

# CLEANING

What's the alternative to our unsustainable, polluting, energy-guzzling way of life? HKUST researchers across different fields are coming up with answers

# UP



**T**he Paris global climate talks in December 2015. The Beijing smog that caused the city's first red pollution alert warning in the same month. The two events in their very different ways bring home the urgency as well as the enormity of the task facing us all in moving forward to a sustainable way of life.

Researchers at HKUST, combining novel interdisciplinary insights, unique east-west positioning and understanding, and strong links with industry and governmental organizations, are hard at work in this race against time. In 2014-15, 69 environment-related research projects were carried out across the University, supported by HK\$50 million in funding.

Here, the spotlight (naturally, LED) falls on significant HKUST advances in energy-saving technologies and renewables, displays, and air quality monitoring. Other cutting-edge green team contributions will be featured in future issues.

## A BRIGHTER FUTURE

Lighting takes up to 15% of the total power consumption globally, according to the enlighten initiative.\* Demand for lighting will only increase in future years.

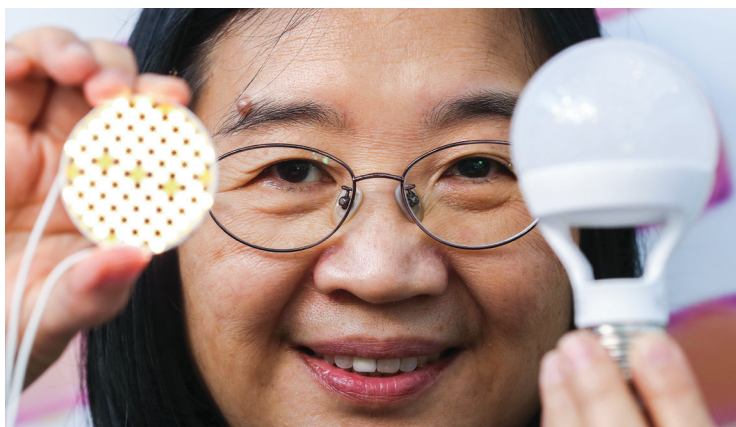
Light-emitting diodes, or LEDs, offer an energy-efficient solution to lighting.

Compared to the legacy incandescent and fluorescent lights, LEDs consume significantly less power and also enjoy a much longer lifetime, upward of 50,000 hours. Unlike fluorescent lights, they are non-hazardous as they do not use mercury. Given all these benefits, LEDs are increasingly being used in general indoor and outdoor lighting, following successful applications such as backlighting LCD televisions, headlights for automobiles, and large-area billboards.

Today, global LED adoption in general lighting is still relatively small mainly because LED lights are expensive in terms of the initial cost compared to incandescent and fluorescent lights. Up to now that cost factor appears to have played a more significant role in decision-making than benefits to the environment, said Prof Kei May Lau, Chair Professor of Electronic and Computer Engineering. Reliability issues of products on the market made by manufacturers cutting corners for lower cost at the expense of good design are another factor.

An expert in semiconductor materials and devices, Prof Lau set up the University's Photonics Technology Center in 2001 to advance LED research. She also coined the term "ecotronics" to describe the economically affordable and environmentally friendly electronic technologies, such as LEDs, that she and her colleagues have been developing. Her work is based around compound semiconductors (GaN, GaAs, InP) and optimization of optoelectronic technologies to assist the devel-

opment of GaN-based LEDs at the early stage, improving the efficiency, stability, as well as packaging designs, benefitting LED performance and consumer perceptions on the capabilities of LEDs as a lighting source.



and her research team developed innovative device design to make the actual LED system more user-friendly. This involved "a delicate balance of optical science, materials science, thermal science and electronics," explained Prof

Lau, who was recently awarded a large-scale Theme-based Research Scheme project, supported by Hong Kong Research Grants Council, to further advance LED-based lighting technologies.

The licensed technologies developed by Prof Lau's team will likely open up new applications, improve reliability and lower manufacturing costs through

integration of LEDs on silicon wafers. Among novel applications, the first LEDoS (GaN-LED on silicon) active micro-displays were successfully demonstrated in 2013, namely a 0.19 inch, 1,700 pixel per inch passive matrix LEDoS micro-display and a high resolution 400 x 240 active-matrix micro-display. Applications include projectors and head-up displays, which allow users to read data without moving their head as required in vehicles today. Advantages include visibility under bright daylight, power efficiency, thermal stability, longer lifespan and robustness under harsh conditions.

\* United Nations Environment Programme (UNEP)-Global Environment Facility (GEF), [www.enlighten-initiative.org](http://www.enlighten-initiative.org)

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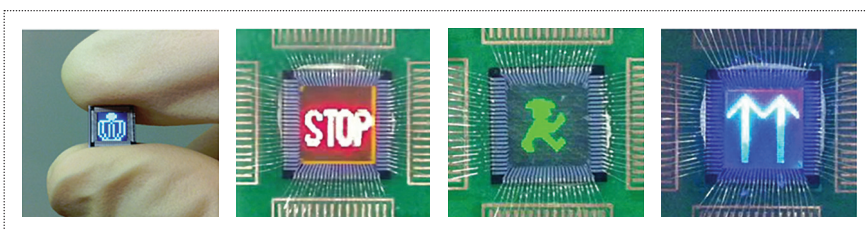
One watt saved is more than  
one watt created

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**PROF KEI MAY LAU**

Fang Professor of Engineering

The HKUST research team is one of the leading groups worldwide in its focus on integrating ICs and LEDs. Using silicon integrated circuit technologies in conjunction with LED lighting, Prof Lau



Light emitting diode on silicon (LEDoS) micro-displays

*IEEE/OSA Journal of Display Technology, Vol.9, Issue 8, 2013*

# WATCH OUT!

Flexible displays that can be rolled up. Healthcare electronic wearables. 3D optically rewritable e-paper available for re-use thousands of times. The next generation of screens is about to catch your eye in numerous innovative ways.

Over the past 20 years HKUST research in optoelectronic displays has already brought many advances that have made an impact on the development of consumer electronics, ranging from computer monitors to watch dials and television screens, making a difference to what we see and how well we see it.

The Center for Display Research was founded in 1995, undertaking both basic research advances on liquid crystal displays (LCDs) and applied work that was later transferred to industry. It was a time when only a handful of universities around the world had ventured into the display area due to its multidisciplinary nature and the need for teamwork, said Prof Hoi-Sing Kwok, Chair Professor of

Electronic and Computer Engineering. “If people work on their own, they can only tackle small problems,” Prof Kwok noted. “In our entire-system approach, several faculty members truly work together, each regarded as important.”

Inventions include liquid crystal on silicon (LCOS) micro-displays, integrating LCDs with silicon-wafer integrated circuits that can be used in high-definition televisions, among other applications; a fundamental new LCD alignment method using light, called photo-alignment, offering top optical quality and good contrast; and a revolutionary thin-film transistor technology that combines the integrated circuit into the glass display panel, offering slimmness, cheaper and better performance, as well as a sharper image. Solutions to specific practical problems have encompassed a multicolor LCD without color filter, later licensed to industry, and reflective displays without a rear polarizer made in collaboration with a watch company.



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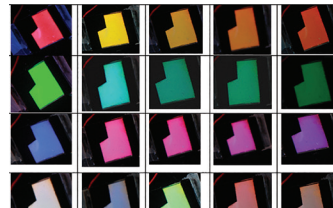
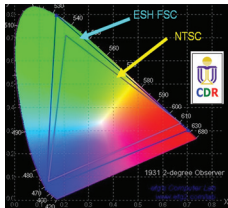
Displays are everywhere. Even small improvements can have large societal and economic impact

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**PROF HOI-SING KWOK**

Dr William MW Mong Professor of Nanotechnology,  
Director, Partner State Key Laboratory on  
Advanced Displays and Optoelectronics

Ferroelectric liquid crystal-based field sequential color display using photo-alignment technology. Applications include micro-display and mobile display, with the advantages of power saving, high contrast ratio, good shock stability, extremely fast switching time (~10 $\mu$ s), wide view angle and large color gamut.



## Partner State Key Laboratory: Focus on Display Excellence

In 2013, the Center for Display Research was awarded the prestigious recognition of Partner State Key Laboratory (PSKL) on Advanced Displays and Optoelectronics Technologies by the Ministry of Science and Technology of China. The laboratory was established in partnership with Sun Yat-sen University in Guangdong, focusing on core research areas in LCD devices, third-generation organic LED (OLED) devices, video signal processing and integrated circuit design, thin-film transistor array technology and frontier technologies including green displays. Prof Hoi-Sing Kwok is the Founding Director.



Opening ceremony for Partner State Key Laboratory on Advanced Displays and Optoelectronics.

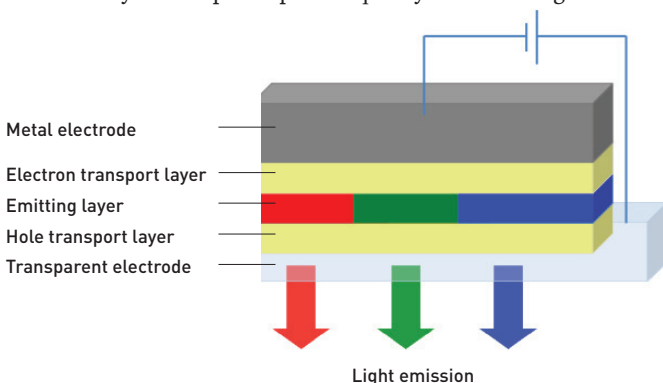


Organic LED (OLED) is another important display research area at HKUST – led by IAS Bank of East Asia Professor Ching W Tang, the first Chinese Wolf Prize Laureate in Chemistry, regarded internationally as the founding father of OLEDs. The OLED revolution sparked by Prof Tang’s discovery of the organic hetero-junction in the early 1980s led to a new display technology and a rapidly growing industry. OLED displays are more energy-efficient, thinner and lighter than conventional liquid-crystal displays (LCD). Because of these superior features, OLED displays are being used in today’s smartphones, tablets, watches, laptops, and large-screen TVs. The next-generation televisions based on OLED will not only have superior picture quality

but can be made flexible and so thin that they can be literally stuck to the wall.

Prof Tang is now embarking on the OLED’s “blue” problem – the instability of blue OLED emitters – and to further improve the lifespan of blue emitters through new material designs and fine-tuning the layer architecture in the device. In addition, Prof Tang’s team will also undertake research to come up with unconventional methods for patterning full color high-resolution display panels, with an aim of lowering the manufacturing cost.

With their highly successful and proven multidisciplinary “entire system” approach, HKUST researchers are well-positioned to embrace the future challenges at the frontier of emerging display technologies.



OLED utilizes a stack of thin organic films to transport charges (electrons and holes) and produce light via electron-hole recombination.



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The ‘blue’ problem is perhaps the last frontier to be tackled in OLED material research; solutions will make quantum jump improvements in performance and cost

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**PROF CHING W TANG**

IAS Bank of East Asia Professor,  
Chair Professor of Electronic and Computer  
Engineering, Chemistry and Physics

# RACE FOR RENEWABLES

Pollutant emissions are largely a byproduct of our need for energy generation and transportation, which today are usually powered by fossil fuels, namely oil, coal and gas. One major emission is carbon dioxide, a greenhouse gas that contributes directly to global warming when generated in quantities that outstrip nature's assimilative capacity. Others, such as particulate matter, are toxic to human health. Yet currently, only 2% of energy is derived from "clean air" renewables, such as wind and solar.

The key challenges for renewables include stability in generation, on-tap availability, cost-efficiency, and high performance. Wind farms require large areas of land and highly efficient solar panels are often expensive to produce. Both face an "intermittent generation" problem and energy storage to cover such gaps remains a huge challenge.

HKUST researchers have set out to address these complex issues that often cut across conventional academic disciplines and boundaries.

## Fuel Cells

Prof Tianshou Zhao has been advancing the potential for wider use of clean energy for the past 15 years through his groundbreaking work on direct alcohol fuel cells and advanced battery technologies.

Prof Zhao sees immense potential in fuel cells as an alternative source of energy. Fuel cells generate electricity through converting the chemical energy of a fuel such as hydrogen, ethanol and methanol, all of which can be directly produced from renewable sources. Fuel cells have high efficiency of around 65%, compared with 30%-35% for traditional heat engines. In addition, they are scalable and can be applied to a wide range of modern lifestyle devices and needs, including cars, mobile phones, computers and buildings.

The main problem with alcohol fuel cells has been low power density, the amount of power produced in relation to the volume of the cell. Based on his seminal work on the underlying mecha-



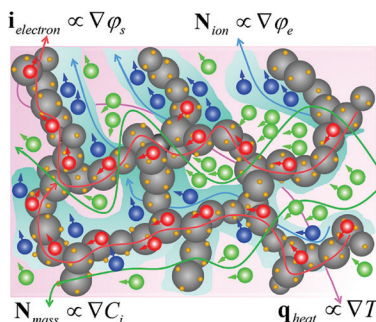
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My dream is a net zero energy community, where all energy is self sustainable

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**PROF TIANSHOU ZHAO**

Chair Professor of Mechanical and Aerospace Engineering, and Director, HKUST Energy Institute



Coupling of heat and mass transfer with electrochemistry.

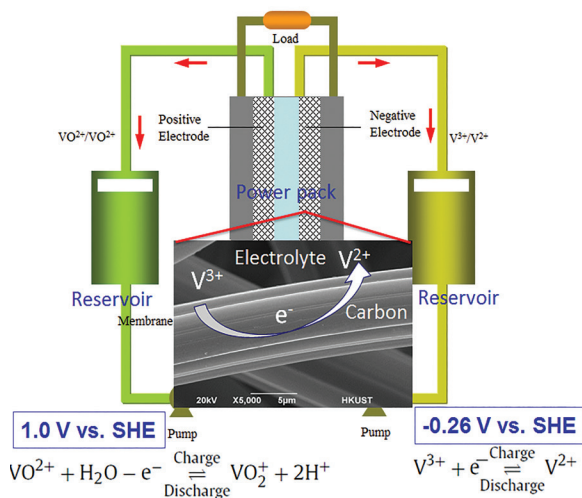
nism of couple heat/mass energy transfer and electrochemical kinetics in fuel cells, Prof Zhao discovered that the issue lay in integrating the understanding of heat and mass transport, and electrochemistry.

With such insight, a new theoretical framework was developed, which led to a dramatic increase in the performance of direct methanol fuel cells by six times and that of direct ethanol fuel cells by four times. Prof Zhao has demonstrated a prototype model car that can run for 10 hours on 5cc of alcohol fuel. And an MP3 player that plays for 20 hours on 2cc of fuel. The researchers have also discovered that hydrogen can evolve spontaneously from a direct methanol fuel cell. This has given rise to a new technique for hydrogen production at room temperature minus the carbon monoxide species common to traditional methanol reformation.

Such theory and discoveries have helped Prof Zhao's research group to tackle further related issues through electrode design improvements for large-scale redox flow battery technologies that can help solve the "intermittent generation" problem for renewables such as solar and wind by raising power density. In contrast to solid state batteries that integrate energy storage and power pack together, a flow battery separates the storage component from the power pack, meaning that power and capacity can be independently sized and making the technology scalable. The battery lifespan

is also increased.

Prof Zhao's unusual blend of electrochemistry and thermo-fluid science is indicative of the non-traditional approach encouraged by HKUST. His team comprises expertise ranging from materials and modeling to fluid sciences and electro-chemistry. He also steers the HKUST Energy Institute, launched in 2014 and now serving as the platform for the University's multidisciplinary research into energy generation, storage, efficiency and policy. Over 50 faculty members across different departments and Schools are involved in such endeavors.



How a vanadium redox flow battery works.

## Organic Solar Cells

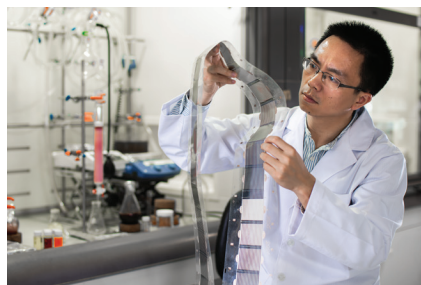
On the solar energy front, the current focus at HKUST is on organic and hybrid organic-inorganic solar cells that could outperform traditional solar cells at a lower cost. Cross-disciplinary research combines novel materials development and nano-scale device engineering to enhance efficiency and durability of the solar cells. To reduce production cost, flexible thin-film organic solar cells are being developed that would take advantage of high-speed manufacturing processes.

Breakthrough records in the efficiency of organic solar cells have been achieved by Prof Henry Yan and his group in the Department of Chemistry. Organic solar cells offer a flexible alternative to the conventional rigid inorganic solar cells that make up today's solar panels.

The advantages of organic solar cells include faster and cheaper mass production processes due to their flexibility, including roll-to-roll printing similar to newspaper production. These solar cells are also light in weight and environmentally friendly. Such features open up integrated applications for windows, buildings, vehicles, and for charging mobile devices, such as smartphones, among others. Different shapes and colors add to commercialization potential.

The major challenge is to improve performance. While today's inorganic silicon crystalline solar cell has power conversion efficiency of around 20%, most published research results for organic solar cells remain at around 10%, which is still not sufficient for wide-spread commercial applications.

Through observation of a significant material motif that has enabled a novel method of controlling the morphology –



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This is a really exciting scientific development. Our new organic solar cells have the potential to reach conventional inorganic performance levels

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**PROF HENRY YAN**

Assistant Professor of Chemistry

the mixing – of materials in the solar cell based on temperature control, Prof Yan has made a major stride in this global race by achieving record-breaking efficiency for single-junction organic solar cells of up to 11.5%. For the first time, Hong Kong research has been featured in the US-based National Renewable Energy Laboratory (NREL) table – an authoritative record of data from around the globe on the best research cell efficiencies. These findings have also appeared in *Nature Communications* (2014) and *Nature Energy* (2016).

Prof Yan and his group have also developed a “family” of polymer and fuller-

ene materials for use in high-efficiency polymer solar cells. In addition, he is working together with Prof Ching W Tang and physics colleagues, including Prof KS Wong and Prof Jiannong Wang, to better understand the properties of the new synthesized materials and improve solar cell performance. Other HKUST researchers are working on harvesting solar energy through chemical means. Prof Zhiyong Fan and his research team focus on engineering nanostructured materials with enhanced light absorbing characteristics, while Prof Shihe Yang and his group have developed methodologies for synthesizing monodispersed nanostructured materials of transition metals with specific properties to be used for solar cells.



## HKUST Energy Institute: Powering Forward

The HKUST Energy Institute is a leading international center for energy research and education, with a reputation for excellence across a broad range of fields, which includes sustainable energy generation, storage, distribution and utilization. It is a multidisciplinary platform for integrating, facilitating and enabling University-wide programs in energy-related research, development and education.

Building on HKUST's existing research strengths, the Institute strives to provide a strong and visible leadership role in energy research in Hong Kong, as well as to engage in emerging energy research that will have a long-term, transformative effect on Hong Kong and the nation's energy future. The Institute also promotes knowledge transfer in collaboration with local and international partners and establishes a channel of communication between the University and the public through outreach activities.

### Temperature-dependent aggregation enables ideal morphology

The polymer solution is not aggregated at high temperatures, but strongly aggregated at room temperature. This unique property allowed HKUST researchers to achieve multiple cases of record efficiency organic solar cells.

