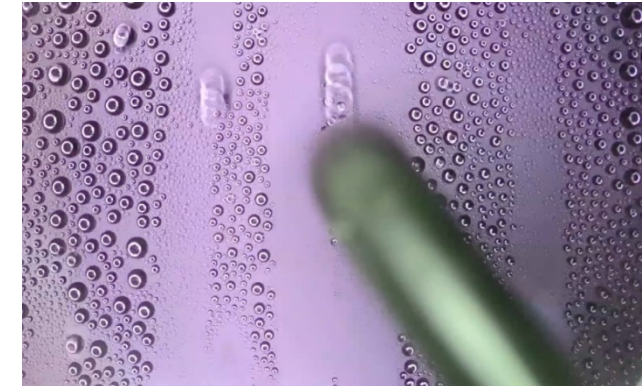
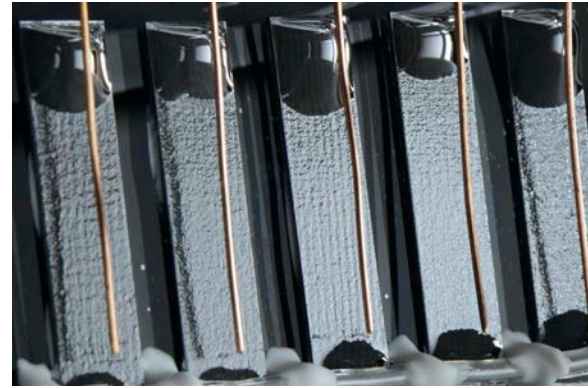
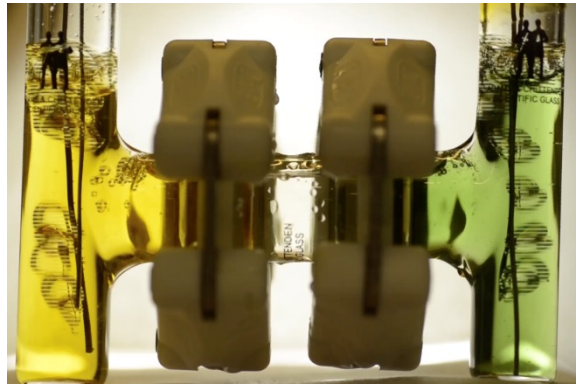
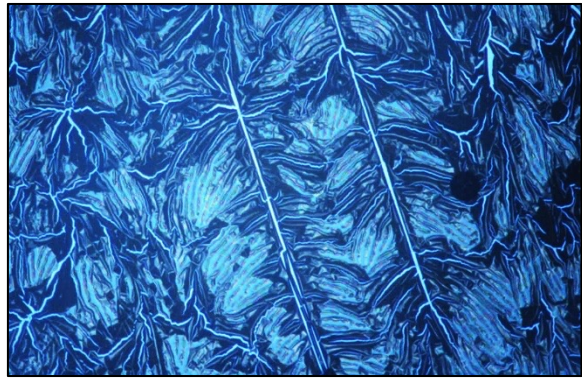


Innovating at Interfaces: Enhancing Performance and Longevity in Sustainable Energy Systems



Uio

Dr. Sami Khan
Assistant Professor
Simon Fraser University



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)



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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 performance and longevity of sustainable energy systems

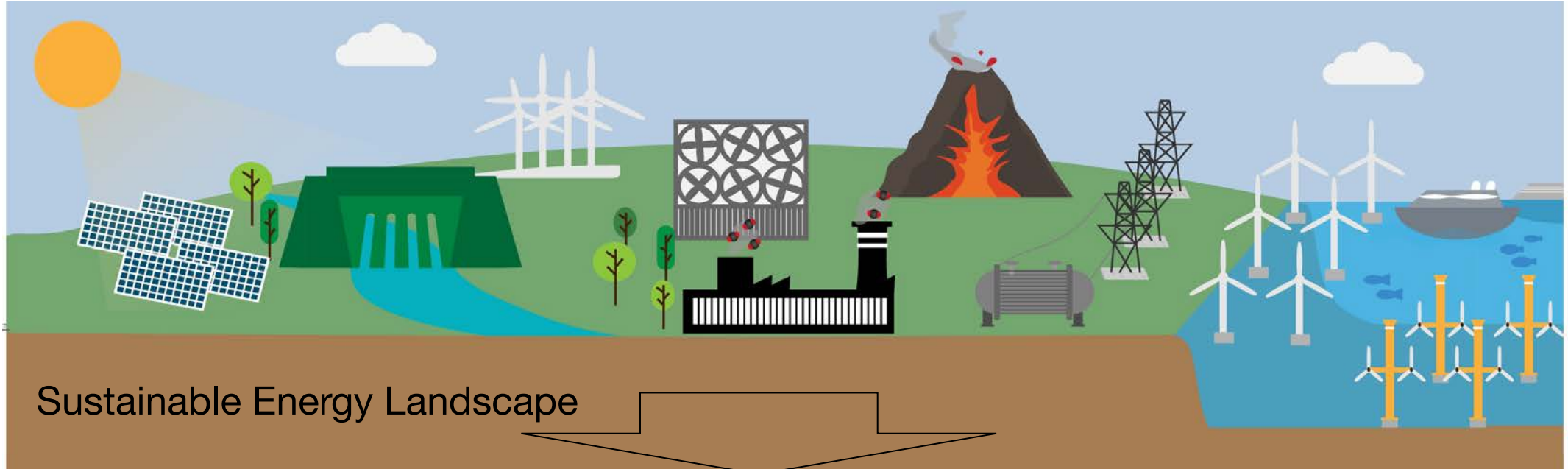


Performance

Challenges



Longevity



Sustainable Energy Landscape

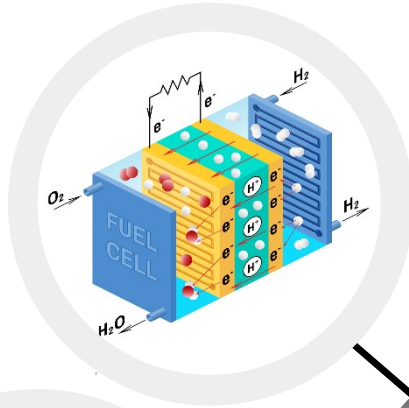


Interfacial Interactions

Challenges in Sustainable Energy Systems at Interfaces

Hydrogen Energy Systems

Challenges: Hydrogen embrittlement and wetting of reactants/products



Geothermal Energy Systems

Challenges: Corrosion and fouling



Solar Energy Systems

Challenges: Dust sticking



CO₂ Capture + Conversion Systems

Challenges: Sluggish mass transfer of CO₂, kinetics, corrosion



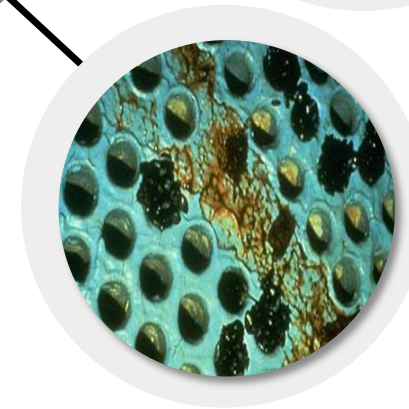
Wind Energy Systems

Challenges: Ice accretion, corrosion



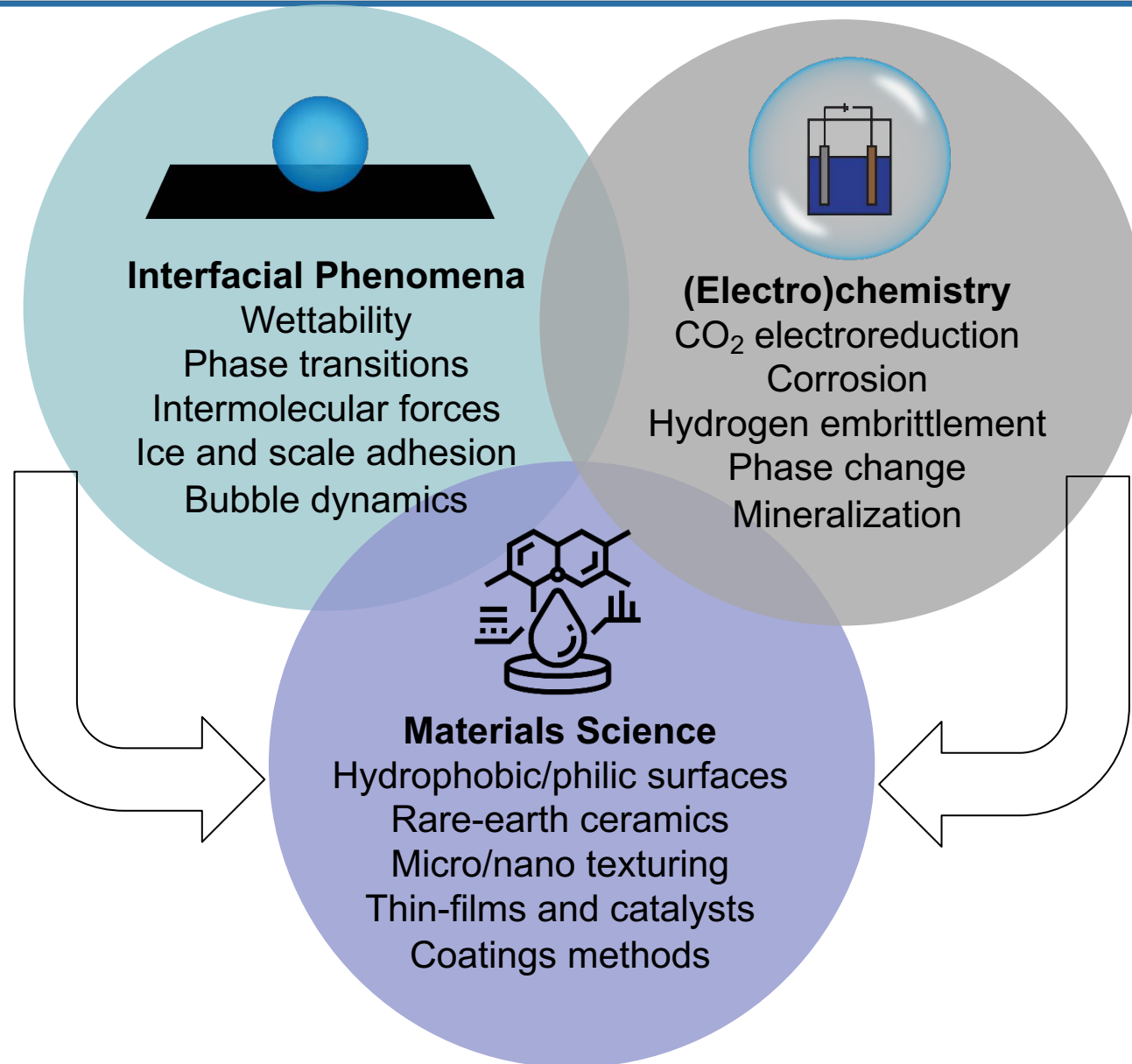
Hydropower Systems

Challenges: Biofouling, corrosion, erosion



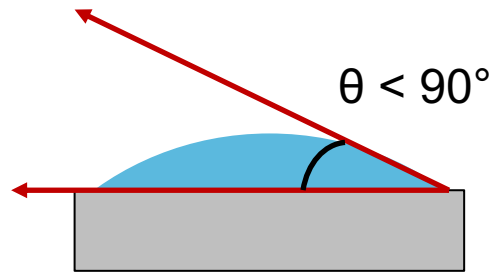
Engineered Interfaces

Fundamental scientific domains in our research



Wetting – Hydrophilicity and Hydrophobicity

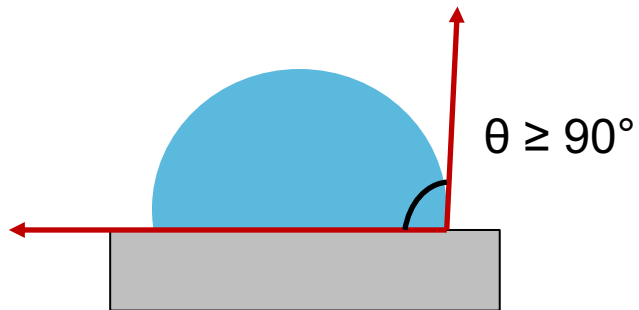
Hydrophilic Surfaces



Hydrophobicity around us

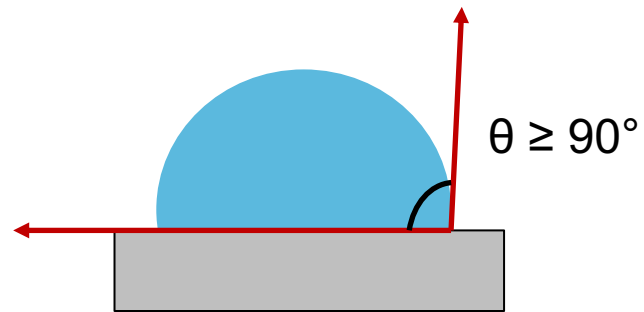


Hydrophobic Surfaces

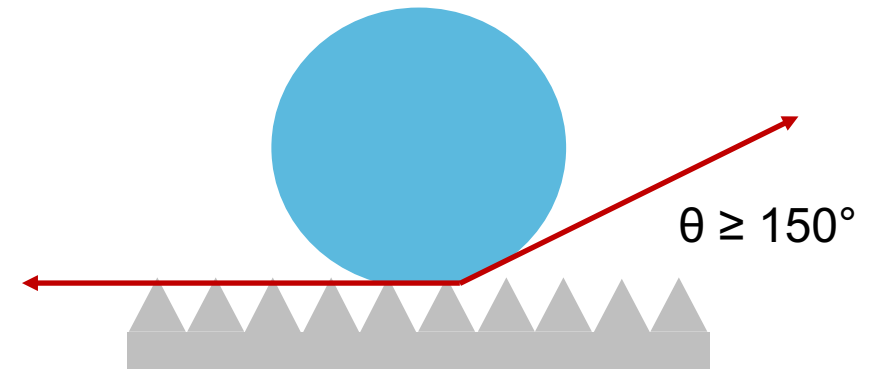


Superhydrophobicity

Hydrophobic Surfaces



Superhydrophobic Surfaces



Combination of surface texturing and surface chemistry results in superhydrophobicity

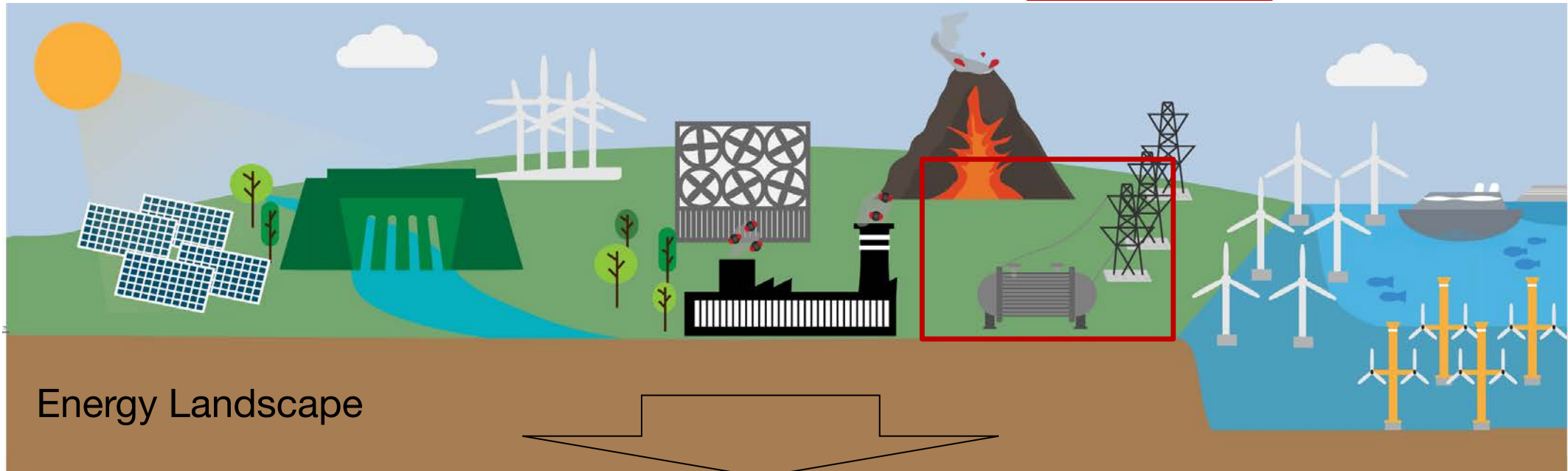


Performance

Challenges



Longevity



Energy Landscape

**Enhancing Longevity with Robust
Hydrophobic Coatings**

Rare-earth oxide ceramic coatings

hydrogen 1 H 1.0079																	helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122											boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305											aluminum 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078	scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62	yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	lanthanum 57-70 * Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	actinium 89-102 ** Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnillium 110 Uun [271]	ununnilium 111 Uuu [272]	ununbium 112 Uub [277]	ununtrium 113 Uut [289]	ununquadium 114 Uuq [289]				



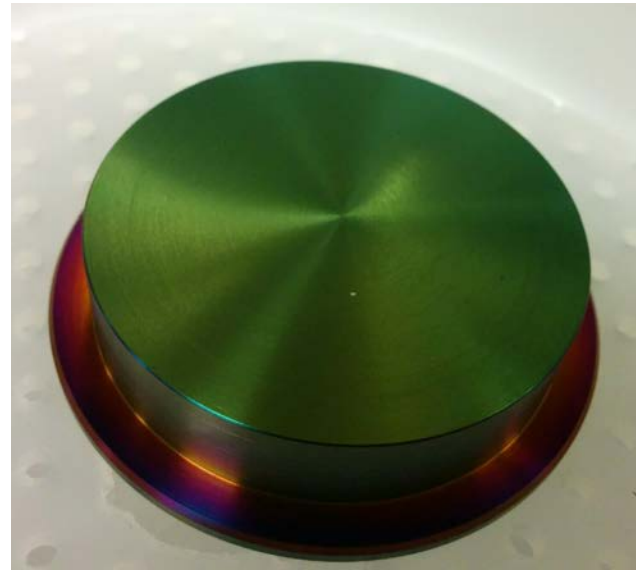
* Lanthanide series

** Actinide series

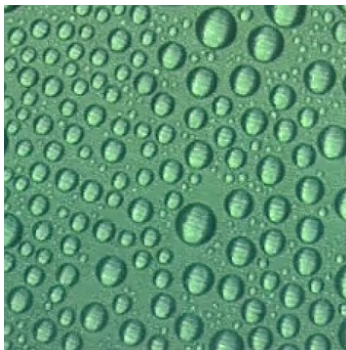
lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.05
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]



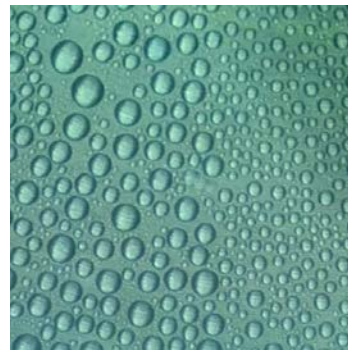
Thin film of cerium oxide withstands harsh steam



0 hrs



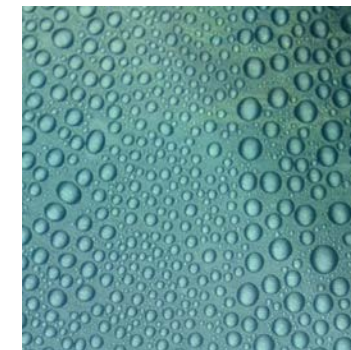
25 hrs



50 hrs

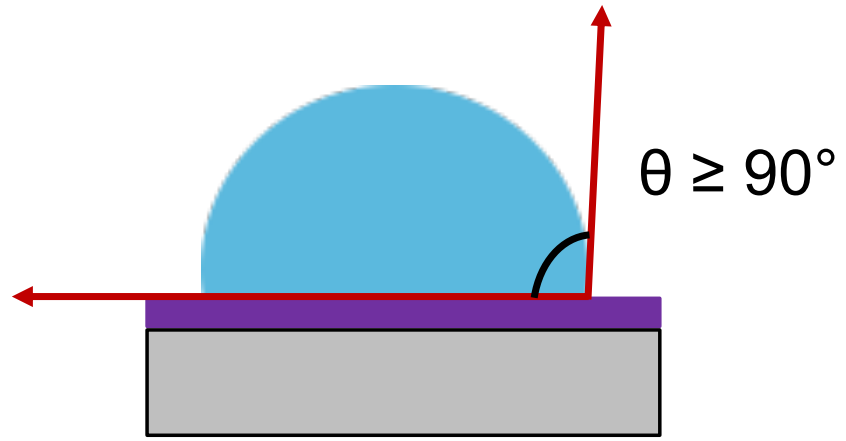


100 hrs

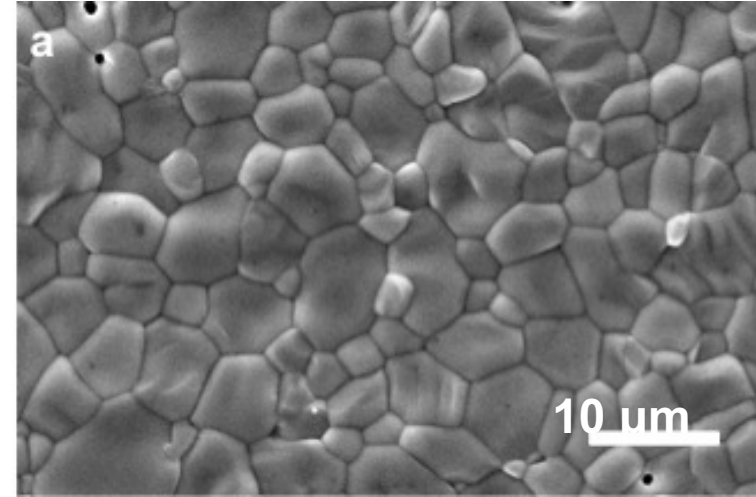


Khan S., Azimi G., Paxson A., Varanasi K. K., *Hydrophobic materials incorporating rare earth elements and methods of manufacture* (U.S. patent granted: US20190111063A1)

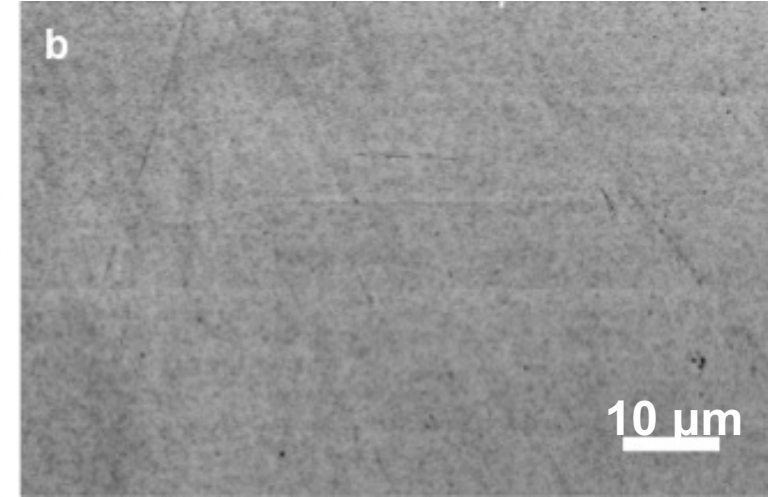
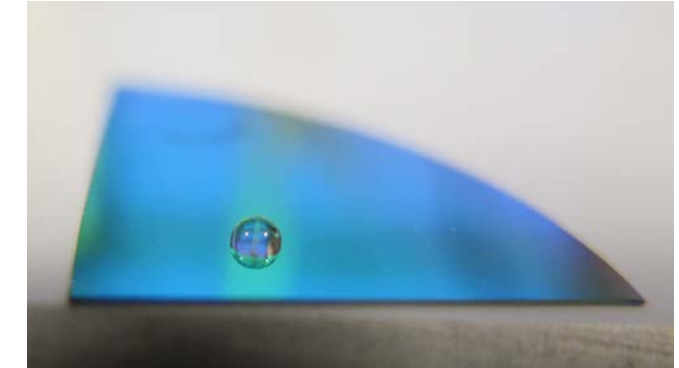
Challenges with solid coatings – pinning sites/defects



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

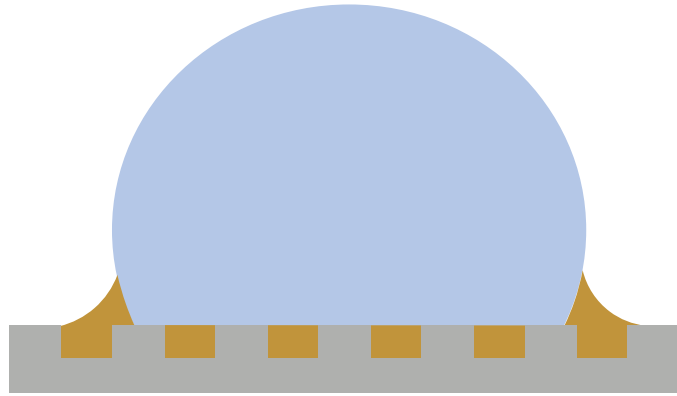


Pellets
Grain boundaries, pinning sites,
contact angle hysteresis: $\sim 48^\circ$

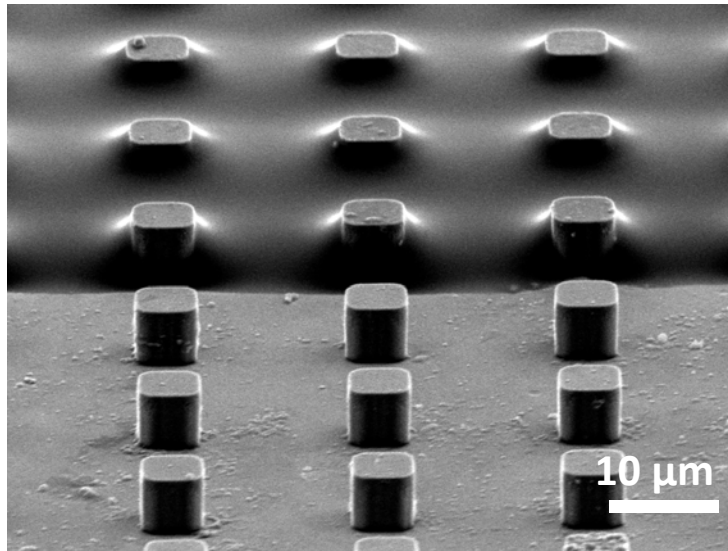
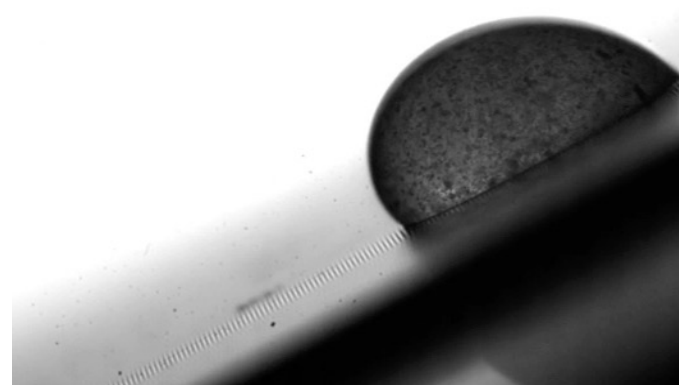


Sputtered Thin Films (~ 300 nm)
No grain boundaries, on smooth silicon
contact angle hysteresis: $\sim 15^\circ$

Liquid-impregnated surfaces (LIS)



Schematic of LIS



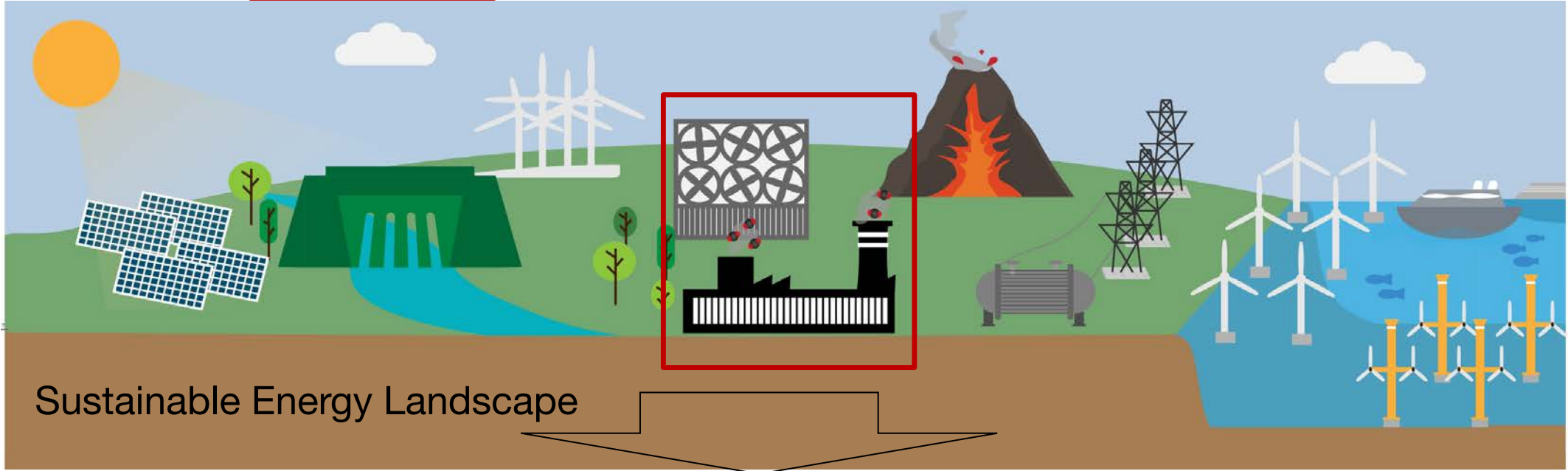
LIS as seen under SEM



Remarkably slippery!

Pitcher plant uses slippery surfaces to catch prey!





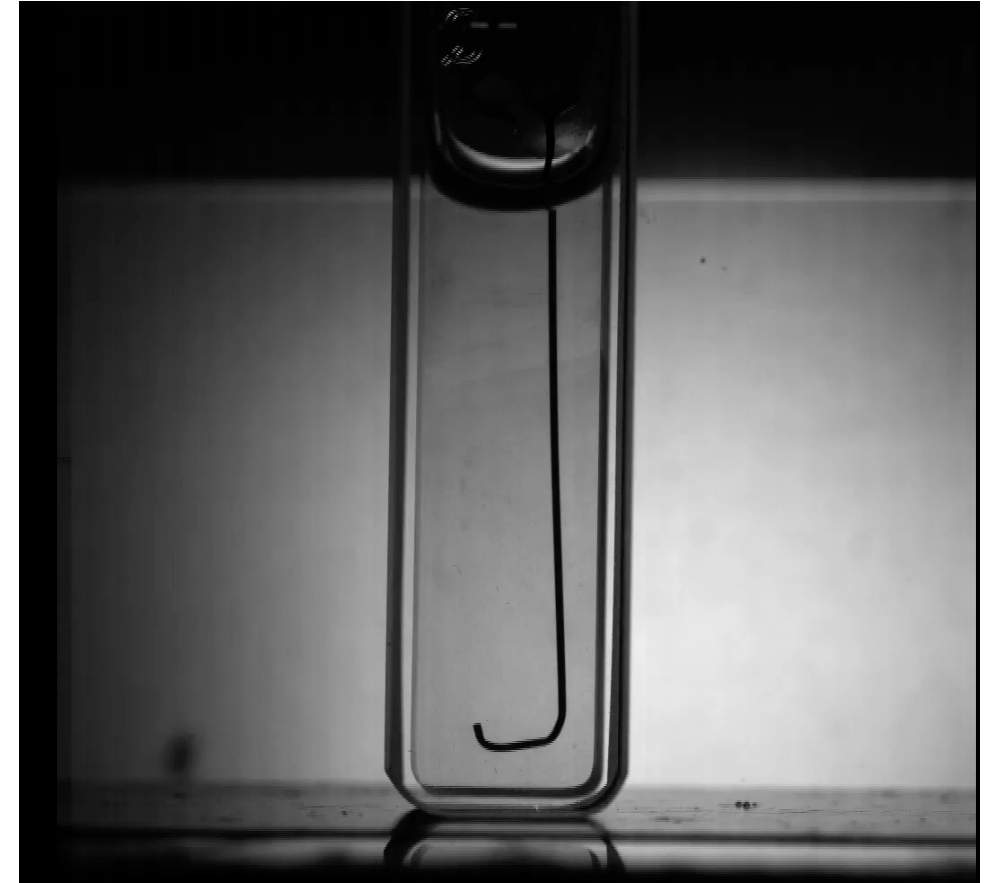
Sustainable Energy Landscape

**Enhancing Performance of
CO₂ Capture and Conversion**

Capturing CO₂ is a pressing technological challenge



Growing need to capture CO₂ from exhaust streams and directly from air



Lime water (Ca(OH)₂) slowly turns milky when CO₂ is bubbled

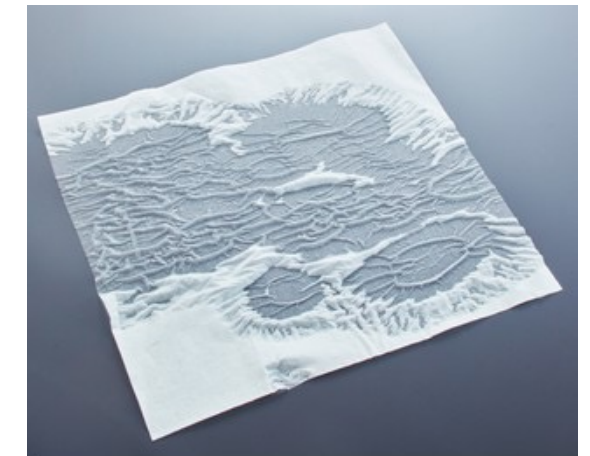
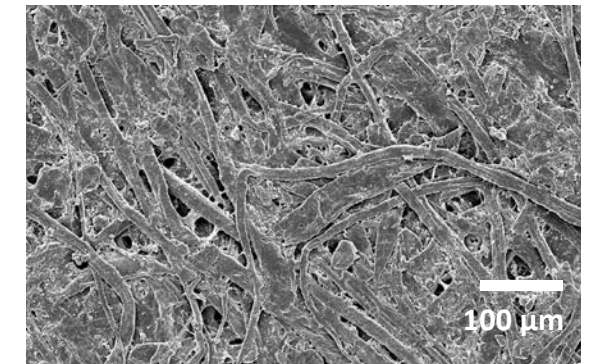
Hastening mass transfer – evaporation of water



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 CO₂ bubbles



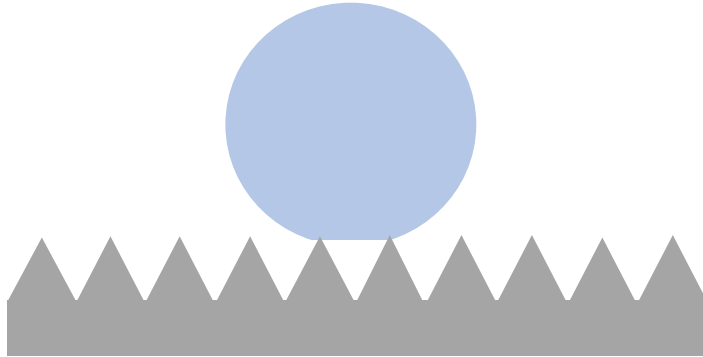
Bubble bounce off common surfaces (eg: metals)



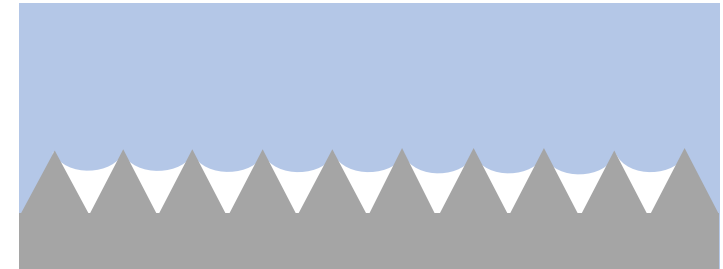
A gas-capturing “paper towel” traps CO₂ bubbles

Superhydrophobic surfaces capture gas

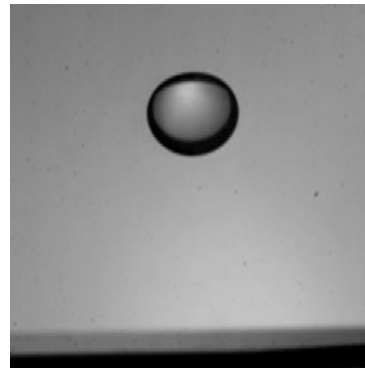
Superhydrophobic surfaces



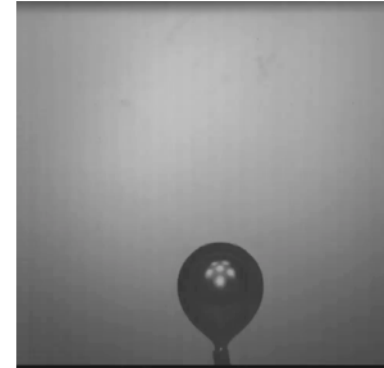
Gas capturing surfaces



Lotus leaf showing superior water repellency



Drop Impacting a Superhydrophobic Surface



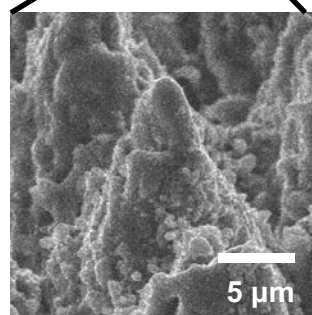
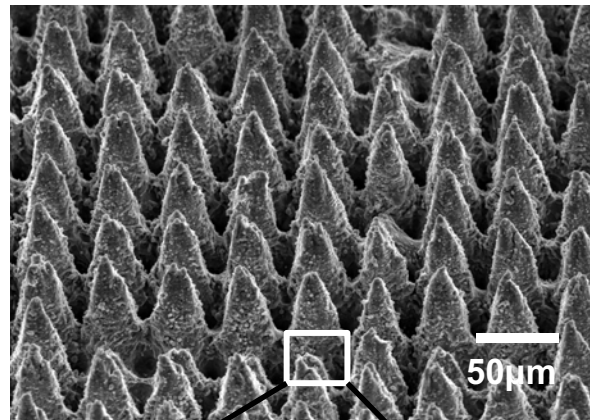
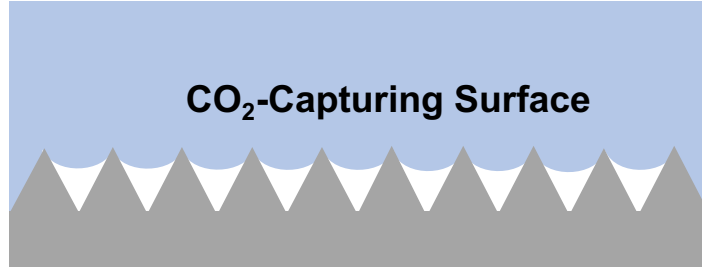
Bubble Impacting a Supergasphilic Surface



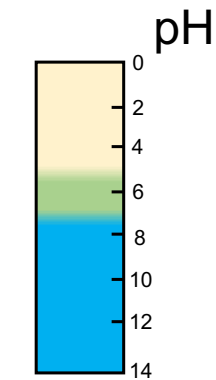
Diving Bell Spider with a captured air bubble to breathe

Gas-capturing surfaces enhance CO₂ dissolution

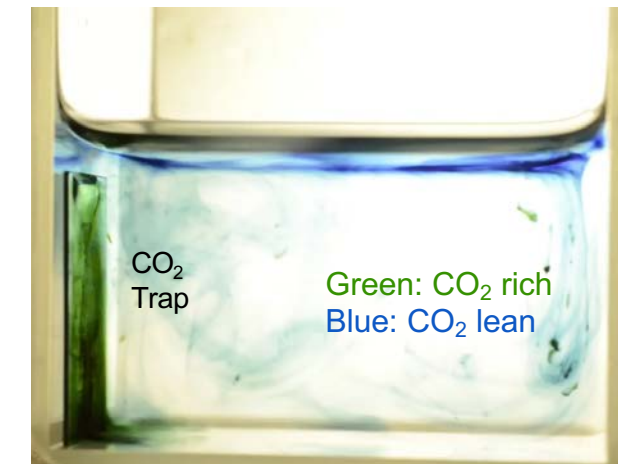
Conventional bubbling (only blue)



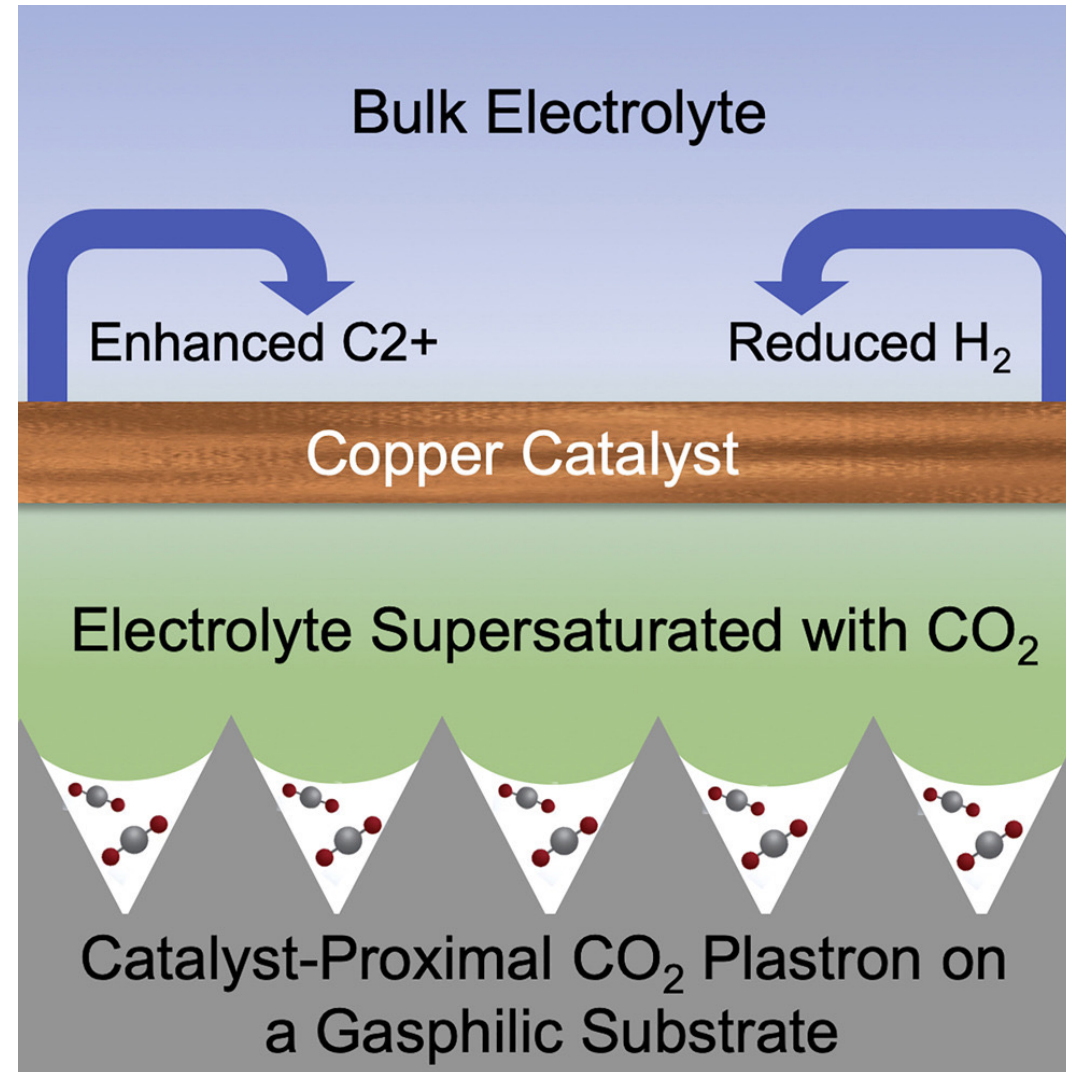
Enhanced CO₂ concentration near the trap (green)



Green: CO₂ rich
Blue: CO₂ lean

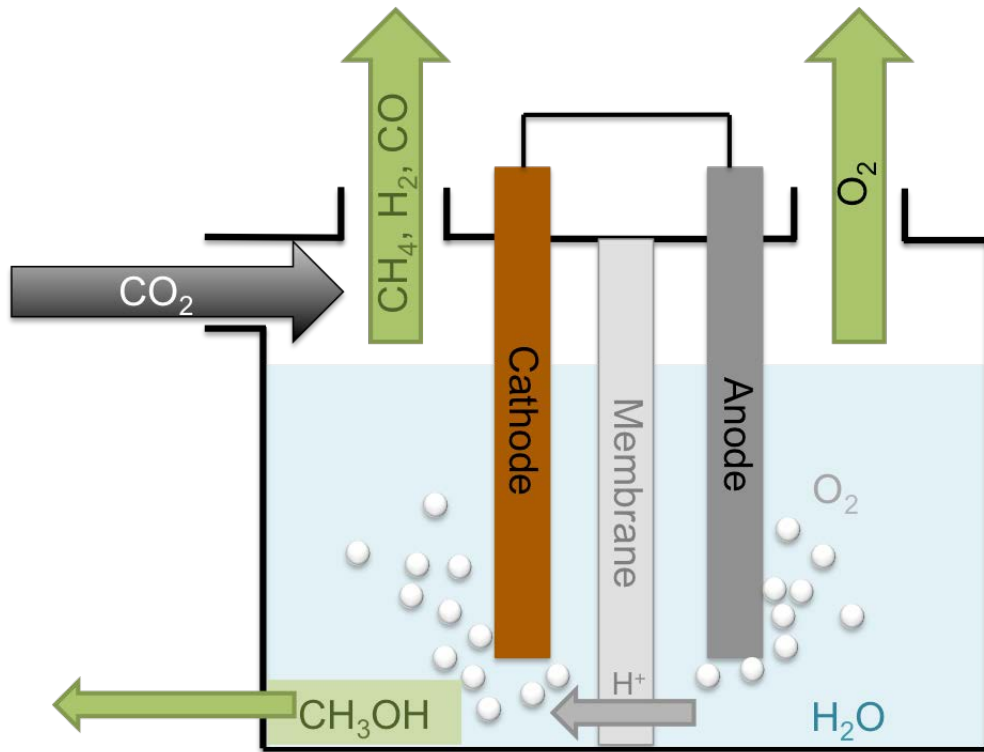


Can these CO₂-capturing surfaces enhance CO₂ conversion?

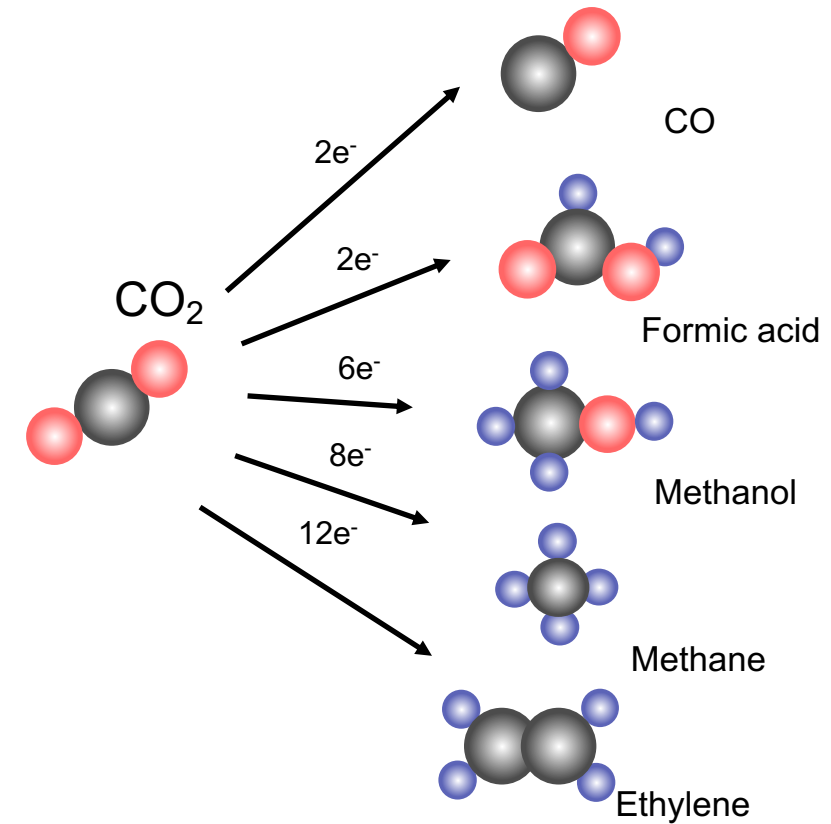
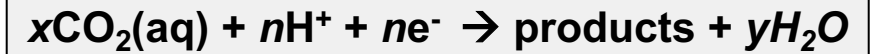


Electrochemical Reduction of CO₂

Electrochemical reduction of CO₂ converts CO₂ (aq) to combustible fuel products by passage of electric current through an electrocatalyst



Fundamental Reaction:



Competing H₂ Co-evolution:



Why Electrochemical Reduction of CO₂?



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)

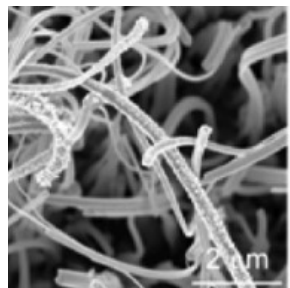


Operate at ambient pressure and temperature conditions

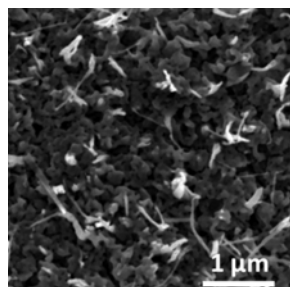


Value-added products such as ethylene can also be generated which serves as precursor to produce useful polymers such as polyethylene

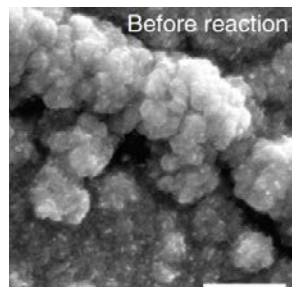
Previous CO₂RR studies: nanostructured Cu catalyst



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

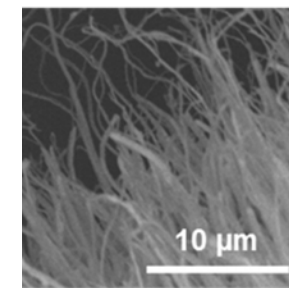
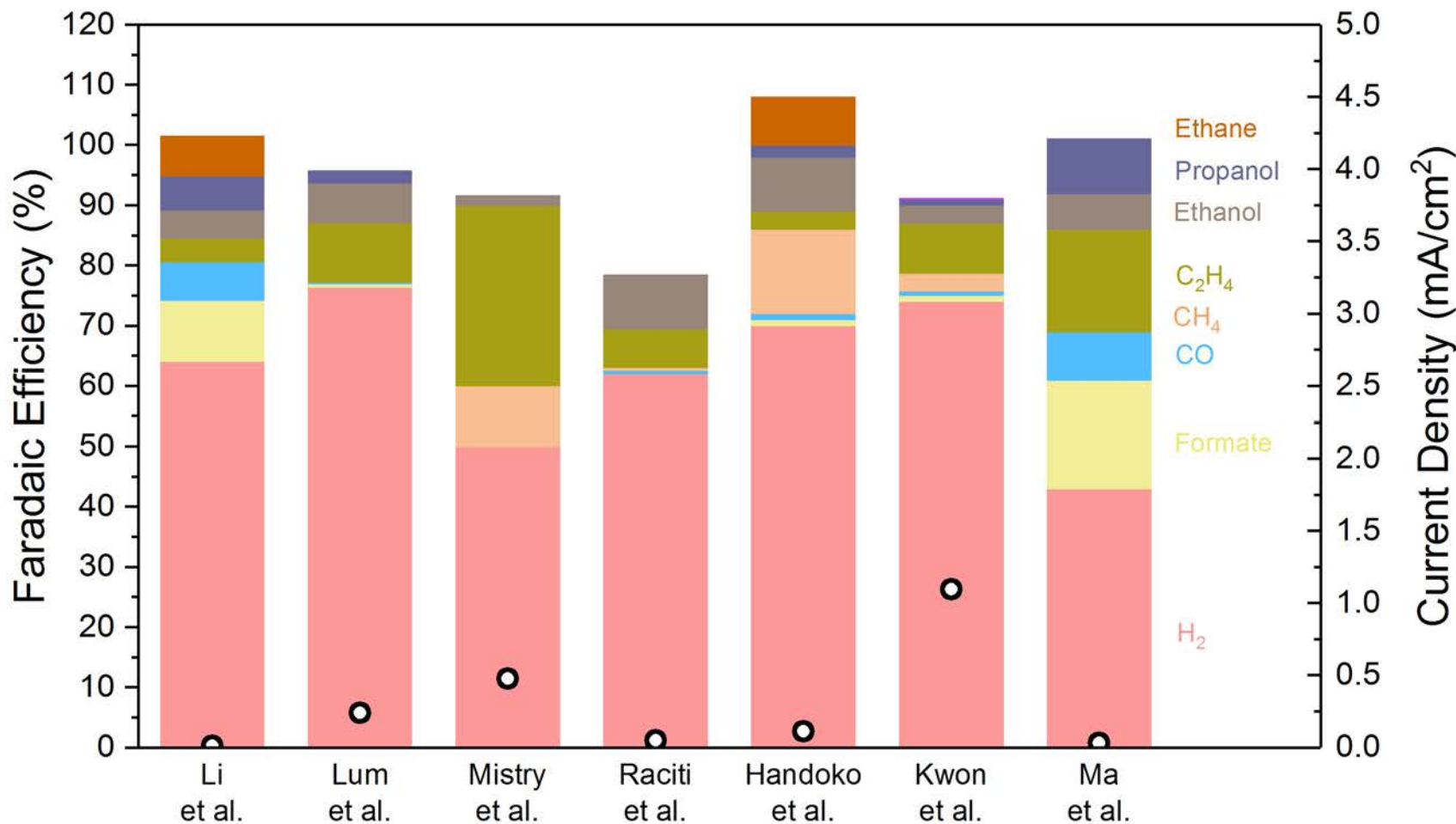


Lum et al. *JPC* (2017) 121; 14191

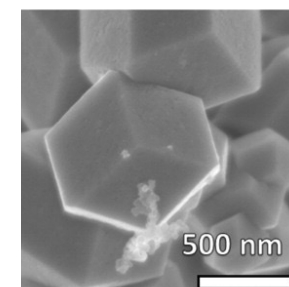


Mistry et al. *Nat. Comm* (2017) 7;12131

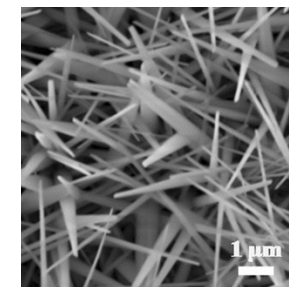
-1.1 V vs RHE



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



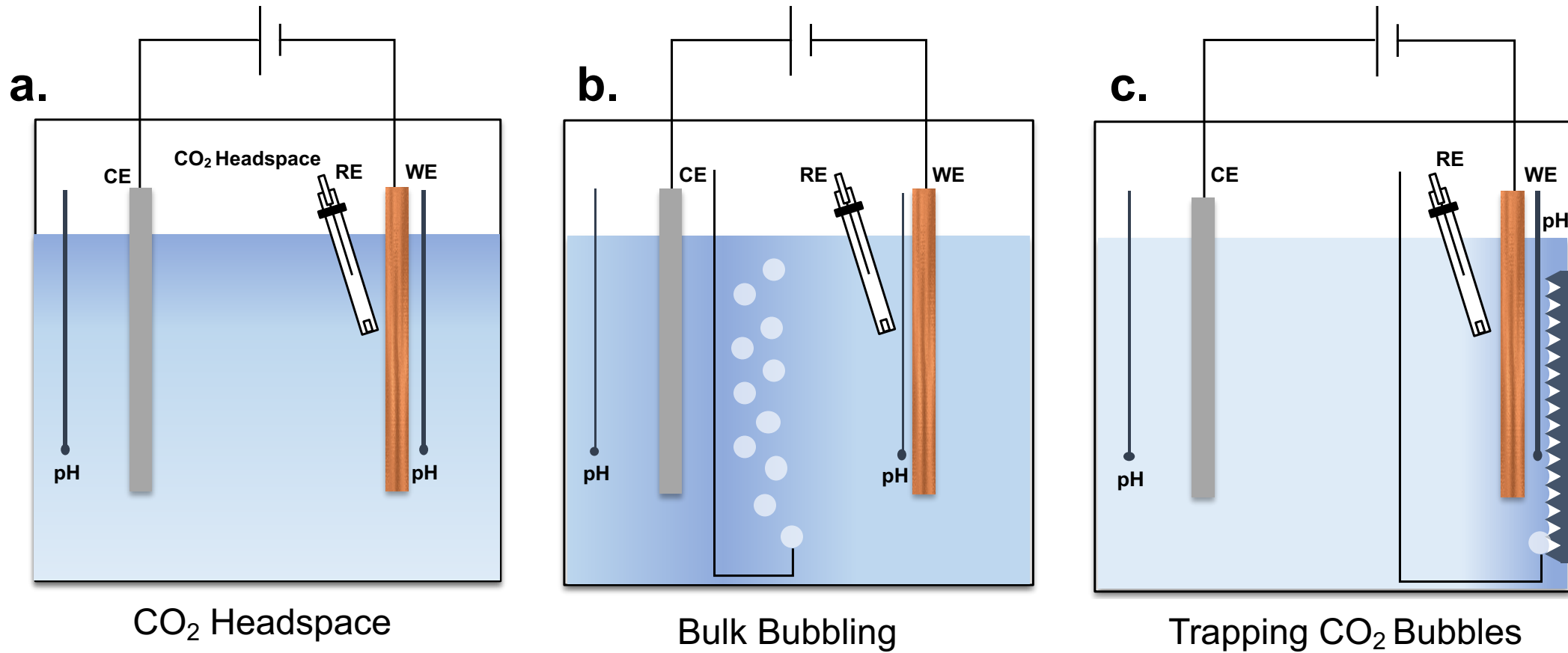
Handoko et al. *JPC* (2015) 120; 20058



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

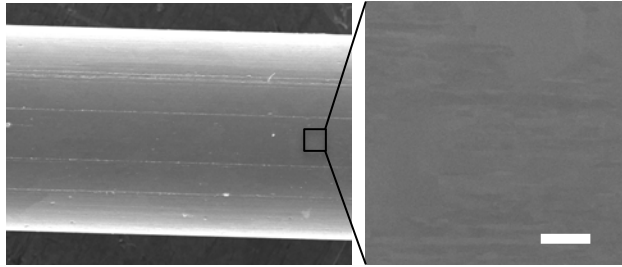
Significant CO₂ availability limitations impacts efficiency

Comparing against conventional CO₂ delivery approaches

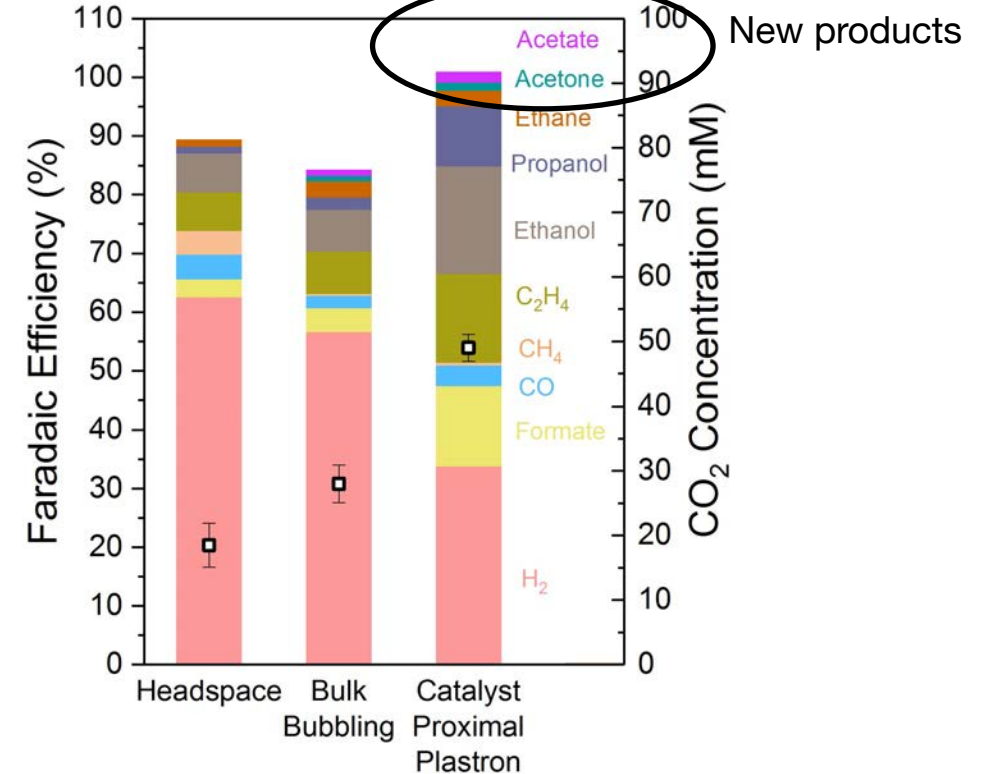
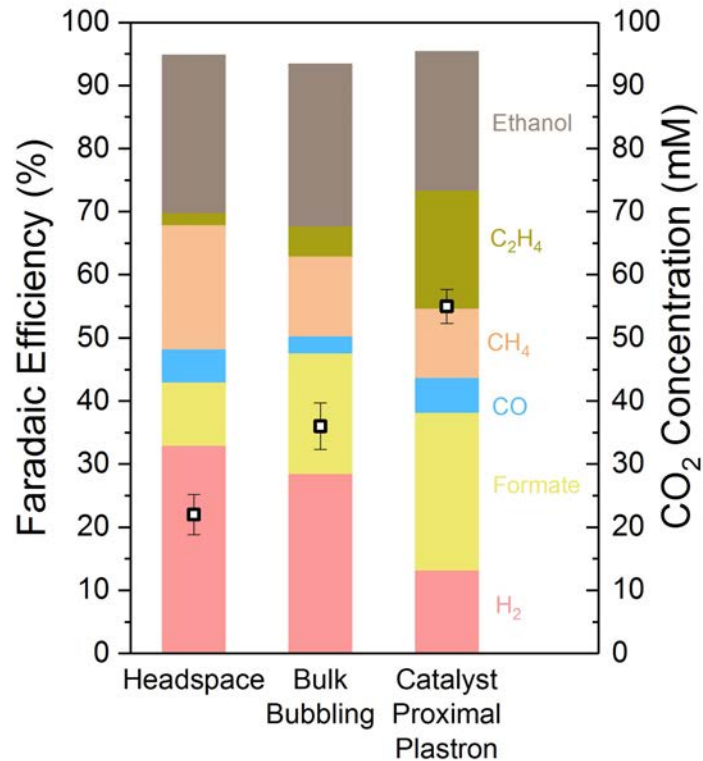
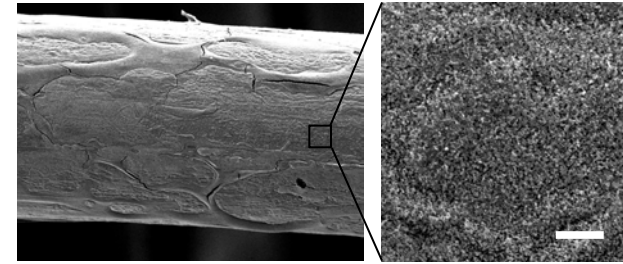


Catalyst-Proximal Plastron: Product Distribution

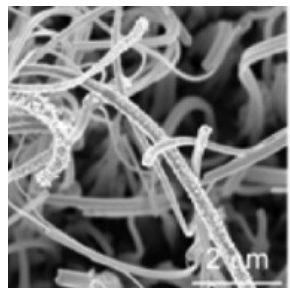
Smooth Copper



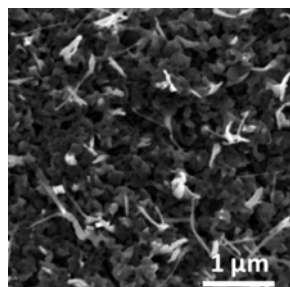
Nanostructured Copper



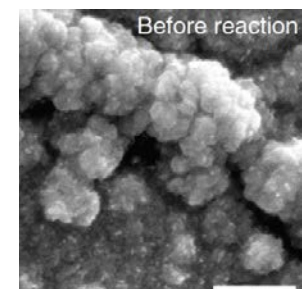
Comparison with other state-of-the-art nanostructured catalysts



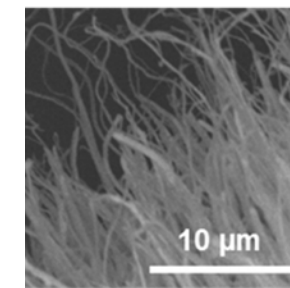
Li et al. *JACS* (2012) 134; 7231



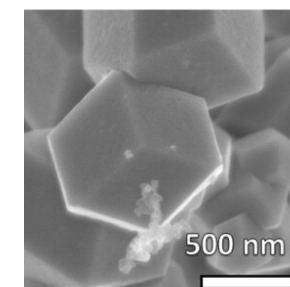
Lum et al. *JPC* (2017) 121; 14191



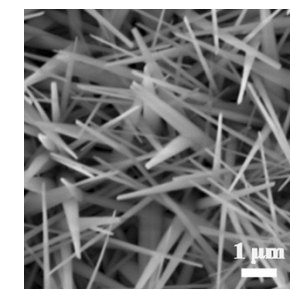
Mistry et al. *Nat. Comm* (2017) 7;12131



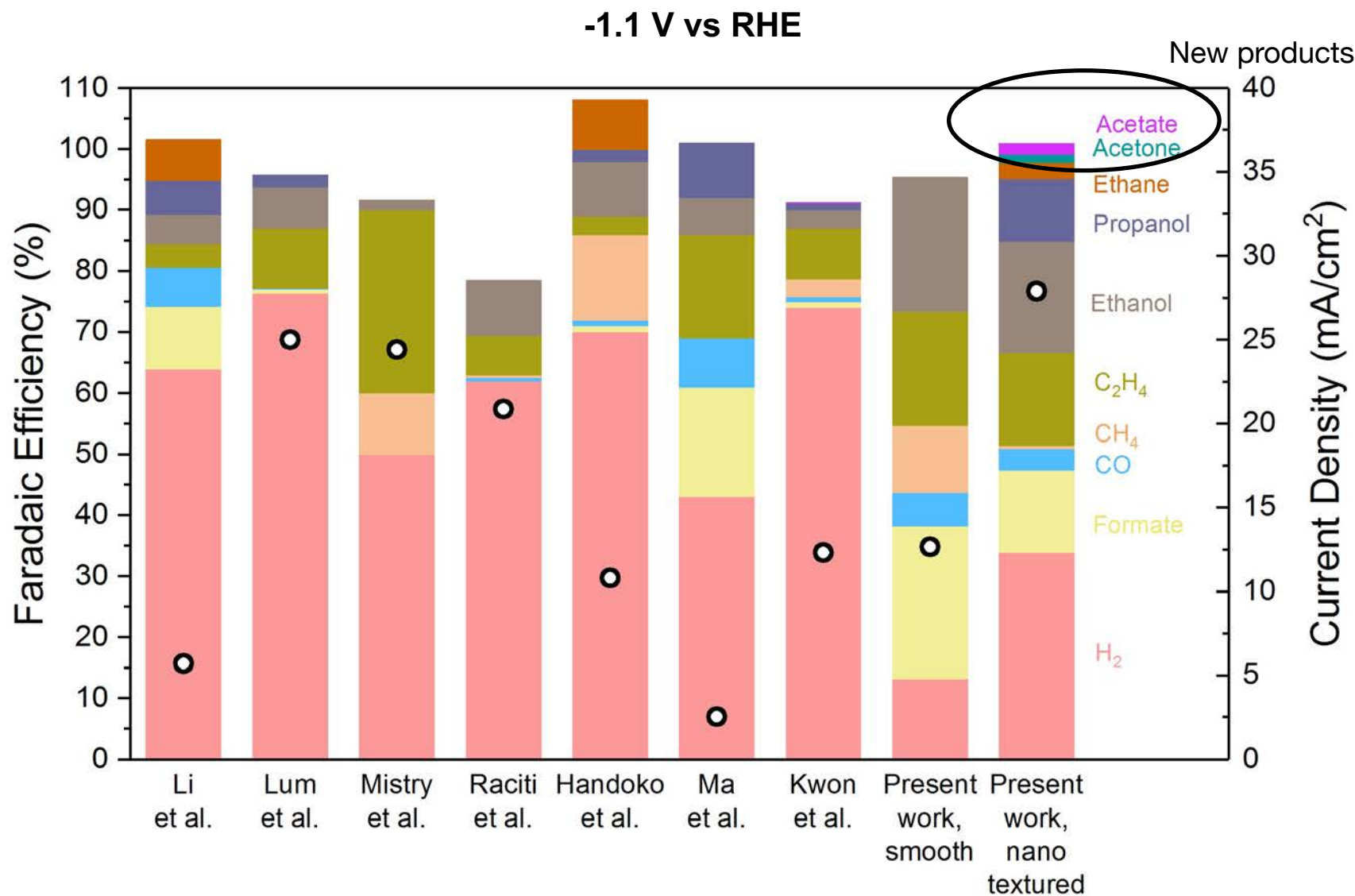
Raciti. et al. *Nano Letters* (2015) 15; 6829



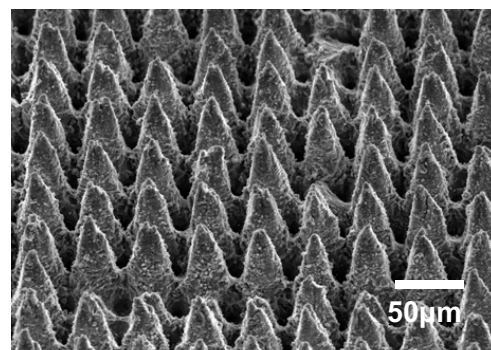
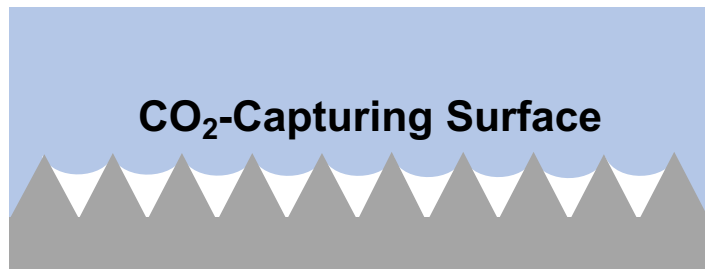
Handoko et al. *JPC* (2015) 120; 20058



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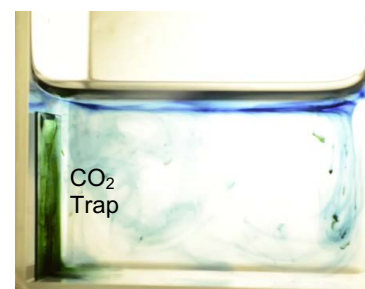
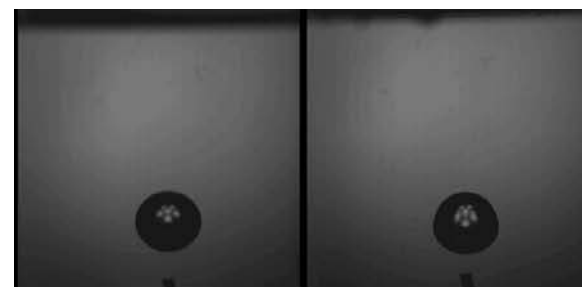
Gas-capturing surfaces to enhance CO₂ capture + conversion



Diving bell spiders with their "breathing pouch"

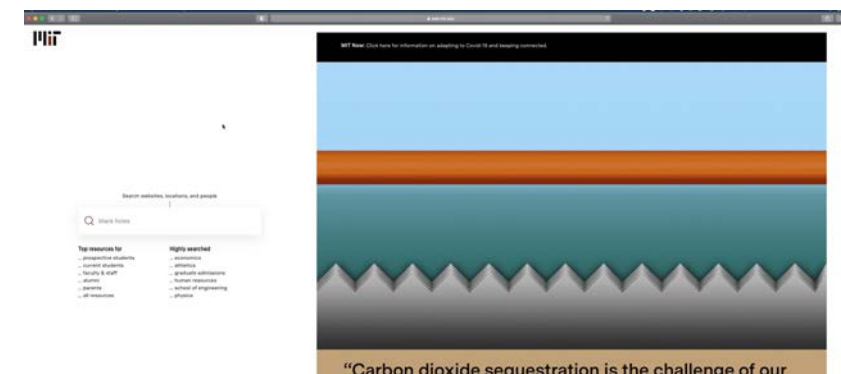


Bubble-philic Bubble-phobic

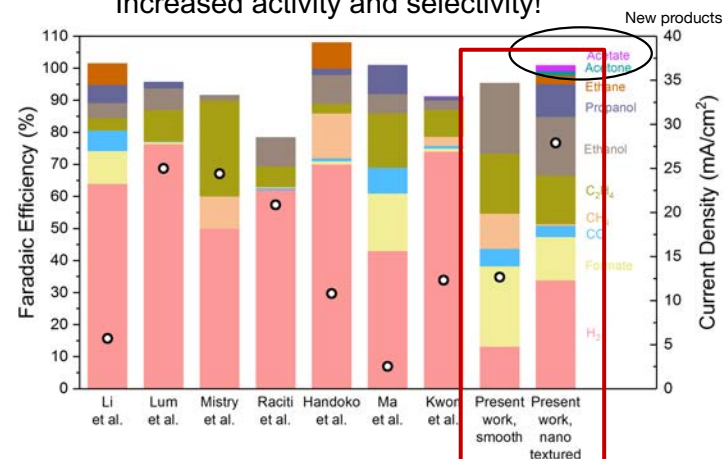


Green: CO₂ rich
Blue: CO₂ lean

News Highlights



Increased activity and selectivity!



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

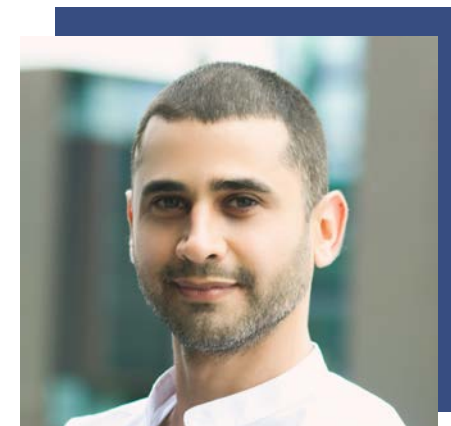
Gahee Im
MASC Student



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)



Canadian Society for Chemical Engineering | *For Our Future*
Société canadienne de génie chimique | *Pour notre avenir*

This is to certify that

Elaheh Hantoosh Zadeh

Simon Fraser University

received

3rd Place

3 Minute Poster (3MP) Competition

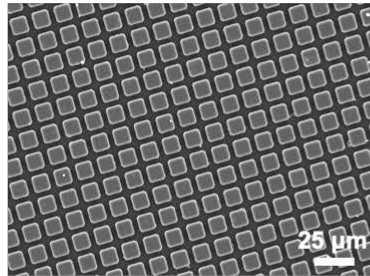
Presented on October 25, 2021, at the virtual 71st Canadian
Chemical Engineering Conference

www.cheminst.ca

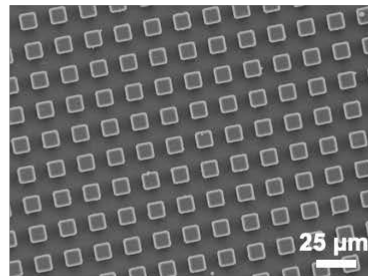
Micro/nanofabrication at SFU 4D labs

Microtextures

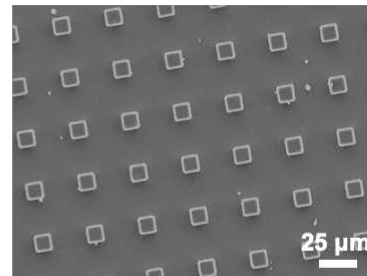
5 μm



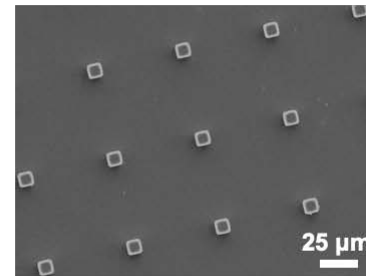
10 μm



25 μm

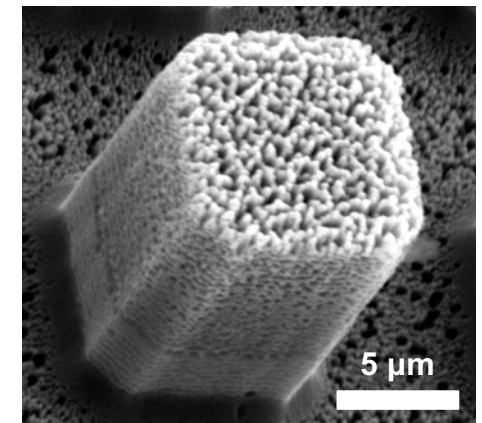
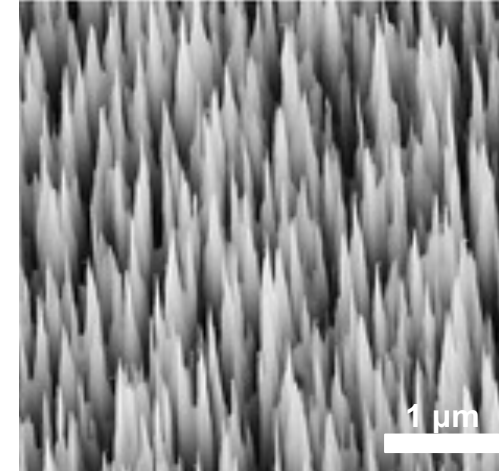
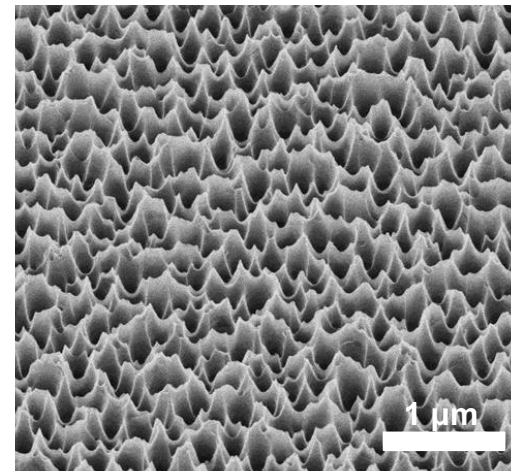
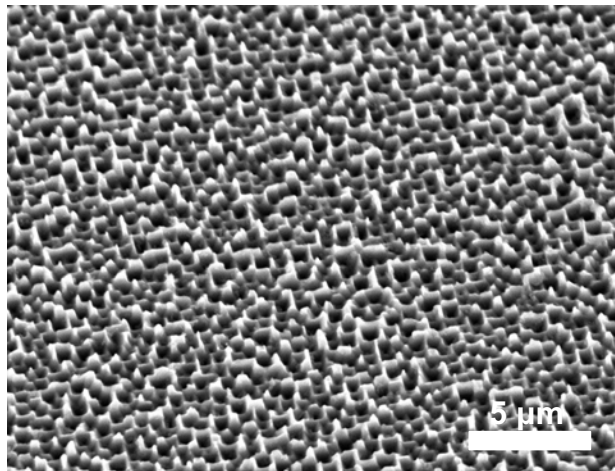


50 μm



SFU 4D LABS

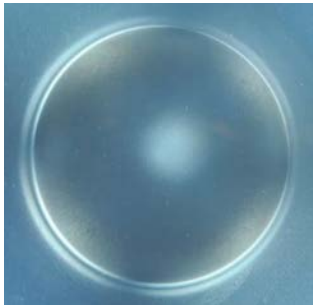
Nanotextures





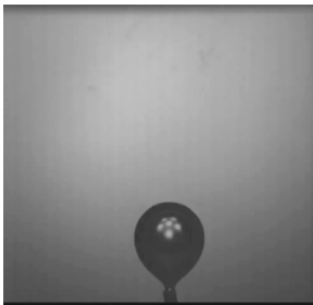
- **Hydrophobic ceramic coatings**

- 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 CO₂
- Gas remains stable within textures and enhance CO₂ concentration locally
- Increase selectivity to C₂+ products over hydrogen



**Thank you for your attention!
Questions?**

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Email: s_khan@sfu.ca