



# Direct Thermal Charging Cell for Waste Heat to Electricity Conversion

Associate Professor Tony Shien-Ping Feng  
Department of Mechanical Engineering  
Faculty of Engineering

HKU team members: Dr. Yu-Ting Huang, Ms Xinya Wu,  
Mr. Chunlin Pang, Ms Kaiyu Mu and Ms Xun Wang

June 22, 2020

# Summary of the Impact

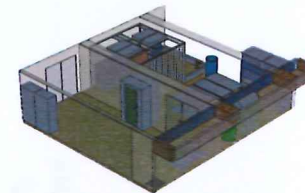
- We invent a **Direct Thermal Charging Cell (DTCC)** for efficiently converting low-grade heat to electricity, surpassing all existing technologies in low grade heat regime.
- DTCCs have uniqueness and advantages for practical application including a wide operation window, isothermal and continuous charging/discharging operation, low-cost, bendable, simple system and the ability to form stacks of cells.
- By establishing startup and collaborating with industries, the invention has been moved from academic research toward real products in various applications, such as HVAC, smart window and self-powered/wearable technologies.

**HK – HKSTP**  
**R&D & Business Center**

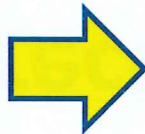
HKU,  
HKSTP,  
iAXON

**Taiwan – Taichung**  
**Manufacturing Site**

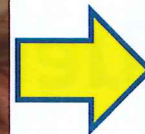
Incubation &  
manufacturing  
center



**2018 Q3**  
**Lab-scale DTCC**



**2019 Q3**  
**DTCC-module product**

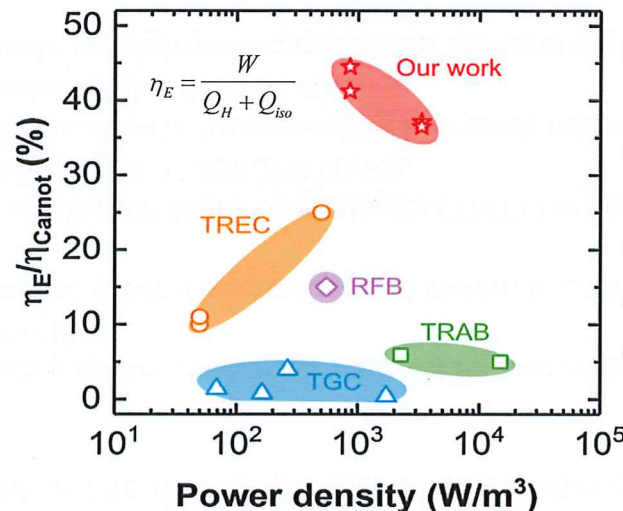
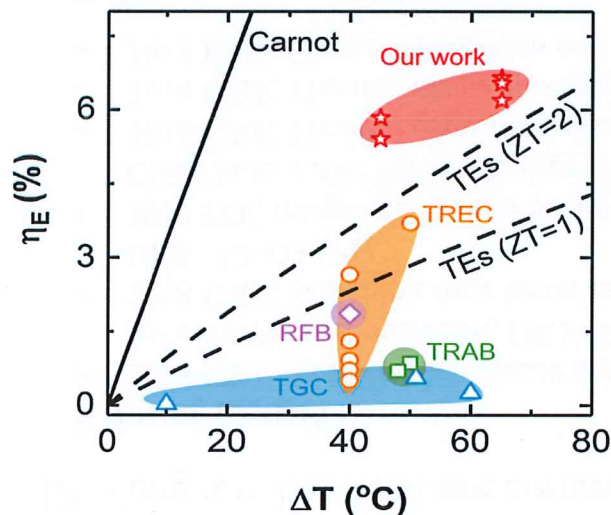
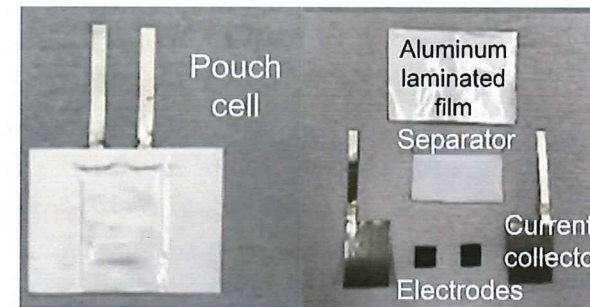
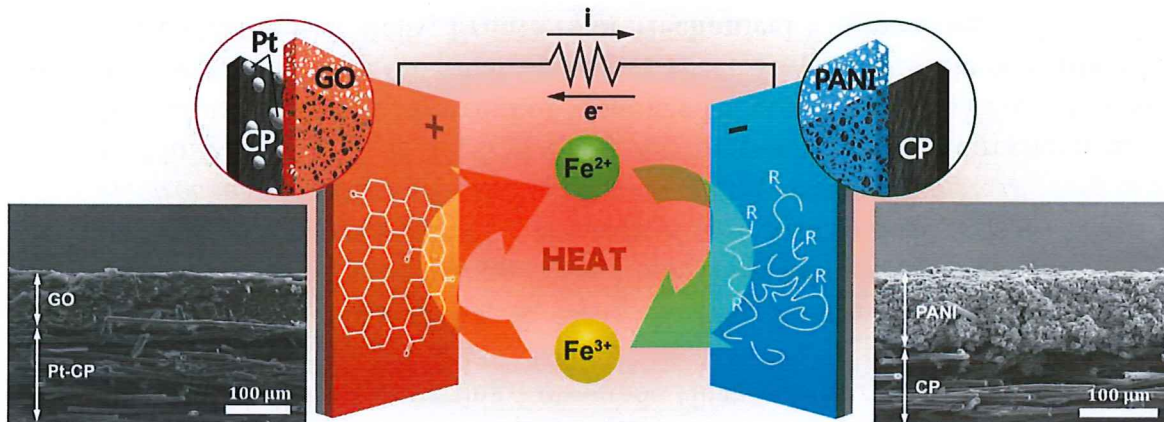


**2020 Q1**  
**flexible DTCC product**



# Underpinning Research

A revolutionary electrochemical system named direct thermal charging cell (DTCC), using asymmetric electrodes of a graphene oxide (GO)/platinum nanoparticles (PtNPs) cathode and a polyaniline anode (PANI) in  $\text{Fe}^{2+}/\text{Fe}^{3+}$  redox electrolyte via isothermal heating operation. The cell generates energy when heated and can be self-regenerated when cooled down.



**Eff% = 3.5~5 %**

- No.1 Thermoelectric conversion efficiency
- Isothermal heating operation  $>30^\circ\text{C}$
- US Patent: Appl. 62/617514, 2018
- PCT/CN2019/071777
- Published in Nature Communications and featured in Editors' Highlights

# Underpinning Research

Dr. Feng and his team are committed to the development of innovative heat-to-electricity conversion.

## Related grants

- 2019 **GRF**, Redox-couple based asymmetric thermoelectrochemical cell for harvesting and recycling low grade heat under isothermal operation, HK\$ 695,919 (PI).
- 2018 **GRF**, Searching for a better asymmetric thermo-electrochemical system to convert low-grade heat into electricity, HK\$ 632,421 (PI).
- 2017 **ITF**, Integrated System of Advanced Thermal Nano Technologies (TNT) for Energy-Efficient Air-Conditioning and Clean Indoor Air: Part 1 - Energy Efficiency, HK\$ 21,636,230 (Co-I).
- 2016 **GRF**, Thermal capacitive electrochemical cycle for converting low-grade heat to electricity, HK\$ 844,559 (PI).
- 2014 **GRF**, Thermal-charging supercapacitors, HK\$ 692,894 (PI)
- 2012 **ECS**, Contact fabrication and its study for high-performance solar thermoelectric generators, HK\$ 550,000 (PI).

## Related papers (selected)

- 1) X. Wang, Y. T. Huang, C. Liu, K. Mu, K. H. Li, S. Wang, Y. Yang, L. Wang, C. H. Su, S. P. Feng, Direct Thermal Charging Cell for Converting Low-grade Heat to Electricity, **Nature Communications**, 10, 4151, 2019. (Featured in editor's highlights)
- 2) C. G. Han, X. Qian, Q. Li, B. Deng, Y. Zhu, Z. Han, W. Zhang, W. Wang, S. P. Feng, G. Chen, W. Liu, Giant Thermopower of Ionic Gelatin Near Room Temperature, **Science**, 368, 1091, 2020. (*According to the understanding and design concept of DTCC, we worked with MIT and Sustech and were involved in this paper. Another our own electrochemical thermoelectric work, also collaborated with MIT, is going to submit soon.*)
- 3) K. Mu, X. Wang, K. H. Li, S. P. Feng, Asymmetric Thermoelectrochemical Cell for Harvesting Low-grade Heat under Isothermal Operation, **Journal of Visualized Experiments (JoVE)**, 156, e60768, 2020.
- 4) X. Wang, S. P. Feng, Thermal Capacitive Electrochemical Cycle on Carbon-based Supercapacitor for Converting Low-grade Heat to Electricity, **Frontiers in Mechanical Engineering**, 3, 20, 2017.

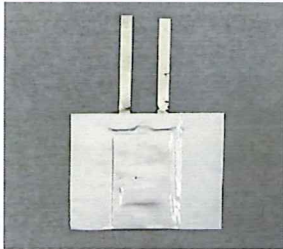
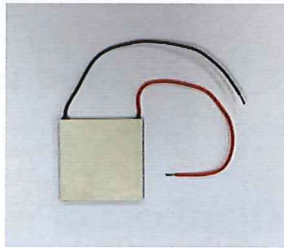
## Patents (HKU)

- 1) S. P. Feng, X. Wang, Y. T. Huang, Z. Zheng, L. Wang, K. H. Li, K. Mu, Thermo-electric capacitor, US Appl. 62/617514, PCT/CN2019/071777, TW 201935723. (*The HKU patent committee has decided to file national applications in China, US and Europe on June 22, 2020.*)
- 2) S. P. Feng, C. Liu, Q. Li, High-thermopower and stretchable ionic thermoelectric (i-TE) hydrogel, under application through HKU TTO (O/ref: IP00925).



# Underpinning Research

Technology Comparison between DTCC and commercial TE

	DTCC	Solid State TE
Cost (USD/Watt)	✓ \$0.05-\$1.00	\$0.5-\$10
Efficiency ( $\eta$ )	✓ 5%-10%	5%-10% (<1%)
Efficiency/Carnot Efficiency ( $\eta/\eta_{\text{Carnot}}$ )	30%-50% ( $\eta_{\text{Carnot}}$ : 15-40%)	12-16% ( $\eta_{\text{Carnot}}$ : 40-60%)
Operating Temperature	✓ 30-90°C	350-650°C (30-90°C)
Operating mode	Temperature cycle	Temperature gradient
Power (W/kg)	50-100W/kg	200-500W/kg
Product Characteristics	Bendable	Rigid
Appearance		

# Underpinning Research

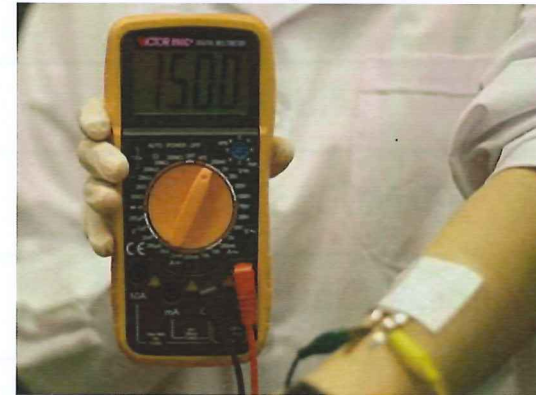
Open new horizons for many applications to convert low-grade heat to electricity

**Waste heat recovery from exhaust pipe**



<https://www.hku.hk/press/press-releases/detail/20140.html>

**from body-heat**



**from car engine**



**from power plants**



Heat: 5,040,000 GWh/year

**from HVAC**



In HK, 3 million family ACs  
Heat: 6,279 GWh/ year

**from Data center**



In Finland, the largest  
Data Center TELIA  
Heat: 200 GWh/ year



# Engagement: Startup company

2018

## Patent

USA Appl. 62/617514, 2018  
PCT/CN2019/071777

2018 HKU DreamCatchers  
100K Entrepreneurship Seed Fund

## Startup



## Business partnership

Principal, MIGGIN ProLogium  
China Impact Technology Technology  
Ventures Co., Ltd. Co., Ltd.

TSSSU@HKU  
Technology Startup Support  
Scheme for Universities at HKU  
FY2018-19

TSSSU@HKU  
450k \$HKD



2019

The X-PLAN Graduation Roadshow  
Top Potential Award

TSSSU@HKU  
Technology Startup Support  
Scheme for Universities at HKU  
FY2018-19

TSSSU@HKU  
750k \$HKD



## Business partnership



## HKSTP Incubation

1.29M HKD

Incu-Tech  
科技, 創業, 培育  
HKSTP  
香港科技園

2020

TSSSU@HKU  
Technology Startup Support  
Scheme for Universities at HKU  
FY2020-21

TSSSU@HKU  
500k \$HKD





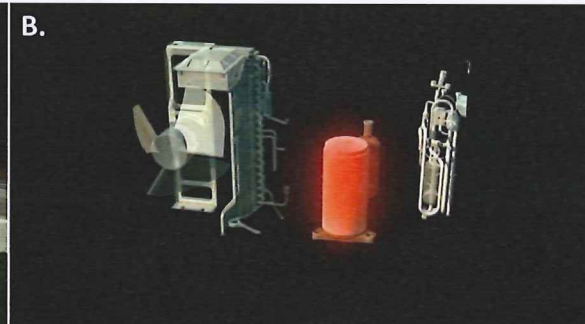

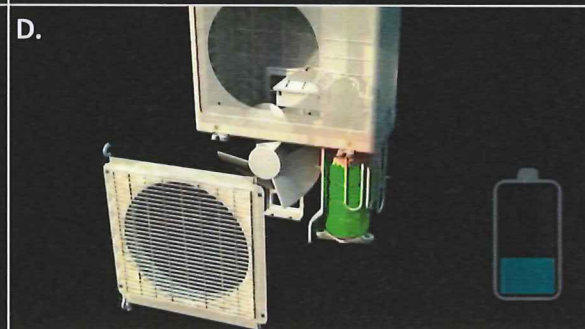
## Industry collaboration



## Investment Activities VC Fundraise



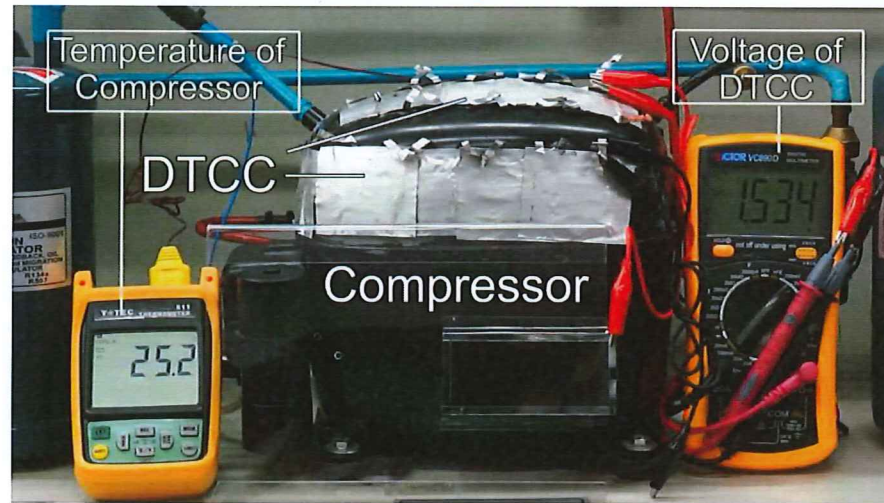
# Engagement: Innovativeness with partner I

Lunched Product	Energy-Saving AC		
Industrial Partner	Techskill (Asia) Limited (Hong Kong) <a href="https://hktrade.mingluji.com/node/57375">https://hktrade.mingluji.com/node/57375</a>		
Business Model	<ul style="list-style-type: none"><li>• DTCC modules sales</li><li>• Customized design service</li></ul>		
Product Design	<div><div>A.</div><div>B.</div><div>C.</div><div>D.</div></div>		
IP	Two patents will be filed in 2020		



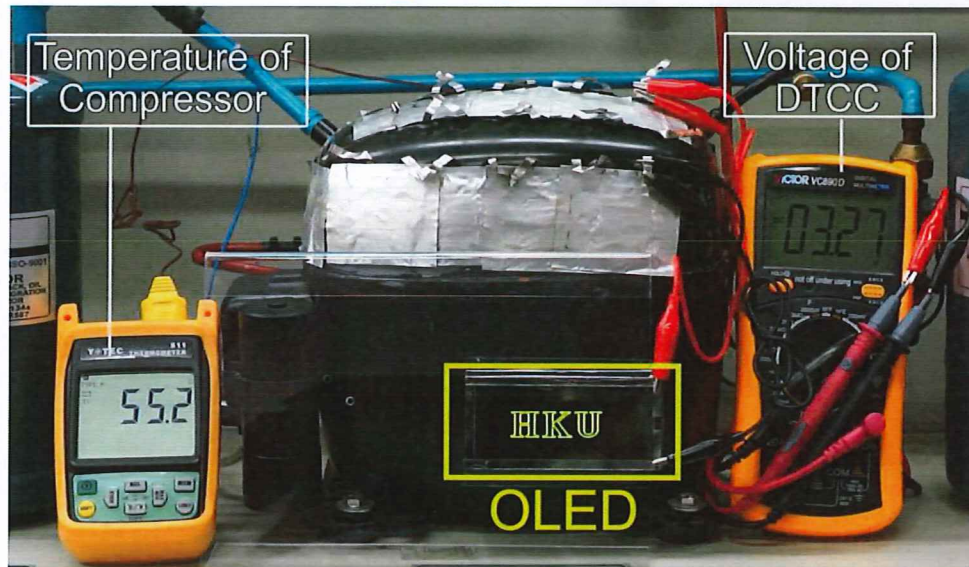
# Engagement: Innovativeness with partner I

## Demonstration: Waste heat recovery from HVAC running compressor




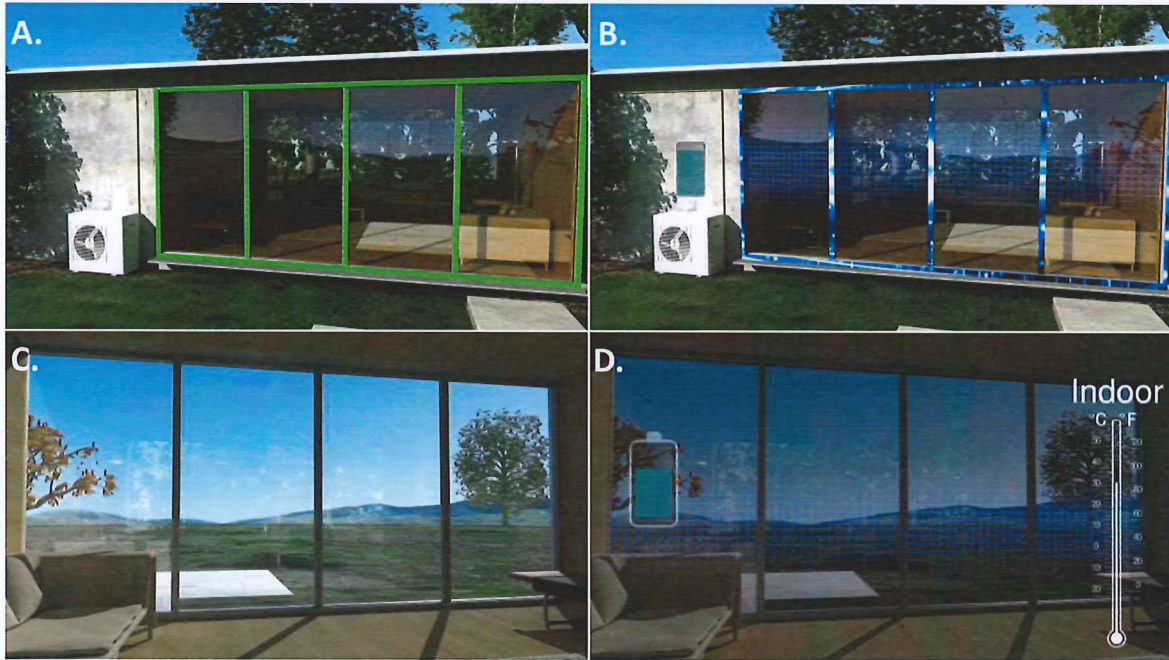
Light up OLED

Power a fan



Video [link](#)

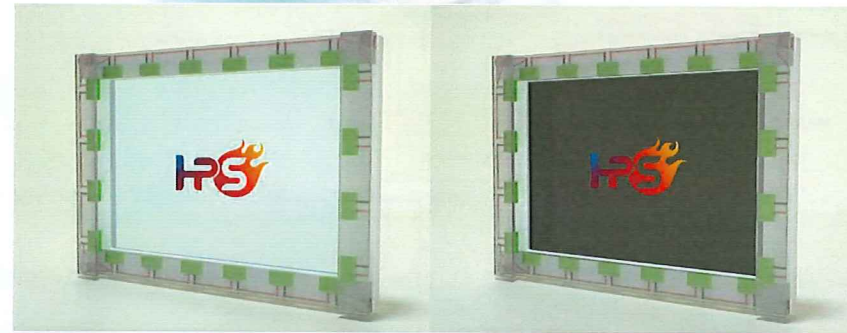
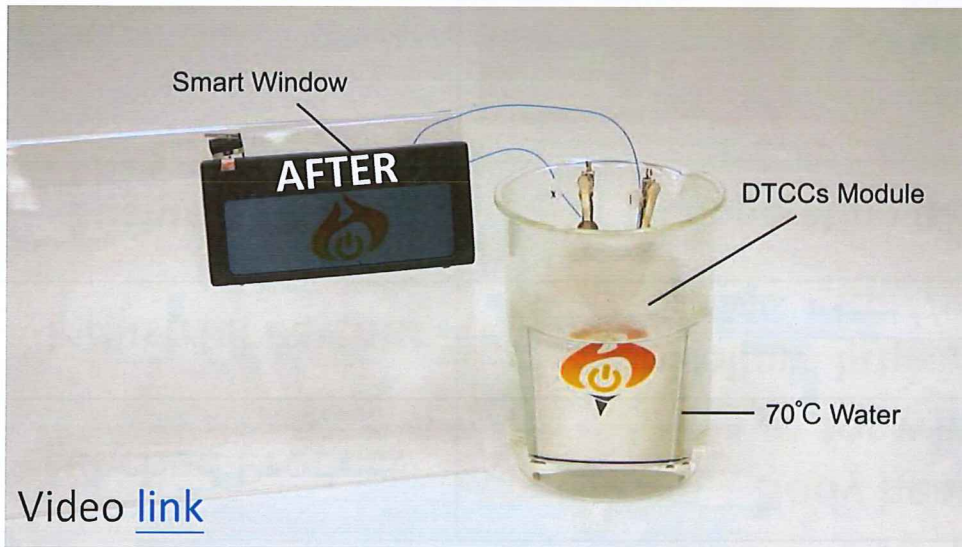
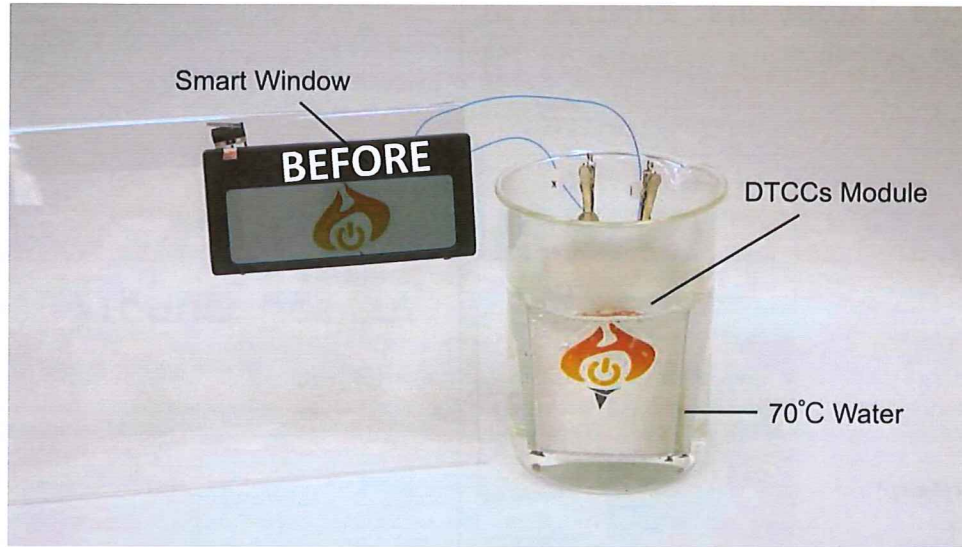
# Engagement: Innovativeness with partner II

Lunched Product	Smart Window
Industrial Partner	<b>Brilliant Optronics (Taiwan)</b> <a href="https://www.brilliantoptronics.com/">https://www.brilliantoptronics.com/</a> 
Business Model	<b>Cooperation partner</b> <b>Product revenue share (20~30%)</b>
Product Design	 <p>The product design section contains four sub-images labeled A, B, C, and D. Images A and B show the exterior of a building with large windows. Image A has a green frame around the window, and image B has a blue frame. Images C and D show the interior of a room with large windows looking out onto a landscape. Image C shows a clear view, while image D shows a view with a blue overlay and a thermometer on the right side. The thermometer is labeled 'Indoor' and shows a temperature of approximately 25°C (77°F).</p>
IP	Three patents will be filed in 2021




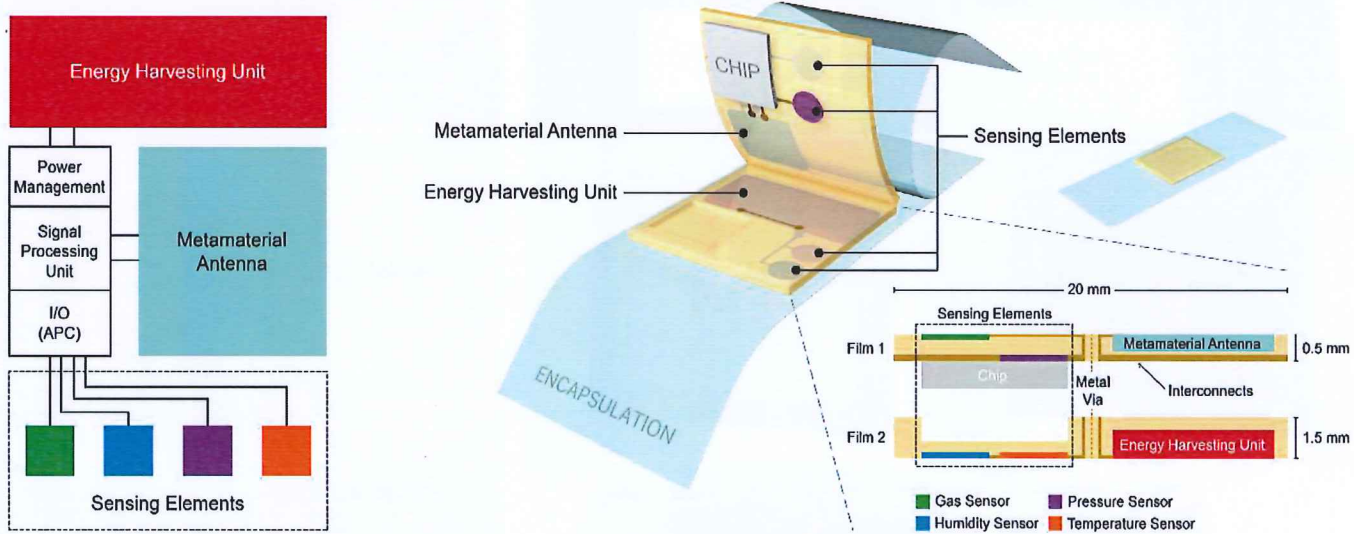


# Engagement: Innovativeness with partner II

## Demonstration: Smart Window powered by DTCC Module



# Engagement: Innovativeness with partner III

Lunched Product	Body heat-powered DTCC technology for wireless smart sensor patch
Industrial Partner	 Ecoflow <a href="https://ecoflow.com/">https://ecoflow.com/</a>  HHMC <a href="http://www.hhmcems.con">http://www.hhmcems.con</a>  H & H Microelectronics
Business Model	<ul style="list-style-type: none"> <li>Cooperation partner</li> </ul>
Product Design	 <p>(L) Schematic diagram of smart sensor patch system, (R) Layered structure of sensing elements, energy harvesting unit, metamaterial antenna, interconnects incorporated into the flexible polymer substrate.</p>

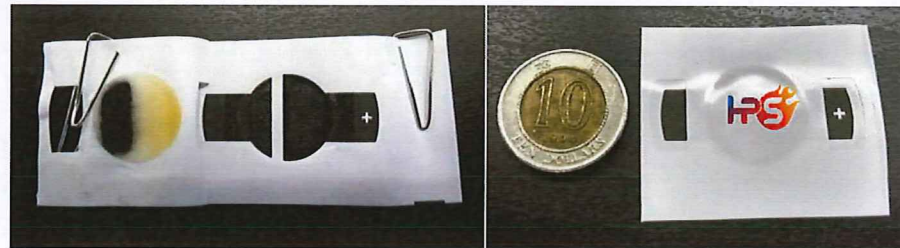
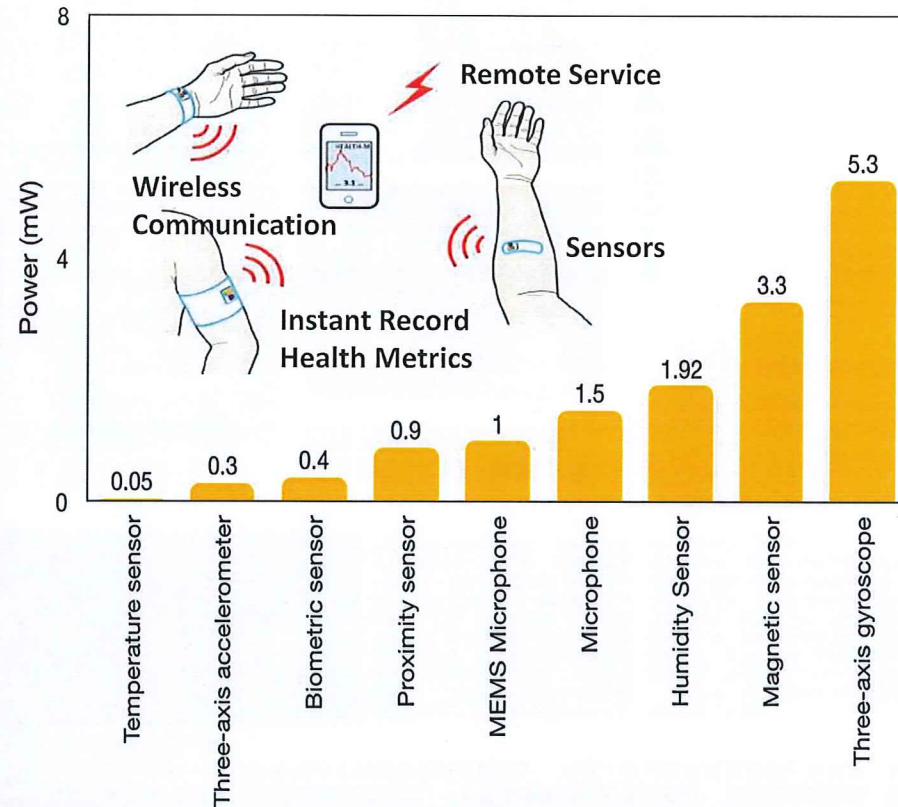


# Engagement: Innovativeness with partner III

## Demonstration: DTCC as Power Source of Wearable Devices



<https://youtu.be/EP3-VIEHyNY>



Flexible DTCC product



# Impacts Achieved: Press Release

兩地攜手科研成果產業化 2019-09-27 18:00



「X-Plan」創科超人團畢業路演 21個團隊展示創科計劃 梁振英：非常羨慕香港創科青年、把握大灣區勢頭、創一番事業

讚好 49 分享



## 港大研發「直接熱充電電池」將電器低溫廢熱轉化電能

在使用電子設備的過程中，均會產生廢棄熱能，港大機械工程團隊便花約八年時間，研發新熱電轉換技術「直接熱充電電池」，可直接將電器排出低於攝氏一百度的低溫廢熱，轉化成電能。此外，這種新電池也可安裝在便攜式裝置上，可將人體體溫熱能直接轉化為電能，為不同的智能產品供電。



港大機械工程系副教授馮憲平指出，「直接熱充電電池」的熱電轉換效率，超過百分之三點五，且不需充電，它自備了一個可自行再生能源轉換循環系統，接觸廢熱後，即能自動充電和發電。此外，即使在攝氏三十度的環境下，電池仍可以運作，能把電器排出低於攝氏一百度的低溫廢熱，轉化成電能，循環再用。他強調，「熱電化學電池」的轉換效率看似很低，技術與理論層面卻是一大突破。

他又指，新電池的成本較熱電化學電池為低，每塊只需約一元，並且應用範圍廣泛，如只需把約一百塊新電池連接至冷氣機，便可將排出的廢熱，轉化為電能發電，整體上，料可節約百分之五至七的能量。正為新電池申請美國專利和PCT專利，也與不同投資者磋商，預料可應用在節能冷氣機和智能變色窗，期望兩年內推出市場。

晴報 News 16

6.11.2019 Wed | skypost.hk

讀者人數免費報第2位

港大研新電池 變電能 可將廢熱

有別於一般的電池需充電運作，港大機械工程系馮憲平博士團隊研發的DTCC電池，利用可自行再生的能源轉換循環系統，當電池接觸廢熱即會自動充電和發電；可把攝氏50至60度的太陽能轉化為電能，為電子產品充電，或整合到大廈的窗框上為智能變色窗供電等，甚至可將人體的體溫，直接轉化成電能。

摺疊裝置，於野外收集熱能作應急求生，或應用於體感發電，以及可穿戴產品作監測血氧、血壓等生命迹象，作醫療監測用途。

馮指出，目前回收低溫廢熱在技術上很困難，在一般環境溫度下更難達到，現時較廣泛使用的固態熱電裝置熱電轉換效率，不但運作成本高，在低溫條件下的運行效果不理想，熱電轉換效率小於1%。新的DTCC電池在低溫環境下，可有效把約3.5%的廢熱轉化成電能，在技術和理論層面均是突破。

馮又稱，若能有效回收低溫廢熱，可顯著減少排放溫室氣體，並減少溫室溫室氣體 最快2年面世

DTCC電池的厚度只有1至1.5毫米，且每個電池單元面積細小，只有1.5平方厘米，可結合並開發成便攜式

初級能源以廢熱形式被浪費，有利地球資源的可持續發展。他表示，目前正申請相關專利，亦與投資者磋商及合作，料先推出即能冷氣機及智能變色窗，期望2年內可推出市場。

每塊成本\$1 百塊慳電5%

馮憲平表示，團隊過去試驗約50種導體，3年前終找出能穩定導電的石墨層，與導電型聚苯胺為兩極，研發出DTCC電池，每塊電池只需約1港元；若把約100塊電池連接冷氣機轉化廢熱發電，料整體可節省約5%至7%。

### 創新南山2019·創業之星 香港賽區決賽暨頒獎禮





# Impacts Achieved: Press Release

## TECH BRIEFS

NOVEMBER 20, 2019 | ENERGY | SENSORS/DATA ACQUISITION | WEARABLES

### 'Direct Thermal Charging Cell' Turns Waste Heat into Power



Dr. Tony Shien-Ping Feng of the University of Hong Kong (HKU)

Our industrial processes generate plenty of low-grade heat – energy that is often lost and never put to valuable use.

What if you could use those extra emissions to power electronics?



The Direct Thermal Charging Cell (Image Credit: Feng)

This is a Direct Thermal Charging Cell. Its creator, Dr. Tony Shien-Ping Feng of the University of Hong Kong (HKU), sees the 1.5-cm-square, 1-mm-thick device someday finding a place on HVAC systems, electrochromic windows, and even the human body. The bendable "DTCC" converts heat to electricity better than traditional thermal processes, according to the technology's inventor.



HOME TECHNOLOGY NEWS

### Direct Thermal Charging Cell Converts Waste Heat Into Usable Electricity

TOPICS: Energy Green Energy  
The University Of Hong Kong  
By THE UNIVERSITY OF HONG KONG NOVEMBER 18, 2019



Video Demonstration: DTCC can harness body heat to power wearable electronic devices or medical devices for monitoring body health conditions.

### Engineering team invents novel direct thermal charging cell for converting low-grade waste heat to usable electricity

November 18, 2019, The University of Hong Kong



Science NOVEMBER 5, 2019 5:16 PM AEST

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### HKU Engineering team invents novel Direct Thermal Charging Cell for Converting low-grade waste heat

Converting low-grade waste heat to usable electricity



Top Early Stage Startups Come to Bahrain for My Startup Bootcamp by Yostartups at CH9

87 次观看



Home > Medicine >

### HKU Engineering Team Invents Novel Direct Thermal Charging Cell For Converting Low-Grade Waste Heat To Usable Electricity

MEDICINE

On Nov 18, 2019



### HKU Engineering team invents novel Direct Thermal Charging Cell for Converting low-grade waste heat to usable electricity

Dr Tony Shien-Ping Feng of the Department of Mechanical Engineering at the University of Hong Kong (HKU) and his team invented a Direct Thermal Charging Cell (DTCC) which can effectively convert heat to electricity, creating a huge potential to reduce greenhouse effects by capturing exhaust heat and cutting down primary energy wastage.

The new invention is recently published in the prestigious journal *Nature Communications* (<http://www.nature.com/communications>), and the research has been featured in the *Nature Communications* Editors' Highlights webpage. HKU's Technology Transfer Office has filed for the invention's US provisional patent and PCT (Patent Cooperation Treaty) patent.



NEWS RELEASE 18-NOV-2019

### HKU Engineering team invents novel Direct Thermal Charging Cell for Converting low-grade waste heat to usable electricity

THE UNIVERSITY OF HONG KONG



VIDEO: COVERED BY TEN DTCCs, WASTE HEAT FROM THE HEATED PIPE IS CONVERTED INTO ELECTRICITY TO LIGHT UP THE OLED (LEFT), AND CHANGE THE COLOUR OF WINDOW GLASS (RIGHT). [view more](#)

CREDIT: @THE UNIVERSITY OF HONG KONG





# Impacts Achieved: Awards

- ✓ The First “X-PLAN” Graduation Pitching Competition cum The Greater Bay Area Innovation and Technology Talent Development Forum

## Most Promising Award

- ✓ 2019 The Innovation Nanshan Entrepreneurs Star Contest

## Excellence

- ✓ The 11th Shenzhen Innovation & Entrepreneurship Competition

## Excellence

- ✓ Deep Tech Regional Summit Singapore HelloTomorrow

## Enter top 16 finals in Hello tomorrow global challenge

HPS has been selected as one of the 16 finalists out of 300 applications and one of the only two finalists in Hong Kong competing in the Hello Tomorrow Regional Summit 2019.

- ✓ 2nd ASIA EXHIBITION OF INVENTIONS HONG KONG Silver Metal

- ✓ Energy Saving Championship 2018 (HK Environment Bureau)

## Hanson Outstanding Awards

- ✓ The 6th Hong Kong University Student Innovation and Entrepreneurship Competition

## Third Prize





# Impacts Achieved: Fundraising

## 海柏斯熱電轉換技術先進 獲千萬天使投資

第 45 分享 用LINE傳送

2020-01-22 16:27 經濟日報 徐谷楨

新創企業海柏斯在「低溫熱轉電」領域技術領先，日前收到數百萬元訂單，農曆年前更確定獲得「MBC天使會」的千萬資金，這筆資金將用於客製化產品開發與試產，可望第三季出貨。

海柏斯總公司設於香港，獲香港大學育成補助，2018年在香港拿下大型創業比賽冠軍，2019年進駐到香港科學園，也來台灣設立分公司，地點就在中興大學創新育成中心。



海柏斯創辦人馮德平（右三起），技術長黃榆婷及團隊合影，海柏斯／提供

## 經濟日報

首頁 即時 會員專區 產業 證券 行情 >

首頁 即時 會員專區 產業 證券 >

## 海柏斯熱電池高效率低成本商業應用廣

讚 139 分享 用LINE傳送

2019-09-23 10:58 經濟日報 徐谷楨

台灣人創辦的香港海柏斯公司，研發出效率高、輕量化、成本低的熱電轉換器，只有火柴盒大小，在香港拿下大型創業比賽冠軍，獲得官方支持創業基金，產品將邁入多種商業化應用，將大眾生活常見的廢熱轉為電能，實現綠色經濟。



## 經濟日報

首頁 即時 會員專區 產業 證券 行情 >

首頁 即時 會員專區 產業 證券 >

## 香港秋電展初創亮點 海柏斯秀「體溫發電」應用

讚 30 分享 用LINE傳送

2019-10-09 20:33 經濟日報 徐谷楨

全球最大的電子產品商貿平台——香港秋季電子產品展，「初創企業專區」將迎來許多潛力新創，其中由台灣人在香港創辦的「海柏斯」公司，獲得香港大學支持與推薦參展，將秀出技術領先的專利熱能轉電能解決方案，爭取投資人青睞。



海柏斯熱電池高效率低成本 商業應用廣 | 熱門亮點 | 商情 | 經濟日報 <https://money.udn.com/money/story/5635/4062981>

香港秋電展初創亮點 海柏斯秀「體溫發電」應用 | 熱門亮點 | 商情 | 經濟日報 <https://money.udn.com/money/story/5635/4096259>

海柏斯熱電轉換技術先進 獲千萬天使投資 | 熱門亮點 | 商情 | 經濟日報 <https://money.udn.com/money/story/5722/4303111>



# Impacts Achieved: Manufacturing line

Establish a manufacturing site in Taiwan to produce prototype products. Trail production in Q1 2020 and income generation (>2M HK\$)

**R&D Centre**  
Hong Kong  
HKU,  
HKSTP,  
iAXON



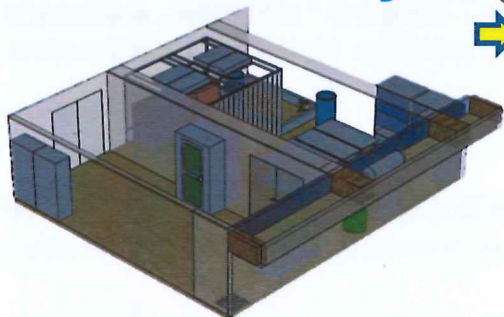
**HK – HKSTP R&D & Business Center**

**HKSTP-HKU iAXON**  
科技園公司西區中心

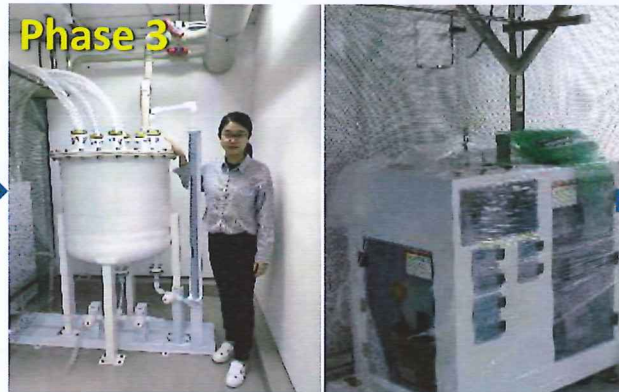
## Taiwan – Taichung Manufacturing Line



**Incubation & manufacturing center**



**Class 10k Clean Room**



**200 L mixing tank for electrode slurry**



**DTCC-module product**



# Impacts Achieved: Product implementation

- The first trail production for HVAC, smart window and electronic applications was launched in 2020 Q1, which has generated revenue of more than 2M HK\$.
- The DTCC module is going to implement in Hong Kong Electrical and Mechanical Services Department (**EMSD**) in 2020 Q2 for reliability testing and demonstration.
- We have signed NDA and work with Tunbow HK (<https://www.tunbow.com/en/>) for product development.

機電工程署 EMSD

Our reference 本署編號: (1) in EMSD/DTD/B-40048

Your reference 來函編號:

Telephone 電話號碼:

Facsimile 傳真號碼: (852) 2873 2154

By Email

15 November 2019  
High-Performance Solution Limited,  
Unit 203D, 2/F, IC Development Centre,  
No. 6 Science Park West Avenue, Hong Kong Science Park,  
Shatin, New Territories, Hong Kong  
(Attn: Dr. Vivian HUANG)

Dear Sir,

**Quotation No. B-40048-1-2019**  
**Development of Thermo-electrochemical Capacitor Device for Converting**  
**Low Grade Waste Heat Into Electricity**  
**(Acceptance Letter)**

Mutual Non-Disclosure Agreement  
保密協議

Party A: High Performance Solution Limited  
甲方: 海柏斯股份有限公司

Party B: Tunbow Group Limited  
乙方: 東保集團有限公司



Legal / Authorized Representative  
法定代表人/授權代表:

*Shien-Ping Feng*

Name 姓名: Shien-Ping Feng  
Title 職稱: Director  
Date 日期: 10/12/2019



Legal / Authorized Representative  
法定代表人/授權代表:

*Wayne Yu*

Name 姓名: Wayne Yu  
Title 職稱: Marketing Director  
Date 日期: 09 DEC 2019

*Smart window/DTCC implementation for reliability testing in Resound Tech Ltd. in Kaohsiung, Taiwan*



# Thanks to our collaborators

## Academic

Prof. Gang Chen, MIT. <<http://web.mit.edu/nanoengineering/>>

Prof. Yuan Yang, Columbia University. <<http://blogs.cuit.columbia.edu/yanggroup/>>

Prof. Shun-Wei Liu, Ming Chi University of Technology.  
<<https://en.mcut.edu.tw/p/405-1051-28147,c6777.php?Lang=en>>

Prpf. Chia-Hung Su, Ming Chi University of Technology.  
<<https://ce.mcut.edu.tw/p/404-1042-2785.php?Lang=zh-tw>>

Prof. Weishu Liu, Southern University of Science and Technology  
<<http://faculty.sustech.edu.cn/liuws/en/>>

Prof. Chih-Ming Chen, National Chung Hsing University. <<http://web.nchu.edu.tw/~cmchen/>>



## Industry

Mr. Frank Leung, Techskill (Asia) Ltd. (Hong Kong)

Dr. Lei Wang, Ecoflow Tech (Shenzhen) <<https://ecoflow.com/>>

HHMC Microelectronics Co., Ltd., (Shenzhen) <<http://www.hhmcems.com/>>

Brilliant Optronics (Taiwan) <<https://www.brilliantoptronics.com/>>

Resound (Taiwan) <<http://www.resoundtech.com.tw/>>



## Business Partners

Workmate

MBC

凱博聯合會計師事務所

Formosan Brothers Attorneys-at-Law



凱博聯合會計師事務所  
KSP Certified Public Accountants Limited

宸瀛法律事務所  
FORMOSAN BROTHERS  
ATTORNEYS-AT-LAW



利紳科技股份有限公司  
RESOUND TECHNOLOGY INC.