THE PARTICLE TECHNOLOGY FORUM (PTF) NEWSLETTER

An American Institute of Chemical Engineers (AIChE) Forum

Message From The Chair

Greetings and Celebration of 30 Years of PTF Community Achievements

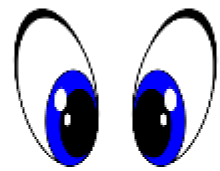
As we move into spring season with the promise of most of the things returning to normal, I hope you and your families and friends are doing well.

Let me start by introducing myself. I held a variety of leadership roles at Particulate Solid Research, Inc. as President & CEO, Technical and Consulting Director for the last 35 years. I am fortunate to work with all kinds of unit operations in particle technology and fluid-particle systems such as fluidized beds, circulating fluidized beds, cyclones, diplegs, standpipes, risers, nonmechanical valves, pneumatic conveying, solids feeding and discharge systems. Working with Dr. Ted Knowlton and others at PSRI, we worked on how the fine particles clump/cluster together, gas bypassing in fluidized beds and scale-up of particle technology unit operations. I firmly believe in the formation of clusters that make up galaxies which in turn form the universe (hence the picture representing my term as the chair).

These sub-micron and nano particles are playing a major role in the emerging technologies in particle technology in paradigm shift in energy sector:

- Hydrogen production via chemical looping, pyrolysis of natural gas, dehydrogenation of methane,
- Production of solar grade polysilicon using FBR,
- Dehydrogenation of propane and ethane,
- CO2 capture from atmospheric air and flue gases for sequestration,
- Biomass pyrolysis using heat carrying inert particles or catalyst particles,
- Biomass gasification,
- Plastic pyrolysis using catalyst particles,

A Peek At The Contents



- Decarbonization of the conventional travel with fossil fuels,
- Graphene production for battery electrode materials and composites, and
- Carbon capture technologies.

These are exciting times for particle technology members playing a pivotal role in both old and new energy sectors. We need to attract more of the graduates in chemical engineering proficient in particle technology. The energy paradigm shift needs more of these graduates by the industry. Not all academic institutions are offering courses in this field. Particle Technology Forum (PTF) leadership initiating new webinar series to expose the current undergraduate and graduate students to these exciting new areas of particle technology and how they can be part of the new emerging technologies. The goal is to get them interested in this field and offer the tools (AICHE online courses) for them to prepare for the future jobs in the new energy sector.

Based on input from the PTF community, we have launched a new initiatives including increasing diversity, equity, and inclusion efforts. PTF community I know is the most friendly and great folks. However, I am saddened to report that few bad apples behaved badly at the last year's PTF dinner. We will take extra precautions at this year's dinner to prevent these incidents.

My gratitude to this newsletter's editor, Dr. Shrikant Dhodapkar, for creating informative newsletter, Dr. Ben Freireich for planning all PTF sessions, and all members of the executive committee who keep programming and events running smoothly. Prof. Maria Tomassone, Vice-Chair, is taking care of award nominations. Please take a lead in nominating well deserved nominees for various. PTF awards. Finally, I'm grateful to Prof. James Gilchrist, former PTF Chair, for a smooth transition in handing me the baton. We have worked closely over the last couple of years and his mentorship through this process was extremely valuable.

Hope to see you in person at AIChE Annual Meeting - November 5-10, 2023, Hyatt Regency Orlando, Orlando, FL, USA.

S.B. Reddy Karri, PhD, President &. CEO, PSRI
Chair, The Particle Technology Forum of AIChE
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PSRI Particulate Solid Research, Inc.

EDITORIAL

I, once again, have the privilege of being the editor of the Particle Technology Forum Newsletter. Our newsletter has had a longstanding track record of providing an equal opportunity platform to communicate, share knowledge, bring awareness and celebrate the accomplishments of our colleagues. The newsletter is a collective effort where the content is enriched through voluntary contributions. It requires active participation from all the members. Therefore, I will be reaching out to you for new ideas, technical contributions and information which can benefit all of us. If you have any ideas or suggestions about the newsletter, please do not hesitate to reach out to me by email (sdhodapkar@dow.com).

PTF will continue to publish three newsletters (Spring, Summer and Fall) each year. I will be striving to add new topics aligned with the current interests, such as process intensification, sustainability, carbon neutrality and circularity. The breadth of topics covered in our newsletter must reflect the evolving interests of our readership. Further, we need to enhance our engagement with other societies and forums in the field of particle technology.

I want to express my gratitude to Dr. Ray Cocco, Dr. Reza Mostofi, Dr. Mike Molnar, Dr. Mayank Kashyap, Dr. George Klinzing, Dr. Reddy Karri and Dr. Maria Silvina Tomassone for agreeing to serve as the Editorial Advisory Group.

Finally, I want to thank Dr. Mayank Kashyap for his extraordinary service to the PTF as the editor of the newsletter for the past four years. He has done an outstanding job of maintaining the highest quality during his tenure.

Shrikant Dhodapkar, PhD

Senior R&D Fellow
The Dow Chemical Company
sdhodapkar@dow.com

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2023 PTF Award Nominations – Opened since March, 2023

Dear PTF Members:

The deadline for nominations is approaching fast….

The full package (a single PDF document) is due by Wednesday, May 31st, 2023

The nomination information, award criteria, and previous winners for each of these awards can be found here - https://www.aiche.org/community/sites/divisions-forums/ptf/awards

PSRI Fluidization and Fluid-Particle Systems:

https://www.aiche.org/community/awards/psri-fluidization-and-fluid-particle-systems

Shell Thomas Baron Award in Fluid-Particle Systems:

https://www.aiche.org/community/awards/shell-thomas-baron-award-fluid-particle-systems

Elsevier Particle Technology Forum Award for Lifetime Achievements:

https://www.aiche.org/community/awards/elsevier-particle-technology-forum-award-lifetime-achievements

Dow Particle Processing Recognition Award:

https://www.aiche.org/community/awards/dow-particle-processing-recognition-award

Sabic Young Professional Award:

https://www.aiche.org/community/awards/sabic-young-professional-award

George Klinzing Best PhD Award:

https://www.aiche.org/community/awards/george-klinzing-best-phd-award

Ansys Particle Technology Forum Service Award:

https://www.aiche.org/community/awards/ansys-particle-technology-forum-service-award

The PTF Executive Committee strongly encourages nominations from all qualified applicants for each award, especially nominees who are women and/or otherwise underrepresented backgrounds in our Forum, the Institute, and in STEM fields.

Key Information To Consider:

- **The Nomination process is a single step.**
- The full package (a single PDF document) is due by **Wednesday, May 31st, 2023**, containing items specific to each award.
- If the nominee has previously received any award from PTF, an explicit statement of new accomplishments or work over and above those cited for the earlier award(s) must be included (maximum of 1 double spaced page).

  Selected bibliography (including major papers published, books, and patents)
- In a given year, the same person cannot win more than one PTF award
- Wait period for nomination after previous award -

  A former PTF award winner cannot be nominated for another award for at least three years after receiving any previous PTF award
- **It is required that the nominators are current PTF members.**
- **Nominees are not required to be PTF members**

- For the PTF Lifetime Achievement Award, one of the support letters must be from a former PTF Lifetime Achievement Award winner.
- Except for the PTF Service Award, the Executive Committee has released the nominee PTF membership requirement. PTF membership is still expected for the PTF Service Award.

All questions and concerns should be addressed to me by email to silvina@soe.rutgers.edu with the subject line including the name of the award. The Executive Committee is actively developing processes to ensure equity, diversity, and inclusion in the forum and its awards.

We encourage the PTF members to nominate those well deserving candidates for various awards.

Maria Silvina Tomassone
PTF Vice Chair 2023-2024

S.B. Reddy Karri
PTF Chair 2023-2024

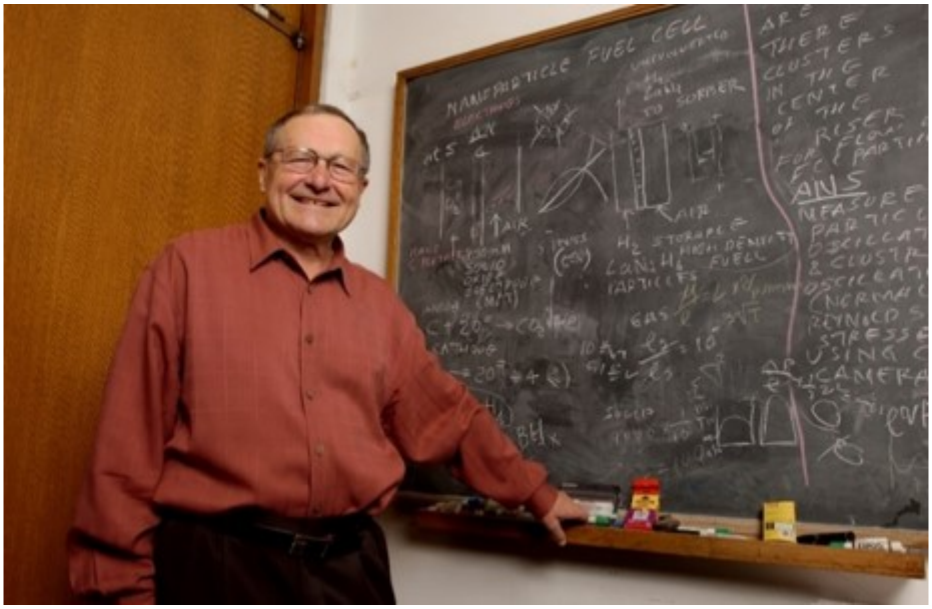
Dr. Jennifer Sinclair Curtis
Elected to National Academy of Engineering

One of our own PTF members - Jennifer Sinclair Curtis, Distinguished Professor of Chemical Engineering at the University of California, Davis - has been elected to the National Academy of Engineering's Class of 2023. Election to the National Academy of Engineering is among the highest professional distinctions accorded to an engineer. Jennifer was recognized for "work on particle-laden flows and industrially used algorithms for dilute and dense-phase gas-solid flow". The PTF has previously recognized the quality and impact of her research through her receipt of the Elsevier Lifetime Achievement Award, the Shell Thomas Baron Award in Fluid-Particle Systems, and the PSRI Fluidization and Fluid-Particle Systems Award.

Jennifer has been very active in the PTF, previous serving as PTF Chair (2013-2014), Treasurer (2009-2011), Member of the Executive Committee (1994-1998 and 2006-2010) and Newsletter Editor (1996-2000). She has also been very active within AIChE serving as a Member of the Board of Directors (2008-2011), Chair of the Executive Board of the National Programming Committee (2013), Chair of the Publications Committee (2016 – 2019), and Meeting Chair for the 2020 Annual Meeting. She currently serves as Vice-Chair of AIChE's Foundation Board of Trustees.

Congratulations Jennifer!

In Memoriam – Professor Dimitri Gidaspow (1934-2023)



It is with deep sadness that we mourn the passing of **Dr. Dimitri Gidaspow**, a distinguished university professor, emeritus, at the Illinois Institute of Technology (IIT), who passed away on January 9, 2023, at the age of 88, after a long battle with prostate cancer. He leaves behind a legacy of excellence in the field of chemical engineering and a lifetime of achievements and contributions to the scientific community.

Dr. Gidaspow was a devoted husband of 62 years of Mrs. Helene Gidaspow, a loving father of Michael ("Misha"), a father-in-law of Julie, and a cherished grandfather of Alex and Zach. His impact extended far beyond his family, as he was also a Ph.D. advisor of 52 students and a mentor to numerous researchers.

He was a man of exceptional character, well known for his kindness, honesty, generosity, and integrity. Dr. Gidaspow's background will serve to shed some light on the nature of his breadth of character. He was born in 1934 in Kobeliaki, Ukraine, southeast of Kyiv. His mother was an entomologist, and his father was an agricultural engineer. They both worked in a rural agricultural experimental station called Veseliy Podol, which was located in the country and run from Kyiv. His mother received a medal from Nikita Khrushchev, former Premier of the Soviet Union, for her joint development of the Russian version of Dichlorodi-phenyltrichloroethane (DDT) used to eradicate insects that devoured sugar beet plants. Dr. Gidaspow was educated by his mother and did not attend grade school until about nine, after which he attended several schools for about a year. While his parents worked, he stayed with his grandmother. He learned to read Ukrainian, as well as read and write Russian, which came in handy in the future years. He moved to Germany with his family during World War II before arriving in the United States at the age of 15 on the USS General C.H. Muir. He went to Seward Park high school in New York City, and graduated in 1952 as valedictorian of his class. He went on to earn a B.Ch.E. (cum laude) from the City College of New York, an M.Ch.E. from the Polytechnic Institute of Brooklyn, and a Ph.D. from IIT. He married his childhood sweetheart from Ukraine, Helene, in 1960.

Before joining the IIT faculty, Dr. Gidaspow was a Full Professor at the Institute of Gas Technology (IGT), where he made significant contributions to the fields of fuel cells and desiccant air conditioning, earning him an award from the Marshall Space Flight Center. He authored numerous peer-reviewed publications in these areas. Dr. Robert W. Lyczkowski recounts, "When I started working at IGT in September 1964, the number of faculty at the Gas Technology Department was quite small. There were only seven graduate students, including myself. Dr. Gidaspow alone taught the only graduate courses at IGT. He also directed graduate students' research in areas of his interest at the time, which included combustion, mass transfer, and heat transfer in fuel cells."

Dr. Ralph Peck, then Chair of the Chemical Engineering Department at IIT, who was also Dr. Gidaspow's former advisor, offered him a teaching position. He accepted the offer, expecting to spend at most one year in Chicago, which happily turned out to be an unfulfilled expectation for his numerous students over the next five decades, including all the co-authors of this tribute. As a teacher, he taught some of the major chemical engineering graduate courses at IIT, including heat transfer, transport phenomena, fluidization, computational techniques, and undergraduate thermodynamics.

Dr. Gidaspow's pioneering research in multiphase flow, starting in the 1970s, created a widely used simulation capability for solving practical problems involving industrial fluidized bed reactors, which defy conventional scale-up methods. He played a major role in modeling and simulating the complex flows that occur in fluidized beds and other multiphase-flow devices and in training and inspiring many researchers in that field worldwide. A predictive methodology using the kinetic theory for fluidized bed systems resulted from the research effort pioneered by Dr. Gidaspow. He analytically formulated expressions for the solid-phase stresses and solid-phase viscosity, which are crucial parameters in the closure relationship required in the kinetic theory approach. He then methodically devised experimental systems to verify these expressions and other important computational fluid dynamics (CFD) parameters. He effectively used CFD principles to describe the dynamic features in flow regime transitions of fluidization. He was one of a handful of pioneering researchers who successfully simulated industrial-scale multiphase flow systems.

His work on multiphase flow and fluidization is frequently cited in scholarly publications on constitutive relations, numerical simulations, experimental investigations, validation studies, and applications of simulations to industrial problems. His 1994 text-book, *"Multiphase Flow and Fluidization: Continuum and Kinetic Theory Descriptions,"* published by Academic Press, is widely used by students and industrial practitioners worldwide. Dr. Gidaspow's contribution to research and education of Fluidization and Fluid Particle systems has been extraordinary. His work has had a huge impact in shortening the gap between lab-scale research and commercial process development. What was mainly an academic pursuit in the 1980s is now available in commercial CFD software that the industry routinely uses for design and troubleshooting. Constitutive equations that Dr. Gidaspow developed, such as equations for drag and solids stress in gas-particle flow, implemented in commercial CFD software, are widely used for industrial problem-solving.

Dr. Gidaspow—Over the years...

With Dr. George D. Cody, Dr. Robert W. Lyczkowski, Dr. Frank Kulacki, Dr. Hamid Arastoopour, and Dr. Madhava Syamlal, at 1999 National Heat Transfer Conference, Albuquerque, NM, Festschrift honoring Dr. Gidaspow's 65th birthday

In the early 1970s, Dr. Gidaspow organized the first meetings to discuss problems arising in the fledgling field of two-phase flow, such as formulation of the field equations and scale-up of coal conversion processes. One was the Round Table Discussion, "Modeling of Two Phase Flow," held in 1974, at the Fifth International Heat Transfer Conference in Tokyo, Japan, and another was the "NSF Workshop on Mathematical Modeling," held in 1976, at the Two-Phase Flow and Heat Transfer Symposium-Workshop, Fort Lauderdale, Florida.

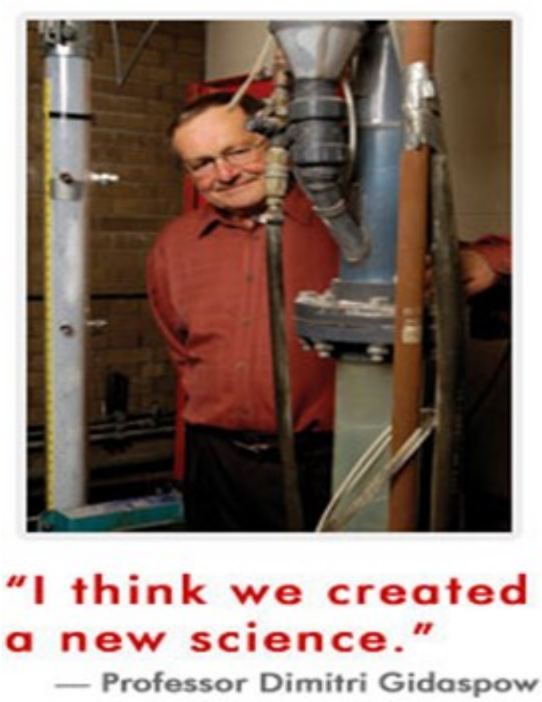
Dr. Gidaspow was a prolific and innovative contributor to chemical engineering research and literature. He made critical contributions to the understanding and ability to predict flows in fluidized bed reactors. Through 10 patents, 8 books, and more than 200 publications with close to 20,000 citations that covered a broad range of subjects in chemical engineering, he gained global recognition as a leader in the area of Kinetic Theory and CFD approach to Fluidization and Fluid/Particle systems. "The CFD approach to fluidization and fluid particle research would not be at the stage of progress it is at today without the extraordinary and outstanding research contributions from Dr. Gidaspow throughout the last 40 years," says Henry R. Linden Professor of Engineering at IIT, Hamid Arastoopour.

With Dr. Arastoopour, Dr. Huang, Dr. Liu, Dr. Mehdi Yassaie, and Mr. Dilip Dharia, 1976

With Dr. Arastoopour

His eight books have significantly improved our ability to understand and simulate fluidized bed systems -

1. *Dimitri Gidaspow, "Multiphase Flow and Fluidization: Continuum and Kinetic Theory Description," Academic Press, 1994;*
2. *Dimitri Gidaspow and Veeraya Jiradilok, "Computational Techniques. The Multiphase CFD Approach to Fluidization* and G*reen Energy Technologies," Nova Science Publishers, 2009;*
3. *Jonghwun Jung, Dimitri Gidaspow, and Isaac K. Gamwo, "Design and Understanding of Fluidized Bed Reactors," Lambert Academic Publishing, 2009;*
4. *Mayank Kashyap and Dimitri Gidaspow, "Dispersion and Mass Transfer Coefficients in Fluidized Beds," Lambert Academic Publishing, 2012;*
5. *Hamid Arastoopour, Dimitri Gidaspow, and Emad Abbasi, "Computational Transport Phenomena of Fluid-Particle Systems," Springer, 2017;*
6. *Robert W. Lyczkowski and Dimitri Gidaspow, "Topics in Multiphase Transport Phenomena," AuthorHouse, 2020;*
7. *Lu Huilin, Dimitri Gidaspow, and Shuyan Wang, "Computational Fluid Dynamics and the Theory of Fluidization Applications of the Kinetic Theory of Granular Flow," Springer, 2021;*
8. *Hamid Arastoopour, Dimitri Gidaspow, and Robert W. Lyczkowski, "Transport Phenomena in Multiphase Systems," Springer, 2022.*



During his illustrious career, Dr. Gidaspow served as a consultant to several esteemed organizations, including the Atomic Energy Commission (AEC), Lawrence Livermore Laboratory, Energy Research Corp., Argonne National Laboratory, the U.S. Department of Energy (DOE), Exxon, Mobil, Westinghouse, UOP (a Honeywell Company), and many others.

Dr. Gidaspow's contributions to the field of particle technology extended far beyond research. He was very active in the American Institute of Chemical Engineers (AIChE), serving as organizer and chair of numerous sessions over the years and in the Particle Technology Forum (PTF) at AIChE annual meetings. "Dr. Gidaspow is also one of the most energetic and enthusiastic individuals that I have known, as well as one of the nicest. People who contribute as much as Dr. Gidaspow to his field come along perhaps once in a generation," said Dr. Ted Knowlton, Technical Consultant and Fellow, Particulate Solid Research Inc. (PSRI).

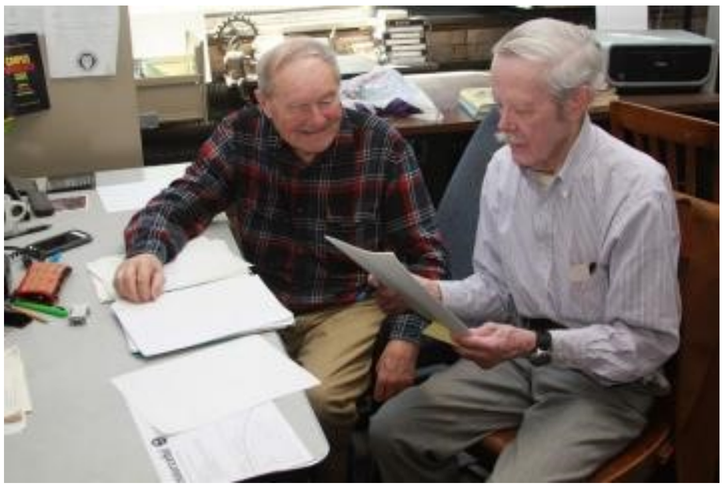
In the late 1970s, Dr. Darsh Wasan, Chemical Engineering Department chair, and Dr. Gidaspow began a highly productive collaboration at IIT, which led to, among other things, the invention of two practical devices based on electrokinetic phenomena — a cross-flow electrofilter and a lamella electrosettler to separate carbonaceous particles from nonaqueous media. They shared the 1986 NSF Creativity Award for that work.

Dr. Gidaspow's contributions were recognized through several prestigious awards. In 2000, he became Distinguished University Professor, the highest recognition IIT gave to a faculty member. He was a 60-year member and a Fellow of AIChE. His other awards include the AIChE 1984 Donald Q. Kern Award with the lecture: "Hydrodynamics of Fluidization and Heat Transfer: Supercomputer Modeling," published in Appl. Mech. Rev. 39, No. 1, 1-23, 1986; the AIChE Flour-Daniel Lectureship Award in Fluidization by the PTF (2002); the IIT/Sigma Xi Research Award (2005); the Ernst W. Thiele Award from the AIChE Chicago Section (2005); the AIChE Thomas Baron Award (2006); and the AIChE PTF Lifetime Achievement Award (2013).

At Ernst W. Thiele Award from the AIChE Chicago Section for fundamental contributions to CFD, multiphase flow and fluidized bed systems and as an educator, 2005

He was a fair and astute judge of character who was quick to recognize talented and promising students and researchers. "Dr. Gidaspow was a natural choice as an M.S. thesis committee member, as I had used in my thesis methods he taught in his computational techniques course. My advisor, young Professor Charles Wittmann, was Dr. Gidaspow's office neighbor and friend. At my M.S. thesis defense, Dr. Gidaspow asked, "Did you come up with this equation, referring to the main equation in my thesis?" Having recently come from India, I was unfamiliar with claiming ownership of any equation and could not give a "yes" or "no" answer. Then, he asked a series of questions: "Did you do this?" "How did you get that term?" and so on. Ultimately, he gave his verdict, "You derived it; it is your equation." In a week or so, he invited me to work with him on my Ph.D. thesis," says Dr. Madhava Syamlal.

Dr. Gidaspow was sympathetic to others' situations and was very generous in financially supporting his students (and at least one colleague, as recounted later). "Around the time I was finishing my M.S. thesis, Dr. Gidaspow informed me that although he had written a proposal for funding through the DOE, there was no guarantee for its acceptance. Despite the fact that he wanted me to pursue Ph.D. in his group, he shared his honest view that it would be unfair to me, especially as an international student at the time, to start working on my Ph.D. thesis without the guarantee of funding through a research assistantship. I was also not ready to give up on my dream of obtaining a Ph.D. by being forced to return to India due to the lack of funding. Therefore, he asked me to reach out to another professor who had a fully-funded project. With tremendous respect for him in my heart (both on personal and professional levels), I told him, Sir, I would really love to pursue Ph.D. under your guidance, even if you fund me through a teaching assistantship. Another reason for my refusal to leave his group was that I felt a special connection with him because his Ph.D. thesis advisor, Dr. Peck, had established the Chemical Engineering Department at Panjab University, India, in the 1950s, from where I obtained a B.E. degree decades later. After about a 10-second pause, he gave me an invaluable gift by saying something to the effect, “OK, you can continue. Let’s hope the DOE funding comes through”. Within a couple of weeks, the proposal was funded, and I continued my research, becoming his last full-time Ph.D. student before retirement (a fact I will always take pride in and cherish). It was one of the best decisions I ever took at a very important point in my life that worked out beautifully, professionally and personally, as I met and later married my wife, Dr. Teresita Kashyap, who was also a student at IIT. On one occasion, he even used his summer salary to pay my tuition, which was not covered by project funding. It was an unprecedented act of generosity that spoke volumes of his helping nature. During Dr. Gidaspow’s retirement party, one professor spoke that even he was the beneficiary of Dr. Gidaspow’s generosity in the form of summer salary,” recounts Dr. Mayank Kashyap. Dr. Syamlal remembers a similar act of kindness when Dr. Gidapow gave him an additional project and upfront payment when he realized he could not start working right after his Ph.D. thesis defense due to the delay in work visa approval. Dr. Gidaspow also gave him his old car at no cost, a yellow-colored Dodge Omni hatchback, which Dr. Syamlal drove to Morgantown, West Virginia, where his new job was located.



With Dr. Lyczkowski, 2019

Dr. Arastoopour says, “Dr. Gidaspow was a man with beautiful heart and love for his research and students. He went out of his way to help and promote his students. He was a man of honesty and integrity. I remember a few times around 9 PM, when I was a student (mid 1970's), getting calls from Mrs. Gidaspow looking for Dr. Gidaspow. He was so involved in research that he often forgot what time it was. We knew he was in the building because he sometimes used to come to the vending machine to get a pop.” He, along with his wife, beautifully played the role of foster parents to students who flew into Chicago to pursue higher studies far away from their families.

With Mrs. Helene Gidaspow, Dr. Ali Cinar, Mr. Ahmad Zarnegar, Dr. Arastoopour, Dr. Fouad Teymour, Dr. Sohail Murad, Dr. Lyczkowski, and Dr. Darsh Wasan during the get-together at the Gidaspow residence (60+ club), 2018

"In the many years of my interactions with Dr. Gidaspow, I had witnessed and experienced his willingness to help others at any level he possibly could. I had surely benefited from his support at the technical meetings, where he made sure that I made the right connections and encouraged me to participate and present. He was constantly looking for ways to celebrate others, either by nominating his peers for various PTF awards or by supporting them through letters. He was generous in the true sense of the word," recounts Dr. Reza Mostofi.

With Dr. Reza Mostofi and Dr. Arastoopour at the Gidaspow residence in 2014

With Dr. Arastopour, Dr. Mostofi, Dr. Teymour, and Dr. Cinar at the Gidaspow residence in 2014

Dr. Gidaspow treated his students as peers, which, according to Dr. Kashyap, was intimidating in the first few months of their partnership, as it was initially hard to grasp concepts that Dr. Gidaspow pioneered in the kinetic theory of granular flow. "He often took his students out for lunch and talked endlessly about all his great ideas for research. Students soon realized his mind was so full of ideas that he usually did not hear them. Students learned to state their thoughts multiple times, and in the end, Dr. Gidaspow would bend his head sideways and say something to the effect, *"Oh, Gee. That makes sense",*" says Dr. Syamlal.

With Dr. Mostofi, Dr. Azita Ahmadzadeh, Mrs. Gidaspow, and Dr. Lyczkowski, 2014

With Dr. Cinar, Dr. Ahmadzadeh, Dr. Wasan, Dr. Arastoopour, Mrs. Nasrin Arastoopour, Dr. Teymour, Dr. Mostofi, Mr. Yasha Mostofi, and Dr. Lyczkowski at the Gidaspow residence, on his 80^{th} birthday, 2014

With Dr. Ahmadzadeh, Dr. Mostofi, and Dr. Mehmet Tartan at the Gidaspow residence in 1997

With Dr. Bing Sun, Dr. Augusto Neri, Dr. Mostofi, and Dr. Alex Nikolov at the Gidaspow residence in 1997

With Dr. Teresita Kashyap and Mrs. Gidaspow at the Kashyap residence in 2009

With Dr. Teresita and Dr. Mayank Kashyap, 2010

Dr. Gidaspow respected his students and researchers and did not hesitate to change his mind after listening to students' new ideas (and different from own his). Although he was passionate about research, he always tried to focus on collaboration rather than competition. He believed in speaking his mind respectfully without intending to hurt anyone. "On one occasion, Dr. Gidaspow told me that obtaining inlet and outlet gas concentrations for mass transfer measurements in a fluidized bed setup was sufficient. His rationale was that obtaining gas concentrations at various elevations was risky, as it would require careful drilling of several holes through the glass interface without breaking. He listened to my argument that the benefits were worth the risk and gave me a green signal to proceed. I ended up drilling 7 holes without breaking the glass, which made him happy," recounts Dr. Kashyap.

Dr. Syamlal remembers an occasion when someone challenged Dr. Gidaspow's mathematical equation. He says, "Dr. Gidaspow was well-known at IIT for his mathematical prowess, for example, his use of Green's Functions for solving transient heat transfer equations. I was aware of this reputation when I took his "Transport Phenomena" class in the Fall of 1980, having joined IIT in the Spring of 1980. In the first class, Dr. Gidaspow distributed his notes on the equations of fluid motion. At the start of the second class, a student sitting beside me got up and told him, "Professor Gidaspow, your equations are wrong." Dr. Gidaspow was taken aback, perhaps the first time anyone, let alone a new graduate student in his first week at IIT, questioned his mathematical equations. That was my friend, Rama. Both brilliant and blunt. Not unlike Dr. Gidaspow. It turned out that Dr. Gidaspow used a sign convention for the stress tensor different from the one Rama followed. All was good. Dr. Gidaspow and Rama became good friends."

With Dr. Kashyap, 2005

On his 72^{nd} birthday, 2006

With Dr. Gidaspow's last batch of students before retirement (Mr. Ta-Wei Tsai, Dr. Veeraya Jiradilok, Dr. Kashyap, and Dr. Jing Huang (co-advised by Dr. Lyczkowski)), on his 72^{nd} birthday, 2006

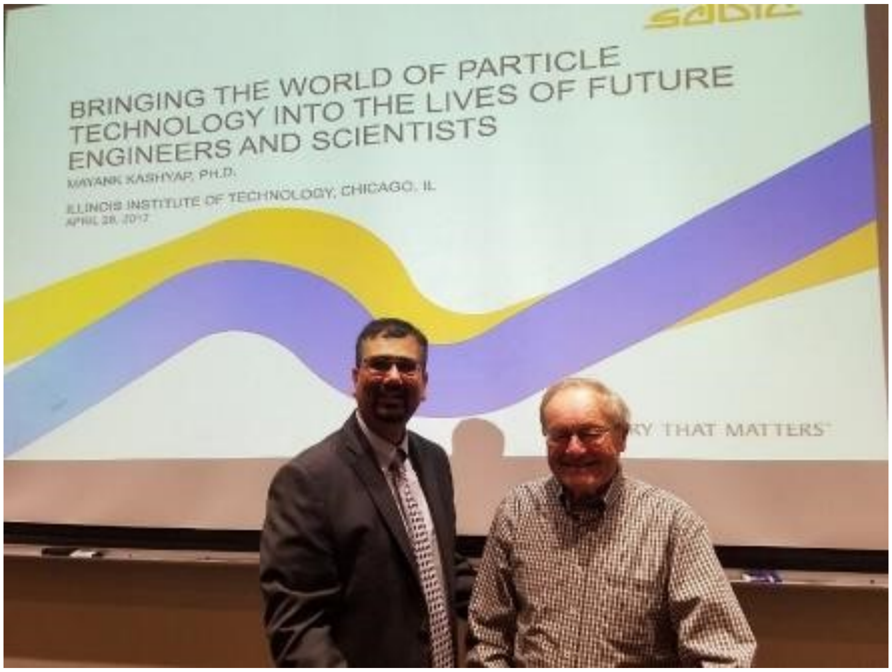
With Dr. Teresita Kashyap and Dr. Lyczkowski at the Gidaspow residence in 2017

Supporting his students to the fullest extent possible came naturally to Dr. Gidaspow. “One evening, right after finishing his graduate-level Transport Phenomena class, he told me that his *inguinal hernia* condition had worsened that required him to be rushed to the hospital. For someone who had less than a 3-month-old U.S. driver’s license under his belt and the huge responsibility of transporting *one’s boss* to the hospital in an emergency on his shoulder, I nervously accepted the challenge. Having gone through a similar surgery several years later, I now understand the pain he was under, and the trust he must have had in me to deliver under pressure. To my relief, everything, including his surgery, went well. I was scheduled to leave for the AIChE annual meeting along with him the following week to deliver my first talk in the U.S. Despite receiving instructions for bed rest from the doctors, realizing the importance of his presence at my talk, he came with me to the meeting, as planned,” says Dr. Kashyap.

On a lighter note, Dr. Robert W. Lyczkowski used to say, *“Dr. Gidaspow doesn’t age; in fact, he just gets better with age.”* He shares a photo to explain, “What keeps Dr. Gidaspow young.”

After the Gidaspow Festschrift in honor of his 80th birthday, at the 2014 AIChE annual meeting in Atlanta, Dr. Gidaspow, Mrs. Gidaspow, Dr. Jacques Bouillard (who traveled from France), Dr. Gamwo, Dr. Syamlal, Dr. Mostofi, Dr. Lu Huilin and his colleague, Dr. Guodong Liu, (who traveled from Harbin University in China), and Dr. Lyczkowski, walked to a Turkish restaurant where this photo was taken. Dr. Huilin is looking over Dr. Gidaspow’s shoulder. Dr. Gidaspow is wearing his favorite “brown suit.”

Dr. Lyczkowski shares another amusing account. “Dr. Susan Gelderbloom finished her Ph.D. thesis in 2001, with Dr. Gidaspow and I as co-advisors. She worked full-time at Dow Corning in Midland, Michigan, while taking online courses and working on her thesis. She visited Chicago every few months for us to go over the progress of her thesis together. She was also writing a paper for the AIChE Journal using voice recognition software, which was turning out to be a very slow process. Hence, Dr. Gidaspow convinced me to accompany him to visit Dr. Gelderbloom to finish the manuscript of the paper. I drove us to Midland in August 2001. The three of us could put together the draft in one afternoon, which we celebrated with dinner and beer in the evening. Since it was too late for us to return to Chicago the same night, we decided to stay overnight at a motel. We shared a room to save on expenses. As night approached, we retired to our beds. Dr. Gidaspow fell asleep as soon as his head hit the pillow. Suddenly, I heard this horribly loud noise - Dr. Gidaspow snoring extremely loudly, making it very hard for me to sleep. However, I did not want to wake him, and it was inconvenient for me to check into another room. We left the next morning for Chicago. I survived this experience and never revealed that Dr. Gidaspow snored to anyone, including him. I wonder how his wife, Helene, put up with it for decades,” says Dr. Lyczkowski.



With Dr. Kashyap at IIT, 2017

Delivering CFD Workshop at the World Congress on Particle Technology VIII (WCPT-8), Orlando, 2018

Even students' families recognized the positive and consequential impact that Dr. Gidaspow made on their loved ones. For example, Dr. Kashyap's father, Mr. Rajendra Kashyap recounts, "I had the good fortune of meeting Dr. Gidaspow and interacting with him on a few occasions during my visits to the U.S. and found the man to be a walking marvel. Besides being extremely knowledgeable and erudite, the professor was clear-headed, outspoken, and modest." He adds, "Dr. Gidaspow is the person who played a defining role in chiseling Mayank to become what he has become. He was a teacher, mentor, guardian, and foster-father – all rolled into one – for Mayank. No wonder Mayank's wife Teresita holds him in the similar highest esteem, and their little children Ziva and Eli were visibly delighted whenever they visited the Gidaspow home. In his passing, we have lost a most noble and invaluable personality." Dr. Kashyap agrees, "For me, he went above and beyond to mold me into the person I have become. I will be forever indebted to him for his love, support, guidance, and respect. He was a surrogate father figure to us. He will be missed dearly."

With CFD Workshop Co-Presenters (Dr. Huilin Lu, Dr. Mostofi, Dr. Kashyap, Dr. Syamlal, and Mr. Oleh Baran) at WCPT-8, Orlando, 2018

With Dr. Kashyap at WCPT-8, Orlando, 2018

With Dr. Isaac Gamwo at WCPT-8, Orlando, 2018 (he is wearing his favorite "brown-suit")

Dr. Gidaspow loved swimming, especially in the ocean or Lake Michigan. He also enjoyed skiing, gardening *(he was so proud of growing veggies and flowers that he used to give tours of his garden during get-togethers at the Gidaspow residence and occasionally took flowers and fruit to place at the front desk at IIT)*, traveling all over the world, and going out to dinner. He also loved learning about history with a special focus on World War II. Recently, he really enjoyed teaching his grandsons about history.

Left: With Eli Kashyap, Dr. Mayank Kashyap, Mrs. Helene Gidaspow, Dr. Teresita Kashyap, and Ziva Kashyap, 2020
Right: With Ziva Kashyap, 2021

With Dr. Arastoopour

With Kashyaps, 2022

Dr. Gidaspow's contributions to the field of chemical engineering and his dedication to teaching and mentoring will be deeply missed by all who knew him. His memory will continue to inspire future generations of scientists and engineers to strive for excellence and uphold the values of kindness, honesty, generosity, and integrity he embodied throughout his remarkable life.

Godspeed, Professor Dimitri Gidaspow!

Contributed by the following Dr. Gidaspow's Ph.D. students,
- **Robert W. Lyczkowski (Ph.D., 1970)**
- **Hamid Arastoopour (Ph.D., 1978)**
- **Madhava Syamlal (Ph.D., 1985)**
- **Reza Mostofi (Ph.D., 2002)**
- **Mayank Kashyap (Ph.D., 2010)**

PSRI Fluidization and Fluid Particle Systems Award Winner

Dr. Naoko Ellis

Professor, Department of Chemical and Biological Engineering
Associate Director, Clean Energy Research Centre (CERC) | Faculty Associate, Institute for Resources, Environment and Sustainability (IRES)
University of British Columbia (UBC), Canada
naoko.ellis@ubc.ca
Profile: https://chbe.ubc.ca/naoko-ellis/
Systems Beings Lab: https://systemsbeingslab.ubc.ca/

Key Research Areas:

Chemical reaction engineering, multiphase systems, biomass utilization, sustainability, carbon capture and conversion, transdisciplinary education, complexity and systems learning

Seeing in systems: How Powder Technology Has Shaped My World View

Particles are everywhere. They increase in significance with advanced materials and powders. We continue to expand the way we understand, handle, characterize, and define particles. We are constantly mesmerized by them, and for good reasons.

My journey with particles began when the late Maurice A. Bergougnou took me in as a Master's student. While at Western University in Canada, he encouraged me to look at liquid fluidization of irregular particles, which motived me to explore various ways of characterizing irregular particles and analyzing irregular behaviours like channeling. As it turns out, channeling occurs not only with irregular particles, but also in many industrial gas-solid reactors (Issangya et al. 2023).

Demonstrating a bubbling fluidized bed in a transparent column solicited reactions from students as 'cool!!' Of course, this aligned with my own enthusiasm. I became interested by the movement of particles in a fluidized bed and continue to fuel my curiosity around powder technology.

One of the curiosities in the area of hydrodynamics in fluidization is how fines can affect the overall fluidization behaviour. While at Delft University of Technology (TU Delft) in the Netherlands, I worked with Ruud van Ommen on electrostatic forces of fines in coating host particles (van Ommen et al. 2010). We found that small particles behave differently and can be applied to take advantage of their often problematic behaviour, such as electrostatics to have them stick to other surfaces.

Additionally, solenoid controlled bubble injection in a 2D fluidized bed of various fines content resulted in bubble size changes. The dense phase voidage was also influenced by the fines content. Some of the current knowledge is summarized in *Essentials of Fluidization Technology* (Grace et al. 2020). It is curious to understand how fines, the smallest physical scale of particles can influence the behaviour of a whole fluidized bed, even in industrial sized large reactors.

When beginning my faculty career at the University of British Columbia 20 years ago, I focused on clean energy through application of fluidized beds, namely looping systems and biomass utilization. Chemical looping combustion presented itself as an elegant way of separating CO_2 from flue gas, while thermochemical conversion of biomass produced syngas, bio-oil and biochar, all of which numerous applications were examined.

In the backdrop of urgency posed by climate emergency, I sensed that incremental knowledge advancement alone was not the only contribution I can make. While working on clean energy research, I became acutely aware that some of our engineering trainees and students believed that technology was going to solve the climate emergency. I was motivated to understand how to educate the next generation of engineers who were equipped with exploring where clean technology resides and how we as engineers can affect and support change in society.

It became apparent that systems approaches were essential not only to avoid unintended consequences of technologies, but also understanding the interconnectedness, leverage points and holistic understanding the system we wished to affect change. The ability to acknowledge the interconnections, see multiple perspectives, and recognize complexity is key to seeing in systems.

As it happens, exercising the ability to *see in systems* also allows us to make better decisions in our everyday lives. For example, we can develop biofuel technologies. And yet, we need to understand how supply chain and social acceptance may play a role in how technologies are adopted as possible solutions. Similar to fines in a fluidized bed, being able to understand the implications of crossing various boundaries of scales is necessary to predict how a system may behave holistically.

While a PhD student under the late John R. Grace – my great mentor, colleague and friend – I remember something that has stuck with me all of these years. In teaching about hydrodynamics of fluidization, he would invite us to imagine what we may see if we were to "ride a particle in a fluidized bed." He suggested developing a different kind of relationship with the particle, one that expanded our capacity to see beyond the technical. Naturally, we followed his advice!

Changing perspectives and in an almost Eisnteinesque relativity fashion, we tried to "experience" being as a particle to gain further insight into a fluidized bed. We attempted to be in relationship with the bed. We would then follow up with various questions: "How would a particle behave in various local pressure distributions? How would the roughness of the reactor wall feel as a particle? How about collision with other particles?" This was my first memory of seeing, experiencing, and thinking in systems through fluidized beds.

As I cultivated my own understanding and application of systems in my life, I became deeply interested in how we may teach and learn about systems in technical fields. In educating engineers, the attributes defined by the Washington Accord include the ability to address complex engineering problems, while considering both problem contexts and the impacts of engineering actions on cultural, societal, and environmental systems (International Engineering Alliance, 2014). Society requires engineers to have the deep technical knowledge along with breadth of contextual and sociocultural implications.

Systems approaches are familiar to engineers who design processes. We not only need to understand and design the unit operations, but also to connect and operate in a manner that all work well together. Spanning the scales occurs from predicting particle behaviour in a reactor to ensuring efficiency of a complete process, and by understanding individual components and their relationships that exist in a process.

When designing a solution to a complex challenge, we are similarly required to understand the context, see multiple perspectives, and allow that solution to emerge. These are messy, process-oriented approaches requiring non-linear dynamic learning. We are encouraged to not only recognize we are beings who are part of this complex system, but also that our relationships to and experiences with others are part of this complexity.

Understanding and learning about particles has allowed me to expand the way I view complex systems. Albeit focused on the technical, the exercise of viewing particles from different perspectives and crossing scales to understand impacts of fines helps cultivate a systems approach. Seeing the interconnections of various aspects of a system can invite further understanding and curiosity.

Recognizing that how we may intuitively approach particle systems may also apply to other systems, we can continue to expand how we experience the world around us, and see in systems. A carbon capture technology such as a chemical looping combustion unit resides in a process of energy conversion which is in the context of a societal energy transition. How we navigate through the complex system of energy transition in the midst of the climate emergency will have profound effects on future generations. We cannot deny the interconnections in temporal, spatial, and societal scales in which we operate.

Ultimately, systems approaches are becoming increasingly important to respond to a world of disruption, volatility, uncertainty, complexity, and ambiguity. Particle technology has a role to play in seeing these systems.

For me, particles continue to activate my curiosity for not only how they dance within reactors, but also for the interactive ways that I see the world. Returning to John's playful advice, I continue to ride particles and discover new perspectives in my research and also in myself. See you in the system!

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Late Prof. John R. Grace

George Klinzing Best PhD Award Winner

Dr. Tony Feric

ORISE Science, Technology and Policy Postdoctoral Fellow
Office of Fossil Energy and Carbon Management
Carbon Dioxide Removal and Conversion Division
Department of Energy

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Research Interests:

Materials design and characterization, CO2 capture, CO2 conversion, Reactive CO2 capture, Carbon Dioxide Removal (CDR), Direct Air Capture, Enhanced rock weathering, Measurement, reporting and verification of CDR

Investigation of Nanoparticle Organic Hybrid Materials (NOHMs) as Electrolytes Enabling the Integrated Capture and Conversion of Carbon Dioxide

Because of the heat-trapping capacity of CO_2, the average global temperature has increased over the years, resulting in adverse effects on the climate and ecosystems. Carbon capture and sequestration (CCS) is the process of capturing CO_2 from a point source and subsequently storing this CO_2 in the form of a liquid or gas deep beneath the earth's surface. Today, in spite of global efforts on pricing carbon, it is difficult to make CCS deployment economically viable, thus limiting its wide scale deployment.

Electrochemical Conversion of CO_2 Appears Promising.

Carbon capture and utilization (CCU) involves a suite of technologies and processes that enable the CO_2 captured from a process to be converted into a valuable commodity, hence adding an additional revenue stream and thereby improving the economics of the technology deployment. The electrochemical upgrade of CO_2 to chemicals and fuels appears to be one of the most promising utilization pathways because it usually requires near-ambient operating conditions and can be directly integrated with renewable energy technologies. Integration of renewable energy technologies with the grid is currently challenged by intermittency and storage issues. The renewables-powered electrochemical conversion of CO_2 to chemicals and fuels is an attractive means of avoiding and/or reducing CO_2 emissions. Over the last decades, it is evident that several advances have been made in terms of catalyst and reactor design for the electrochemical conversion of CO_2, though aqueous CO_2 electroreduction remains limited due to the low solubility of CO_2 in the electrolyte phase (34 mM).

Combined CO_2 Capture and Conversion Approach.

To overcome the strict energy penalty associated with the regeneration of aqueous amine CO_2 capture solvents, ionic liquids (ILs), Deep Eutectic Solvents (DES), CO_2 Binding Organic Liquids (CO_2BOLs), Nanoparticle Organic Hybrid Materials (NOHMs) have been suggested as water-lean solvents for CO_2 capture applications. Although these "green solvents" appear to be promising CO_2 capture materials, their practical application is limited by their inherently high viscosity. Therefore, the incorporation of these novel materials into electrolytes has been proposed to improve CO_2 solubility and the performance of the CO_2 reduction reaction (CO_2RR). In addition to improving the CO_2 solubility of the electrolytes, in some cases, electrolyte additives behaved as co-catalysts for the CO_2RR as a reduction in overpotential, tuned product selectivity and/or improved reaction rates were observed. As a result, electrolytes with a high CO_2 binding energy that can enhance the performance of the CO_2RR are highly sought after because an integration of CO_2 capture with the CO_2RR can remove the need for the energy intensive CO_2 capture solvent regeneration, as illustrated in **Figure 1**..

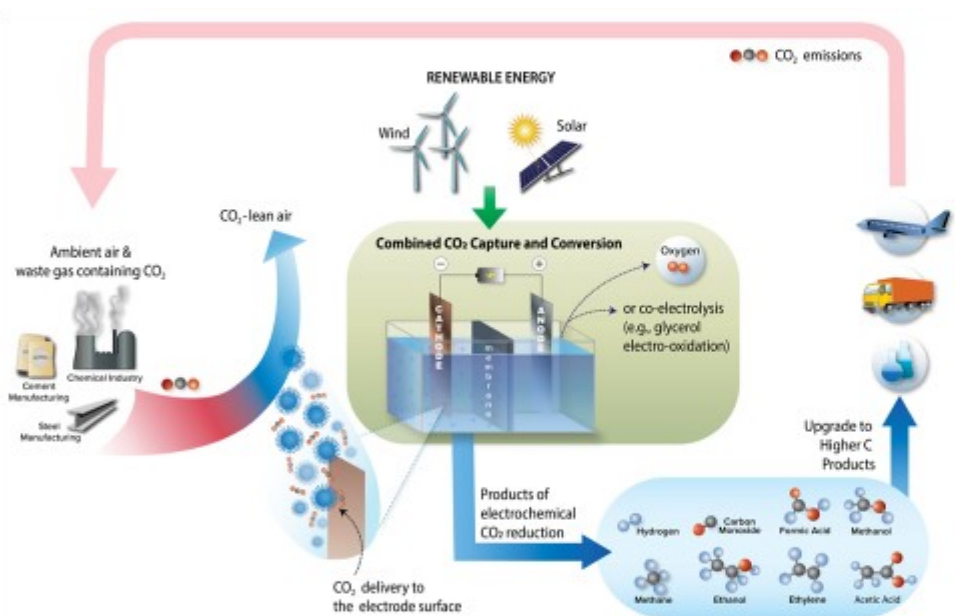

Figure 1. The proposed integrated capture and conversion of CO_2, mediated by Nanoparticle Organic Hybrid Material (NOHM)-based electrolytes.

NOHMs for the Integrated Capture and Conversion of CO_2.

As shown in **Figure 2**, Nanoparticle Organic Hybrid Materials (NOHMs) are composed of an organic polymer tethered to an inorganic nanoparticle core via either covalent or ionic bond. Owing to their favorable properties, including negligible vapor pressure, oxidative-thermal stability, chemical tunability and high conductivity, NOHMs have been extensively studied for CO_2 capture and several electrochemical applications. In this dissertation, NOHMs were proposed as structured electrolytes for the combined capture and conversion of CO_2. For energy storage applications in particular, developing an understanding the structural and transport properties of innovative electrolyte materials has been shown to be essential to improving the overall system performance. **Therefore, in this dissertation, the thermal, structural and transport behaviors of NOHMs have been explored for their application in integrated CO_2 capture and conversion.**

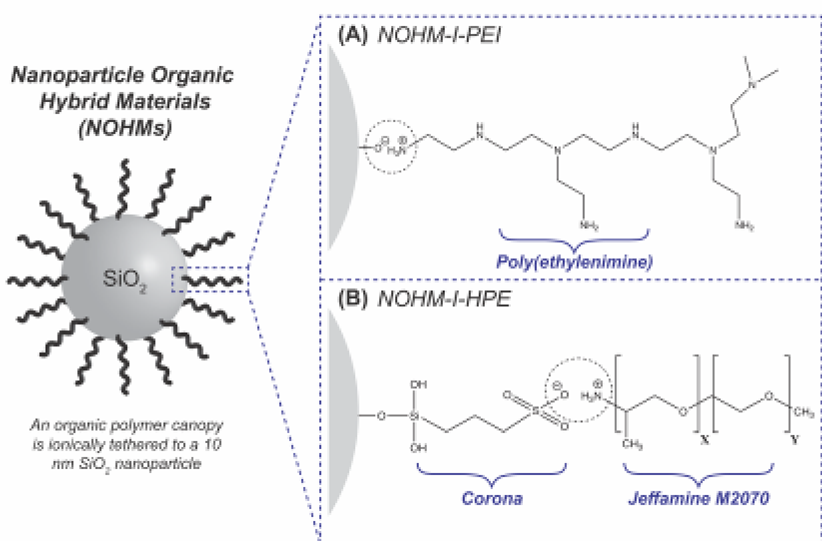

Figure 2. Schematic of **(A)** NOHM-I-PEI and **(B)** NOHM-I-HPE. The X and Y in the Jeffamine M2070 (HPE) canopy represent the number of poly(propyleneoxide) groups (10) and poly(ethyleneoxide) groups (31).

Oxidative-Thermal Stability of CO_2 Capture Materials is Imperative.

Liquid-like NOHMs functionalized with an ionic bond have been shown to display greatly enhanced oxidative thermal stability compared to the untethered polymer. However, our previous studies were limited in terms of reaction conditions and the detailed mechanisms of the oxidative thermal degradation were not reported. In this study, a kinetic thermal degradation analysis was performed on NOHM-I-HPE and the neat polymer, Jeffamine M2070 (HPE), in both non-oxidative and oxidative conditions. NOHM-I-HPE displayed similar thermal stability to the untethered polymer in a nitrogen environment, but interestingly, the thermal stability of the ionically tethered polymer was significantly enhanced in the presence of air. This observed enhancement of oxidative thermal stability is attributed to the orders of magnitude larger viscosity of the liquid-like NOHMs compared to untethered polymer and the bond stabilization of the ionically tethered polymer in the NOHMs canopy. This study illustrated that NOHMs can serve as functional materials for sustainable energy storage applications because of their excellent oxidative thermal stability, when compared to the untethered polymer.

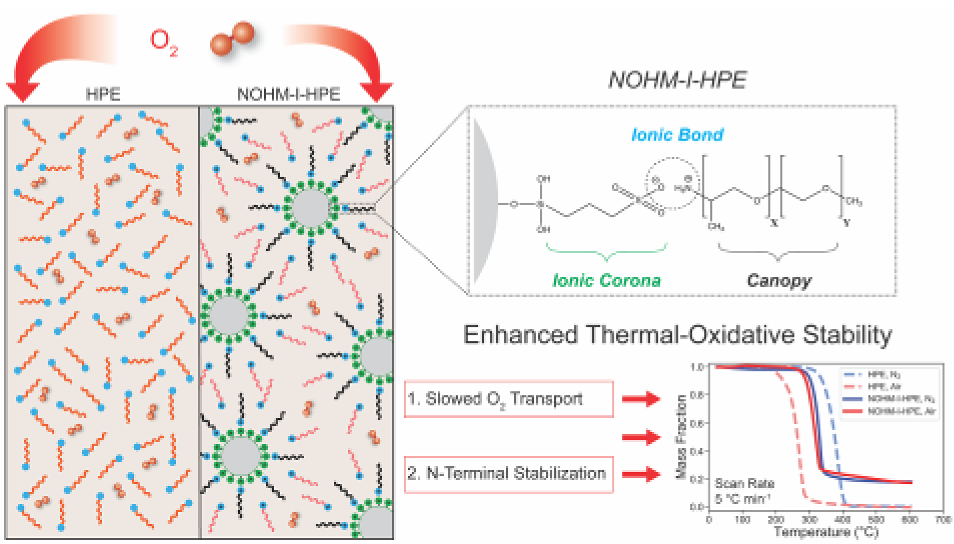

Figure 3. Enhanced oxidative-thermal stability of ionically tethered polymers in NOHM-I-HPE resulted from a combination of O_2 mass transfer limitation and ionic bond stabilization.

Dynamic Mixing Behaviors of the Ionically Tethered Polymers in NOHMs.

Though NOHMs composed of an ionic bond have demonstrated a high conductivity and an enhanced oxidative thermal stability, their practical application in the neat state is limited by an inherently high viscosity. Thus, when incorporating NOHMs in electrolytes for CO_2 capture and conversion applications, it will be necessary to mix them with a secondary fluid. In this study, a series of binary mixtures of NOHM-I-HPE with five different secondary fluids – water, chloroform, toluene, acetonitrile, and ethyl acetate – were prepared to reduce the fluid viscosity and investigate the effects of secondary fluid properties (*i.e.,* hydrogen bonding ability, polarity, and molar volume) on their transport behaviors including viscosity and diffusivity (as determined by a PFG-NMR technique). Our results revealed that the molecular ratio of secondary fluid to the ether groups of Jeffamine M2070 (λ_{SF}) was able to describe the effect that secondary fluid has on transport properties. Our findings also suggest that in solution, the Jeffamine M2070 molecules exist in different nano-scale environments, where some are more strongly associated with the nanoparticle surface than others, and the conformation of the polymer canopy was dependent on the secondary fluid. This understanding of the polymer conformation in NOHMs can allow for the better design of an electrolyte capable of capturing and releasing small gaseous or ionic species.

Impact of Bond Type on the Thermal and Transport Behaviors of NOHMs.

To further investigate the effect of the bond type on the thermal stability as well as the structural and transport properties of the tethered HPE, NOHMs were synthesized by tethering HPE to SiO_2 nanocores via ionic (NOHM-I-HPE) and covalent (NOHM-C-HPE) bonding at two grafting densities. In the neat state, NOHM-C-HPE displayed the highest thermal stability in a nitrogen atmosphere, while NOHM-I-HPE was the most thermally stable under oxidative conditions. Small angle neutron scattering (SANS) revealed the presence of multiple types of Jeffamine

M2070 (HPE) polymers in aqueous solutions of NOHM-I-HPE (*i.e.,* tethered, interacting and free), whereas only tethered HPE chains were observed in NOHM-C-HPE systems. Moreover, the SANS profiles identified clustering of NOHM-C-HPE in dilute aqueous solutions, but not in the corresponding NOHM-I-HPE samples, suggesting that the different types of HPE chains in solutions of NOHM-I-HPE may be crucial to the uniform NOHMs dispersion. Additionally, our investigation of the viscosity and conductivity of different NOHM-based electrolytes revealed that in response to ionic stimulus, the covalently tethered HPE remained fixed at the nanoparticle surface, whereas there was a partial disassociation of HPE chains from the nanoparticle in NOHM-I-HPE. Overall, the results of this study highlight that NOHMs are highly tunable materials whose properties can be strategically altered by changing the bond type linking the polymer to the nanoparticle, as well as grafting density.

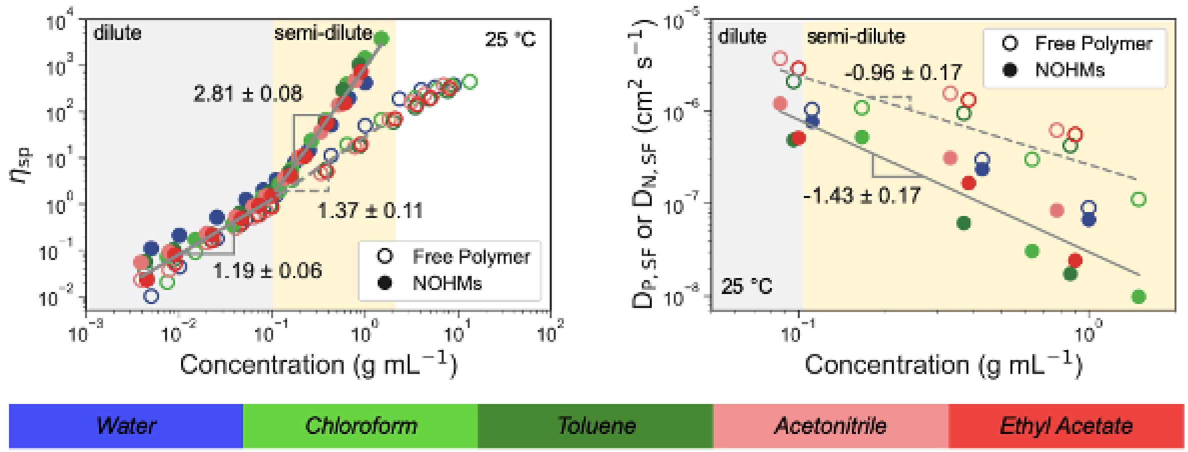

Figure 4. Scaling behaviors for the specific viscosity (η_{sp}) and PFG-NMR determined self-diffusion coefficients (*D*) of the untethered HPE polymer and ionically tethered polymers in NOHM-I-HPE, in secondary fluids of varying physical and chemical properties.

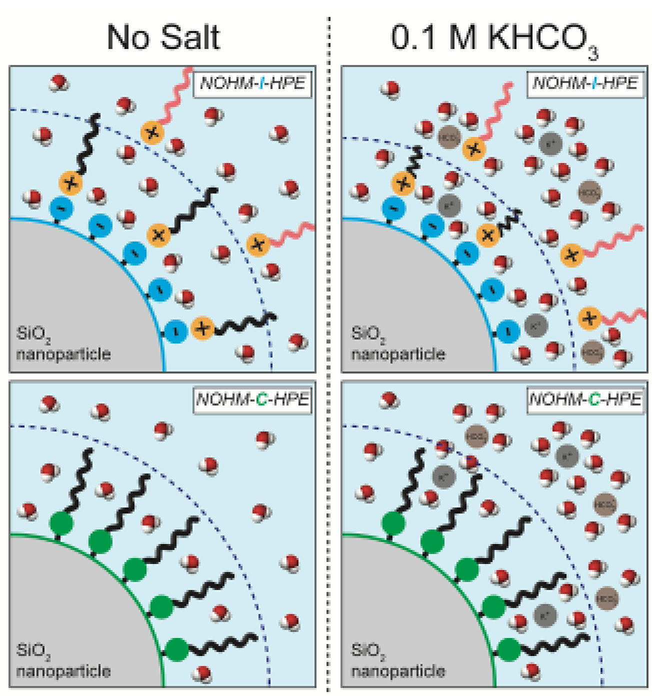

Figure 5. Effect of 0.1 M $KHCO_3$ on the structure and conformation of ionically and covalently tethered polymers, as determined from viscosity, ionic conductivity and small-angle neutron scattering measurements.

Polymer Functionality Dictates Product Distribution and Rates of CO_2 Conversion.

Two types of aqueous NOHM-based electrolytes were prepared to study the effect of CO_2 binding energy (*i.e.,* chemisorption vs. physisorption) on the CO_2 reduction reaction (CO_2RR) over a silver nanoparticle catalyst for the production of syngas, a mixture of H_2 and CO, at various ratios. Poly(ethylenimine) (PEI) and Jeffamine M2070 (HPE) were ionically tethered to SiO_2 nanoparticles to form the amine containing NOHM-I-PEI and ether containing NOHM-I-HPE, respectively. At less negative cathode potentials, PEI and NOHM-I-PEI based electrolytes produced CO at higher rates than 0.1 molal. $KHCO_3$ due to favorable catalyst-electrolyte interactions, while at more negative potentials, H_2 production was significantly favored because of the electrochemical inactivity of carbamates. Conversely, HPE and NOHM-I-HPE electrolytes displayed poor CO_2RR performance at less negative potentials, though at more negative potentials, their performance approached that of 0.1 molal. $KHCO_3$, highlighting how the polymer canopy of NOHMs can be strategically selected to produce highly tunable H_2/CO compositions. The results of this study illustrate that more conductive polymer canopies with intermediate binding energies for CO_2 should be explored to improve the performance of NOHM-mediated CO_2 reduction.

NOHMs are Promising Materials for the Combined Capture and Conversion of CO_2.

The results of this dissertation demonstrate the ability of NOHM-based electrolytes to be used for systems enabling the integrated capture and electrochemical conversion of CO_2. The polymer grafting density, polymer canopy functionalities, bond type linking the polymer to the nanoparticle, secondary fluid selection and ionic stimulus were all found to play an important role in determining the thermal stability of NOHMs and/or the structural and transport properties of the corresponding NOHM-based fluids/electrolytes. Overall, these findings can be applied to further develop a deeper understanding of a wide range of structured electrolyte materials which can enable the reactive capture of CO_2.

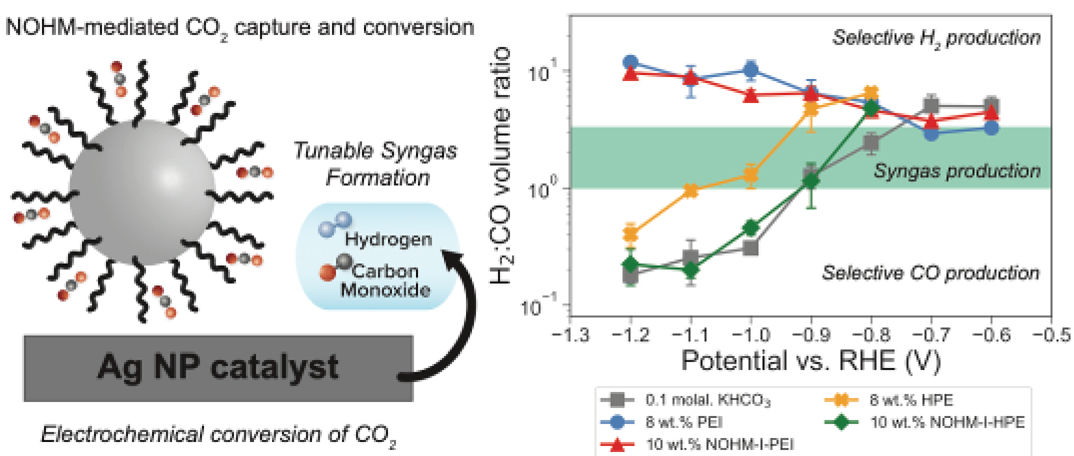

Figure 6. Highly tunable syngas ratios are feasible by varying the polymer functional groups in NOHM-mediated CO_2RR over a silver nanoparticle catalyst.

Considerations for Technology Deployment.

In addition to the importance of electrolyte properties and reactor configurations there are various considerations including raw materials availability, energy use, systems integration and societal impacts that need to be carefully examined when designing processes that enable the capture and conversion of CO_2. As processes scale from laboratory settings to demonstration environments, the electrolyte materials should be accessible through existing manufacturing and supply chains. In this case, renewable electricity would be the ideal energy source for the electrochemical conversion of CO_2, though systems-level integration with the grid or some form of long-term energy storage will be required. Additionally, plant siting would depend on a variety of factors including the form factor of the technology, CO_2 source location, regional materials availability and existing product supply chains. Lastly, it will be important to explore the effects of technology deployment on communities through robust lifecycle analysis (LCA) and engage with local representatives early and often.

SABIC Young Professional Award Winner

Dr. Edison Huixiang Ang
Assistant Professor
National Institute of Education/Nanyang Technological University, Singapore

Research Focus: Strategies for engineering two-dimensional nanomaterials for efficient water transportation. Engineering two-dimensional (2D) nanomaterials is important in water fluid transportation especially for membrane technology. This 2D nanomaterial serves as “LEGO” block for making into selective membrane with layered structure. This layered structure possesses interlayer channels which provide multiple pathways for the water fluid to pass through while retaining the impurities solutes for purifying dirty water.

Dr Edison H. Ang’s research work primarily focuses on the strategies used to engineer 2D nanomaterials such as noble metals, MXenes, metal organic frameworks (MOFs), layered double hydroxide (LDH), transition metal dichalcogenides (TMS) and graphene for efficient membrane-based water purification technologies, such as nanofiltration, solar still, and membrane distillation applications, as illustrated in Figure 1. The correlation of the unique properties and rational design of 2D nanomaterials with respect to their performances will be described using experimental data and computational simulations. Finally, an innovative approach to using advanced three-dimensional (3D) printing technology (i.e., aerosol jet printing) of two-dimensional graphene-based materials and turning organic wastes into useful 2D materials for membrane technology will also be discussed.

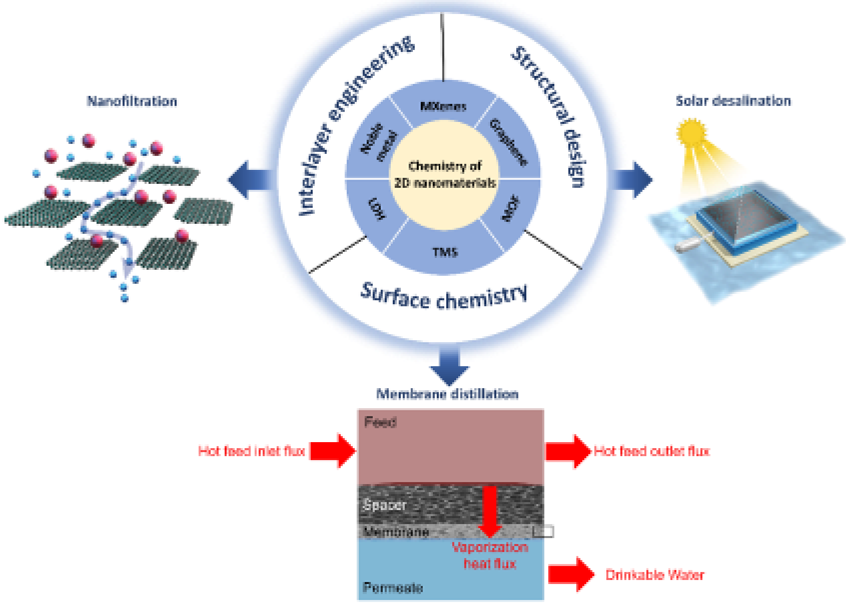

Fig 1. Summary of the strategies for rational design 2D nanomaterial-based membranes for various membrane technologies.

2D nanomaterials is an emerging class of materials that possesses sheet-like structure with the lateral size larger than 100 nm, but the thickness is typically less than 5 nm.[1] Although their exploration dated back a few decades ago, 2004 marked the year of 2D nanomaterials resurgence when Novoselov and his co-workers successfully exfoliated graphene from graphite using Scotch tape.[2]

Alternatively, there are other techniques which can be employed to separate the 2D monolayer from its bulk layered structure, for instance, in situ synthetic intercalation, solvent intercalation, electrochemical redox and ion exchange methods, as illustrated in Figure 2. The figure of merits in term of price, production rate, condition for production yield, scalability, and size for these methods are also described in detailed in their review.[3]

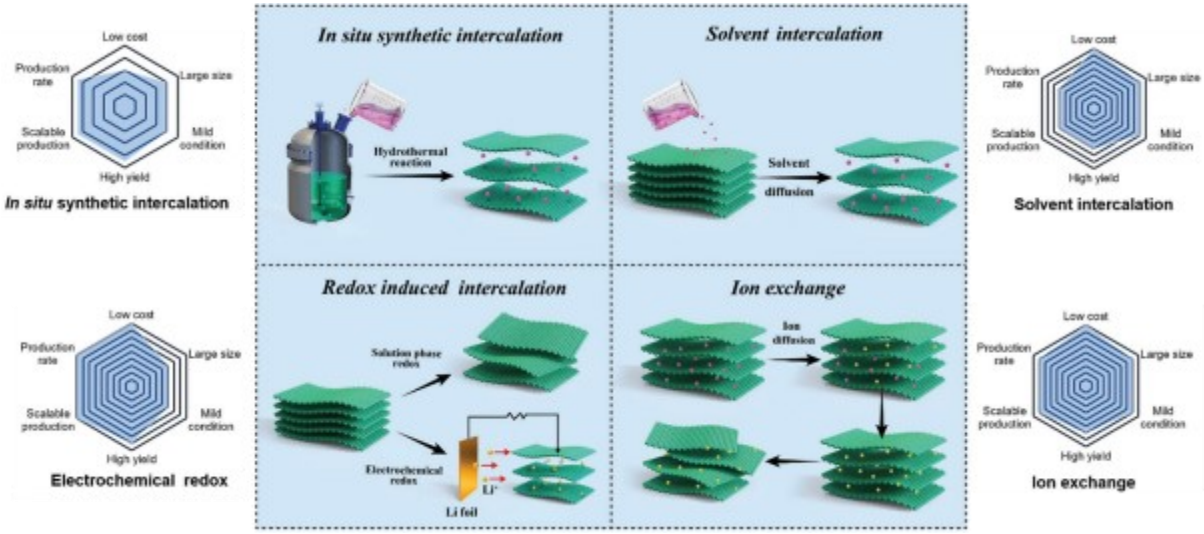

Fig 2. Summary of the strategies available for exfoliating 2D nanomaterials.[3]

By employing the three unique strategies: (1) interlayer engineering; (2) structural design and (3) surface chemistry modification, the physical and chemical properties of the 2D nanomaterials can significantly improve the performances of membrane technologies.

For instance, polycation was used to regulate the interlayer spacing of the anionic 2D metal organic framework (MOF) nanosheets.[4] In this work, Dr Edison H. Ang's team is the first to report the use of 2D MOF as building block for nanofiltration membrane and by using this configuration, the water production rate can be improved by almost 2X at a rejection cut-off of 90% with around 50 nm thick of selective layer. It is also worth noting that the energy consumption is over three orders of magnitude less than the commercial nanofiltration membrane, as shown in Figure 3.

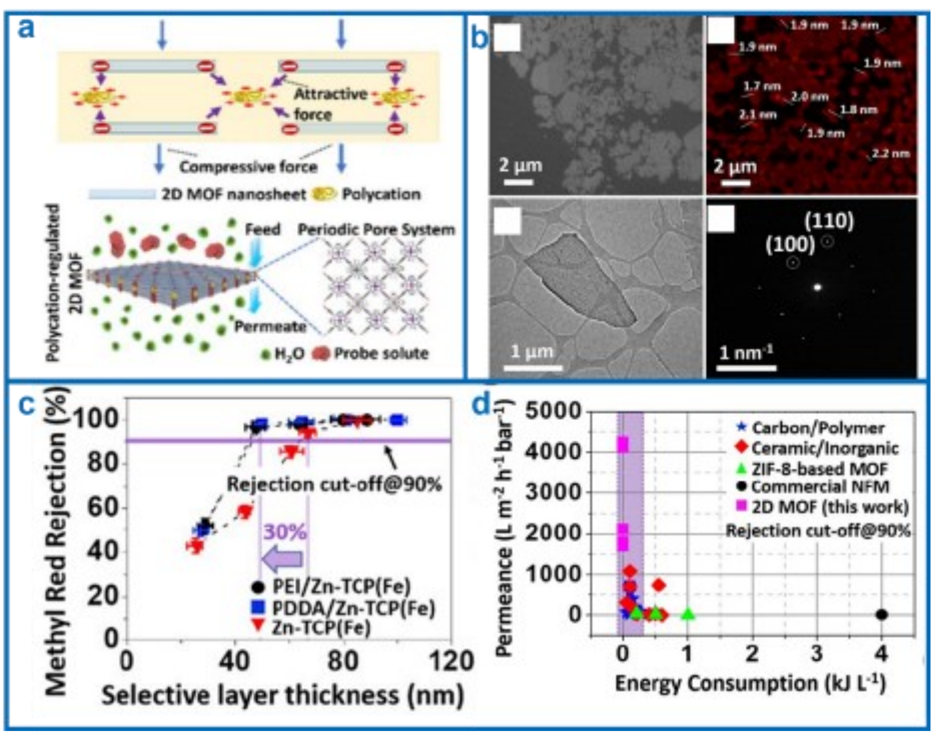

Fig 3. Interlayer engineering: the 2D materials-based MOF membrane using polycation.[4]

In another study, his team also demonstrated that the nanochannel width of the selective layers can be fine-tuned by electrostatic heteroassembly of 2D anionic transition metal dichalcogenides (TMS) nanosheets and cationic layered double hydroxide LDH nanosheets.[5] This heteroassembly increases the energy barrier for solute permeation which in turn enhanced the rejection percentage to almost 100% with a submicrometer thick of membrane, as shown in Figure 4.

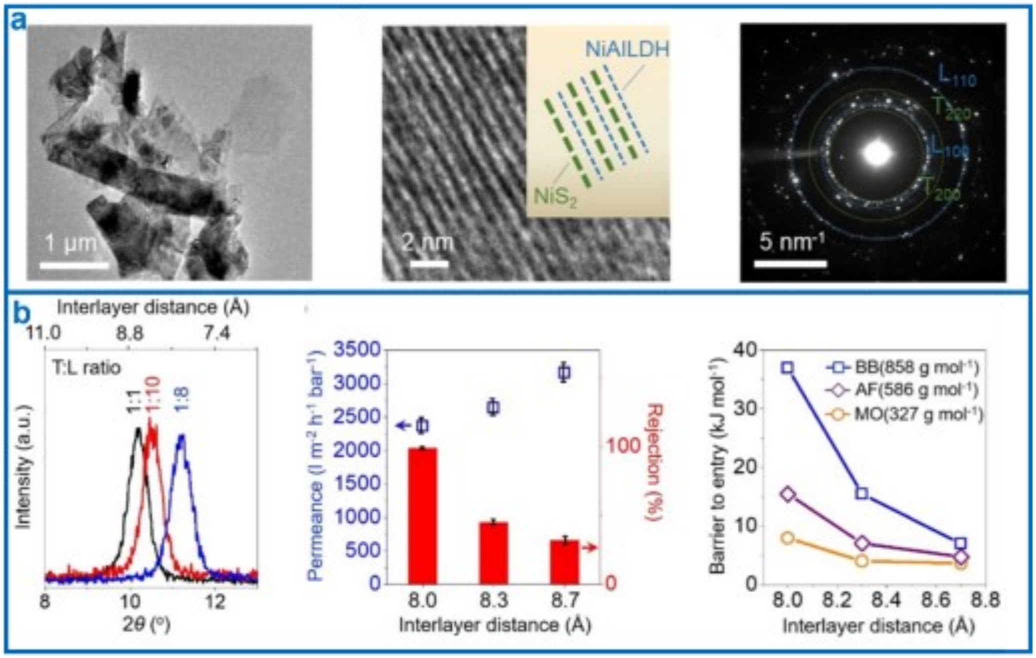

Fig 4. Interlayer engineering: heteroassembly of 2D TMS and LDH materials for nanofiltration.[5]

And in another study, Dr Ediosn has developed one-in-a-kind method to synthesize defect-rich Ni-based nanosheets (i.e. NiOH, NiO, NiS_2, and Ni_2P).[6] These defects serve as additional nanochannels for water transportation. As a result, the water permeance can go up to 2 orders of magnitude higher than that of commercial nanofiltration membrane (see Figure 5).

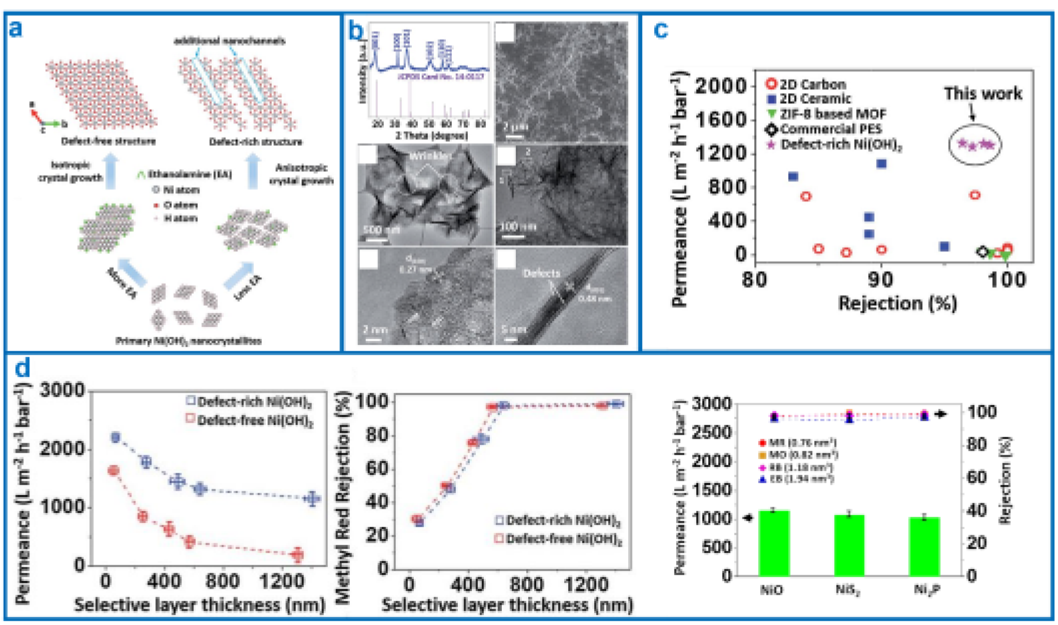

Fig 5. Structural design: defect engineering of Ni-related nanosheets membrane.[6]

Recently, his team has formulated, and patented graphene inks cater for three-dimensional (3D) printing technology, as shown in Figure 6. The advantages of using 3D printing technology are that it is automated, and we can reduce the manufacturing and manpower cost, we can also use 3D printing technology to tailor various shapes and sizes with precise dimension of the desired architecture. So far, they have successfully employed this 3D-printed graphene materials for the removal of dyes from wastewater using nanofiltration membrane. And they strongly believe that such technology can be extended to other electronic devices and sensors. All interested companies are welcomed to contact Dr Edison H. Ang for licensing of the patents or any interesting collaboration works related to 3D-printing of graphene materials. This work has been featured on the higher education review[7] and philstar news.[8]

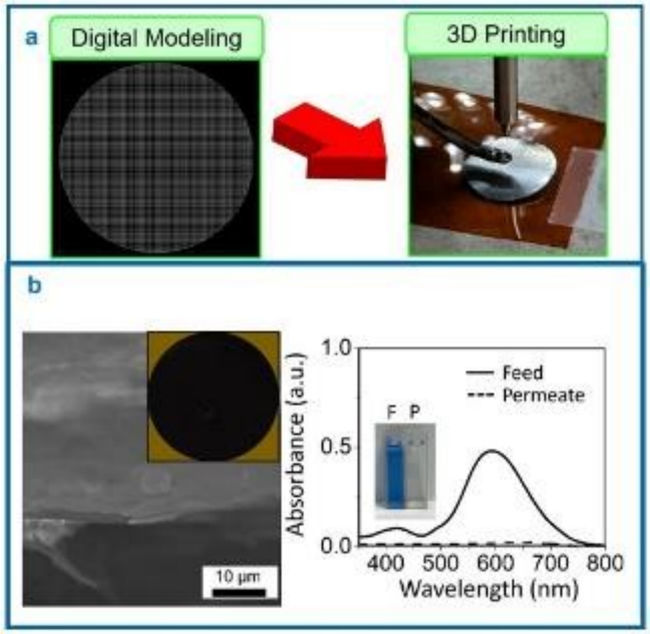

Fig 6. Structural design: Using additive manufacturing of graphene-based membrane.[9]

Other than interlayer engineering and structural design of 2D nanomaterials, Dr Edison H. Ang also employed surface modification method to alter the property of the membrane. For instance, in one of his studies,[10] by changing the metal in 2D LDH nanoheets, the interaction energy of the LDH with the solvent can be lowered (see Figure 7). This reduces the resistance of the solvent permeation through the membrane and leading to high permeability in nanofiltration.

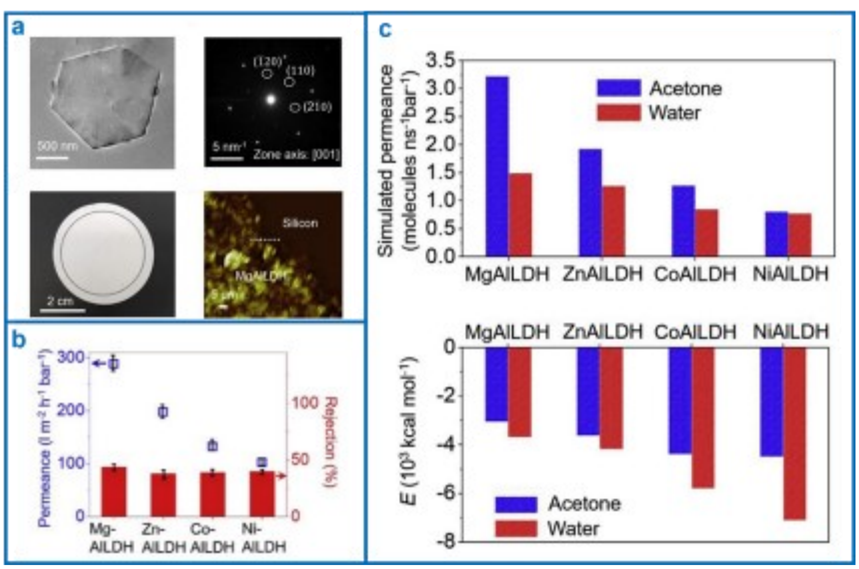

Fig 7. Surface chemistry: Interaction between modified 2D LDH and solvents.[10]

Unlike nanofiltration which is driven by pressure difference, the membrane distillation is driven by temperature difference. In another study, Dr Edison Ang has employed an innovative approach of using plasmonic effect to reduce the energy consumption in membrane distillation. Localized heating of this plasmonic material consisting of ligand embedded in 0D Ag nanoparticles and 2D Pt nanosheets allows the reduction of energy consumption by almost 30% and improve the distillate flux by almost 40% (see Figure 8).

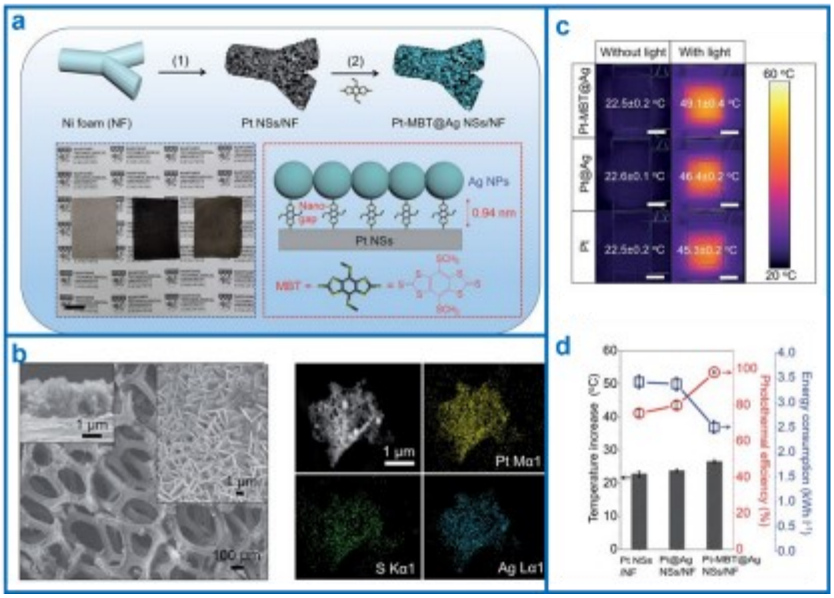

Fig 8. Surface chemistry: Plasmonic effect of noble metal for localized heating of spacer.[11]

There has been a significant surge in household plastic waste, resulting in a global waste management crisis. Improper plastic waste management can have a negative impact on the environment, wildlife, and public health. To address this concern, Dr Edison's team has turned common household plastic wastes like plastic bags (PB), laundry detergent bottles (LB) and Tupperware containers (TC) into graphite materials which is used for water purifier.[12] And the average light-to-heat conversion efficiency of the graphene-based solar absorber derived from plastic waste is ~ more than 90%, which is ~30% higher than that of the commercial solar absorber, and as a result the water production rate is ~50% higher than that of the commercial ones, as shown in Figure 9.

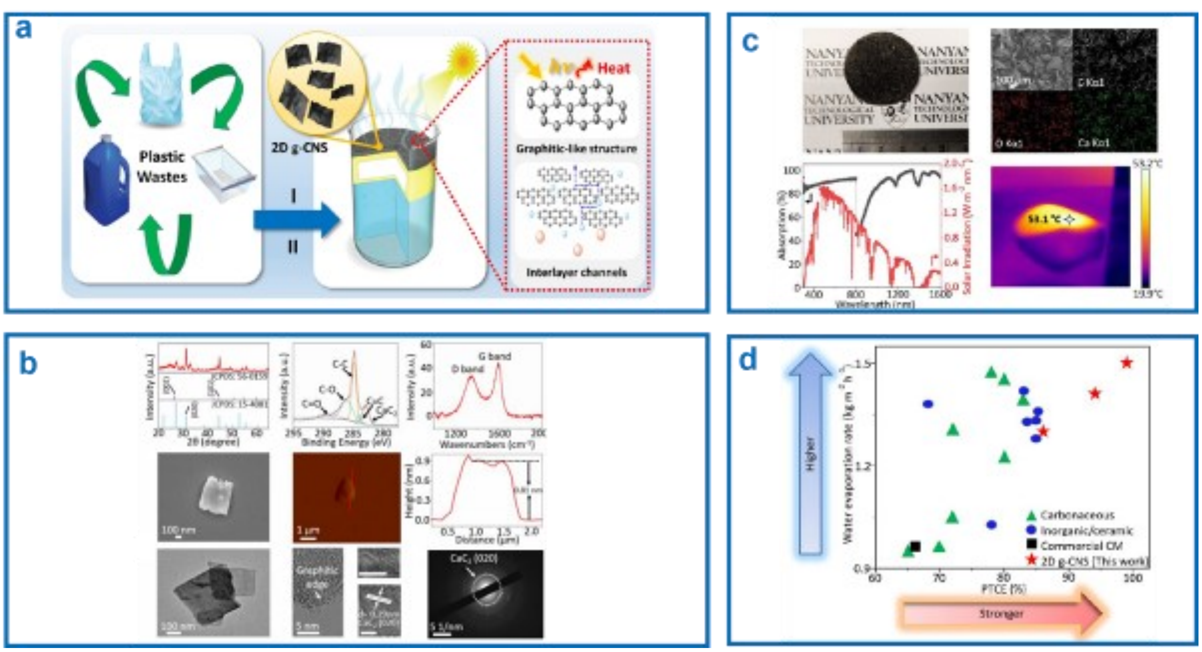

Fig 9. Surface chemistry: Photothermal effect of graphene-based nanosheets derived from plastic wastes for solar desalination.[12]

Food waste was estimated to be produced annually, with fruit waste accounting for roughly 60% of this total, even though large amounts of it have been discarded in landfills, and they have slowly leaked into groundwater, contaminating it and the surrounding land [13]. To address this issue, fruit waste can be recycled and converted into valuable raw materials (for example, carbon). In this work, these carbon materials derived from fruit wastes like coconut husks, orange peels and banana peels are converted into value added materials like MXene, which is used for purifying dirty water.[14] Converting fruit waste into two-dimensional MXenes is something new. Others reported synthesis of MXenes typically in spherical in shape. The motivation of conducting this work is to turn fruit waste which is something useless into something valuable. And the advantages of using 2D MXenes materials are as following: (1) the interlayer channels can provide fast water transportation in water purifier and (2) it has good light-to-heat energy conversion efficiency which can be used in solar desalination process for example in this case of study. This amazing work has been featured in the straits times[15] and TOC Asia.[16]

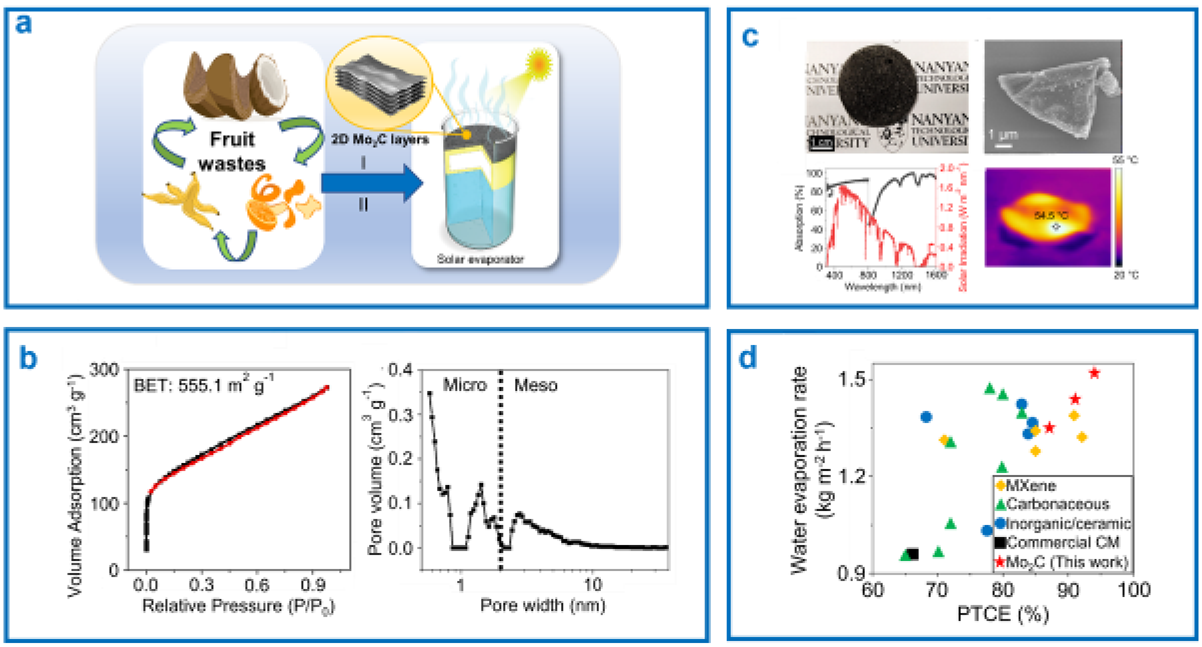

Fig 10. Surface chemistry: Solar to heat conversion of MXenes-derived from fruit wastes for purifying salt water.[14]

Leadership activities in the field of particle technology

Dr Edison H. Ang is currently an Early Career Editorial Board of Chemical Engineering Journal, Young Editorial Board of Journal of Energy Chemistry, Editorial Board Member of Scientific Reports, Associate Editor of Frontiers in Chemistry, Frontiers in Environmental Chemistry and Frontiers in Electronic Materials, handling manuscript related to particle technology for energy storage and membrane technology. In addition, he has successfully secured 8 research grants for the past 2 years and lead and completed 4 of the projects relating to the combination of particle technology and additive manufacturing to solve the issues of food-energy-water nexus.

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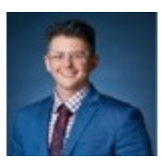

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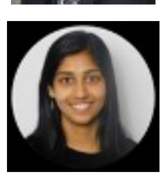

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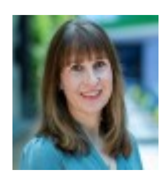

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