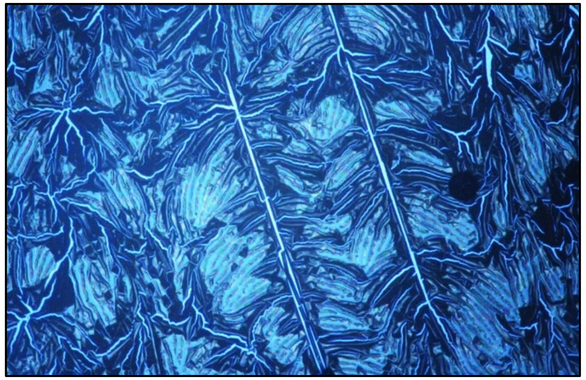
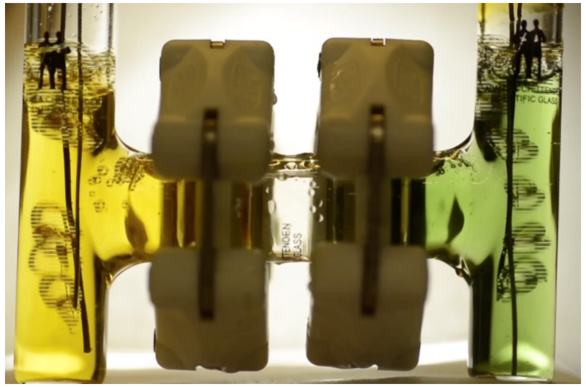
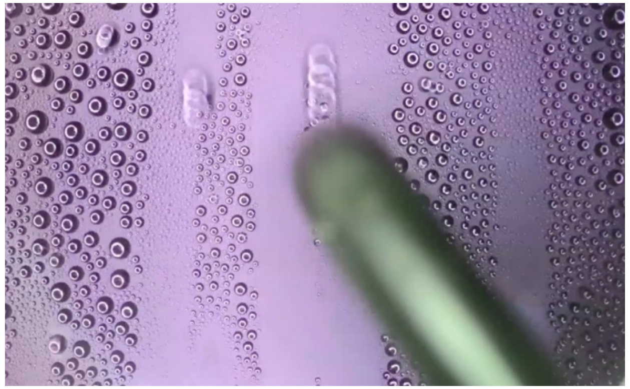
# Innovating at Interfaces: Enhancing Performance and Longevity in Sustainable Energy Systems







UiO

**Dr. Sami Khan**
Assistant Professor
Simon Fraser University

NOUS SOMMES PRÊTS

SFU SIMON FRASER UNIVERSITY
ENGAGING THE WORLD
School of Sustainable Energy Engineering

SFU SCHOOL OF SUSTAINABLE ENERGY ENGINEERING
Engineered Interfaces for Sustainable Energy
EISEn

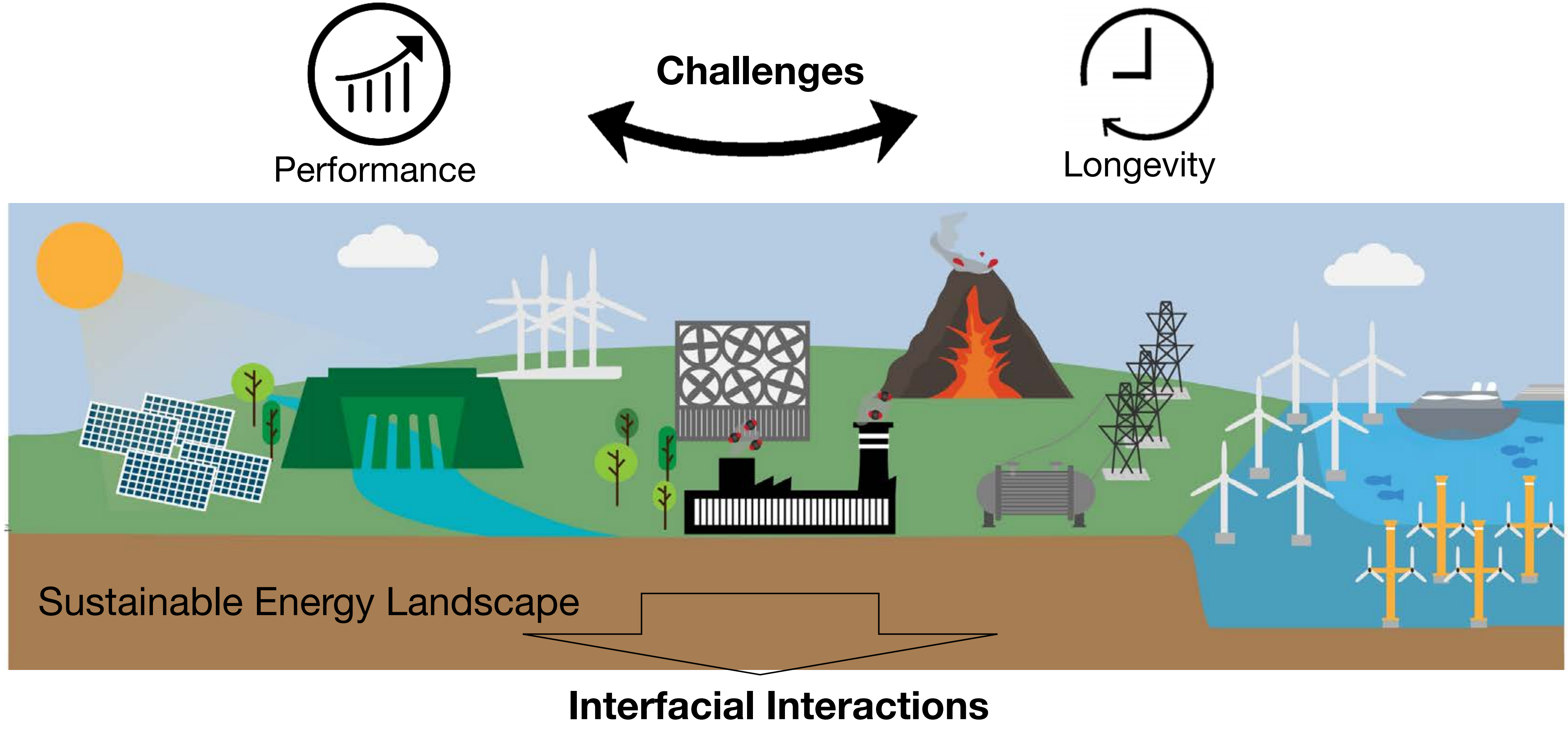
# Engineered Interfaces for Sustainable Energy (EISEn)


**Dr. Sami Khan**
Assistant Professor, School of Sustainable Energy Engineering,
Associate Member, Department of Chemistry
Simon Fraser University
Email: s_khan@sfu.ca
Website: http://www.khanresearchlab.com

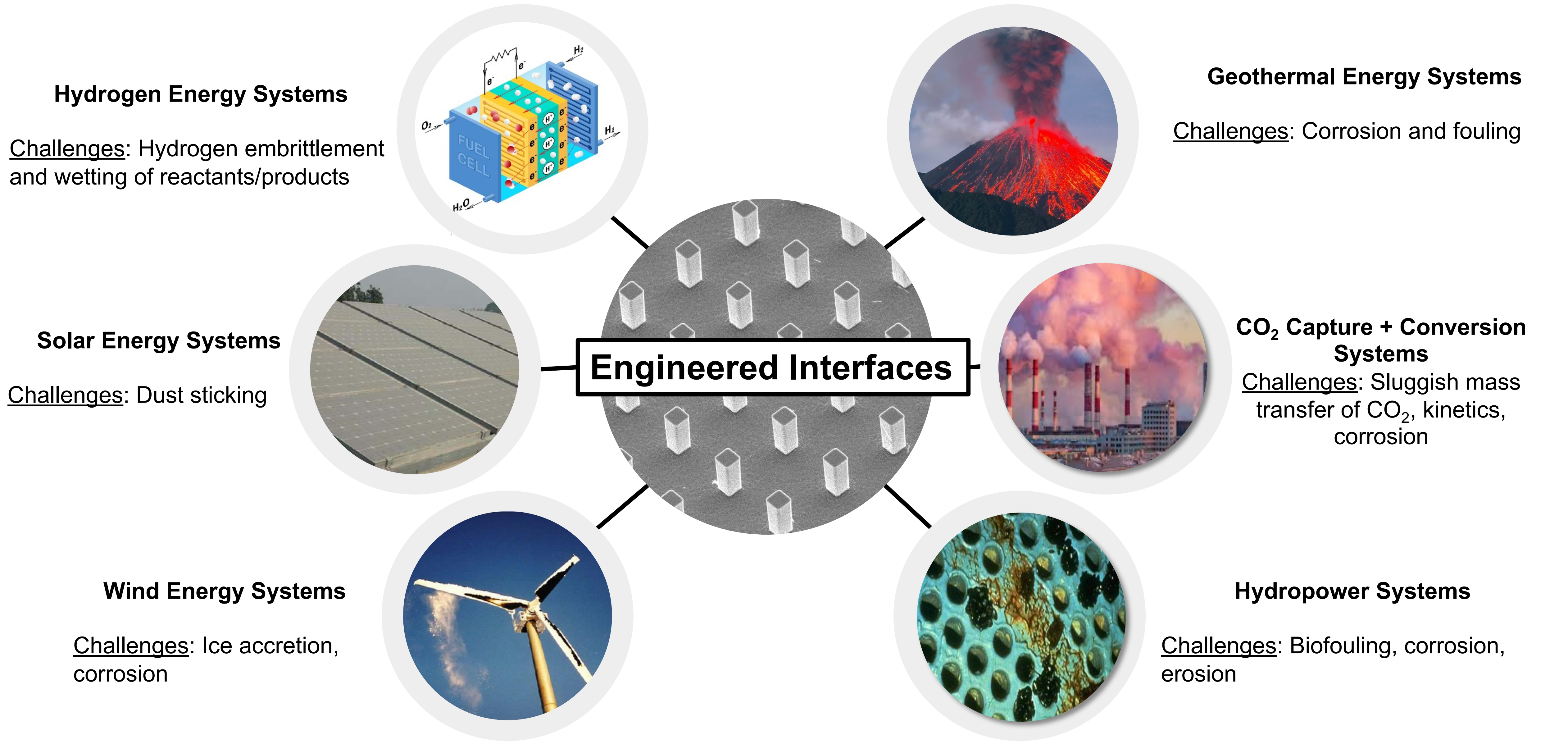
**Education:**
Ph.D. Mechanical Engineering, MIT, 2020
S.M. Mechanical Engineering, MIT, 2016
S.M. Technology and Policy Studies, MIT, 2016
B.A.Sc. Chemical Engineering, University of Toronto, 2012

**Experience:**
- Assistant Professor, **SFU**, September 2020 - present
- Science and Technology Advisor, **Natural Resources Canada**, Apr - Aug 2020
- Postdoctoral Associate, **University of Toronto**, Jan - April 2020
- Junior Chemical Engineer, **Avalon Rare Metals**, June 2012 – July 2013
- Engineering Intern, **Ontario Power Generation**, Aug 2010 – July 2010

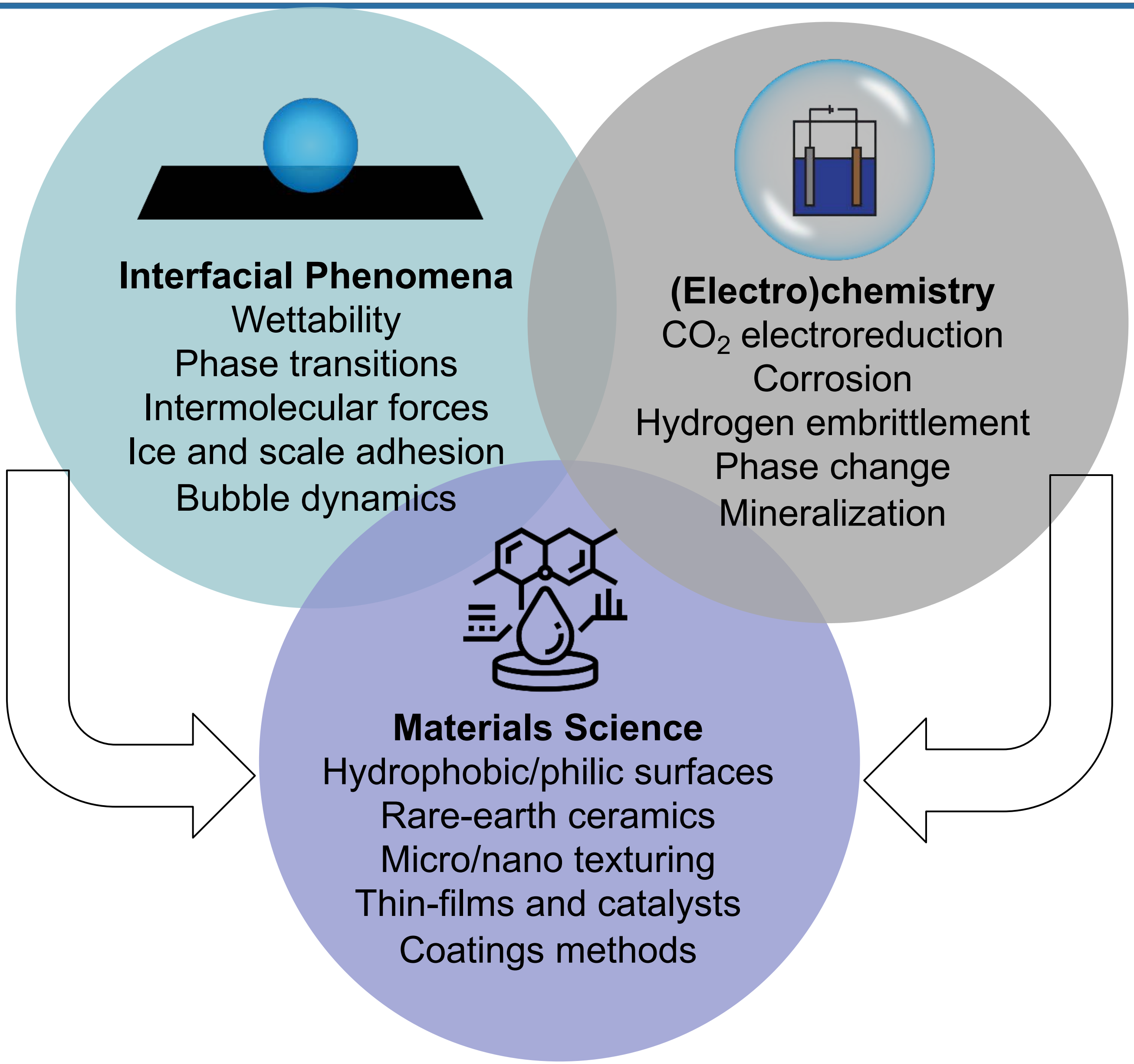
**Research Focus:** Elucidate and tune interfacial interactions to enhance <u>performance</u> and <u>longevity</u> of sustainable energy systems


Challenges
Performance
Longevity
Sustainable Energy Landscape
Interfacial Interactions

# Challenges in Sustainable Energy Systems at Interfaces

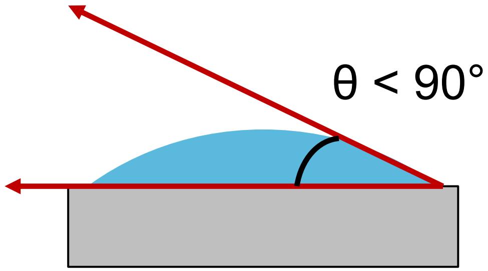


# Fundamental scientific domains in our research

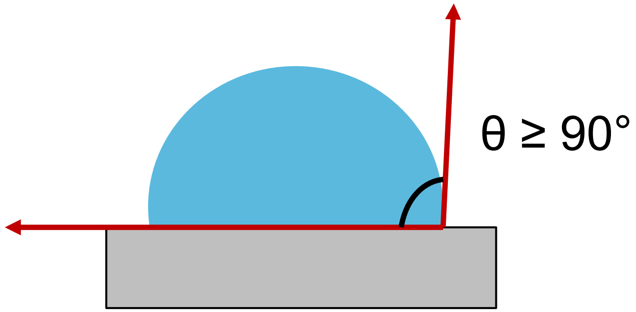


# Wetting – Hydrophilicity and Hydrophobicity

**Hydrophilic Surfaces**



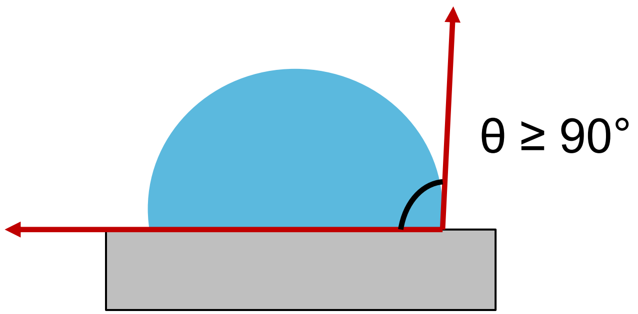

**Hydrophobic Surfaces**



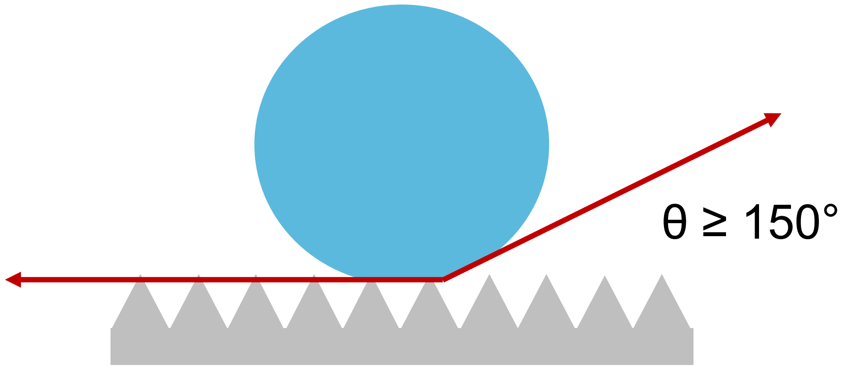

**Hydrophobicity around us**


# Superhydrophobicity

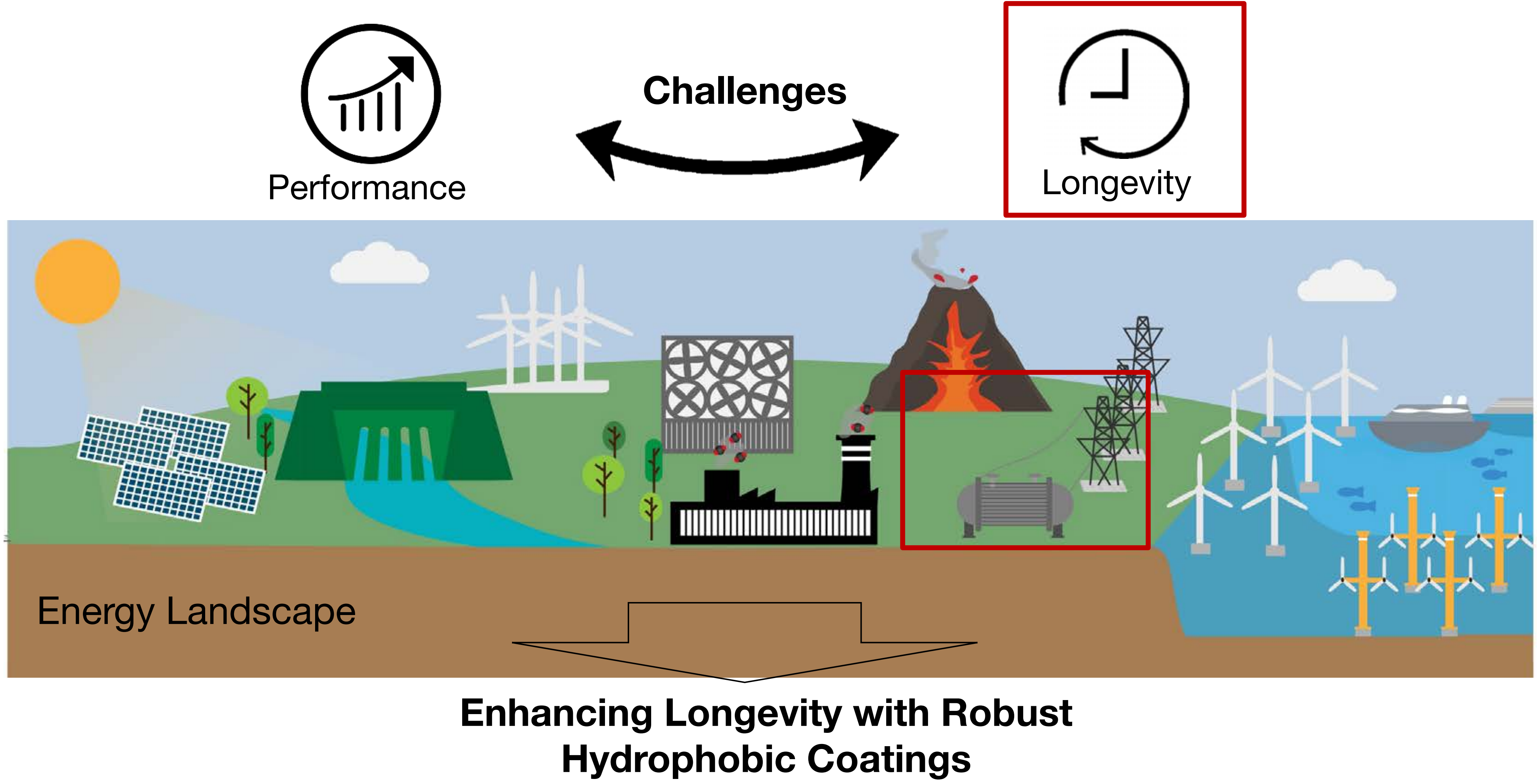
**Hydrophobic Surfaces**



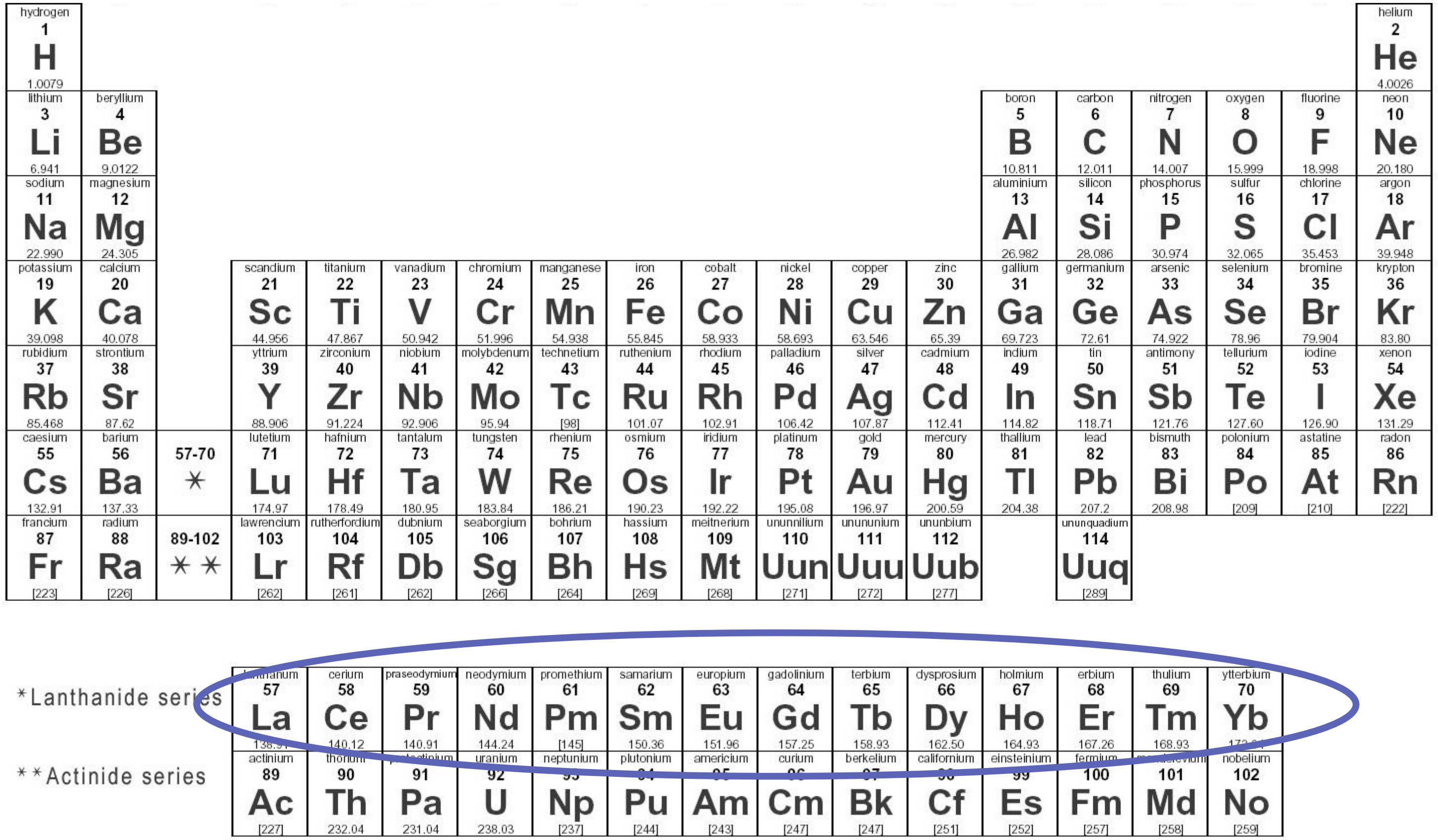

**Superhydrophobic Surfaces**

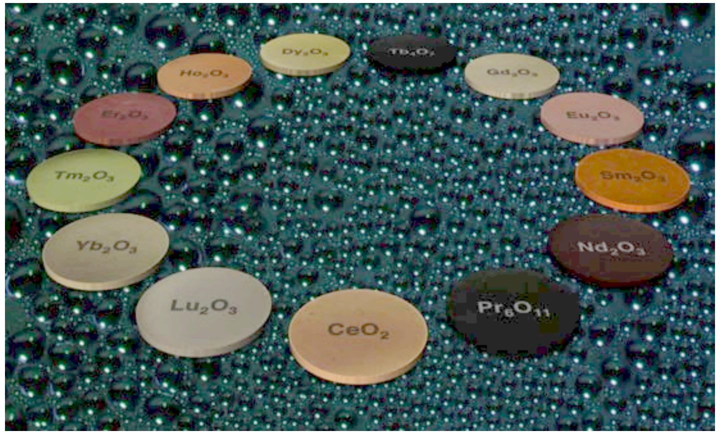



Combination of surface texturing and surface chemistry results in superhydrophobicity


Challenges
Performance
Longevity
Energy Landscape
Enhancing Longevity with Robust Hydrophobic Coatings

# Rare-earth oxide ceramic coatings

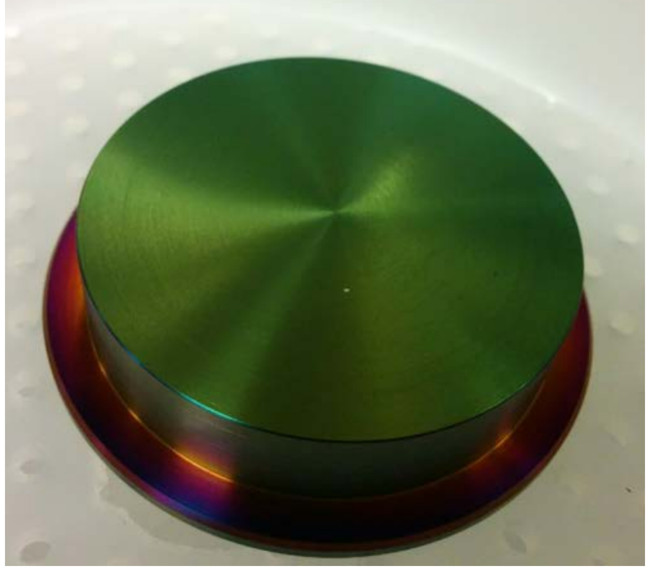


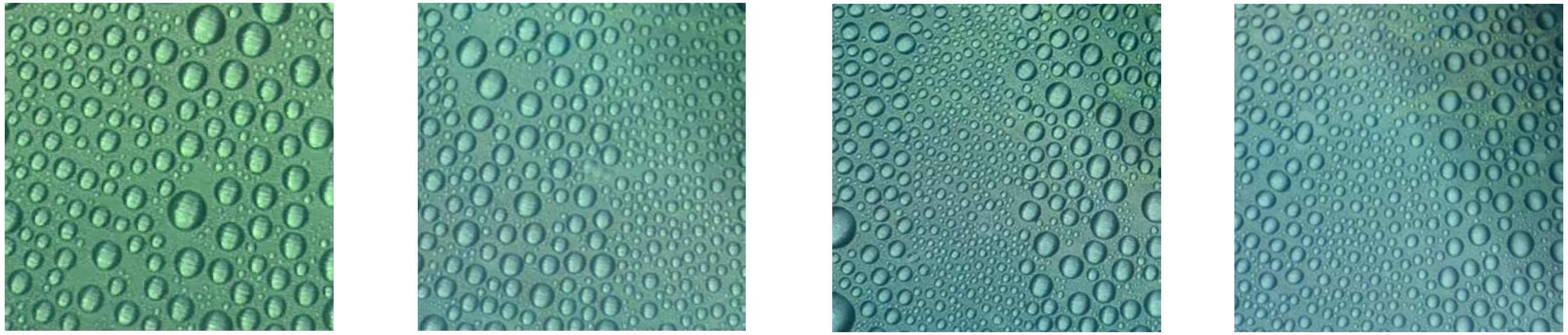

**Khan S.**, et al. *Applied Physics Letters* **2015**, *106*, 061601

# Thin film of cerium oxide withstands harsh steam

SIMON FRASER UNIVERSITY

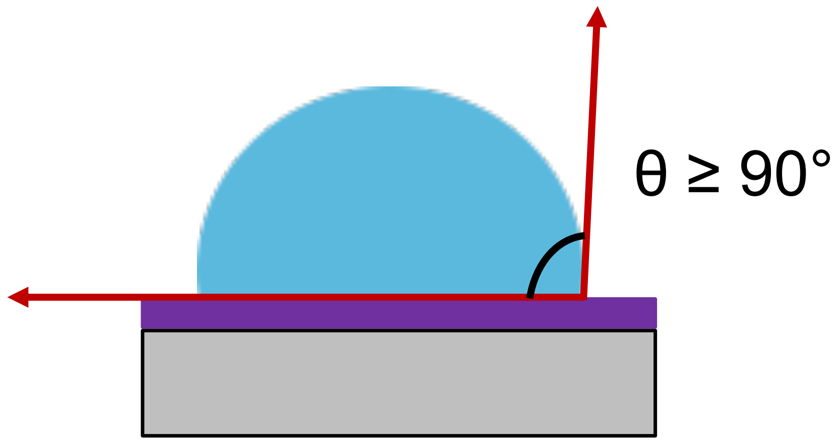


0 hrs | 25 hrs | 50 hrs | 100 hrs

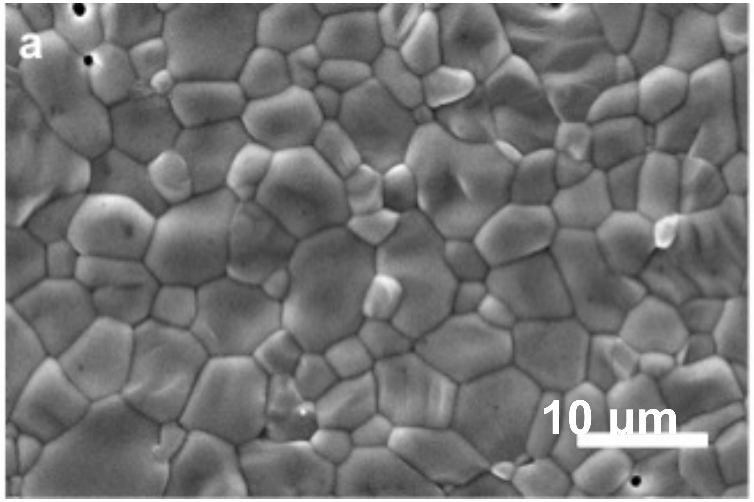


**Khan S.,** Azimi G., Paxson A., Varanasi K. K., *Hydrophobic materials incorporating rare earth elements and methods of manufacture* (U.S. patent granted: US20190111063A1)

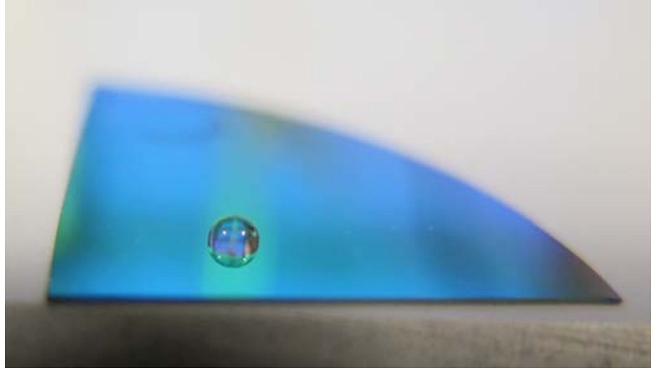
# Challenges with solid coatings – pinning sites/defects

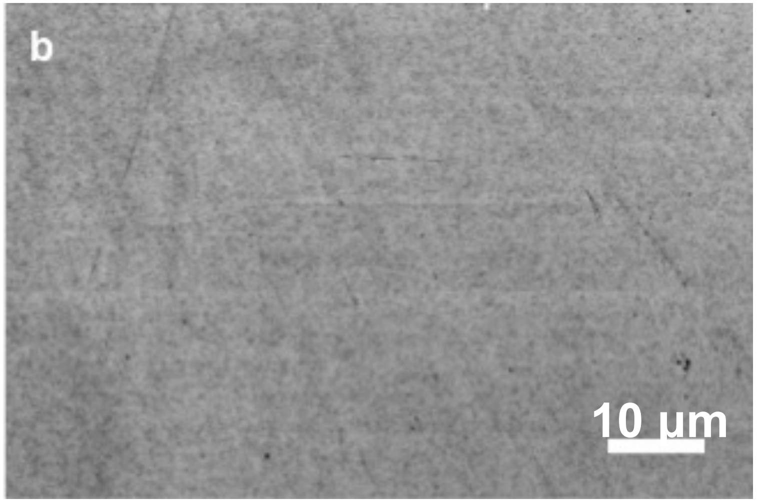



- Pinning sites reduce drop shedding
- Defects/holes are entry points for fluids



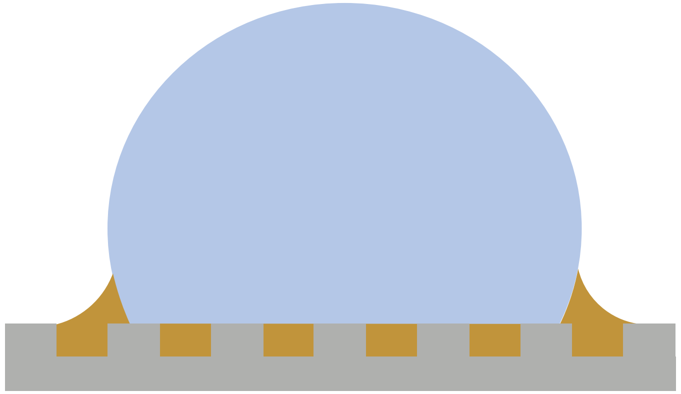

**Pellets**
Grain boundaries, pinning sites, contact angle hysteresis: ~48°



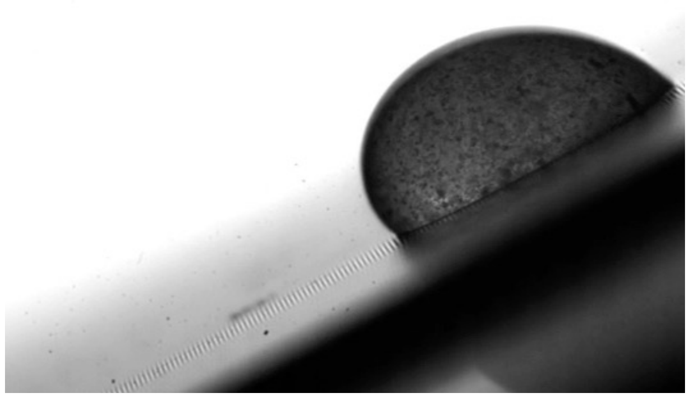



**Sputtered Thin Films (~300 nm)**
No grain boundaries, on smooth silicon contact angle hysteresis: ~15°

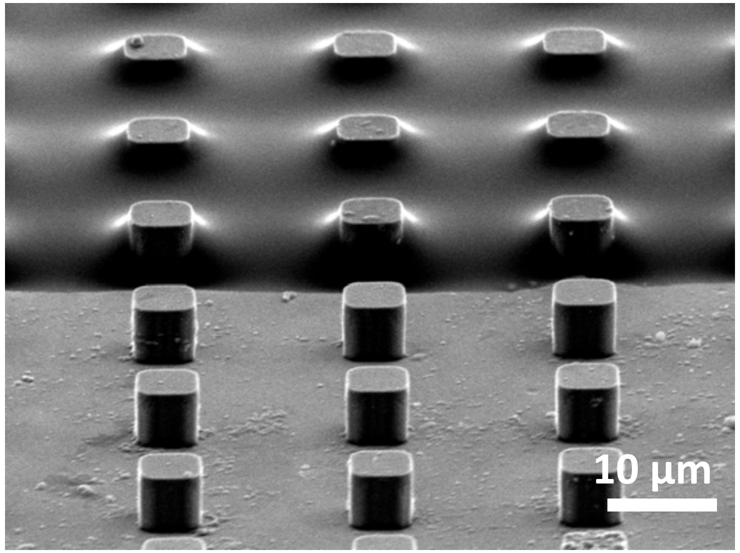
# Liquid-impregnated surfaces (LIS)



**Schematic of LIS**



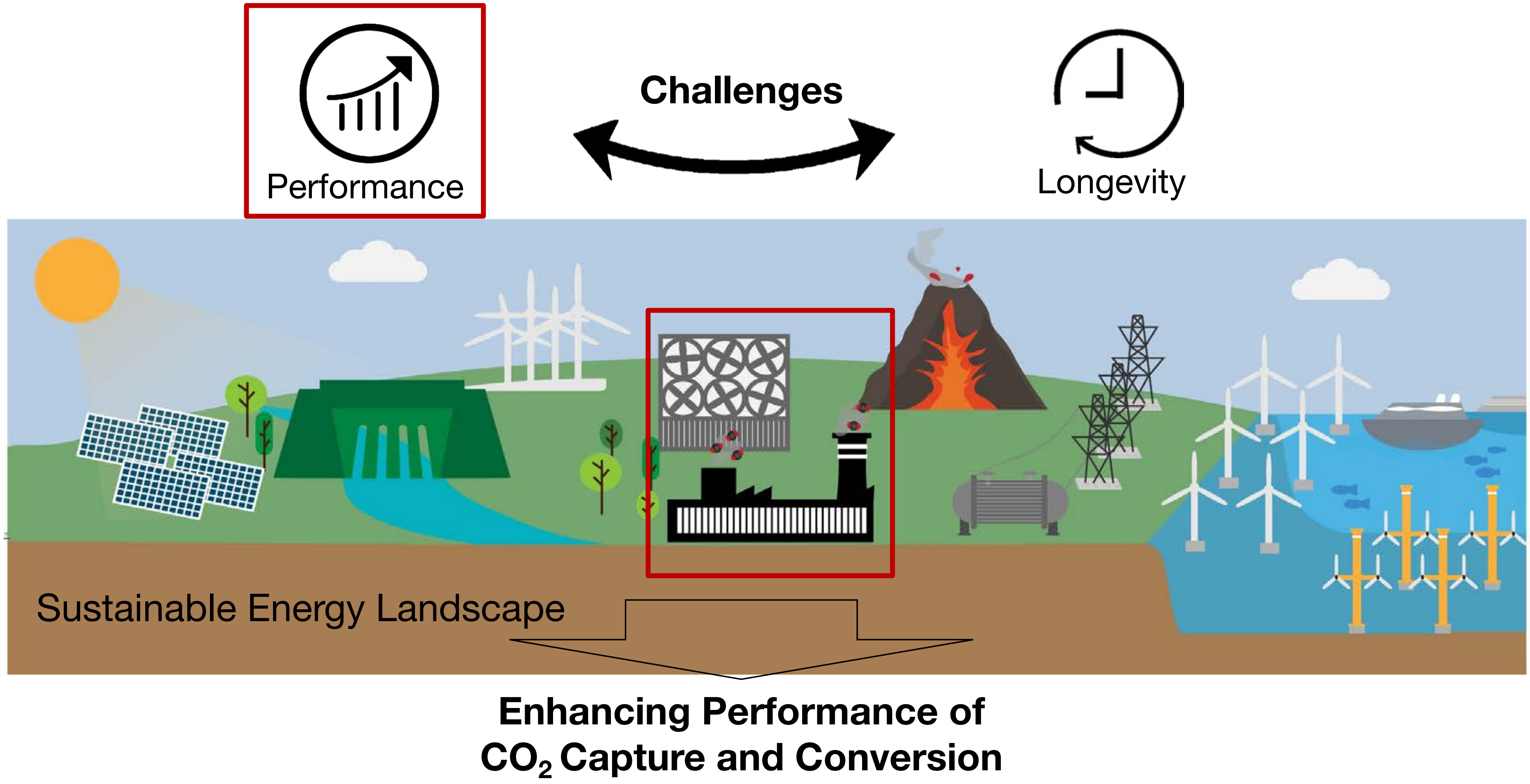
**Pitcher plant uses slippery surfaces to catch prey!**




**LIS as seen under SEM**

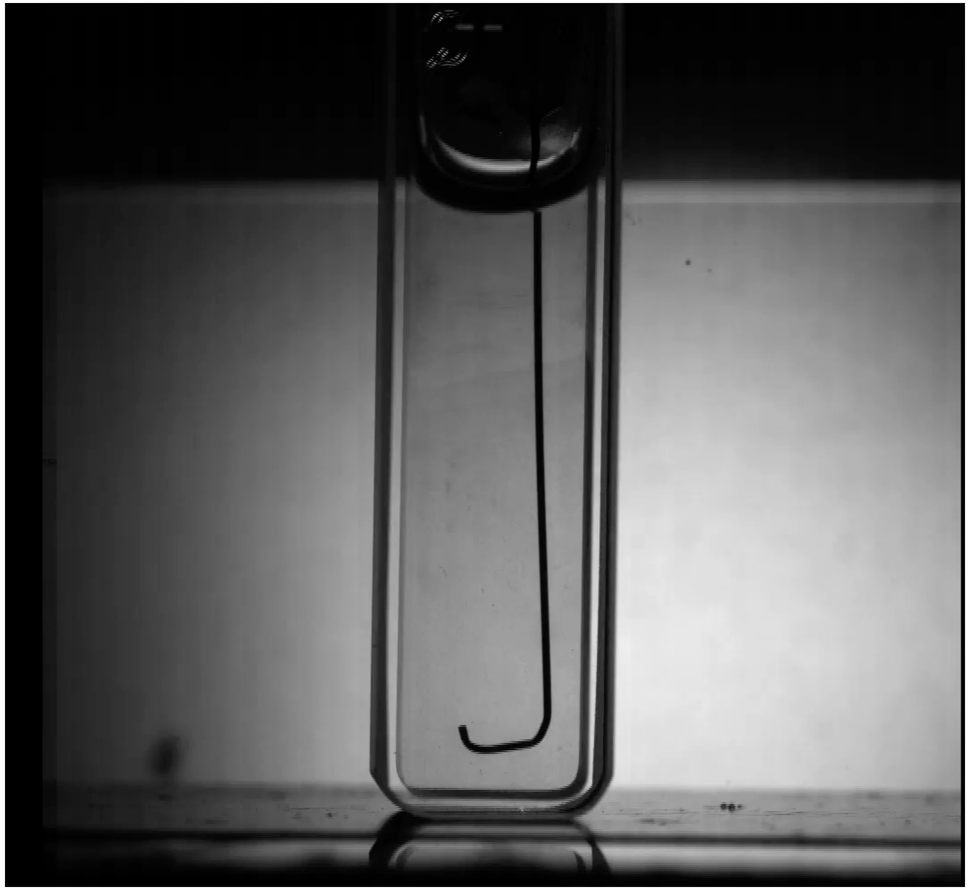
Remarkably slippery!

T.-S. Wong et al. *Nature* **2011**, *477*, 443.
J. D. Smith, et al. *Soft Matter* **2013**, *9*, 1772.


Performance
Challenges
Longevity
Sustainable Energy Landscape
Enhancing Performance of
$CO_2$ Capture and Conversion

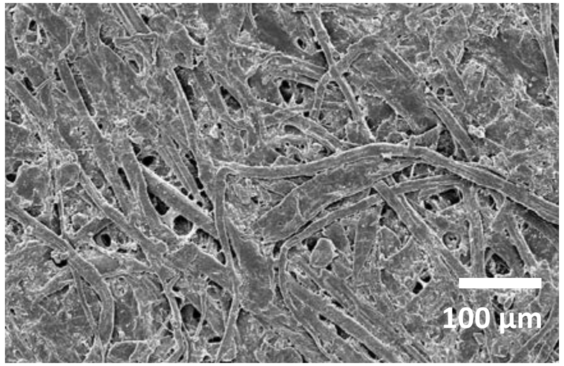
# Capturing $CO_2$ is a pressing technological challenge

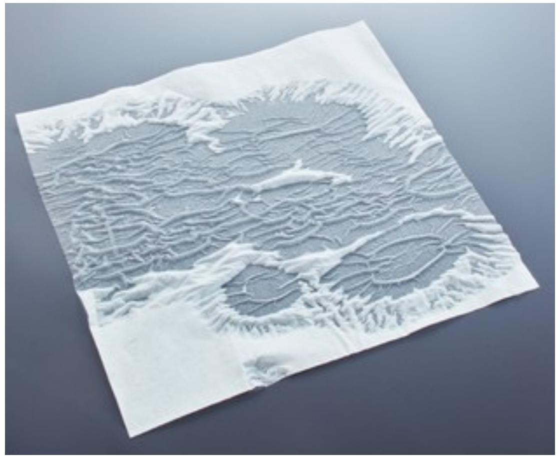
Growing need to capture $CO_2$ from exhaust streams and directly from air



Lime water ($Ca(OH)_2$) slowly turns milky when $CO_2$ is bubbled

# Hastening mass transfer – evaporation of water



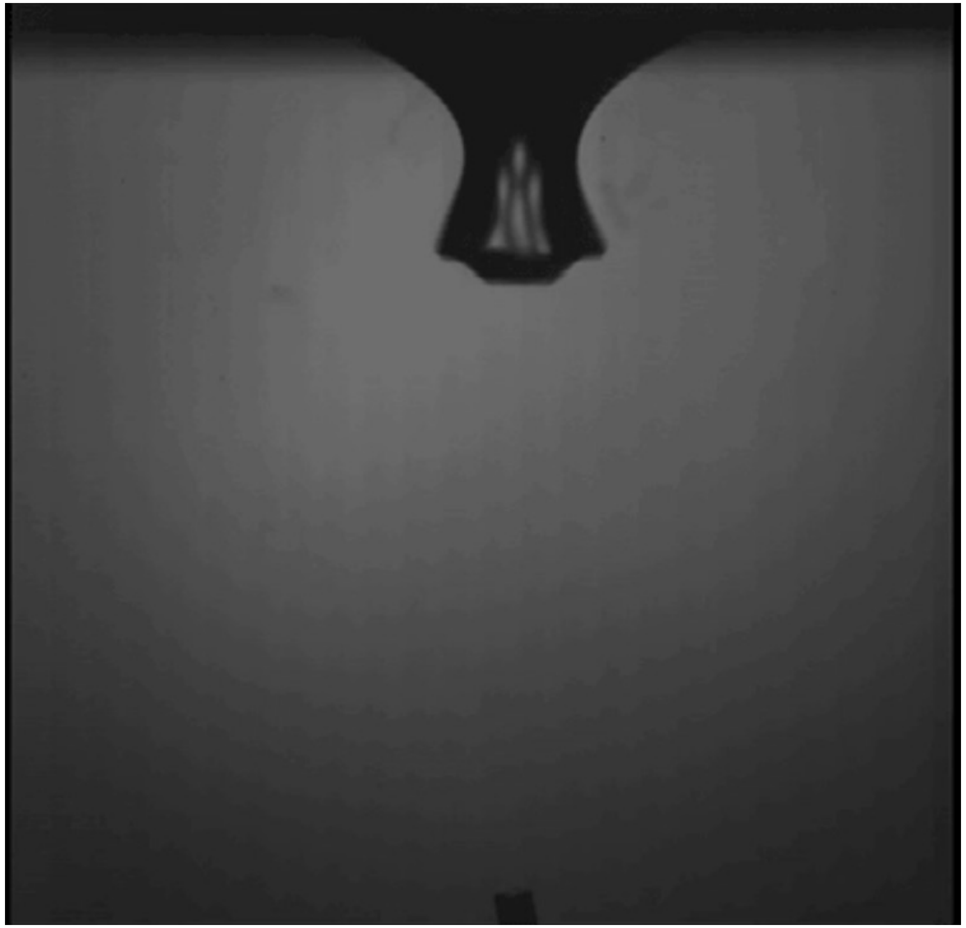



A beaker of water takes many days to fully evaporate

Absorbing and spreading water in thin sheets (like paper towels) can hasten evaporation

# A “paper towel” to absorb $CO_2$ bubbles

Bubble bounce off common surfaces (eg: metals)

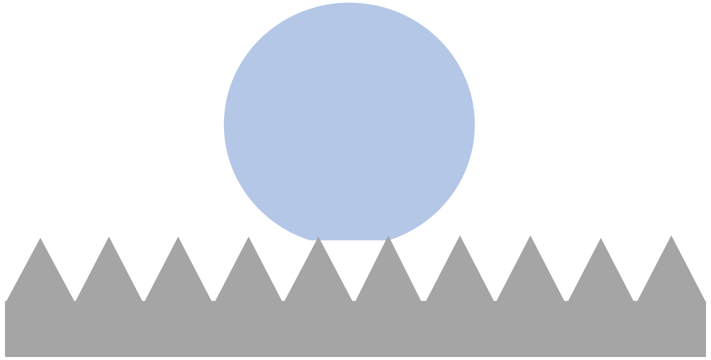


A gas-capturing “paper towel” traps $CO_2$ bubbles

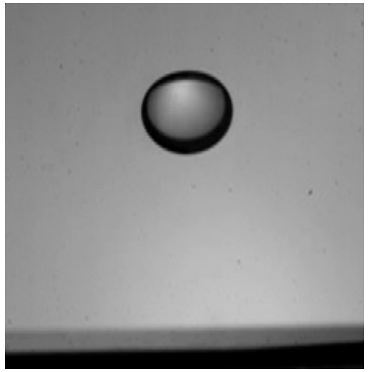
Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

# Superhydrophobic surfaces capture gas

## Superhydrophobic surfaces

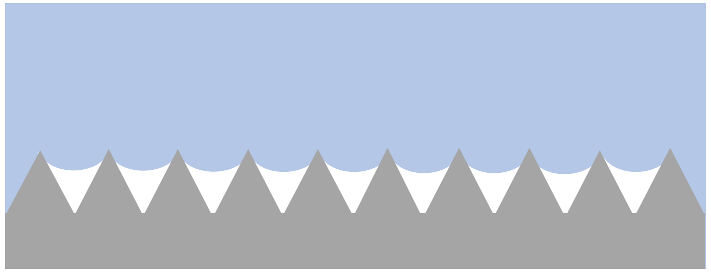


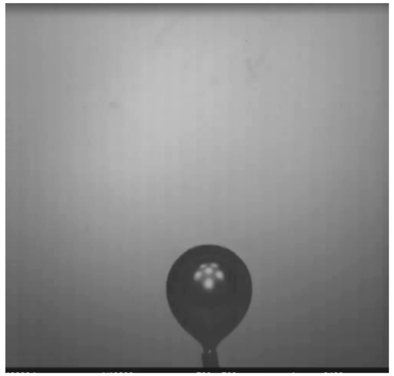
Lotus leaf showing superior water repellency



Drop Impacting a Superhydrophobic Surface

## Gas capturing surfaces

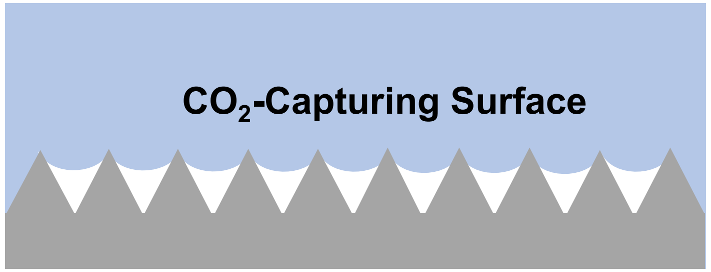


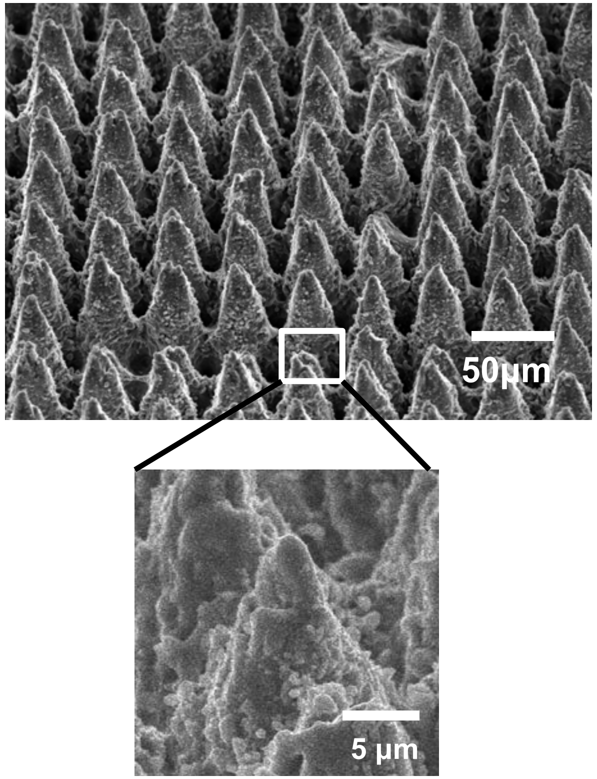


Bubble Impacting a Supergasphilic Surface

Diving Bell Spider with a captured air bubble to breath

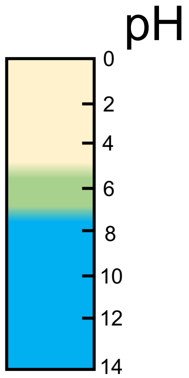
# Gas-capturing surfaces enhance $CO_2$ dissolution



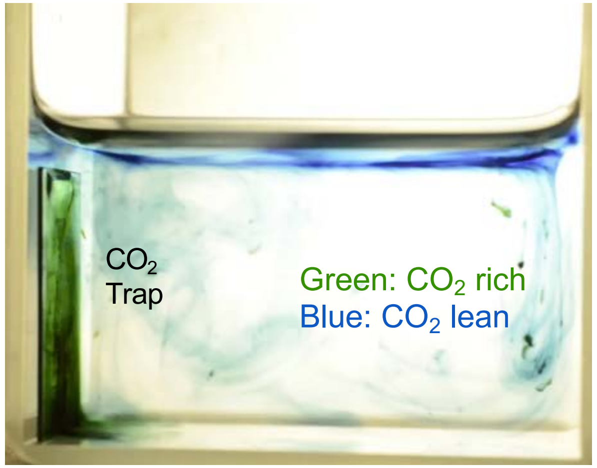




**Conventional bubbling (only blue)**

**Enhanced $CO_2$ concentration near the trap (green)**

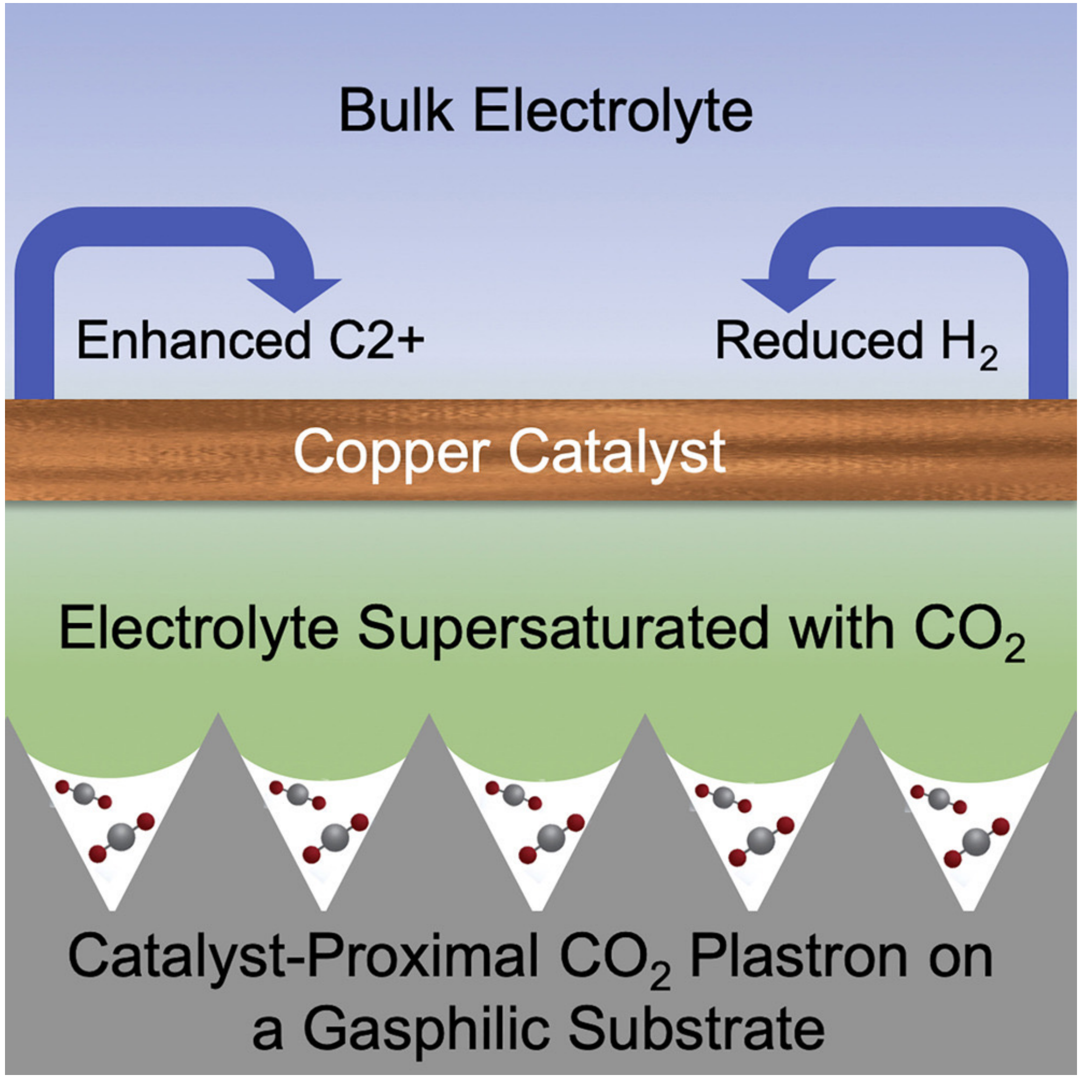



**Green: $CO_2$ rich**
**Blue: $CO_2$ lean**




Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

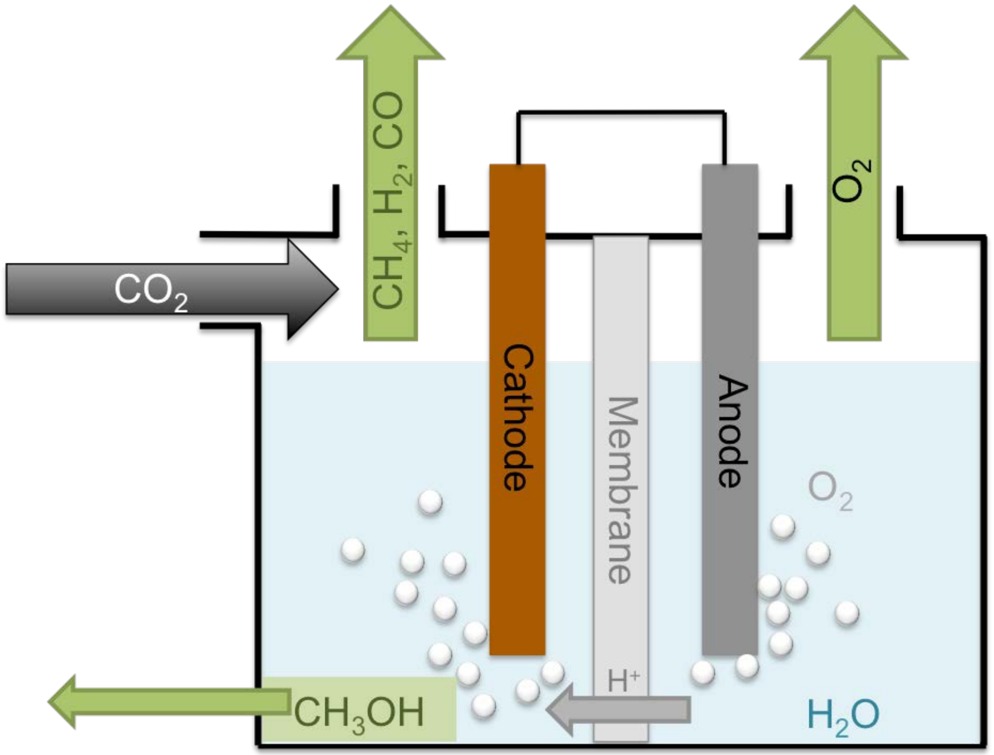
# Can these $CO_2$-capturing surfaces enhance $CO_2$ conversion?



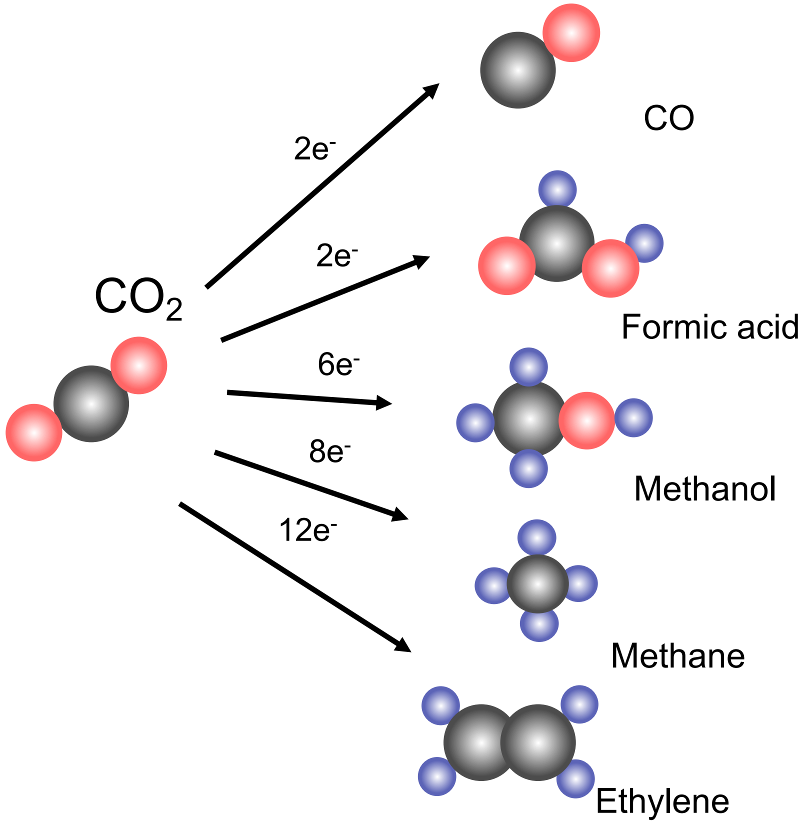

Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

# Electrochemical Reduction of $CO_2$

Electrochemical reduction of $CO_2$ converts $CO_2$ (aq) to combustible fuel products by passage of electric current through an electrocatalyst




**Fundamental Reaction:** $xCO_2(aq) + nH^+ + ne^- \rightarrow products + yH_2O$




**Competing $H_2$ Co-evolution:** $2H^+ + 2e^- \rightarrow H_2(g)$

# Why Electrochemical Reduction of $CO_2$?

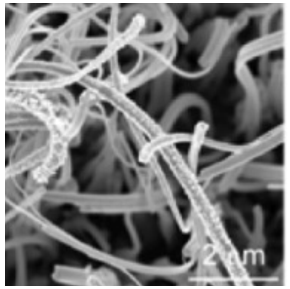
Can be coupled with renewable sources of energy such as wind, solar and hydropower to provide the electricity needed to run the conversion

Dense energy carriers such as ethanol, propanol and formate can be generated (based on the selected electrocatalyst and the applied potential)

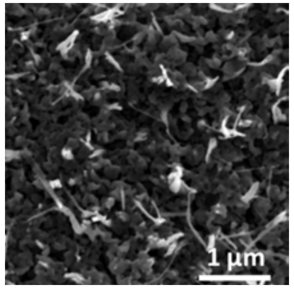
Operate at ambient pressure and temperature conditions

Value-added products such as ethylene can also be generated which serves as precursor to produce useful polymers such as polyethylene

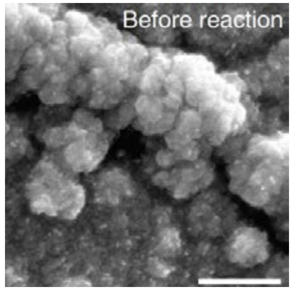
# Previous $CO_2$RR studies: nanostructured Cu catalyst




Li et al. *JACS* (2012) 134; 7231

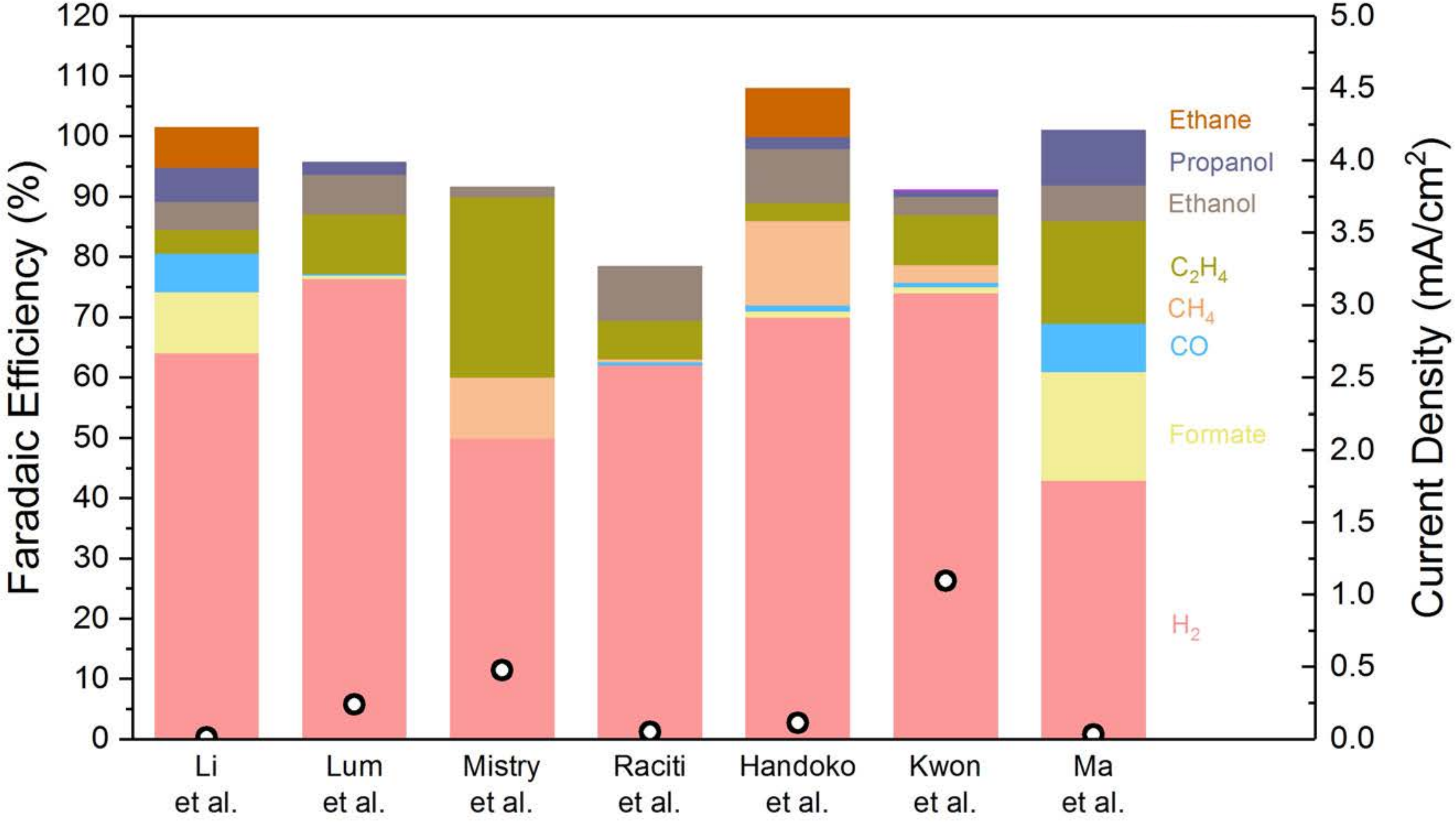


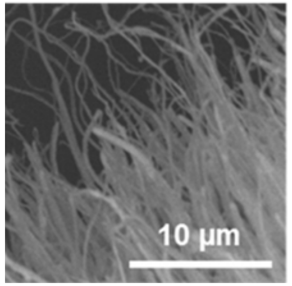

Lum et al. *JPCC* (2017) 121; 14191



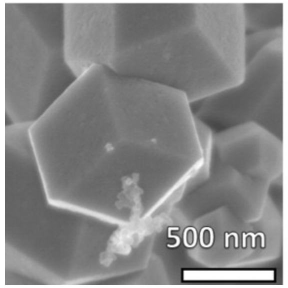

Mistry et al. *Nat. Comm* (2017) 7;12131

**-1.1 V vs RHE**

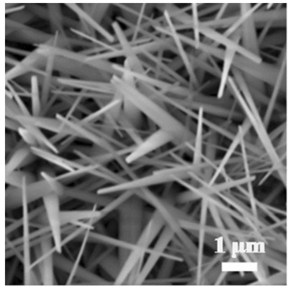



Raciti. et al. *Nano Letters* (2015) 15; 6829



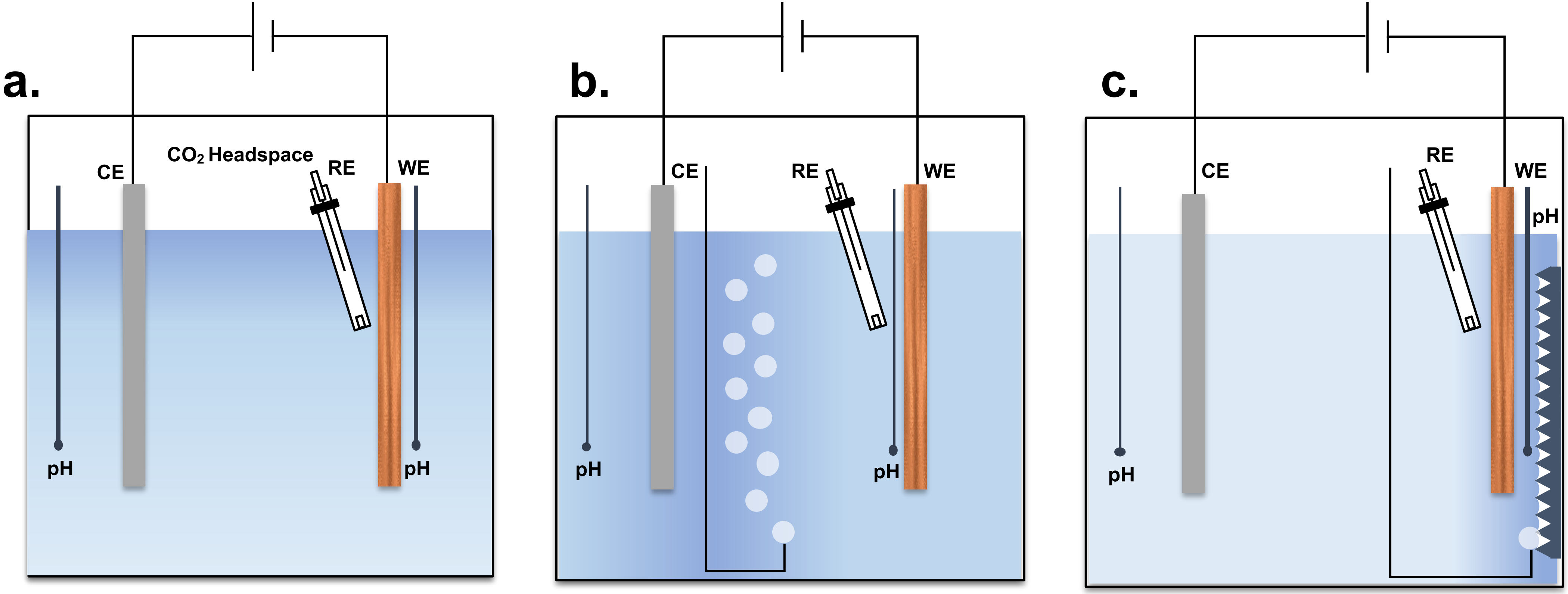

Handoko et al. *JPCC* (2015) 120; 20058




Ma et al. *Ang. Chem.* (2016) 55; 6680

Significant $CO_2$ availability limitations impacts efficiency

# Comparing against conventional $CO_2$ delivery approaches




$CO_2$ Headspace

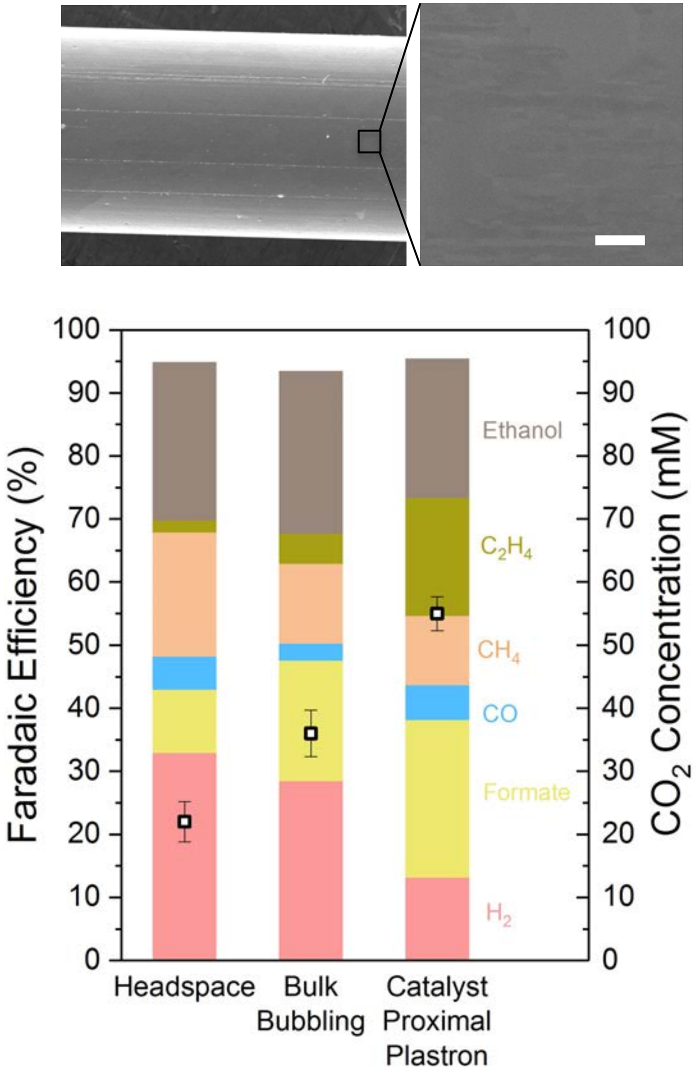
Bulk Bubbling

Trapping $CO_2$ Bubbles

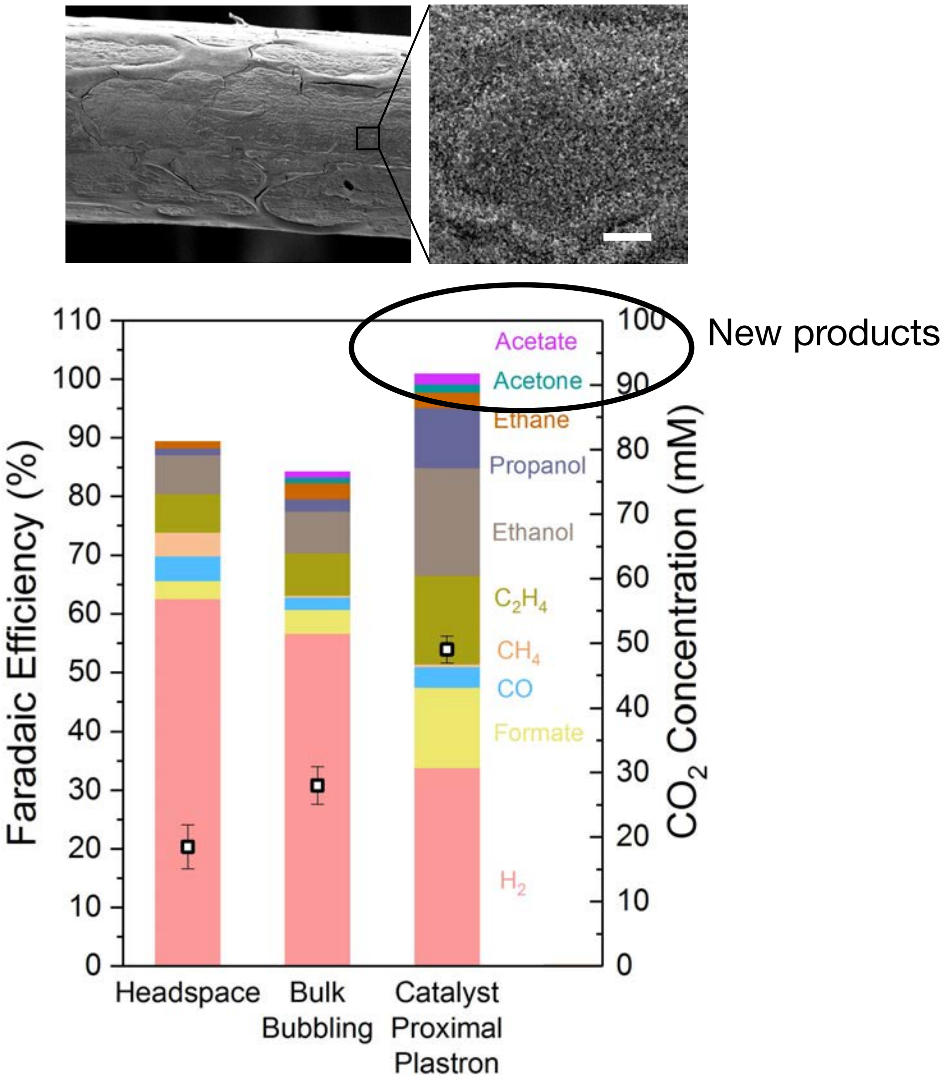
Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

# Catalyst-Proximal Plastron: Product Distribution

**Smooth Copper**

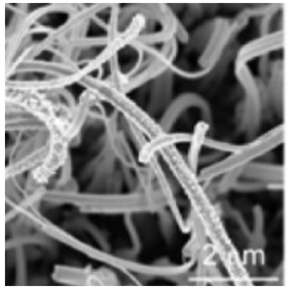



**Nanostructured Copper**

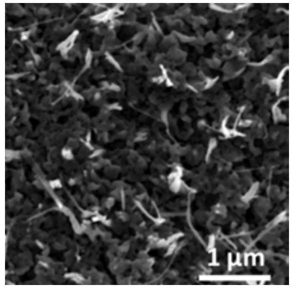



Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

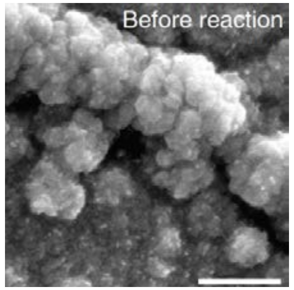
# Comparison with other state-of-the-art nanostructured catalysts



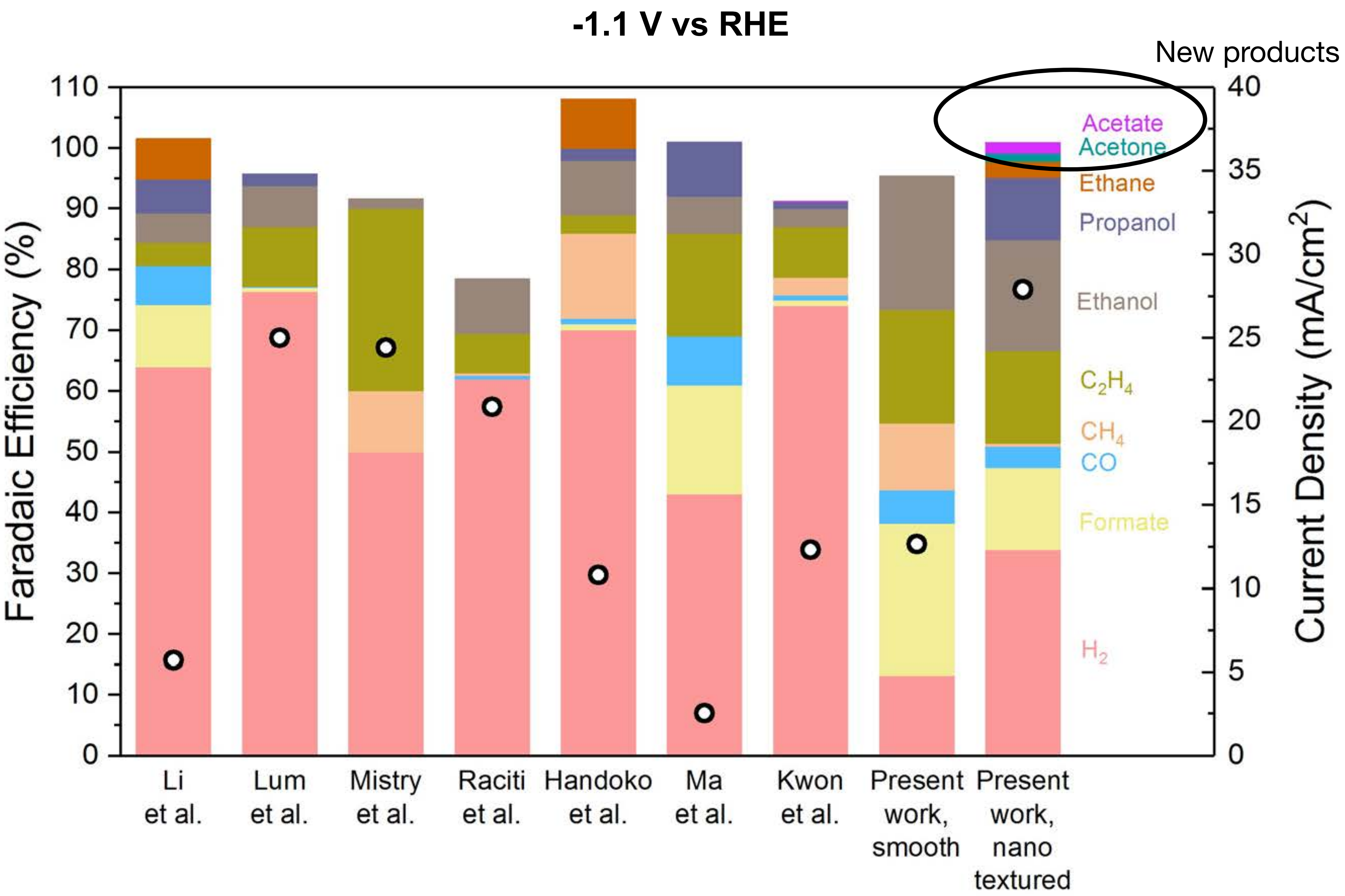

Li et al. *JACS* (2012) 134; 7231

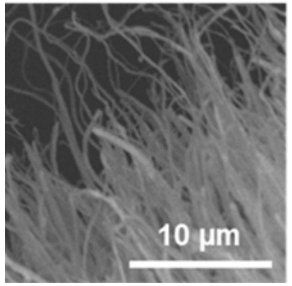



Lum et al. *JPCC* (2017) 121; 14191

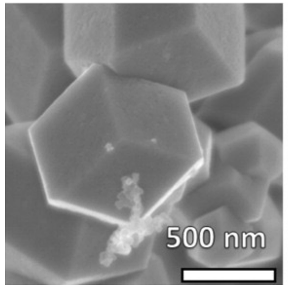



Mistry et al. *Nat. Comm* (2017) 7;12131

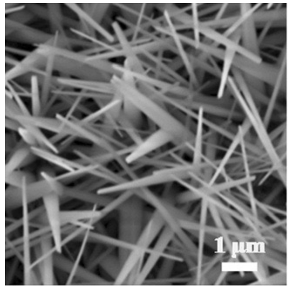



Raciti. et al. *Nano Letters* (2015) 15; 6829



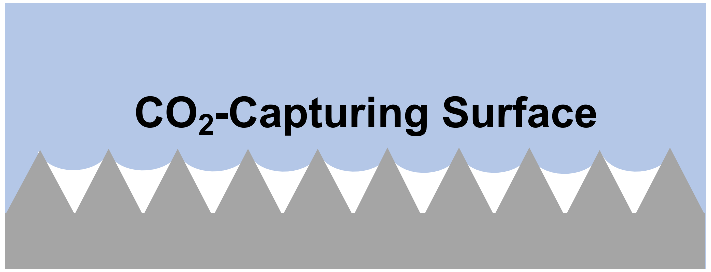

Handoko et al. *JPCC* (2015) 120; 20058

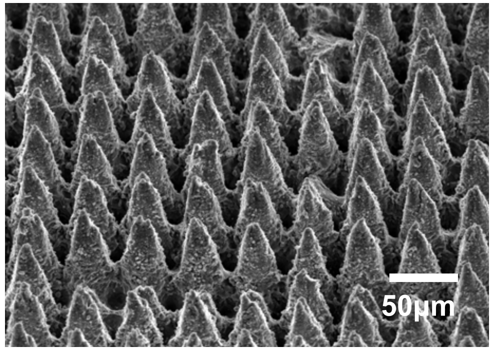



Ma et al. *Ang. Chem.* (2016) 55; 6680

Khan, S., Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

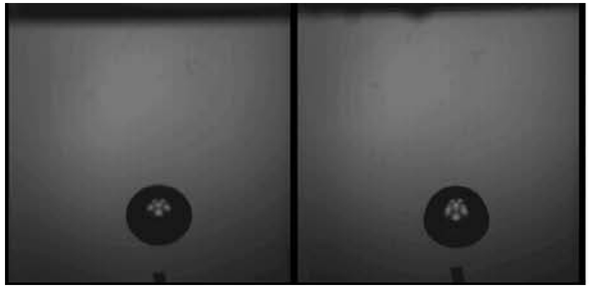
# Gas-capturing surfaces to enhance $CO_2$ capture + conversion

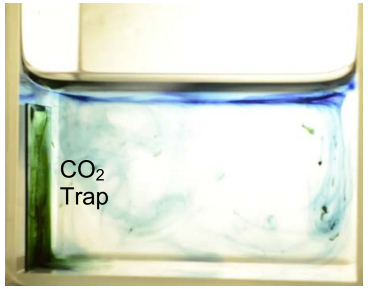



Diving bell spiders with their “breathing pouch”

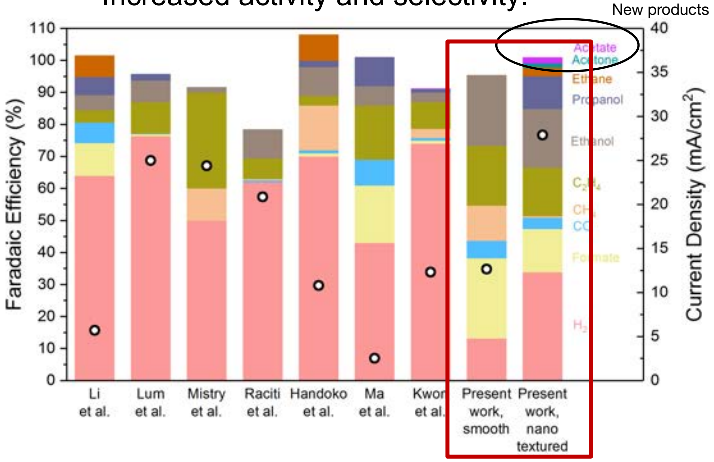
Bubble-philic Bubble-phobic






Green: $CO_2$ rich
Blue: $CO_2$ lean

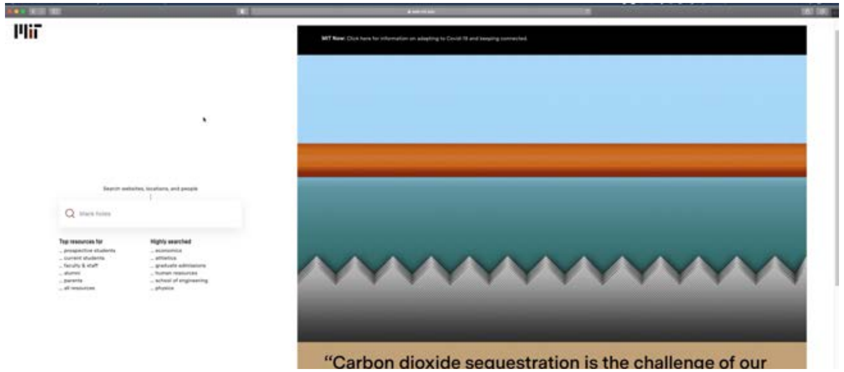
Increased activity and selectivity!

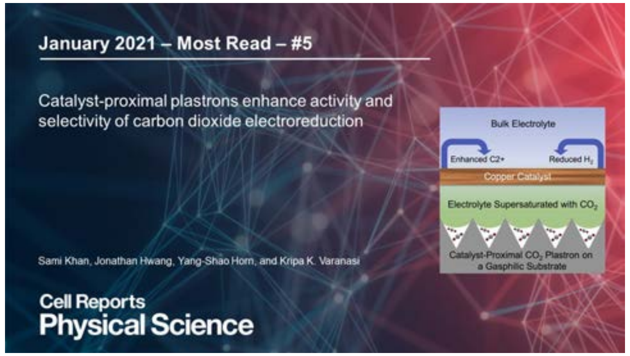



News Highlights

MIT News ON CAMPUS AND AROUND THE WORLD

PHYS.ORG




**Khan, S.**, Hwang J., Shao-Horn Y., and Varanasi, K.K., 2021. Catalyst-proximal plastrons enhance activity and selectivity of carbon dioxide electroreduction. Cell Reports Physical Science, 100318

# SFU: Sustainable Energy Engineering


**Key highlights:**
- Multidisciplinary graduate and undergraduate curriculum
- ~40-50 undergraduate students per class
- 20 graduate students (Masters and Ph.D.)
- 10 faculty members (and growing!)
- Location: Surrey, British Columbia, Canada
- Website: https://www.sfu.ca/see.html

# Graduate students in my group

**Elaheh Hantoosh Zadeh**
MASc student

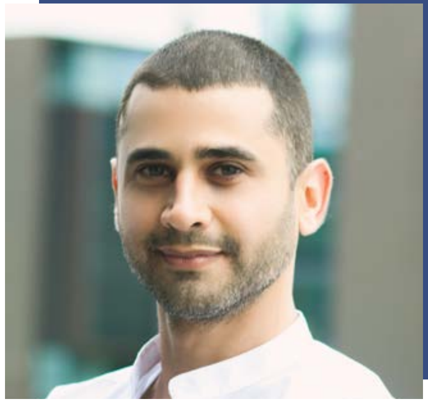
Evaporation patterns in inks on nanotextured substrates

Undergrad: Sharif University, Iran

**Gahee Im**
MASc Student

Protective coatings in biomass combustion reactors
Undergrad:
Gangneung-Wonju University, S. Korea

**Oz Oren**
MASc Student



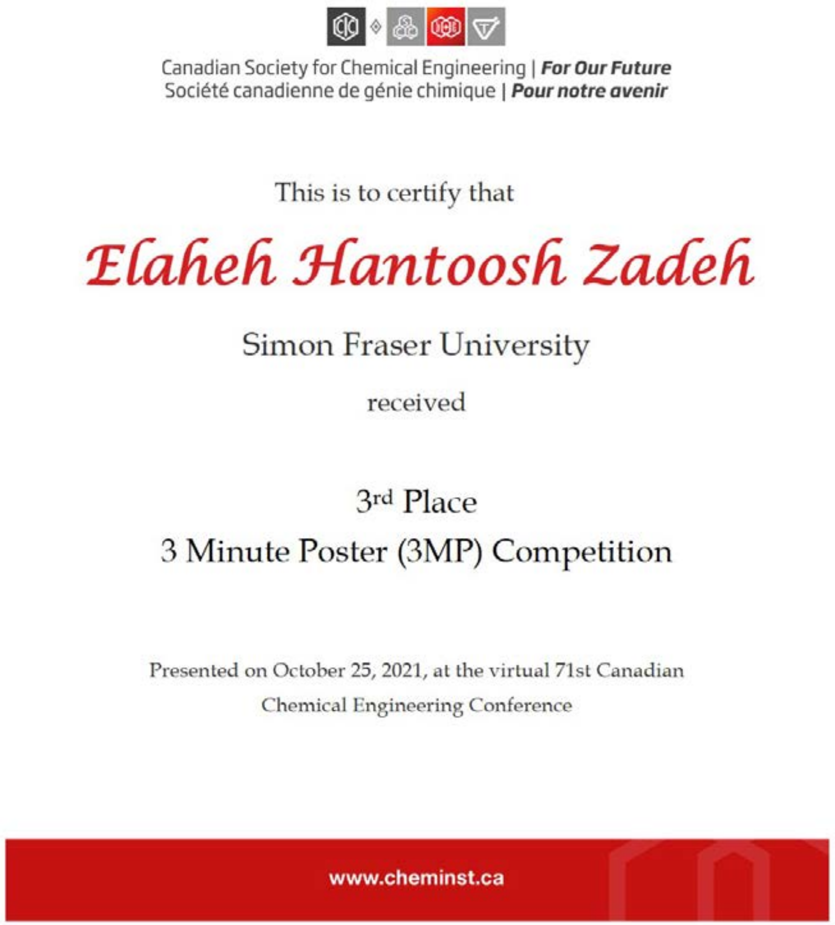
Nucleation and crystallization of phase change materials

Undergrad: Israel Institute of Technology (Technion)

Sponsors and partners:

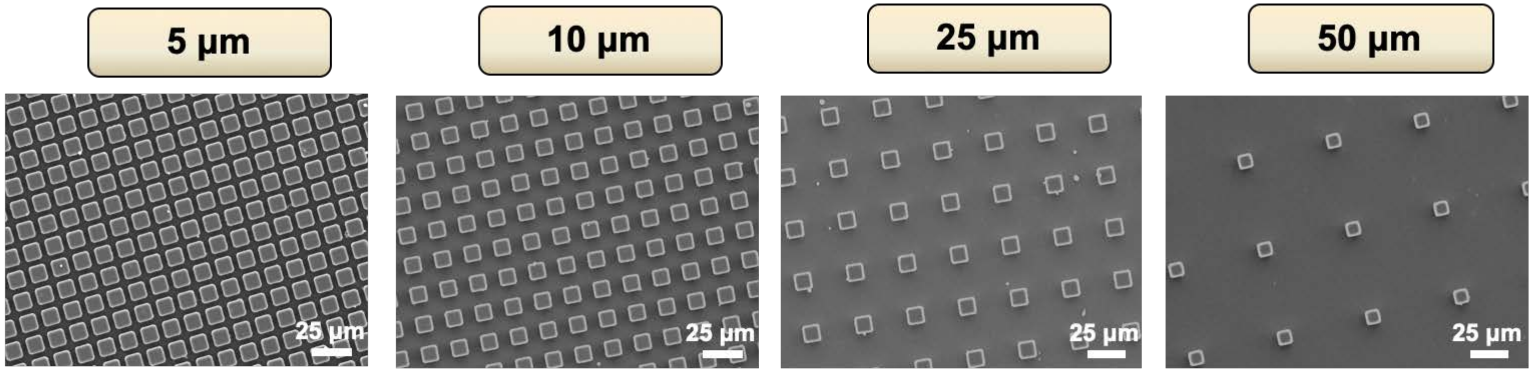
# Student funding and awards

- SFU Entrance Scholarship (all students)
- Mitacs Globalink Awards
  - Gahee Im and Clara Park (undergrad)
  - Exchange internships at University of Kansas
  - Possible exchanges in future with UiO
- 3-minute thesis competition (Elaheh - 3rd)

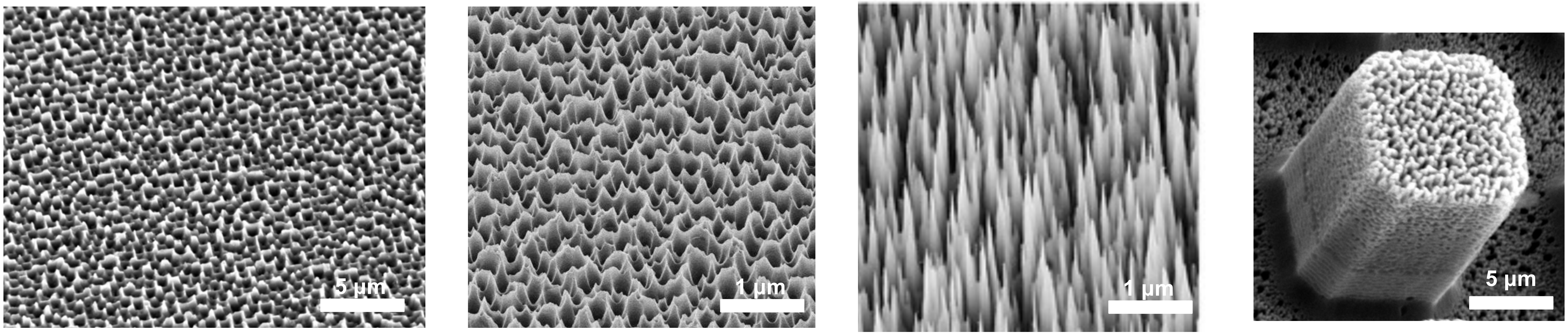


# Micro/nanofabrication at SFU 4D labs

**Microtextures**

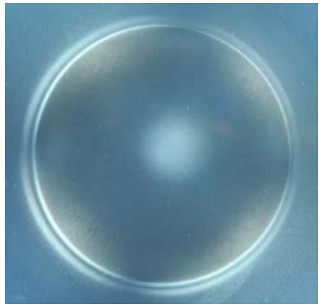



**Nanotextures**

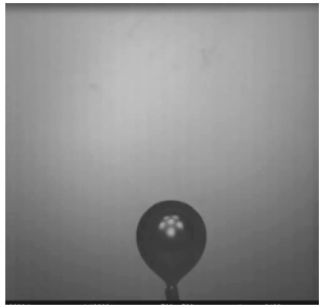


# Summary and takeaways

- **Hydrophobic ceramic coatings**
  - Thin films of rare-earth oxide ceramics are inherently hydrophobic
  - Reducing hydrogen-bonding sites increases hydrophobicity
  - Promote drop-wise condensation



- **Anti-corrosion liquid layers** (lubricant-impregnated surfaces)
  - Remarkably slippery – no defects
  - Spreading vs non spreading characteristics are important
  - Significantly enhance corrosion protection



- **Gas capturing surfaces**
  - Superhydrophobic textures capture $CO_2$
  - Gas remains stable within textures and enhance $CO_2$ concentration locally
  - Increase selectivity to C2+ products over hydrogen

SFU SCHOOL OF SUSTAINABLE ENERGY ENGINEERING

Engineered Interfaces for Sustainable Energy EISEn

# Thank you for your attention!
# Questions?

Website: http://www.khanresearchlab.com

Email: s_khan@sfu.ca