的溫差下生產電力。然而，它的效率不高，阻礙了它的應用發展。

Thermoelectric Generators (TEGs) are devices that can directly convert heat (temperature difference) into electricity. In our daily life, a lot of thermal energy is wasted, e.g.:

- Industrial heat (High / low quality waste heat)
- Transport vehicles (exhaust gas)
- Environmental heat (solar heat, hot spring)
- Others (hot water pipe, residential appliances)

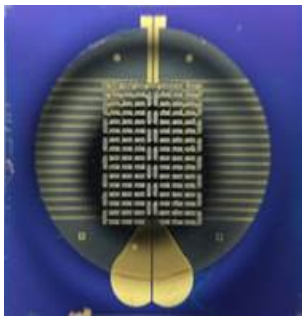
If these heat sources are harvested well, they can be utilized again. TEGs have many advantages including high reliability, long lifetime, and environmental friendliness. Especially, compared to conventional heat engines, TEGs are compact, scalable, and can be easily driven by small temperature differences. However, its low energy conversion efficiency hindered its widespread applications.

全球文獻記錄中功率密度最高
World record high power density

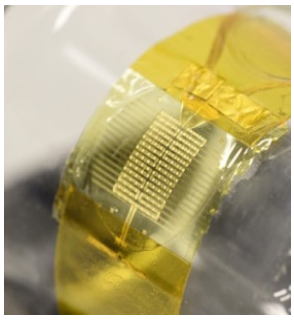
團隊結合了脈衝電鍍法及微細加工，在溫度差 52.5 K 之下製造出**功率密度高達 9.2 mW cm^{-2}** 的熱電發電機，是文獻紀錄中電鍍微型熱電發電機之中最高。

此外，柔性 TEG 更可應用在無線傳感器及微電子器件（如可穿戴醫學傳感器及智能手表）上，以收集人體之熱能來為設備供電。柔性可穿戴設備具有彈性，與皮膚貼合的更好，佩戴舒適度更佳。團隊目前正在致力於柔性TEG 的開發。該項技術目前正在申請一項美國專利。

The team developed thermoelectric generators (TEGs) by combining pulsed electroplating with microfabrication processes. It achieved a **power density as high as 9.2 mW cm^{-2}** at a temperature difference of 52.5 K, **which is the highest value reported so far** for the electroplated micro-TEGs in the literature (*J Microelectromechan. Syst. 25*: 744-9).



非柔性熱電發電機
Non-flexible TEG



柔性熱電發電機
Flexible TEG

Flexible TEGs could be used for thermal energy harvesting from the human body to power microelectronic devices (such as wearable medical sensors and wristwatches). They are very flexible, making them well adhered to the skin and comfortable for the users. The team is currently developing the flexible TEGs.

可授權專利
Available Patent

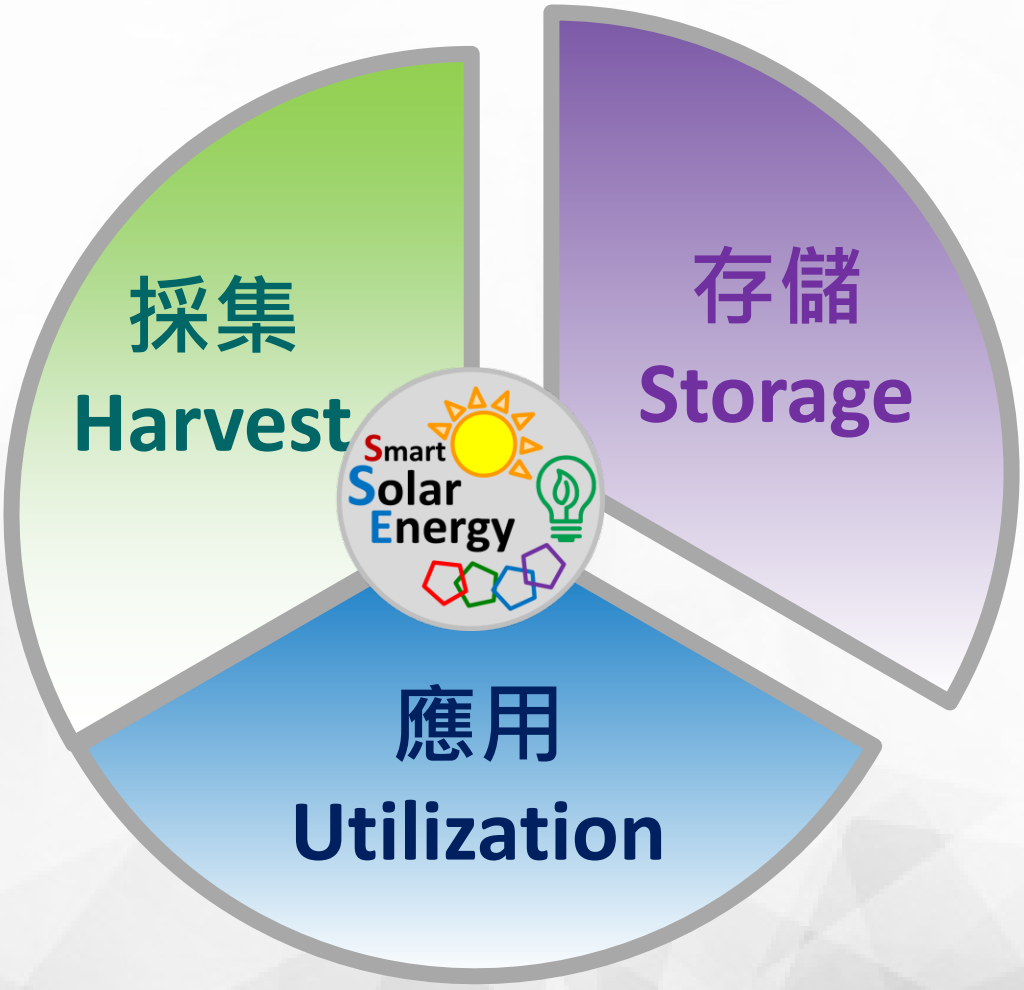
更多項目資訊
More information

相關文獻 Related Paper:

- Wenhua Zhang*, Juekuan Yang* & Dongyan Xu*. (2016). A high power density micro-thermoelectric generator fabricated by an integrated bottom-up approach. *Journal of Microelectromechan. Syst. 25*: 744-9 [Link]

Methods of fabrication of flexible micro-thermoelectric generators
(US Patent Application: US 2017/0345989)

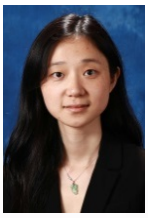
我們的整全策略
Our Holistic Approach



08. 三維多孔碳高效能超級電容器
3D Porous Carbon Foam-based Composites for High Performance Supercapacitors

香港中文大學電子工程系 Department of Electronic Engineering, CUHK

汪正平教授 Professor Ching-ping Wong
Email: cpwong@cuhk.edu.hk

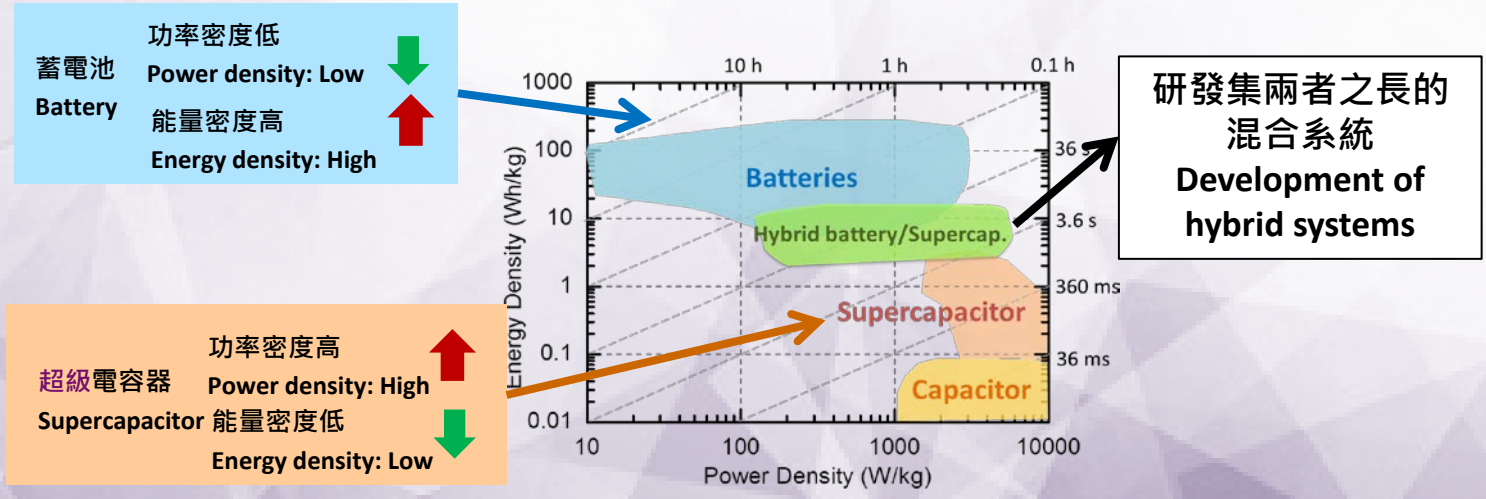


趙鈮教授 Professor Ni Zhao
Email: nzhao@ee.cuhk.edu.hk

項目說明 Project Description

一般來說，超級電容器的功率密度高但能量密度低，而蓄電池則反之。為了提高超級電容器的能量密度，發展多孔碳材料以及贗電容型材料更為適合。因為多孔碳材料（特別是石墨烯）可以增加電極的比表面積和導電性，而贗電容型材料通過表面的氧化還原反應可以儲存更多的電量和能量。

In general, supercapacitors show high power density, but suffer from low energy density; while batteries exhibit high energy density but low power density. To increase the energy density of a supercapacitor, it is desirable to use porous carbon materials and highly pseudocapacitive materials, as porous carbon materials (especially porous graphene) can increase the specific surface area and electrical conductivity, while the surface redox reaction occurred in the pseudocapacitive materials can store more energy.



全球文獻記錄中最高效能的非對稱性超級電容器 The highest reported performance asymmetric supercapacitors

團隊證實了一種低溫的化學沉積法製備高品質的三維彎曲石墨烯材料，並應用於超級電容器，可以實現高能源密度（40.9 W h kg-1）和高功率密度（70 kW kg-1)，以及長期的使用穩定性。該研究結果發表在 *Nano Energy* 2015, 13, 458。

The research group demonstrated a low-temperature chemical vapor deposition method to grow high-quality three-dimensional (3D) curved graphene, which can be used as the supercapacitor electrode to deliver high energy density (40.9 Wh kg^{-1}) and power density (70 kW kg^{-1}) as well as long-term stability. (See *Nano Energy* **2015**, 13, 458.)

1. 多孔碳材料 → 增加電極的比表面積和導電性
   - ✓ 高能量密度（40.9 Wh kg^{-1}）
   - ✓ 高功率密度（70 kW kg^{-1})
   - ✓ 長期使用穩定性

2. 贗電容型材料 → 表面的氧化還原反應
   - ✓ 儲存更多的電量和能量
   - ✓ 高能量密度 (98.0 Wh kg^{-1})
   - ✓ 高功率密度 (22.9 kW kg^{-1})

另外該研究團隊還開發了一種可以自支撐的三維多級孔泡沫碳電極，其合成方法溫和，可擴展並成本划算。該多級孔結構可以組裝大量的大孔和微孔，為離子的傳播提供了充分的空間，同時也提供了大量的表面積來儲存能量。此泡沫碳可以用來作為贗電容型材料（例如金屬氧化物或者硫化物）的力學支撐及生長點，可以表現出更為優異的電化學性能，主要表現為高的能量密度和高功率密度，分別為93.9 Wh kg-1和21.1 kW kg-1，此數值可媲美報導過的最高的非對稱性超級電容器的性能。該研究結果發表在Nano Energy 2016, 25, 193。

Another hierarchically carbon-based free-standing 3D electrode was fabricated via a facile, scalable, and cost-effective route. The hierarchically porous structure integrates a lot of macropores and micropores, thus providing sufficient space for ion transport while offering a large amount of surface sites for energy storage. In addition, the carbon foam can be used as a mechanical support for pseudocapacitive materials (metal oxides or sulfides), showing even better electrochemical performance with a high energy density of 93.9 Wh kg^{-1} and a high power density of 21.1 kW kg^{-1}, among the highest reported values for asymmetric supercapacitors. (*Nano Energy* **2016**, 25, 193.)

3. 自支撐的三維多級孔泡沫碳電極

➢可以組裝大量的大孔和微孔，為離子的傳播提供了充分的空間，同時也提供了大量的表面積來儲存能量
➢可以用來作為贗電容型材料（例如金屬氧化物或者硫化物）的力學支撐及生長點，可以表現出更為優異的電化學性能

- ✓ 合成方法溫和
- ✓ 可擴展
- ✓ 成本划算
- ✓ 高能量密度 (93.9 Wh kg^{-1})
- ✓ 高功率密度 (21.1 kW kg^{-1})

相關文獻 Related Papers:

- Jizhang Chen, Junling Xu, Shuang Zhou, Ni Zhao* & Ching-Ping Wong*. (2015) Template-grown graphene/porous Fe2O3 nanocomposite: A high-performance anode material for pseudocapacitors. *Nano Energy, 15*: 719–728 [Link]
- Jizhang Chen, Junling Xu, Shuang Zhou, Ni Zhao* & Ching-ping Wong*. (2016). Nitrogen-doped hierarchically porous carbon foam: A free-standing electrode and mechanical support for high-performance supercapacitors. *Nano Energy, 25*: 193-202. [Link]

潛在應用領域 Potential Applications

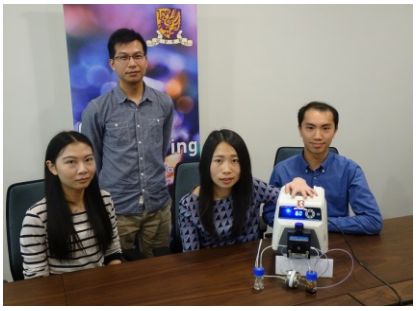
- **電動汽車**
  Electric vehicles
- **備用電源**
  Backup power
- **柔性電子器件**
  Flexible electronic devices

更多項目資訊
More information

09. 高能量密度而價格低廉的鋅 - 碘溴液流電池

High-energy-density and Low-cost Zinc/iodine-bromide Redox Flow Battery (ZIBB)

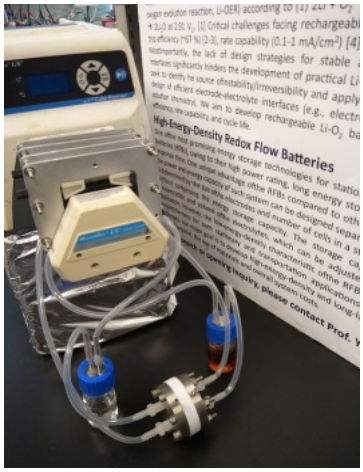
盧怡君教授 Professor Yi-Chun Lu
香港中文大學 機械與自動化工程系
Department of Mechanical and Automation Engineering, CUHK
Email: yichunlu@mae.cuhk.edu.hk



（左起）中大機械與自動化工程學系博士研究生李喆珺小姐、副研究員翁國明博士、盧怡君教授，以及研究助理譚朗彥先生。
Members of the research team from CUHK Department of Mechanical and Automation Engineering, CUHK. (From left) Ms. Zhejun Li, PhD student; Dr. Guo-Ming Weng, Research Associate; Prof. Yi-Chun Lu, and Mr. Simon Long-yin Tam, Research Assistant.

項目說明 Project Description

在本港，為電動車補給的公共充電車位數量遠遠趕不上車輛增幅。如能提高電動車電池的儲能容量，充電站的負荷將大大降低。科學家已不斷在儲能技術，尤其是電化學研究方向尋求突破。
In Hong Kong, the number of charging stations lags far behind the growth of electric vehicles they are supposed to serve. Increasing the energy capacity in electric car batteries would considerably relieve the burden for charging stations. Scientists have been making efforts in advancing the energy storage technology, especially on the electrochemical front.
香港中文大學（中大）機械與自動化工程學系助理教授盧怡君教授及其科研團隊最近研發了一種高能量新型鋅-碘溴液流電池，刷新了目前水系液流電池能量密度的紀錄 (101 Wh L^{-1})。這項突破性的成果近日在國際知名學術期刊《能源及環境科學》（Energy & Environmental Science）發表，並獲英國皇家化學會旗下雜誌《化學世界》（Chemistry World）重點報導。
A high-energy-density zinc/iodine-bromide redox flow battery (ZIBB) has been developed by **Prof. Yi-Chun Lu**, of the Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong and her research team. ZIBB achieved the highest reported energy density for aqueous redox flow batteries to-date (101 Wh L^{-1}). The breakthrough was published in the renowned journal *Energy & Environmental Science* in early 2017, and was recently featured by the magazine *Chemistry World*, published by The Royal Society of Chemistry, United Kingdom.

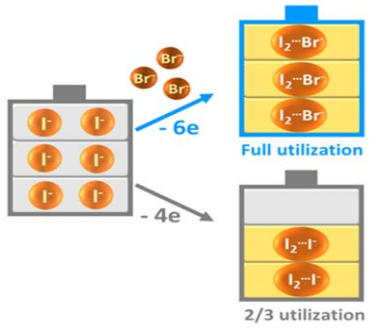


鋅-碘溴液流電池設計原型的外觀。
The zinc/iodine-bromide redox flow battery prototype.

溴離子(Br-)的秘密：體積更小，容量更大
The Secret of Bromide Ions (Br-): Less Volume yet More Capacity

鋅-碘液流電池以高溶解度的碘化鋅為主要的活性電解液原料，碘離子(I-)和鋅(Zn)分別為正極與負極的電化學活性物質。在傳統的設計中，電池的高循環壽命得以穩定維持（經五十圈充放電循環後，電池容量保持率高達95%），是由於在充電的電化學反應中，有三分之一的碘離子(I-)充當了碘二離子(I2)的穩定劑，與之結合成為碘三負離子(I3-)。然而，這些充當穩定劑而失去自由的碘離子(I-)在提升電池容量方面的功能被白白浪費。
新研發的鋅-碘溴液流電池破天荒在碘溶液中添加溴離子(Br-)來充當碘離子(I-)的「替身」。溴離子(Br-)與碘二離子(I2)結合成為碘溴離子(I2Br-)，同樣可發揮穩定循環性的作用，而被釋放的碘離子(I-)則可增加電池容量。

In zinc/iodine RFB, highly soluble zine iodide is the major active material in the electrolyte, with iodide ions (I-) and zinc (Zn) being the electrochemical active ingredients at the positive and negative electrodes, respectively. In the traditional design, the high and stable cycle life (efficiency as high as 95% over 50 cycles) of the battery was ensured by allowing one-third of the iodide ions (I-) acting as a complexing agent to stabilize the iodine (I2), forming triiodide ions (I3-). However, the power of the iodide ions (I-) in contributing to battery capacity is wasted as they are 'trapped' as a stabilizing agent. The team therefore introduced bromide ions as a replacement for the 'trapped' iodide ions (I-), i.e., forming iodine bromide ions (I2Br-) by reacting bromide ions (Br-) with iodine (I2). The process still allows for a stable cycle life in the battery, without sacrificing energy capacity.



在充電過程中，溴離子(Br-)取代碘三負離子中的碘離子(I-)形成碘溴離子，從而釋放了該部分碘離子以增加儲能容量。During the charging process, bromide (Br-) replaces iodide as the complexing agent to form iodine bromide ions, releasing the iodide (I-) to contribute energy capacity.

可授權專利
Available Patent

High-Energy-Density and Low-Cost Flow Electrochemical Devices
(Patent: US15/371,466 • CT/CN2016/109055 • CN201680002631.4)

Features

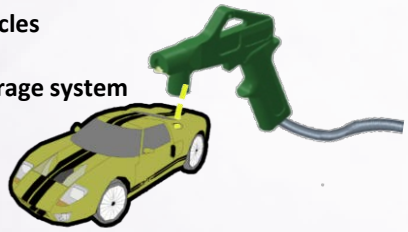
- Higher energy density compared to current redox flow batteries of any given electrode active materials
- No compromised electrical conductivity as compared to the semi-solid approach
- No phase-separation issues
- ↓ usage of ion-permeable membrane
- ↓ costs for suspension optimization & expensive membrane

相關文獻 Related Paper:

- Guo-Ming Weng, Zhejun Li, Guangtao Cong, Yucun Zhou & Yi-Chun Lu*. (2017). Unlocking the capacity of iodide for high-energy-density zinc/polyiodide and lithium/polyiodide redox flow batteries. *Energy & Environmental Science, 10*(3): 735 - 41 [Link]

潛在應用領域 Potential applications

- **電動汽車 Electric vehicles**
- **大型儲能系統 Large-scale energy storage system**



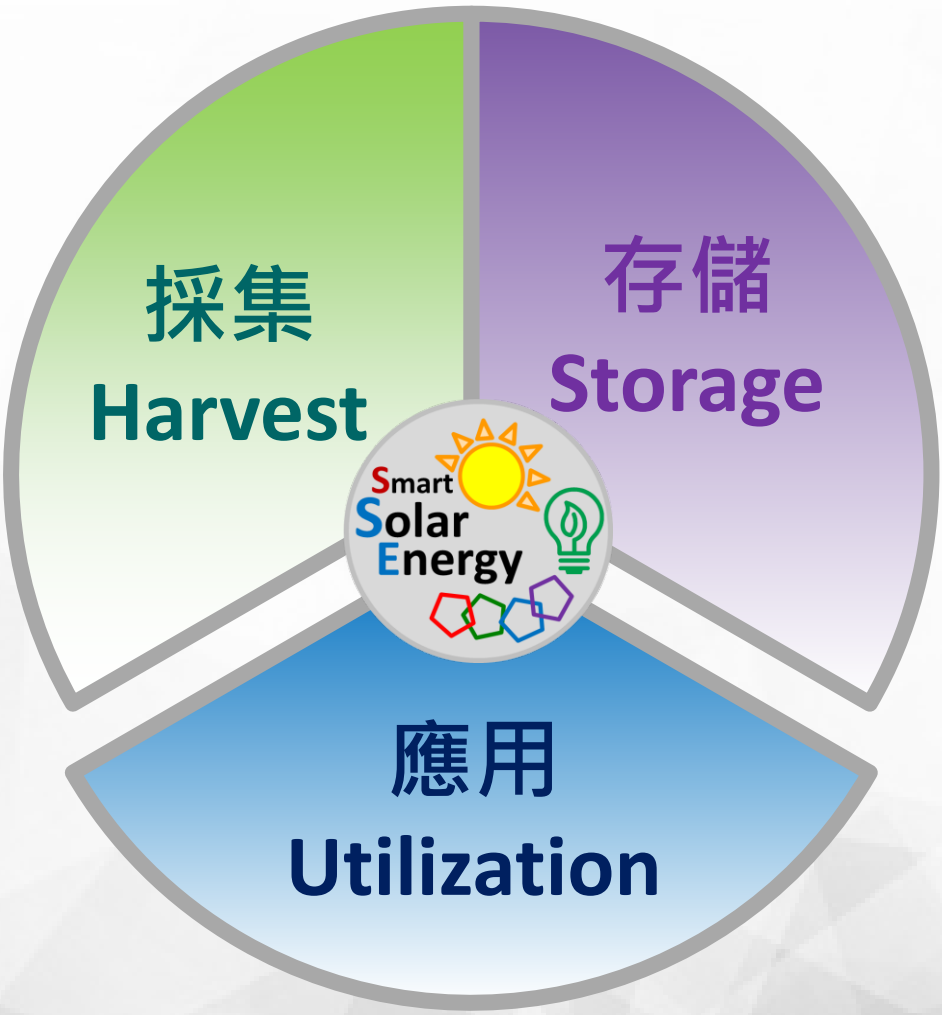
關於盧怡君教授 About Prof. Yi-Chun Lu

盧教授2007年於台灣國立清華大學取得材料工程學系本科學位，並於2012年在美國麻省理工學院材料科學及工程學系取得博士學位。自2013年起，受聘於美國麻省理工學院為附屬研究員。盧教授現為中大機械與自動化工程學系助理教授。盧教授曾獲得多個中大及國際研究及教學獎項，包括中大博文教學獎 (2016)、校長模範教學獎及院長模範教學獎 (2014) 、香港研究資助局傑出青年學者 (2014)，美國麻省理工學院 Martin Family Society of Fellows for Sustainability (2009) 及台灣國家科學委員會傑出研究創新獎等。

Prof. Yi-Chun Lu received her B.S. degree in Materials Science & Engineering from the National Tsing Hua University, Taiwan, in 2007. She received her Ph.D. degree in Materials Science & Engineering from the Massachusetts Institute of Technology (MIT), Cambridge, USA in 2012. Professor Lu has been appointed as a research affiliate of MIT since 2013. She is currently an Assistant Professor in the Department of Mechanical and Automation Engineering at CUHK. Professor Lu has been conferred various CUHK and international research and teaching awards, including the University Education Award, CUHK (2016), the Vice-Chancellor's Exemplary Teaching Award, CUHK (2014), the Early Career Award, Research Grant Council, Hong Kong SAR (2014), Massachusetts Institute of Technology Martin Family Society of Fellows for Sustainability (2009) and the Taiwan National Science Council Outstanding Research Innovation Award (2007).

更多項目資訊
More information

我們的整全策略
Our Holistic Approach



子項目五：微電網監控、管理及全面保安
Subtopic 5: Microgrid Monitoring, Management, and Comprehensive Security

10. 微電網發電調度的在線算法
Online Energy Generation Scheduling for Microgrids

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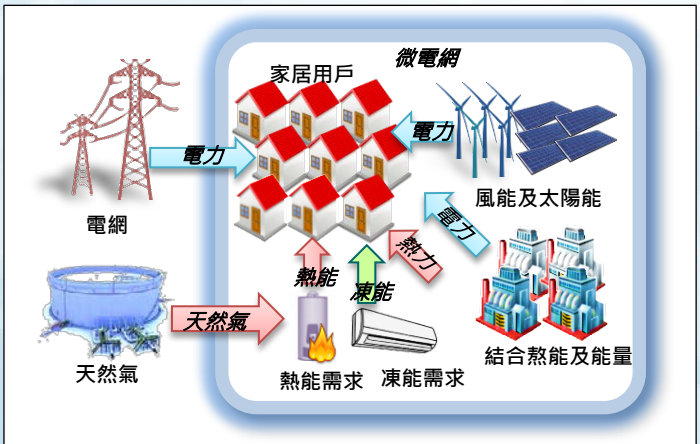
針對問題 Problem to be Solved

微電網 (Microgrid) 是一個小型的發電及配電系統，一座大樓、一家醫院，以至一個小區都可以建構一個屬於自己的微電網 (圖一)。 此系統可同時採用太陽光等再生能源及小型燃氣發電機來提供電力，可以並網或離網運行。微電網能有效提升電力系統穩定性、能源轉換效率、以及再生能源使用比例。美國、日本、德國、丹麥都在積極推動微電網的發展。但再生能源受天氣影響，供應量不穩定，營運商也難以準確預測微電網的負荷，從而無法運用基於預測的傳統發電調度算法。因此，微電網運營的最大挑戰，在於如何安排外部電網和本地能源供電的調配，使之既可滿足電力需求，又能減低營運成本。

Microgrid is a local electric power system with both generation and distribution sub-systems (Fig. 1). A building, a hospital, and even a district can build a microgrid of their own. The network uses solar or other renewable energy generation; it can also use small gas generators to provide electricity in grid-connected or islanded modes.



圖一. 微電網運作圖示。(由本項目合作伙伴及中大校友Masdar學院周志健教授、本項目經理謝雯小姐、以及陳名華教授聯合製作)
Fig. 1 Schematic diagram of microgrid operation. (Collaboratively contributed by a TRS collaborator and CUHK alumnus Prof. Sid Chau from Masdar Institute of Technology, Project Manager Miss Mandy Tse and Prof. Minghua Chen.)

Microgrid can effectively improve power system stability, energy conversion efficiency, and the percentage of renewable energy integration. The United States, Japan, Germany and Denmark are actively promoting the development of microgrid. Renewable energy generation, however, is affected by weather and thus intermittent in nature, the operator also faces difficulty in accurate prediction of the local electricity and heat/cooling demand. As such, conventional energy generation scheduling solutions based on accurate generation/load prediction fail to work in microgrids with the unique generation/load characteristics. Therefore, the key challenge in microgrid operation is to optimally orchestrating external energy supply and local energy generation to meet both power and heat/cooling demands with optimized costs.

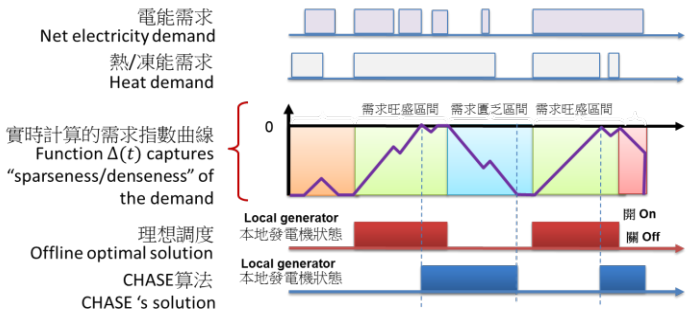
團隊就微電網 營運研發出嶄新的「微電網發電調度的在線算法」，解決再生能源不穩定性帶來的發電調度新挑戰，實現既高效節能又融合再生能源的微電網系統。方案即將結合太陽能採集及存儲之新技術，於中大和聲書院實驗使用，見證效益。

The team developed a paradigm-shift online algorithm for cost-minimized energy generation scheduling in microgrid. The algorithm addresses a key and unprecedented scheduling challenge caused by the intermittency of renewable generation in microgrids, achieving effective cost-saving performance and enabling integration of high-percentage renewable generation in microgrids.

項目說明 Project Description

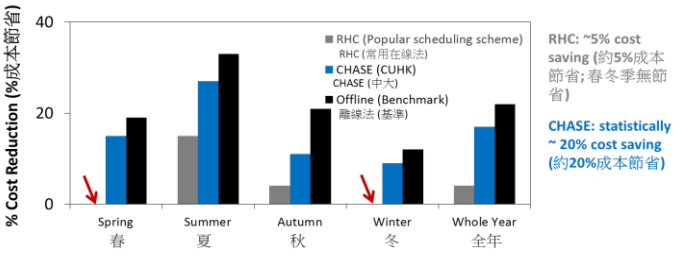
團隊打破基於預測的傳統調度框架，提出一套名為 **CHASE (Competitive Heuristic Algorithms for Scheduling Energy-generation)** 的理想調度追蹤算法 (圖二) 。研究團隊將CHASE算法應用在美國三藩市的模擬微電網案例中，在沒有或極少預測信息的情況下，僅靠過往用電趨勢智能追蹤理想調度，適時調配電力來源，滿足用電需求，**在沒有或極少預測信息的情況下帶來約20%的成本節省 (圖三)**，成效顯著。理想調度指預知未來一切發電及負荷信息後形成的調度方案。最近，CHASE算法的可行性和性能在香港理工大學微電網實驗室得到進一步驗證。大數據量的實驗結果表明，CHASE算法的成本節省接近理想調度所能達到的最低值，兩者相差少於10%。

Professor Minghua Chen and his team broke through the conventional prediction-based scheduling paradigm and proposed an online algorithm called **CHASE (Competitive Heuristic Algorithms for Scheduling Energy-generation) (Fig. 2)**, which is based on intelligent tracking of the behaviors of perfect dispatch. In a case study of a virtual microgrid based on traces in San Francisco area, with little or no generation/load forecast information, **CHASE algorithm was able to bring about remarkable 20% cost saving (Fig. 3)**. Here, perfect dispatch refers to the optimal scheduling solution assuming full knowledge of all future generation and load information. Recently, the feasibility and performance of CHASE algorithm have been further validated at the Hong Kong Polytechnic University Microgrid Laboratory. Extensive experimental results show that the cost saving performance of CHASE algorithm is close to that of the lowest value reached by perfect dispatch, off by less than 10%.



圖二. CHASE 的運作概念圖。理想調度 (紅線表示) 能完全根據用戶需求控制本地發電機的開開，從而滿足用電需求 (紫線表示) 。而 CHASE 算法 (藍線表示) 能僅靠過往用電趨勢智能追蹤理想調度，成本節省接近理想調度所能達到的最低值，兩者相差少於 10% 。

Fig. 2 Schematic diagram of CHASE algorithm. Perfect dispatch (red line) could perfectly satisfy user demand (purple line) by controlling the on / off of local generators. Meanwhile, CHASE (blue line) is an intelligent tracking of the behaviors of perfect dispatch, with cost saving performance close to that of the lowest value reached by perfect dispatch, off by less than 10%.



圖三. 利用**理想調度追蹤算法**，可在極少預測資訊下適時調配電力來源，並節省成本約20%。

Fig.3 The online energy generation scheduling algorithm **CHASE (Competitive Heuristic Algorithms for Scheduling Energy-generation)** can bring about a remarkable 20% cost saving, given little or no generation/load forecast information.

陳教授指出，研究的下一階段是在中大和聲書院進入實地試驗，當技術成熟後，陳教授認為香港的離島是一個合適的試點。

The next stage of the research is to carry out field test in Lee Woo Sing College at CUHK, commented by Prof. Minghua Chen. When the technology is mature, he believes that it provides a viable solution for providing electricity in Hong Kong's outlying islands.

更多項目資訊
More information

相關文獻 Related Paper:

- Ying Zhang, Mohammad H. Hajiesmaili, Sinan Cai Minghua Chen* & Qi Zhu. (2018). Peak-aware online economic dispatching for microgrids. *IEEE Transactions on Smart Grid, 9*(1): 323 - 335. [Link]

11. 重型卡車的油耗節約運作

Energy-efficient Operation of Heavy-duty Truck

針對問題 Problem to be Solved

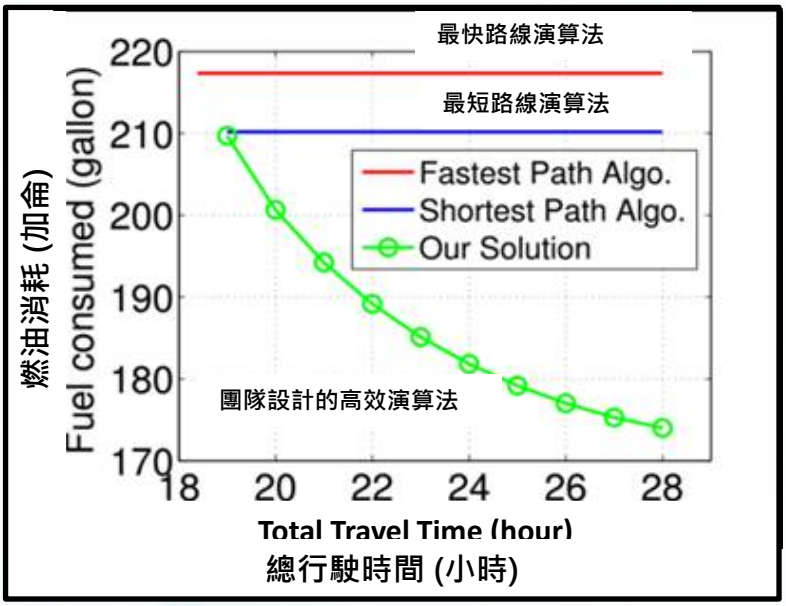
中重型卡車數目僅佔美國公路車輛的 5%，但卻佔了交通領域排放總量的 20%，是交通領域中溫室氣體的第二大排放源。因此，節省中重型卡車的燃油用量對保護環境具有重要意義。Medium and heavy-duty trucks only consist 5% of total vehicle number in USA, but consume 20 % total transportation fuel use. Hence, improving fuel efficiency of these trucks would bring substantial social and economic benefits.

對大部份運輸車輛來說，把貨物（如新鮮食品或有儲存期限的貨品）在特定的運輸期限前準時送到目的地，是十分關鍵的。可是，目前市面上為車輛建議最佳路線的應用軟件，通常只考慮路線長短或時間，並未考慮能源耗用的情況。Delivering goods to the required destinations within a stringent time constraint is important for most transportation vehicles, especially for fresh foods or goods with limited storage time. Nevertheless, the currently available application software in the market only take distance or time into considerations, without considering energy consumption of vehicles.

特長 Advantages

團隊設計的高效演算法，能為需要在兩個目的地間運輸的車輛設計出效能最優的行車車速及路線。團隊採用的方案，透過控制車速 [在上坡（即最浪費燃油時）以較慢車速行駛，在下坡時則較快] 及考慮了風速、路面質素、車輛型號及負重等因素，以達致節省能源的目的。結果表明，相比常用的最短或最快路線演算法，**此算法能為重型卡車節省高達 17% 油耗，同時滿足運輸期限的要求**。

The highly-efficient solution invented by the team is able to deploy an optimized route with speed plan for trucks that have to travel between two designated locations. The approach provides an optimized solution to save energy consumption through the deployment of a lower speed during going up slopes (which is more fuel-consuming) and a higher speed during going down slope, and at the same time considering other factors such as wind speed, surface quality of roads, vehicle model and loading. Results showed that **the solution can reduce the truck's fuel consumption by up to 17% as compared to the common shortest/fastest path algorithm, while meeting the deadline constraint.**



相對常用的最短或最快路線演算法，團隊設計的高效能演算法能為重型卡車節省高達 17% 油耗。

Our solution is able to bring up to 17% fuel consumption saving as compared to traditional approaches.

應用 Applications

任何以燃油或是電力供應能源的車輛，此演算法都能應用。當中，若車輛屬於耗能特別大的重型種類，而且經常行走於交通順暢的高速公路上而較少受交通燈號或擠塞影響，成效更為顯著。此算法亦能安裝於智能手機、平板或手提電腦上應用。

Both oil- or electricity-powered vehicles are suitable for applying our solution. For those types that are heavy duty (with higher energy consumption) and have frequent travels in highways (less restriction by traffic congestion), the energy saving would be more substantial. The algorithm can be installed in smartphone, tablet or laptop computers.

相關文獻 Related Paper:

Lei Deng, Mohammad H. Hajiesmaili, Minghua Chen* and Haibo Zeng. Energy-efficient timely transportation of long-haul heavy-duty trucks. *IEEE Transactions on Smart Grid*, Vol 19, Issue 7, July 2018. [Link]

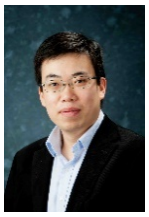
可授權專利
Available Patent

Energy-efficient Operation of Heavy-duty Truck
(Patent US 15/622,742)

更多項目資訊
More information

12. 互聯微電網的合作規劃與運行

Cooperative Planning and Operation of Interconnected Microgrids



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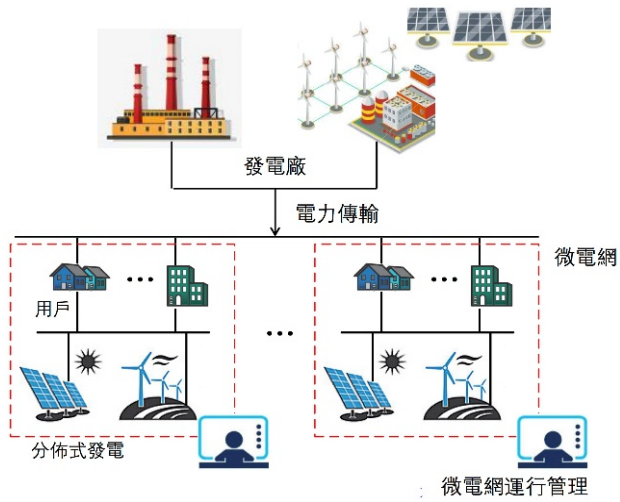
項目說明 Project Description

微電網除了能個別運作，亦能聯繫起來合併運作。新一代電力系統中將出現更多的分佈式可再生能源參與並網發電、以及以微電網為單位的分佈式運行管理。如**圖一**所示，這些微電網往往相互連接，能夠互通電能和信息。與傳統電力系統中集中式的運行方式不同，這些微電網是由獨立的系統運行者管理，當中牽涉各自不同的利益考量。因此，如何規劃和運行互聯微電網系統以達致最佳效能顯得尤為關鍵。

我們面臨三大挑戰：（1）可再生能源發電具有高度隨機和地區差異的特點，目前缺少一個能適用於不同場景的模式能了解可再生能源發電特性；（2）微電網通常獨立運行，並不受控於主電網，因此傳統集中式的運行管理方法並不適用；（3）微電網作為獨立個體，在跟其它微電網或是主電網互動時注重自身運行數據的隱私保護，因此需要設計一個全新的隱私保護運行機制。

Besides operating in single mode, different microgrids can also be connected to operate together. The major features of the next-generation power grid include more distributed power generations especially from renewable energy sources, and decentralized operations of the power grid in the form of microgrids. As shown in **Fig. 1**, these microgrids are often interconnected and can exchange energy and information with each other. Different from the centralized operational paradigm, microgrids are operated by independent microgrid operators and hence have their own local interests. It is essential to understand how to make optimal decisions for the planning and operation of microgrids.

We are facing the following three challenges: (1) renewable generations from solar and wind energy are highly stochastic and location-dependent and therefore lacks a common model to characterize the distributions of different renewable energy sources; (2) microgrids are independently operated instead of being controlled by the grid, such that the traditionally centralized method for the planning and operation does not apply to microgrids; and (3) microgrids care about privacy when interacting with other microgrids and the grid, such that a privacy-preserving operational framework is needed.



圖一. 互聯微電網系統。
Fig. 1. System of Interconnected Microgrids.

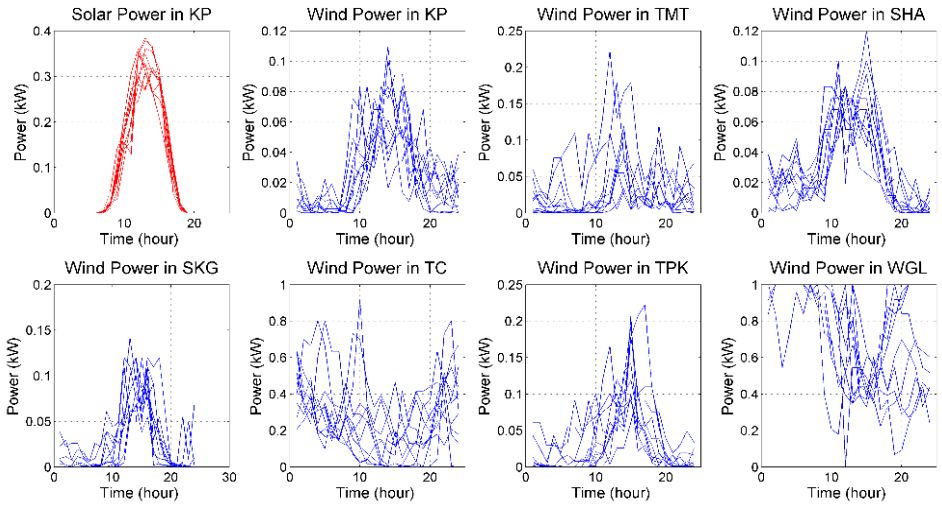
相關文獻 Related Papers:

- Hao Wang & Jianwei Huang. (2018). Incentivizing energy trading for interconnected microgrids. *IEEE Transactions on Smart Grid, 9*(4): 2647 - 2657. [Link]
- Hao Wang* & Jianwei Huang*. (2016). Cooperative planning of renewable generations for interconnected microgrids. *IEEE Transactions on Smart Grid, 7*(5): 2486 - 96. [Link]

可再生能源發電的多樣性 Diversity of Renewable Energy Generation

為了解決第（1）個挑戰，我們開發了一套以數據主導的多地點可再生能源發電分佈模型。如**圖二**所示，使用真實氣象數據，我們創建了香港七個地點包括太陽能和風能在內的可再生能源發電場景。從圖中可以看到，不同地區的可再生能源發電呈現明顯的多樣化特徵，數據有力地証明了由於這種多樣性，有系統地管理及規劃它們將帶來可觀的經濟效益。

To address the first challenge, we developed a data-driven method to model the distributions of renewable energy generations over multiple locations. We used meteorological data to calculate the solar and wind generation scenarios of seven locations in Hong Kong shown in **Fig.2**.



圖二. 可再生能源發電場景，包括如下地點：京士柏 (KP)、大尾篤(TMT) 、沙田(SHA) 、西貢(SKG) 、大老山(TC) 、大埔滘(TPK) 和橫瀾島(WGL)。

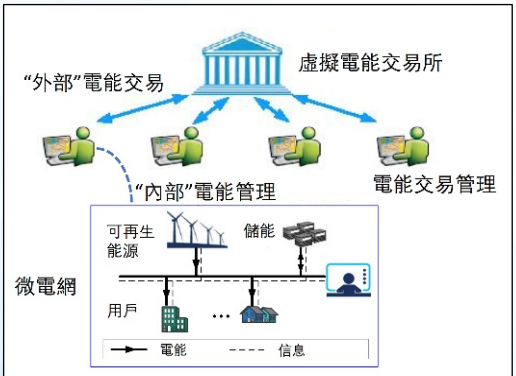
Fig. 2. Scenarios of renewable energy generations in locations: King's Park (KP), Tai Mei Tuk (TMT), Sha Tin (SHA), Sai Kung (SKG), Tate's Cairn (TC), Tai Po Kau (TPK), and Waglan Island (WGL).

The results show diverse profiles of renewable energy generations in terms of technologies and locations, validating the potential economic benefit of cooperative planning of renewable energy generations.

合作規劃方案的成效及數據安全
Performance of Cooperation Planning and Data Security

為了開展互聯微電網的合作，同時解決挑戰（2）和（3），我們提出了一套對於獨立運行微電網系統的合作規劃和合作運行方案。具體來說，基於「納什議價理論」，我們設計了一個公平成本攤分方法，以鼓勵微電網的合作規劃從而令社會成本減至最低。結果表明，**合作規劃方案能能夠節省投資成本達35.9%**。針對微電網的合作運行，我們進一步提出了促進互聯微電網能源交易的分佈式算法，如**圖三**所示。每一個微電網負責優化自身的電能交易和經濟調度，並只需要提交外部電能交易決定，由虛擬交易所負責結算微電網之間的交易從而保護微電網運行中的數據隱私。我們為互聯微電網系統提出了一個理論框架，以協調可再生能源發電的配置和調度。我們的交易算法也為分佈式電源在配電網中的市場設計提供了依據。

To enable such a cooperation among microgrids and address the second and third challenges, we developed cooperative frameworks for the planning and operation of interconnected and self-interested microgrids. Specifically, we designed a fair cost-sharing scheme to split up total investment cost using the "Nash bargaining solution", which incentivizes proactive participation of microgrids toward socially optimal planning of renewable generation. **Such a cooperative planning method can save the total investment cost by 35.9%**. We further designed a distributed energy trading algorithm shown in **Fig. 3**. Our algorithm can protect the privacy of microgrids in a way that each microgrid optimizes its energy trading and scheduling by itself and only reports external trading bids to a virtual energy clearinghouse for the settlement. The trading algorithm sheds light on the design of transactive energy markets for distributed energy resources over power distribution networks.



圖三. 微電網電能交易算法(其中，微電網負責優化自身的發電調度和需求響應，並只需提交電能交易決定)。

Fig. 3. Energy trading algorithm for interconnected microgrids (in which, microgrids optimizes its internal power scheduling and only reports external energy trading).

更多項目資訊
More information

13. 智能化能源管理網上系統：「和聲 Power」

Smart Energy Management Online System: “Woo Sing Power”

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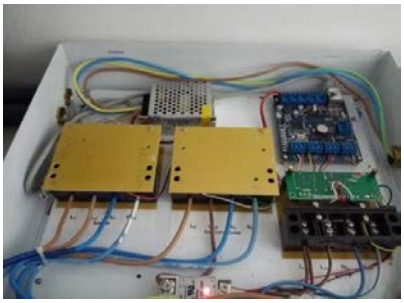
項目說明 Project Description

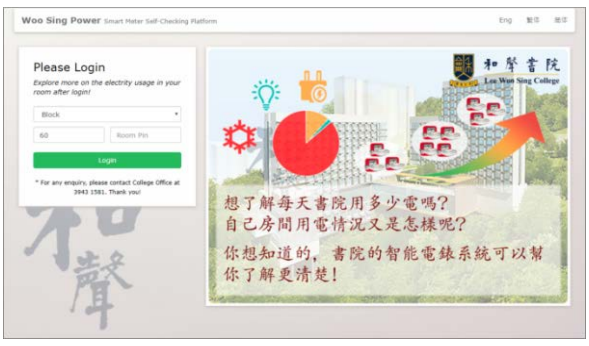
中大和聲書院於創立時已制定節能減碳的方針，在所有300個宿舍房間安裝了獨立的智能電錶，也在VRV冷氣系統、熱水系統及公共空間原有的電錶上安裝了監測系統，數碼監測用電數據。團隊根據宿舍房間的數據，設計了智能化在線能源管理網上系統「和聲 Power」（圖三），為每個宿舍房間提供實時回饋，提升宿生對個人用電量的關注及節能意識，並為管理者找出節能機會及方案（圖四）。宿生透過此網上系統，可了解自己的用電量與其他同學相比屬於較高或偏低，藉此鼓勵同學自發省電行為，減低碳足跡。

LWS College actively invested in smart buildings. They installed individual smart meters in all 300 dormitory rooms, as well as monitoring system in VRV air--conditioning systems and hot water systems in public areas to measure all electricity consumption data digitally. Based on the dormitory usage these data, the research team helped build a smart online energy management platform “Woo Sing Power” (Fig. 3), which provides instantaneous feedback to each room, raises the awareness in the students of energy consumption and conservation and assists administrators to find opportunities and policies to save energy (Fig. 4). Users are able to know their usage pattern compared to others which encourages good behavior towards energy conservation and carbon footprint reduction.

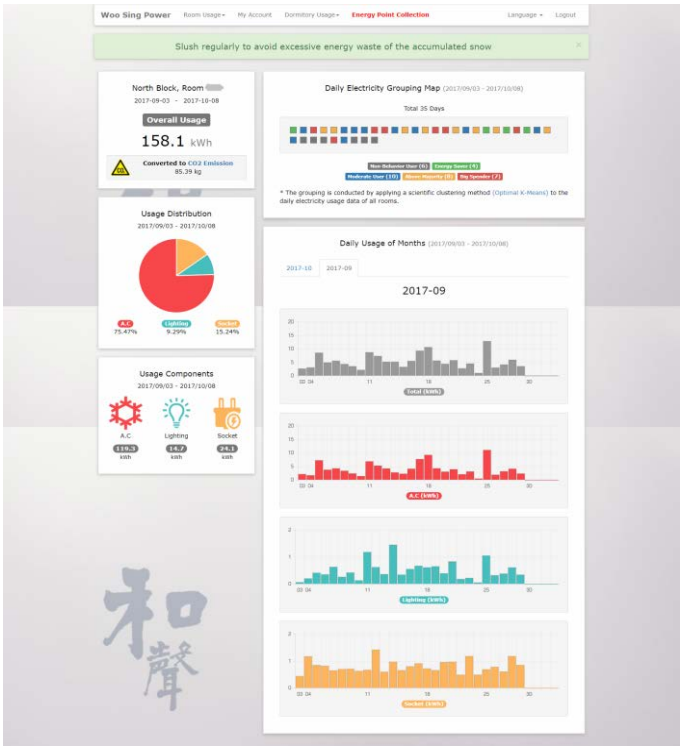


圖一. 安裝在和聲書院全部300個宿生房間的智能電錶。
Fig. 1. The smart meters that were installed in all 300 rooms of LWS hostels .

圖二. 書院宿舍內的八達通收費系統。
Fig. 2. The octopus card payment system at LWS hostels .



圖三. 能源管理網上系統：「和聲 Power」。
Fig. 3. The Smart Energy Management Online System “Woo Sing Power” .



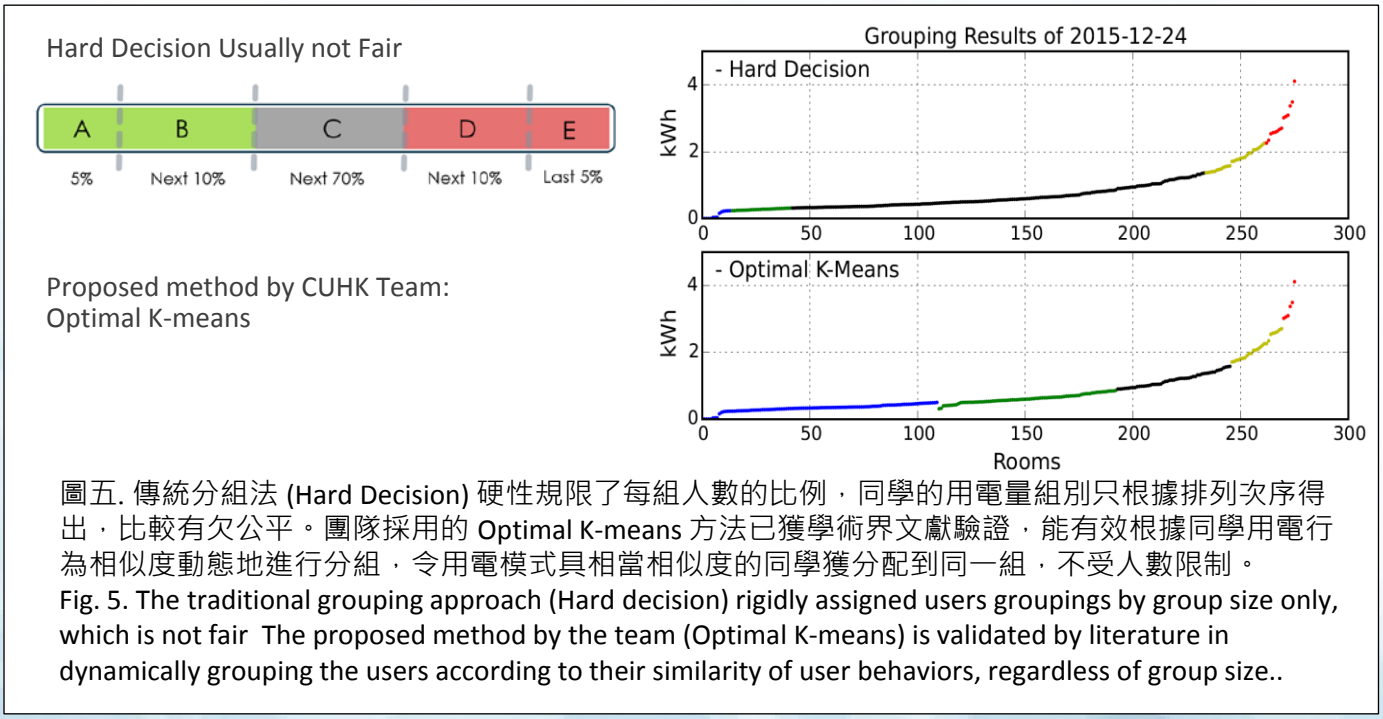
圖四.「和聲 Power」用戶介面。
Fig. 4. User interface of ”Woo Sing Power”.

相對分組法 Group-based Feedback System

傳統上，同學對自己的用電量是沒有實時回饋，書院電費是採用「漸進增值費率」，即當用量超越某水平，每單位電價便較高；可是，此水平的釐定往往難以客觀定義，亦沒有考慮到天氣對用戶所需用電量的影響。故此，團隊構思了新的分組法讓同學清楚自己的用電量與其他同學的比較：以當天行為模式的相似度歸納為四個相對組別，包括「低」、「中」、「平均以上」及「高」。在天氣炎熱時，冷氣需求及整體用電較高，但組別仍是與其他用戶相對而得，不受天氣影響；故此法較為客觀，也更切合實際。團隊亦根據此系統設計了相應的定價機制，概念以同學整體社會規範以鼓勵省電行為。

Traditionally, there is no such feedback for users; and, the monthly pricing scheme in the College is based on "Progressive Pricing Policy - when the usage reaches certain threshold, usage is charged at a higher price.

However, it is never clear what the right threshold for higher prices is, and the weather influence (hence user need) is not taken into consideration. In view of this, "Woo Sing Power" introduced a group-based feedback system to allow the users know their usage pattern compared to others: Users are grouped daily according to similarity of their usage behavior into four relative groups – "Energy savers", "Moderate users", "Above majority", and "Heavy users". On a hot day, the air condition need is high, so overall energy usage is higher, but users still get feedback on their relative usage compared to their peers. The data driven approach makes this scheme more objective and practical. The research team further proposed a pricing scheme based on the same group-based feedback system. The whole idea of group-based feedback and pricing relies on the idea of social norms to encourage good behavior towards energy conservation.



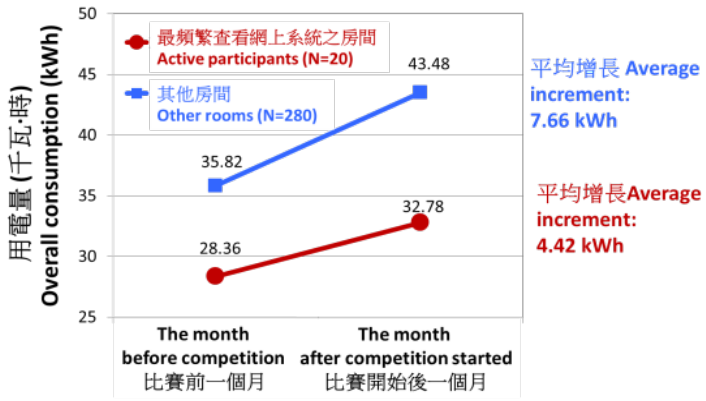
圖五. 傳統分組法 (Hard Decision) 硬性規限了每組人數的比例，同學的用電量組別只根據排列次序得出，比較有欠公平。團隊採用的 Optimal K-means 方法已獲學術界文獻驗證，能有效根據同學用電行為相似度動態地進行分組，令用電模式具相當相似度的同學獲分配到同一組，不受人數限制。

Fig. 5. The traditional grouping approach (Hard decision) rigidly assigned users groupings by group size only, which is not fair The proposed method by the team (Optimal K-means) is validated by literature in dynamically grouping the users according to their similarity of user behaviors, regardless of group size..

省電比賽 Energy Saving Competition

2017年2月至4月，團隊為同學設計了省電比賽，得分除了用電量，也以登入及檢視系統的頻繁程度為額外分數。比賽結果顯示，在該段天氣漸趨炎熱的日子，最頻繁查看網上系統的20個房間及其餘280個房間，雖然用電量均有增長，但前者的平均增幅 (4.42 kWh) 只有後者 (7.66 kWh) 的四成 (約42.3%)，可見參加比賽的同學，省電意識有所提升 (圖六) ，亦真正做到節能。和聲書院的這個試驗計劃，為整所大學成立了很好的階模。

During Feb – Apr During Feb – Apr 2017, the team designed an energy saving competition for the students. The competition points were obtained by both good energy saving behavior (measured by the group based ranking), as well as the frequency of logging in and viewing the daily feedback. During the month (Feb to Apr) when the weather was getting hotter, it was found that although both the participant group (N=20) and non-participant group (N=280) have an increase in electricity consumption, the average increment of the former (4.42 kwh) was only around 42.3% of the latter (7.66 kwh), which showed that the participants had a higher awareness in energy conservation (Fig. 6) and actually saved energy. The LWS College trial project is setting a good example for the whole university.



圖六. 在和聲書院省電比賽中，參與同學的用電量增幅 (4.42 kWh) 只有其他同學 (7.66 kWh) 的四成 (約42.3%) ，顯示其省電意識有所提升，亦真正做到節能。

Fig. 6. Result of the energy saving competition showed, during the month (Feb to Apr) when the weather was getting hotter, it was found that although both the participant group (N=20) and non-participant group (N=280) have an increase in electricity consumption, the average increment of the former (4.42 kwh) was only around 42.3% of the latter (7.66 kwh), which showed that the participants had a higher awareness in energy conservation.

更多項目資訊
More information

相關文獻 Related Paper:

- Lei Zhan* & Dah Ming Chiu*. (2015). Encouraging Energy Conservation in Campus Dormitory via Monitoring and Policies. e-Energy '15 Proceedings of the *2015 ACM Sixth International Conference on Future Energy Systems*, July 14–17, 2015, Bangalore, India. [Link]

14. 香港理工大學智能微電網實驗室
Smart Microgrid Laboratory at The Hong Kong Polytechnic University

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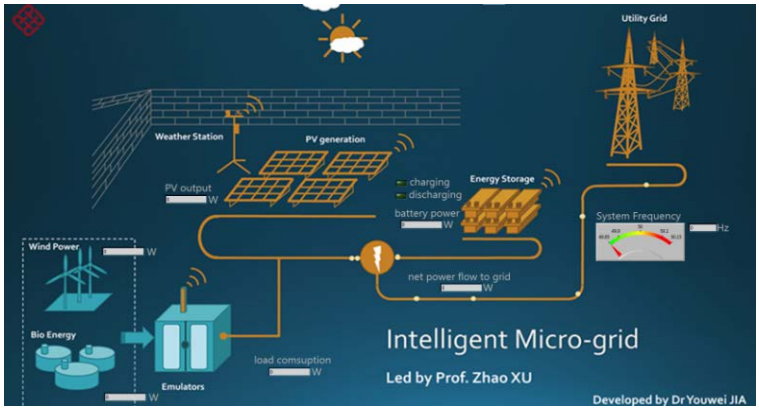
全港首個微網控制實驗室及 CHASE 理想調度追蹤算法的實際應用
First-of-its-kind Laboratory Microgrid Platform and CHASE Algorithm Implementation

研究團隊致力於研究電力的高效應用。團隊構建的智能微電網實驗室集光伏、儲能及電能優化調配為一體，是全港首個微網控制實驗平台，總容量達 4 kw（外觀見圖一，網絡架構見圖二）。團隊以 LabVIEW 軟件開發了智能實時監控系統。同時，作為驗證多種調度及控制策略的在線實驗平台，目前控制週期已短至5秒；其中，中大陳名華教授團隊開發的CHASE在線調度演算法已在此平台得到了成功驗證。

The research crew has been aspiring excellence in the study of efficient utilization of electricity. Their microgrid experimental laboratory platform - a holistic integration comprising photovoltaics, energy storage and optimization dispatch components - is the first-of-its-kind in Hong Kong, with total capacity of 4 kw (See Fig. 1 for the laboratory outlook and Fig. 2 for the network architecture). The team established the smart real-time monitoring system using the software LabVIEW.

圖一. 智能微電網實驗室的外觀。
Fig. 1. Outlook of the laboratory microgrid platform.



圖二. 團隊構建的智能微電網實驗室運行網路架構之圖示。
Fig. 2. Network architecture of the laboratory microgrid platform established by the team.

At the same time, it acts as the implementation verifying platform for various online experimental dispatch and control strategies, with control cycle as rapid as 5 seconds. Here, the CHASE online energy generation scheduling algorithm developed by Prof. Minghua Chen from CUHK was successfully verified.

更多項目資訊
More information

15. 粒化計算為本的概率預測技術

Granular Probabilistic Interval Forecasting

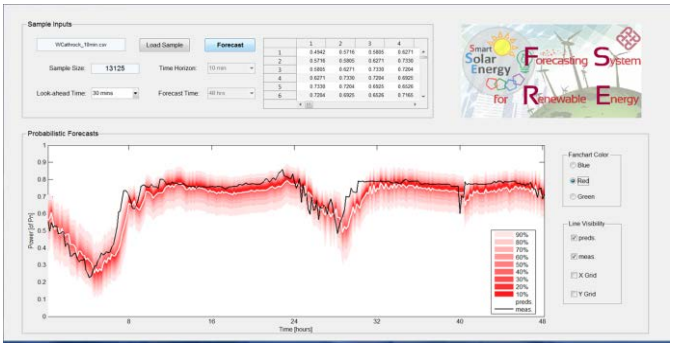
為達到更佳的能源效益，微電網中可再生能源的發電和負荷的準確預測不可或缺。一套準確的預測策略能為微電網提供供需模式的重要資訊，幫助決策者制定適合的控制和調度策略。其中，粒化計算為本的概率預測技術被公認為一種相當有展望的方法。事實上，任何預測都存在不同程度的誤差，概率預測能夠將這種不確定的誤差信息以不同概率等級的預測區間形式體現出來，決策者可以此制定相應的控制策略，保證經濟和可靠運行。團隊與香港天文台合作，開發了性能優秀的粒化概率預測技術。研究結果顯示，在以15分鐘為間隔的光照輻射預測結果中，所產生的可信度為90%的預測區間幾乎可以覆蓋90%的觀測值，證明該方法非常可靠（圖四）。該技術已成功在香港天文台京士柏光照強度數據的短期概率預測上應用，將來更有望應用於太陽能及其他可再生能源的微電網上。

Forecasting the generation and consumption of electricity is essential to achieve energy efficiency. An accurate forecasting strategy can provide important information for supply and demand pattern to the microgrid, assisting policy makers to devise suitable control and dispatch strategy. Here, granular probabilistic forecasting technology has been shown to be a promising approach. Actually, all forecasting approaches involve errors. Probability forecasting is able to reflect different levels of errors by prediction intervals, thereby allowing policy makers to deploy a suitable control strategy to guarantee economic and reliable operation. In collaboration with the Hong Kong Observatory, the team developed high-performing granular probabilistic forecasting technology. (In Fig. 4, the high reliability of the approach was verified by the 90% confidence level of the 15-minute interval prediction results of solar irradiance, which means 90% overlapping of observed values) This technology has been successfully implemented in the short-term probabilistic forecasting of the solar irradiance data of King's Park at the Hong Kong Observatory, and is applicable to solar and other renewable energies in future.

合作伙伴 In collaboration with:

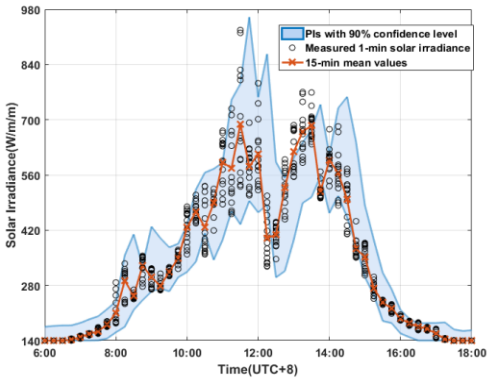
香港天文台
HONG KONG OBSERVATORY

更多項目資訊
More information



圖三. 團隊以 Matlab 軟件設計的**再生能源預測系統 (FSRE)**，以粒化計算為本的概率預測技術來預測太陽光照。

Fig. 3. Using the Matlab software, the team developed the **Forecasting System for Renewable Energy (FSRE)** for forecasting solar irradiance using granule-based interval technology.



圖四. 以 15 分鐘為間隔的光照輻射預測結果中，所產生的可信度為 90% 的預測區間幾乎可覆蓋 90% 的觀測值，證明該方法非常可靠。

Fig. 4. The 15-minute prediction intervals of solar irradiance via the granule-based model have a nominal confidence level as high as 90%.

可授權專利 Available Patent

Granular Predictor for Probabilistic Intervals Construction
(Patent: CN201610537237.2)

Advantages

- No need of pre-assuming the predictive distribution.
- Both stochastic uncertainty and knowledge uncertainty can be well captured by this predictor.
- Fast learning speed thus being applicable to online forecast.

相關文獻 Related Paper:

- Songjian Chai*, Zhao Xu* & Wai Kin Wong*. (2016). Optimal granule-based PIs construction for solar irradiance forecast. *IEEE Transactions on Power Systems, 31*(4): 3332-3. [Link]

16. 全港首個智慧型電氣負載控制器

First-of-its-kind Smart Demand Controller in Hong Kong

維持頻率穩定是保障電力系統安全運行的關鍵因素。傳統上，電網的頻率調節只能由發電方承擔，花費非常昂貴。許教授的團隊成功研發本港首個能實時回應頻率變化的智慧型電氣負載控制器，可用在不同家居電器而且體積細小（約一般信用卡大小），很適合香港家居使用（圖五）。此控制器讓電器即時參與頻率回應，在頻率過低時，切斷非重要負荷；在系統頻率恢復時，迅速恢復供電。此控制器能從用戶方分擔頻率平衡的負荷，對整個電網系統的穩定非常有利。冰箱、空調和熱水器等大型家居電器由於回應快速及可控性高，非常適合使用此控制器。此外，相對於傳統方法，團隊提出的這種策略不僅能提高回應速度，更不會對環境造成任何危害並且可以大幅降低調節成本。此控制器的推廣將對香港電網的穩定運行有重要意義。

Frequency stabilization is the key factor to ensure power system operation safety. Conventionally, frequency regulation is generally provided by the generation side at high cost. The team successfully developed a real-time smart demand controller, the first of its kind in Hong Kong, which can be applied in different home appliances, in sizes as small as a regular credit card, which is very suitable for home use in Hong Kong (Fig. 5). Thanks to the devised controller, the home appliances are able to contribute to frequency stabilization in real time. That is, non-critical appliances are switched off when frequency significantly drops, and rapidly resume power supply once the frequency is restored. This controller can share the load of frequency stabilization from the user side, bringing great benefits to the entire microgrid system. Its fast response and high controllability make this controller very suitable for application to large home appliances like refrigerators, air-conditioners and water heaters. In contrast to the conventional way, the approach suggested by the team not only improves the response rate, but is also environmentally friendly and substantially reduces costs. Widespread application of this controller holds significant potential for supporting system frequency stability in Hong Kong.

圖五. 智慧型電氣負載控制器體積細小，非常適合香港家居使用。

Fig. 5. The smart demand controller is as small as a regular credit card, which is very suitable for home use in Hong Kong.

圖六. 許昭教授的研究團隊。

Fig 6. Research team of Prof. Zhao Xu.

土豆網短片介紹
Tudou Video

更多項目資訊
More information

太陽能電池組件及智能能源儲存之微電網實地應用
Field Demonstration of Microgrids with PV Modules and Smart Storage

合作伙伴 In collaboration with：

和聲書院 Lee Woo Sing College

成果 Milestones

自 2016 年中，本項目與香港中文大學和聲書院合作，在書院的北座及南座頂層設置示範基地，以驗證由本項目研發之再生能源電力系統的效益：

- **安裝了 396 塊 CIGS 太陽能板，共港幣 30 萬元**，由主題研究計劃經費資助，最高容量達 35 kwp。
- 書院另外資助了約港幣 130 萬元於系統的基礎支架及電工安裝上。
- 於 2017 年 5 - 8 月的四個月內，**由此系統生產的電力共 13,600 度** (北座 9,360 度及南座 4,240 度)，相當於電費約港幣 15,400 元
- 由此推算，系統約可在一年內為書院節省約**四萬元電費**
- 若以書院這四個月內的總用電量（57 萬度電）計算，系統供應的電量約佔書院**總用電量的2.4%**

未來，團隊將繼續發掘更出色的研究突破，以結合各種不同系統及高效智能電網應用為最終目標。

Since mid-2016, the project collaborated with the Lee Woo Sing College of CUHK by establishing a field demo at the north and south rooftop of student hostel. The installation validating the performance of the renewable energy system derived from the project:

- **Installed 396 pieces of CIGS solar panels (Around HKD 300,000)**, funded by TRS. Peak capacity reaches 35 kwp.
- The College invested another HKD 1.3 million for the mounting hardware and electrical work of the solar panels.
- During May – Aug 2017, **13,600 kWh of electricity** was generated (North block 9,360 and South block 4,240), equivalent to around HKD 15,400.
- Hence, the system is expected to save around **HKD 40,000 electricity fee** per year.
- This amount is around **2.4% of the total power consumption** (570,000 kWh) of the entire College.

In the future the project is going to further explore even more breakthroughs, with the ultimate goal of integrating diversified systems for high-performing smart microgrids.

圖中背景為位於中大和聲書院頂層的太陽能系統示範基地。
The background of the photo is the solar system field demo LWS rooftop.

（左起）中大工程學院院長汪正平教授 (本項目統籌)、信息工程學系榮休教授邱達民教授、信息工程學系副教授陳名華教授，以及和聲書院副院長任揚教授。
(From left) Prof. Wong Ching-ping, Dean of Engineering, CUHK; Prof. Dah-ming Chiu, Emeritus Professor, Department of Information Engineering; Prof. Minghua Chen, Associate Professor, Department of Information Engineering; and Prof. Yeung Yam, Associate Master, Lee Woo Sing College.

更多項目資訊
More information

關於香港中文大學 -- 和聲書院
About the Lee Woo Sing College, CUHK

和聲書院 Lee Woo Sing College

和聲書院 The LWS College

書院制度是香港中文大學在本港大學中獨特的制度。自 2012 年大學課程改為四年制起，為安排多一年的本科生學額，中大在本來的四所成員書院外，新成立了另外五所書院。於2007 年成立的和聲書院，便是其中之一。

Collegiate system is the unique tradition of The Chinese University of Hong Kong (CUHK) among the local universities in Hong Kong. To cater for the addition of students upon reversion to a four-year undergraduate curriculum in 2012, five more new Colleges were established in addition to the four existing Colleges. Lee Woo Sing College, one of the five new Colleges, was set up in 2007.

和聲書院一直積極推動綠色生活及環保，在香港中文大學的多所書院中推行很多環保先導工作。作為校園內環保技術的領先者，書院已安裝數種全港首個節約及可再生能源的系統，以提高學生的環保意識，共創一所可持續發展的校舍。

和聲綠色措施

- 全港首個宿舍全智能電力讀數系統
- 全港首個高效率CIGS 太陽能發電系統
- 全港首個全反LED 照明系統
- 高效能隔熱玻璃塗料
- 宿舍房間安裝風扇及小型節能雪櫃
- 節能電器裝置及電能爐具
- 綠化休憩庭園及天台種植區
- 師生飲食中心減廢及廚餘處理措施
- 全面樓層廢物分類回收
- 綠色生活大使計劃

The College is committed to green management and education, and is the leading green College in CUHK. Being a pioneer of implementing green technologies on a university campus, they invented and installed a number of first-in-Hong Kong energy saving and renewable energy systems.

The Green Measures

- First-in-Hong Kong hostel smart meter
- First-in-Hong Kong high-efficiency CIGS solar energy system
- First-in-Hong Kong plasmonic crystal LED lighting
- Heat-reduction glass coating
- In-room energy-saving ceiling fan and mini-refrigerator
- Energy-saving appliances and electric cooking
- Green courtyard and roof-top planting area
- Canteen waste reduction and processing scheme
- Waste classification on all floors
- Green life ambassadors

和聲書院的
其他節能工作
More Information of Energy Saving Work Done in LWS College

‘GO!’ 綠色獎勵 2015

和聲書院獲香港中文大學校園規劃及可持續發展處（CPSO）選為 ‘GO!’ 綠色獎勵中之「整體環保行動」、「節約能源」及「環保購物」三個類別中的優勝者。於2015年6月5日(星期五)，中文大學協理副校長馮通教授頒發了獎狀予和聲書院，當天同時是世界環保日。

‘GO!’ Green Award 2015

Lee Woo Sing College has been recognized as a winner of the ‘GO!’ Green Award in the “Overall Green Actions”, the “Energy Conservation” and the “Green Purchasing” categories by the CUHK Campus Planning and Sustainability Office. A brief award presentation officiated by Prof. Fung Tung (Second from right), Associate Vice-President, CUHK, was held on 5 June, 2015 (Friday) in celebration of the World Environment Day.

推廣活動 (節錄) Publicity Activities (Selected)

工作坊 Workshops

CUHK Energy Day 2014

CUHK Energy Day 2015

Smart Materials for Solar Energy Harvesting Workshop 2016

TRS Project Workshop for Energy Storage 2017

展覽 Exhibitions

Inno Carnival 2014

Exhibition on Germany's Energy Transition 2016

International ICT EXPO 2017

The First China University Scientific and Technological Achievements Fair 2017

China (Dongguan) Science & Research Institution Innovation Achievements Fair 2017

Guangdong International Applied Science & Technology Trade Expo 2017

TRS Public Symposium 2017

會議及交流 Meetings and Visits

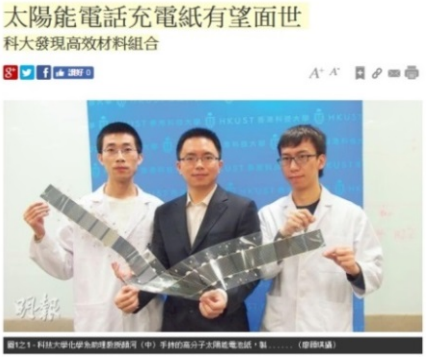
Visit by Prof. Steven Chu, Nobel Laurate in Physics 1997
19 Oct 2016

Distinguished Lecture by Prof. H. Kumar Wickramasinghe
8 Jun 2017

Distinguished Lecture by Prof. Rodney S. Ruoff
19 Jan 2018

傳媒報導 Media Coverage

4港校60科學家
掀太陽能革命
文匯報
6 Aug 2014

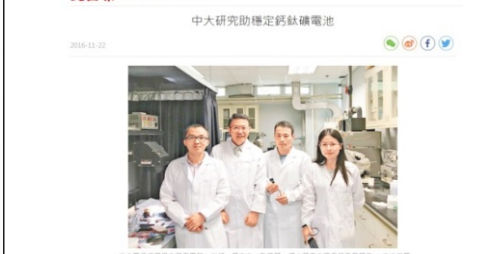


太陽能電話充電紙有望面世
科大發現高效材料組合
明報 14 Nov 2014

中大研新技術提升液流電池能量
都市日報 2 Mar 2015

科大太陽能電池功率破紀錄 - 高效有機環保 輸出功率推高至 11.5%
文匯報 3 Feb 2016

中大最強電容器「狂收落雨柴」文匯報 15 Sep 2016



中大研究助穩定鈣鈦礦電池
文匯報 22 Nov 2016

□ □ □ □ □ □ □ □ □ 電動車五分鐘充畢電
頭條日報 13 Apr 2017

計出微電網調度 年慳20%成本 中大研發算法 理大研製控制器 均助推動環保能源應用
文匯報 16 Oct 2017

合作 COLLABORATION

本項目之各項研究已漸見成果，我們現正為項目尋找各種形式之合作機會，望能把科研成果轉化成高質素產品及服務，回饋社會，為環保及新能源應用科技作出貢獻。其中社會各界人士的合作，我們都十分歡迎。
Various results from the project achieved remarkable records. We are seeking collaborative partners for various kinds of collaboration activities, with the ultimate goal of converting R&D into quality products and services, contributing the well-being of the society in applied technology in renewable and new energy. We welcome collaborations from various stakeholders.

凝聚 CONVENE

合作 COLLABORATE

催化 CATALYSE

大學科研
University R&D

社會各界人士
Various Stakeholders

轉化 CONVERT

環保及新能源應用科技
Applied Technology in Renewable and New Energy

基金申請 Funding Opportunities

香港政府設立了多個不同的科技基金，支持大學進行各種創新科技的研發及應用，旨在提升本地經濟活動的增值力、生產力及競爭力。政府希望透過基金，鼓勵和協助香港的企業提升科技水平，並為其業務注入更多創新意念。

The Hong Kong Government established various kinds of technology funding to support R&D and applications of innovative technology, aims to increase the added value, productivity and competitiveness of our economic activities. The Government hopes that, through thse, Hong Kong companies could be encouraged and assisted to upgrade their technological level and introduce innovative ideas to their businesses.

除了以下基金，另有其他形式的基金可供申請。詳情請瀏覽網頁： https://sse.erg.cuhk.edu.hk/sse/node/85

There are other kinds of funding available. For details, please visit: https://sse.erg.cuhk.edu.hk/sse/node/85

香港政府創新科技署 - 創新及科技基金
Innovation and Technology Fund (ITF)
Innovation and Technology Commission (ITC)

Innovation and Technology Fund
Innovation and Technology Commission
The Government of the Hong Kong Special Administrative Region

ITSP (Tier 3) projects

For projects that are exploratory & forward-looking in nature.

Funding cap: HK$ 1.4 million

Project Duration: Not more than 18 months

Call for application: March and September every year

ITSP (Tier 2) projects

For projects that are Industry-oriented, with potential for commercialization in nature.

Funding cap: HK$ 30 million

Project Duration: Not more than 24 months

Call for application: March and September every year

合作形式 Mode of Collaboration

第三層項目：公司資助並非必須
第二屠項目：公司必須提供 10% 或 50% 資助（現金或實物皆可）。

Tier 3 projects: Company sponsorship not mandatory

Tier 2 projects: Company sponsorship of 10% or 50% is mandatory (Cash or in-kind are accepted)

香港政府創新科技局 - 創科生活基金
Innovation and Technology Fund for Better Living (FBL)
Innovation and Technology Bureau (ITB)

INNOVATION AND TECHNOLOGY FUND FOR BETTER LIVING 創科生活基金

Main features:

a) Projects should be able to benefit the public at large or specific groups, and should be in line with government policies
b) Projects should involve the innovative application of technologies
c) Project themes include daily living, education, environment, health, safety, transport, etc. which can benefit the community

Funding cap: HK$ 5 million

Project Duration: Project deliverables should be rolled out within 12 months and run for at least two consecutive years after roll-out (except for projects that are one-off in nature)

Call for application: Throughout the year

合作形式 Mode of Collaboration

申請機構須投入不少於項目總開支的10%（可來自所屬母機構、預計銷售收益、第三方贊助等）。

Applicants have to bear no less than 10% of the total project cost (e.g. funding from the parent organisation, expected sales proceeds, third party sponsorship). (Cash or in-kind are accepted)

研究影響基金 Research Impact Fund (RIF)

UGC 大學教育資助委員會 University Grants Committee

Objective:

a) encourage local academics to consider and articulate the potential of research to deliver benefit for the wider community;
b) encourage more impactful and translational research projects; and
c) encourage a greater volume of collaborative research beyond academia.

Funding cap: HK$ 3 – 10 million from RGC (Another 30% matching fund from university, industry, non-governmental organizations, stakeholders or private donation)

Project Duration: 3 – 5 years

合作形式 Mode of Collaboration

項目所必須的 30% 資助，可由多方合資提供（大學、業界、 非牟利團體或私人捐款皆可）。

The mandatory 30% matching support can be contributed collectively by universities, industry, NGOs or private donation etc.

專利授權 Patent Licensing

如　貴公司希望取得我們的技術專利授權，詳情請向項目經理查詢。
If your company is interested in licensing our technology patents, please contact us for further information.

1. Prof. Xudong Xiao , **Novel design of barrier layers for deposition of CIGS thin film solar cells on metallic substrates.** (CN201410203029.X)
2. Prof. Xudong Xiao, **System and Method for Laser Scribing a Solar Panel and the Solar Panel** (US 15/455376 • CN 201710141357.5)
3. Prof Shih-Chi Chen, **Roll-To-Roll Printing Systems and Methods for Fabricating Print Roller** (US14/057,320)
4. Prof Shih-Chi Chen, **Positive Microcontact Printing** (US9,575,226)
5. Prof. Jimmy Yu, **Photocatalytic CoP_2-loaded Red Phosphorus for H_2 Formation from Water** (US 8,940,656)
6. Prof. Jianfang Wang, **Converting infrared light into visible light using lanthanide-sensitized oxides** (US14/279,128)
7. Prof. Dongyan Xu, **Methods of fabrication of flexible micro-thermoelectric generators** (US 2017/0345989)
8. Prof. Yi-Chun Lu, **High-Energy-Density and Low-Cost Flow Electrochemical Devices** (US15/371,466 • CT/CN2016/109055 • CN201680002631.4)
9. Prof. Minghua Chen, **Energy-efficient Operation of Heavy-duty Truck** (US 15/622,742)
10. Prof. Zhao Xu, **Granular Predictor for Probabilistic Intervals Construction** (CN201610537237.2)

小型試驗計劃 Trial Site Testing

我們歡迎業界人士以小規模形式試用我們的技術，然後再洽談更多合作模式。詳情請向項目經理查詢。
We welcome related industry partners to try using our technology in small scale trial sites, followed by deeper collaborations in next phases. Please contact us for further information.

Contact Us

Project URL: https://sse.erg.cuhk.edu.hk/sse/

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