HYDROGEN

A newsletter of the Centre for Hydrogen Innovations

2024 Issue #2

NUS National University of Singapore

HYDROGEN

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Newsletter of the Centre for Hydrogen Innovations (CHI)

INSIDE

Photo: Mi Junyu

Official opening ceremony

After two years of operation as a virtual centre, July saw the official opening of the physical Centre for Hydrogen Innovations, ushering in a new era of breakthroughs for our researchers and industry partners alike.

The launch on 25 July 2024 was officiated by Dr Tan See Leng, Minister for Manpower and Second Minister for Trade and Industry, in the presence of distinguished guests from the hydrogen research and industry community in Singapore and beyond.

Dr Tan noted the importance of our work in his keynote speech, "Singapore is seriously studying low-carbon hydrogen as a decarbonisation pathway… However, hydrogen technology is still nascent. Significant technological breakthroughs are required to enable the deployment of hydrogen at scale and in a cost-effective manner. We must prioritise raising the technological readiness levels and the market-readiness levels of hydrogen technologies. This requires closer collaboration across all stakeholders across the ecosystem."

Advisor

Prof Yan Ning

Managing Editor

Dr Jackson Leow

Editor

Ms Keshia Saradima Indriadi

Activities in the new CHI lab

Prof Yan Ning gives guidance to Mr Maxim Dickieson on carbon dioxide hydrogenation next to our state-of-the-art four-channel reactor. Photo: TK.

Ms Zhou Yuxin and Mr Jung Mu Nam discuss the automated production of novel catalysts using our cutting-edge robot. Photo: TK.

Ms Keshia Saradima Indriadi develops novel catalysts and processes for the cracking of ammonia to generate hydrogen. Photo: TK.

In his address, NUS President Professor Tan Eng Chye said, "The launch of the Centre for Hydrogen Innovations represents a bold, significant step that NUS is taking towards building a sustainable future. The Centre is taking off on a strong start, and I look forward to its contributions towards knowledge building, Singapore's climate target of net zero emissions target by 2050, and the global fight against climate change."

Representing Temasek, Head of Emerging Technologies Mr Russell Tham said, "Tackling today's complex sustainability challenges demands a comprehensive, whole-of-system approach, and multi-stakeholder collaboration. A blend of sustained STEM-based R&D; technology-savvy entrepreneurs and investors; global and cross-sector partnerships; and diverse public and private capital with a risk appetite and stamina, can cultivate a vibrant deep-tech innovation ecosystem. As a co-founder of the Centre for Hydrogen Innovations with NUS, we are committed to leveraging our capabilities and networks to help advance low-carbon hydrogen technologies and strengthen their pathways for broader adoption".

Our commitment to strengthening Singapore's hydrogen research infrastructure is exemplified by the awardees of our third grant call (p. 5).

CHI is also dedicated to building a strong talent pool for the future hydrogen economy. Dr Tan has highlighted, "Many new low-carbon technologies will have applications across multiple sectors, in energy and chemicals, chemical storage, marine bunkering, power generation and aviation. Existing talent in these industries would need to be equipped with the necessary knowledge and skills to seize new opportunities".

We intend to recruit more scholars and PhD students as well as introduce courses in hydrogen technologies to better educate experts in the field. CHI also promotes the hydrogen economy to younger audiences and the public through events such as the Hydrogen Innovation Challenge (p. 4) or hosting school visits to our lab (p. 7).

The importance of industry partnerships must also be emphasized. Dr Tan said in his speech, "Industry stakeholders know the problems best and can improve the value proposition and industry relevance of research projects. At the end of the day, we want these projects to deliver commercial value. Our researchers complement industry participation with their domain expertise and thorough research methodologies, to achieve breakthroughs in technological bottlenecks"

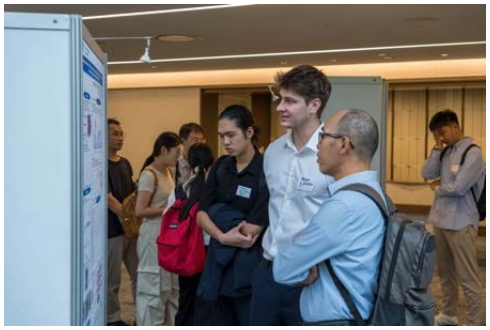
CHI has established close collaborations with more than 25 industry partners. An example is our partnership with a multinational corporation to develop gas turbine technology using partially cracked ammonia/hydrogen blends as feedstock (p. 6).

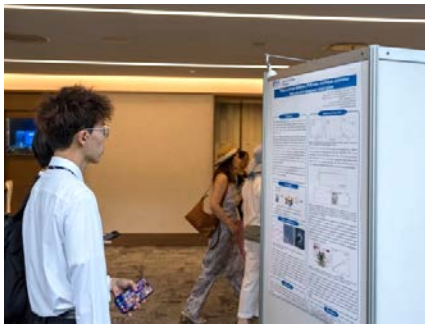
Dr Tan leaves high hopes for our work in the closing of his speech, "With continued investment in industry-relevant research and education, I believe we can cultivate a thriving hydrogen ecosystem, complemented by a skilled, adaptable, and diverse workforce ready for a low carbon future."

Read the full write-up of this event on NUS News and The Straits Times.

Keynote address by Dr Tan See Leng, Minister for Manpower and Second Minister for Trade and Industry. Photos: Mi Junyu.

Welcome addresses by NUS President Prof Tan Eng Chye (left) and Temasek Head of Emerging Technologies Mr Russell Tham (right). Photos: Mi Junyu.





Various snapshots from the lively atmosphere of the Official Opening Ceremony event. Photos: Mi Junyu.

The 2024 Hydrogen Innovation Challenge

The research we do in the CHI lab will be more appreciated if we nurture the next generation of scientists and garner public support for a hydrogen future. These are the two things we aimed to accomplish with the Hydrogen Innovation Challenge, a two-part competition for undergraduates under the theme "Hydrogen for Singapore in 2050".

Inspired by Singapore's national strategy to have 50% of electricity needs be met by hydrogen in 2050, in the first round of this competition we asked students to form groups and create short-form videos exploring this theme in any way, whether it be visualizing such a hydrogen future or the technologies needed to achieve it.

The videos were posted to our Instagram (you can still check them out @chi_at_nus!) and gained 20,000 total views from almost 15,000 unique accounts. The top two teams whose videos got the most likes and four other teams chosen based on expert judges' ranking (on criteria including informativeness and presentation) proceeded to the second round of the competition.

Here, the top six teams battled it out in an exciting quiz show on the topics of hydrogen technology, economics, and policy. Audience members also joined in on the fun with a Kahoot version of the quiz and stood to win prizes too.

Finally, team Green Catalysis emerged as the first winners of the first iteration of the Hydrogen Innovation Challenge, followed by team HydroSG in second place and team HydroGEN in third. The winning teams were invited to the Opening Ceremony to receive their prize checks from the guest of honour Dr Tan See Leng.

We're sincerely proud of our undergraduate challenge participants, and CHI hopes to continue promoting public awareness of green hydrogen in the future.

Top to bottom: Winners receive prize checks from Minister Dr Tan See Leng, awarding certificates at the end of Round 2, contestants answer quiz questions during Round 2. Photos: Mi Junyu.

CHI awarded eight projects in its third grant call

The eight awardees with Deputy President (Research & Technology) Prof Liu Bin and CHI Director Prof Yan Ning. Photo: Mi Junyu.

CHI announced its third grant call in April 2024. Researchers applied for grant funding of up to $350,000 each for projects lasting two years.

Two types of projects may be proposed. The Quantum Leap Hydrogen Research Grant aims to advance the frontiers of knowledge and prioritises groundbreaking ideas with the potential to change the hydrogen sector. On the other hand, the Hydrogen Horizon Prototype Grant fosters new enterprises and will provide resources to create market-oriented prototypes that pave the way for commercialisation.

The latter type of funding will particularly benefit from a close partnership with NUS GRIP (Graduate Research Innovation Programme). Projects will receive support from venture creation to incubation, as well as access to a network of well-known deep-tech start-up investors.

Under the Quantum Leap research grant, the following are the 4 grantees:

1. Dr Gao Jiajian (A*STAR ISCE^2 and CHI) will investigate electro-assisted low-temperature methane coupling;
2. Asst Prof Wang Lei (NUS ChBE and CHI) will unleash the power of direct borohydride fuel cells;
3. Dr Wong Voon Kean (A*STAR IMRE and CHI) will be advancing hydrogen pipeline safety; and
4. A/Prof Zhao Dan (NUS ChBE and CHI) plans to revolutionize H_2 purification using low-energy membranes.

Four projects were also awarded under the Hydrogen Horizon Prototype grant, including

1. Investigations of scalable high-entropy alloy catalysts by A/Prof Huang Yizhong (NTU MSE and CHI);
2. Ammonia-hydrogen fusion marine engines by A/Prof Yang Wenming (NUS ME and CHI);
3. Graphene-based membranes for CO_2 separation by Prof Antonio H Castro Neto (NUS CA2DM and CHI); and
4. Indirect seawater electrolysis by Prof Ho Ghim Wei (NUS ECE and CHI).

The awards were presented by NUS Deputy President (Research and Technology) Prof Liu Bin. Photos: Mi Junyu.

Team leads of the LCER-funded project on ammonia partial cracking and combustion.

Special symposium on clean combustion kicks off S$8 million project on ammonia/hydrogen combustion

Over the next three years, CHI is proud to be hosting some of the research facilities for the project "Development of an integrated system of ammonia partial cracking and gas turbine combustion with cascade waste heat utilisation".

This project is one of six Directed Hydrogen Programmes (DHP) under the Low-Carbon Energy Research (LCER) program funded by Singapore's National Research Foundation. It promises to advance the technologies needed to partially crack ammonia into a hydrogen/ammonia blend and to use this blend as a fuel for clean gas turbine combustion.

The project was kicked off with a meeting on 21 May 2024 attended by all the involved PIs, who come from a variety of institutions including NUS, NTU, A*STAR Institute for High Performance Computing (IHPC), and the Cambridge Centre for Advanced Research and Education in Singapore (CARES). PIs bring their unique expertise to solving this complex problem, from catalysis to combustion and gas turbine system modelling. The project is also strongly supported by various industrial companies, including Siemens Energy, Keppel New Energy, Sembcorp Industries, and CADFEM SEA.

The celebration for this project kick-off continued with a special symposium on clean combustion featuring talks from three world experts on the topic.

Professor Agustin Valera-Medina from Cardiff University in the UK shared about global research trends of ammonia as an energy vector, including the increasing scrutiny on the use of ammonia or ammonia blends as a direct fuel in gas turbines.

A more fundamental look into combustion science was given by Professor Kaoru Maruta from Tohoku University in Japan. Prof Maruta discussed the mechanisms of lean ignition limits and methods for knock prediction.

Lastly, Research Assistant Professor Thibault Guiberti of King Abdullah University of Science and Technology in Saudi Arabia presented on turbulent reactive flows of ammonia and hydrogen for decarbonised power and propulsion. A focus was given to key techniques that can be used to understand turbulence-chemistry interactions, such as gas-phase Raman imaging.

With such expertise and a global network of authority figures in the field, this project may surely bring Singapore one step closer to a decarbonised power sector through ammonia/hydrogen combustion.

The project commenced with a meeting and a symposium on clean combustion. Photo: Jackson Leow.

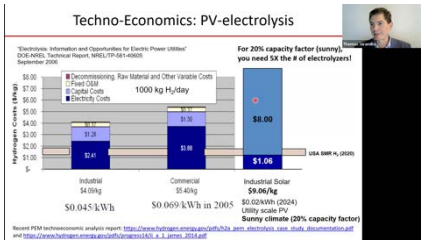
Students from Khon Kaen University Thailand visited CHI

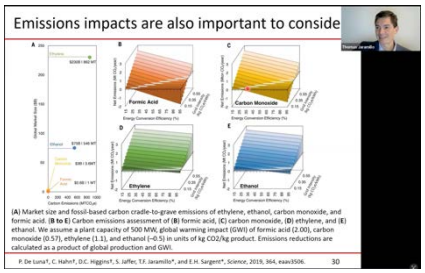
As part of our commitment to nurture the hydrogen talent pipeline, CHI is happy to host visits from students all around the world.

One such visit occurred on April 23, when Assoc. Prof. Duangkanok Tanangteerapong of Khon Kaen University and 25 of his undergraduate students travelled from Thailand to our lab here in Singapore.

The students were given a talk on CHI's research endeavours and learned about the practical research environment outside of Thailand by participating in a lab tour. We hope this visit has inspired the next hydrogen heroes in Thailand and beyond!

Students from Khon Khaen University in Thailand take a tour around NUS and the CHI labs. Photos: Jackson Leow.





Prof Jaramillo shares his expertise on techno-economic analysis

Stanford's Prof Thomas Jaramillo teaches techno-economic analysis

Performing a techno-economic analysis is critical to evaluating the economic viability of technologies at an industrial scale.

This tutorial attracted 91 participants from 7 institutions who tuned in to Prof Thomas Jaramillo's online tutorial on the topic on the morning of March 13 (or the evening of March 12 in Prof Jaramillo's case). Prof Jaramillo discussed what a techno-economic analysis consists of and gave practical examples for different analysis approaches, followed by a Q&A with the audience.

Members of the CHI community who wish to conduct techno-economic analyses of their innovations may refer to the resources posted on our website.

Distinguished Speakers Series

The past six months saw 7 experts sharing their knowledge in our Distinguished Speakers Series, including three of our own Governing Board members, who closed out the Official Opening Ceremony with their riveting lectures.

Dr David Danielson shared his experiences with deep-tech venture creation in Breakthrough Energy and provided insights on the big challenges in hydrogen that need new ventures, such as how to push $1-2/kg delivered hydrogen and how to provide 24/7 delivered hydrogen.

Mr Bernd Heid, global lead for McKinsey & Company's Climate Technologies and Hydrogen services, shared about the climate technologies needed to achieve abatement targets. Interestingly, he introduced the concept of a "Moore's Law" of climate technology, in which roughly a 100x scale-up of technology would bring a 70% decrease in its cost, handy for projecting where technologies may grow.

We were happy to welcome Prof Thomas Jaramillo once again, who brought us back to basics and asked us "What does a chemical engineer do?". He urges us to rethink the processes in our chemical industry, despite its perceived success. For example, why must all industrial chemical production require energy input when they are inherently exothermic? It's a thinker.

Top: Prof. Thomas Jaramillo says we must rewrite the story of the chemical industry. Middle: Mr Bernd Heid talks about scaling climate technologies. Bottom: Dr. David Danielson begins his talk on company creation in the hydrogen industry. Photos: Mi Junyu, Jackson Leow.

Also on the topic of scalable energy innovation, on the 17th of April CHI together with the NUS Department of Chemical and Biomolecular Engineering (ChBE) invited Dr. Hariprasad Subramani of Chevron – Innovation & Technology Ventures (USA) to speak on the topic.

We've also learned about verifying greenhouse gas emissions from methane and blue hydrogen technologies from Prof. David T. Allen, ExxonMobil Visiting Chair Professor at ChBE, who visited us on May 28.

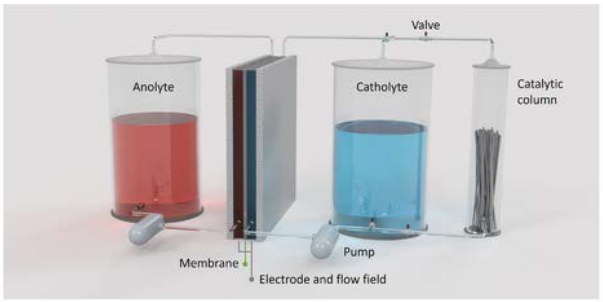
Our other talks focused on catalysis. On May 15, Prof. Zhang Yawen of Peking University spoke of his work on selective catalytic conversion of CO_2 into fuel using nanostructured materials and driven by heat, light, and electricity.

On March 27, Prof. Kazuhiro Watanabe of the University of Tokyo spoke on the importance of electrolyte engineering when performing water electrolysis using diverse water resources.

We also learned more from a materials perspective as Prof. Yong Wang from Washington State University gave a talk on thermally stable single-atom catalytic materials on February 26.

We thank all our distinguished speakers once more for sharing their knowledge with us this year!

Clockwise from top: Q&A during Prof. Yong Wang's talk, Prof. Yan Ning introduces Prof. Yawen Zhang, Q&A with Prof. Yawen Zhang, Prof. Kazuhiro Watanabe gives his talk to a captivated audience, Prof. Yong Wang introduces his work. Photos: Jackson Leow.



Anode reaction:
$[Zn(OH)_4]^{2-}+2e^- \leftrightarrow Zn+4OH^-$

Cathode reaction:
$[Fe(CN)_6]^{3-}+e^- \leftrightarrow [Fe(CN)_6]^{4-}$

Irreversible side reactions at anodic side (CE loss):
$2H_2O+2e^- \rightarrow 2OH^- + H_2\uparrow$
$Zn+2OH^- + 2H_2O \rightarrow [Zn(OH)_4]^{2-}+H_2\uparrow$

OER for CE compensation:
$4OH^- - 4e^- \rightarrow 2H_2O + O_2\uparrow$ (On electrode)
$4[Fe(CN)_6]^{3-}+4OH^- \xrightarrow{Catalyst} 4[Fe(CN)_6]^{4-} + 2H_2O + O_2\uparrow$ (In catalytic column)

Advanced Materials, **36**, 2406366 (2024)

Energy storage in zinc-based flow batteries

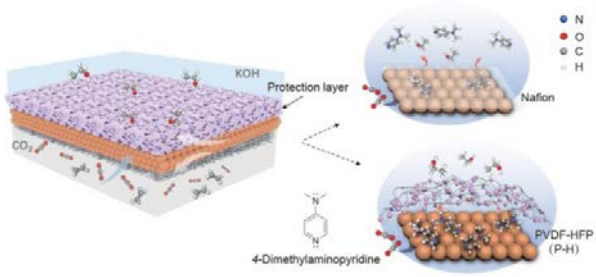
-S. Huang, Qing Wang*

Alkaline zinc-iron flow batteries are well suited for energy storage because they are safe, low-cost, and have a high cell voltage. Unfortunately, the occurrence of irreversible anodic parasitic reactions results in a diminished coulombic efficiency, an unbalanced catholyte/anolyte charge state, and consequently a poor cycling performance. Herein, a strategy is introduced that aims to equalize the catholyte charge state by introducing the oxygen evolution reaction on the cathodic site. This strategy results in a battery with exceptional cycling performance and an extremely low-capacity fading rate. Read the paper.

Enhancing electro-catalytic CO_2-to-ethanol conversion

-W. Fu, Y. Li, Jia Zhang*, Lei Wang*

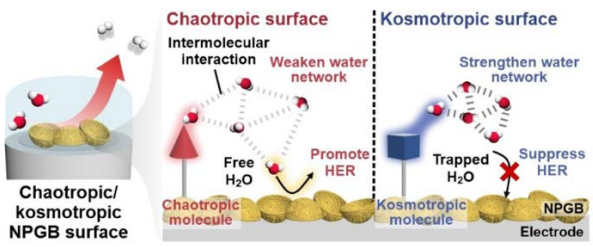
Converting carbon dioxide into multi-carbon products is a challenge. Small molecular additives on a catalyst surface may enhance electrocatalytic performance but are difficult to preserve. Here, a protective layer is introduced onto the electrode surface that prevents catalyst leaching, promoting CO_2-to-multicarbon conversion at low overpotentials. The system with a protective layer exhibits 80% selectivity towards multi-carbon products (primarily ethanol) while an unmodified catalyst achieves only 35% selectivity. This was because the reaction energy for C-C coupling has been reduced. Read the paper.



Angewandte Chemie International Edition, e2024070992 (2024)

Boosting green hydrogen electrosynthesis by disrupting water intermolecular networks

-L. S. Ng, E. L. C. Chah, M. H. Ngieng, Hiang Kwee Lee*



Angewandte Chemie International Edition, **136,** e202317751 (2024)

Hydrogen production from water-splitting is limited by poor hydrogen evolution reaction efficiency because water molecules are thermodynamically trapped within their extensive hydrogen bonding network. By functionalizing the nano-electrocatalyst's surface with a monolayer of chaotropic molecules that chemically weaken water-water interactions, hydrogen evolution is boosted up to 3-fold from previous counterparts, providing a unique molecular approach that can be readily integrated with emerging electrocatalytic materials to rapidly advance electrosynthesis of green hydrogen. Read the paper.