UNIVERSITY OF DELAWARE
ENGINEERING

DEPARTMENT OF CHEMICAL
AND BIOMOLECULAR ENGINEERING

WINTER RESEARCH REVIEW

4TH & 5TH YEAR TALKS

WEDNESDAY, JANUARY 26, 2022

ABSTRACTS AND SCHEDULE GUIDE

CLAYTON HALL CONFERENCE CENTER | 100 DAVID HOLLOWELL DRIVE • NEWARK DE 19716

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UNIVERSITY OF DELAWARE
ENGINEERING
DEPARTMENT OF CHEMICAL AND BIOMOLECULAR ENGINEERING

GRADUATE RECRUITING AGENDA

February 17-19, 2022

SCHEDULE OF TALKS BY ROOM

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 111

SCHEDULE OF TALKS

8:00 – 8:50 AM	**BREAKFAST** (Lobby)
8:50 – 9:00 AM	**WELCOME/Opening Remarks:** Colburn Club (Room **101B**)
9:00 – 9:10 AM	**REMARKS:** Dr. Eric Furst (Room **101B**)

SESSION I — 9:20 AM – 10:40 AM — ROOM 111

9:20 – 9:40 AM	**Alana Szkodny** "Identification of "Difficult-to-Express" mAb Frameworks to Alleviate Expression Bottlenecks in CHO Cells" Advisor: **Kelvin H. Lee** Committee Members: Abraham M. Lenhoff, April M. Kloxin, Christopher J. Roberts
9:40 – 10:00 AM	**Erica Green** "High-yielding processes for transient and stable expression of the SARS-CoV-2 receptor binding domain in HEK293 cells" Advisor: **Kelvin H. Lee** Committee Members: April M. Kloxin and Millicent O. Sullivan
10:00 – 10:20 AM	**William Hilliard** "Identifying stable hotspots of transcriptional activity in the CHO genome" Advisor: **Kelvin H. Lee** Committee Members: Eleftherios T. Papoutsakis, Wilfred Chen
10:20 – 10:40 AM	**Chase Herman** "Modeling weakly adsorbing impurities in flow-through ion-exchange chromatorgraphy" Advisor: **Abraham M. Lenhoff** Committee Members: Eric M. Furst, Kelvin H. Lee

10:40 – 10:45 AM	**BREAK**
10:45 – 11:45 AM	**POSTER SESSION**
11:45 AM – 1:00 PM	**LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

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ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 111

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 111

1:10 – 1:30 PM	**Younghoon Oh** "Alternative mechanisms for persistence of host-cell proteins in monoclonal antibody bioprocessing" Advisor: **Abraham M. Lenhoff** Committee Members: Kelvin H. Lee, Christopher J. Roberts, Steven M. Cramer
1:30 – 1:50 PM	**James Forder** "Quantitative Prediction of MAb Interactions with Experimental and Computational Approaches" Advisor: **Christopher J. Roberts** Committee Members: Arthi Jayaraman, Eric M. Furst
1:50 – 2:10 PM	**Jordan Berger** "Protein Unfolding and Aggregation at High Pressure and Low Temperature: Role of a Fragment" Advisor: **Christopher J. Roberts** Committee Members: Susana C. M. Teixeira, Abraham M. Lenhoff, Norman J. Wagner
2:10 – 2:30 PM	**Neil Butler** "De Novo Biosynthesis and Site-Selective Ribosomal Incorporation of a Nitroaromatic Non-Standard Amino Acid" Advisor: **Aditya M. Kunjapur** Committee Members: Wilfred Chen, E. Terry Papoutsakis

2:30 – 2:50 PM **BREAK**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 111

SCHEDULE OF TALKS

SESSION III	2:50 PM – 5:15 PM	ROOM 111

2:50 – 3:10 PM	**Michaela Jones** "Characterization and expansion of synthetic auxotrophy for microbial biocontainment" Advisor: **Aditya M. Kunjapur** Committee Members: Wilfred Chen, Millicent O. Sullivan, Ethan Garner (Harvard)
3:10 – 3:30 PM	**Sabyasachi Sen** "Engineering the Escherichia coli N-degron pathway for enhanced control of intracellular protein accumulation" Advisor: **Aditya M. Kunjapur** Committee Members: Wilfred Chen, Kelvin H. Lee
3:30 – 3:50 PM	**Katherine Nelson** "Straightforward incorporation of tailorable stromal compartments into microfluidic microphysiological systems" Advisors: **Millicent O. Sullivan, Jason P. Gleghorn** Committee Members: April M. Kloxin and Catherine A. Fromen
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 110

SCHEDULE OF TALKS

8:00 – 8:50 AM	**BREAKFAST** (Lobby)
8:50 – 9:00 AM	**WELCOME/Opening Remarks:** Colburn Club (Room 101B)
9:00 – 9:10 AM	**REMARKS:** Dr. Eric Furst (Room 101B)

SESSION I — 9:20 AM – 10:40 AM — ROOM 110

9:20 – 9:40 AM	**Hopen Yang** "Developing a Highly Specific, Modular Platform for Conditional Protein Degradation" Advisor: **Wilfred Chen** Committee Members: April M. Kloxin, Abraham M. Lenhoff
9:40 – 10:00 AM	**Kartik Bomb** "Utilizing mechanically and biochemically tunable synthetic culture platforms to investigate and modulate immune cell response" Advisors: **Catherine A. Fromen, April M. Kloxin** Committee Members: LaShanda T. Korley, Millicent O. Sullivan
10:00 – 10:20 AM	**Bader Jarai** "Inert Nanoparticles for Enhancing the Survival of Primary Macrophages" Advisor: **Catherine A. Fromen** Committee Members: April M. Kloxin, Millicent O. Sullivan, Jason P. Gleghorn
10:20 – 10:40 AM	**Emily Kolewe** "Anatomical and Geometric Variations Between Adult and Pediatric Airways and Resultant Aerosol Deposition Differences" Advisor: **Catherine A. Fromen** Committee Members: Millicent O. Sullivan, Abraham M. Lenhoff

10:40 – 10:45 AM	**BREAK**
10:45 – 11:45 AM	**POSTER SESSION**
11:45 AM – 1:00 PM	**LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 110

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 110

1:10 – 1:30 PM	**Zachary Stillman** "Utilizing Metal-Organic Framework (MOF) Nanoparticles for Applications in Pulmonary Drug Delivery and Synthetic Vaccines" Advisor: **Catherine A. Fromen** Committee Members: Eric Bloch, Thomas H. Epps III, and Christopher J. Kloxin
1:30 – 1:50 PM	**Ian Woodward** "3D Printed Lattices for Next-Gen Pulmonary Therapeutics" Advisor: **Catherine A. Fromen** Committee Members: April M. Kloxin, Abraham M. Lenhoff, and Jason P. Gleghorn
1:50 – 2:10 PM	**Jessica Belliveau** "Extracellular Vesicles Generated by Chinese Hamster Ovary Cells Under Normal and Stressed Conditions Facilitate Large-Scale, Dynamic Exchange of Proteins and RNA" Advisor: **E. Terry Papoutsakis** Committee Members: Catherine A. Fromen, Millicent O. Sullivan
2:10 – 2:30 PM	**Michael Dahle** "Case Studies in Coculture Metabolic Flux Analysis" Advisors: **Maciek R. Antoniewicz, E. Terry Papoutsakis** Committee Members: Aditya M. Kunjapur, Mark A. Blenner

2:30 – 2:50 PM **BREAK**

UNIVERSITY OF DELAWARE
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CLAYTON HALL | JANUARY 26, 2022

ROOM 110

SCHEDULE OF TALKS

SESSION III	2:50 PM – 5:15 PM	ROOM 110

2:50 – 3:10 PM	**Will Thompson** "The Nature and Physiological Impact of Small RNA Cargo in Microparticles from Megakaryocytes and Chinese Hamster Ovary Cells" Advisor: **E. Terry Papoutsakis** Committee Members: Catherine A. Fromen, April M. Kloxin
3:10 – 3:30 PM	**Samik Das** "In vivo Biological Function, Biodistribution and Targeted Gene Editing and Modulation of Hematopoietic Stem Cells Using Endogenous and Engineered Cas9 and siRNA-loaded Megakaryocytic Membrane Vesicles" Advisor: **E. Terry Papoutsakis** Committee Members: Emily Day, Catherine A. Fromen, Wilfred Chen
3:30 – 3:50 PM	**Jonathan Otten** "Syntrophic Co-Cultures of Clostridium Organisms to Produce C6-C8 Alcohols and Carboxylic Acids" Advisor: **E. Terry Papoutsakis** Committee Members: Wilfred Chen, Catherine A. Fromen, Aditya M. Kunjapur
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 120

SCHEDULE OF TALKS

8:00 – 8:50 AM	**BREAKFAST** (Lobby)
8:50 – 9:00 AM	**WELCOME/Opening Remarks:** Colburn Club (Room 101B)
9:00 – 9:10 AM	**REMARKS:** Dr. Eric Furst (Room 101B)

SESSION I — 9:20 AM – 10:40 AM — ROOM 120

9:20 – 9:40 AM	**Nicholas Oliveira** "Evidence for the Lack of Caffeine Specific Adsorption and its Impact on Water Structure to Increase HOR/HER Activity on Pt" Advisor: **Yushan Yan** Committee Members: Marat Orazov, Feng Jiao
9:40 – 10:00 AM	**Catherine Weiss** "Study of Cell Architecture for Improved Oxygen Transport in Hydroxide Exchange Membrane Fuel Cells" Advisor: **Yushan Yan** Committee Members: Antony N. Beris, Marat Orazov
10:00 – 10:20 AM	**Stephanie Matz** "Electrochemically-Driven CO2 Separation from Ambeint Air using Hydroxide Exchange Membranes" Advisor: **Yushan Yan** Committee Members: Raul F. Lobo, Marat Orazov
10:20 – 10:40 AM	**Jon Wilson** "Insights into Surface Charge Effects on the Volmer Step on Pt(111) through Controlled-Potential Anderson-Newns Molecular Dynamics" Advisors: **Yushan Yan, Dionisios G. Vlachos** Committee Members: Stavros Caratzoulas, Arthi Jayaraman, Marat Orazov

10:40 – 10:45 AM	**BREAK**
10:45 – 11:45 AM	**POSTER SESSION**
11:45 AM – 1:00 PM	**LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

UNIVERSITY OF DELAWARE
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CLAYTON HALL | JANUARY 26, 2022

ROOM 120

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 120

1:10 – 1:30 PM	**Sean Overa** "Electrochemical conversion of carbon monoxide to acetate and ethylene" Advisor: **Feng Jiao** Committee Members: Raul F. Lobo, Dionisios G. Vlachos
1:30 – 1:50 PM	**Haeun Shin** "The local mass transport of ketene and acetate selectivity in electrochemical CO reduction" Advisor: **Feng Jiao** Committee Members: Dionisios G. Vlachos, Yushan Yan
1:50 – 2:10 PM	**Byung Hee Ko** "Impact of nitrogen oxides on electrochemical carbon dioxide reduction" Advisor: **Feng Jiao** Committee Members: Raul F. Lobo, Yushan Yan
2:10 – 2:30 PM	**Haoran Ding** "Electrochemical Generation of Reactive Intermediates as a Tool for Aromatics Upgrading" Advisor: **Marat Orazov** Committee Members: Raul F. Lobo, Feng Jiao

2:30 – 2:50 PM **BREAK**

UNIVERSITY OF DELAWARE
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CLAYTON HALL | JANUARY 26, 2022

ROOM 120

SCHEDULE OF TALKS

SESSION III	2:50 PM – 5:15 PM	ROOM 120

2:50 – 3:10 PM	**Jian Pan** "Catalytic Dehydrogenation of Etrhane over Metal Exchanged Chabazite Zeolite" Advisor: **Raul F. Lobo** Committee Members: Abraham M. Lenhoff, Feng Jiao, Marat Orazov, Aditya M. Kunjapur
3:10 – 3:30 PM	**Eric Steinman** "Ethylbenzene via Consecutive Oxidative Dehydrogenation of Ethane and Benzene Alkylation" Advisor: **Marat Orazov** Committee Members: Douglas J. Buttrey, Yushan Yan
3:30 – 3:50 PM	**Roshaan Surendhran** "Developing an encapsulated catalyst for the direct conversion of glucose to ethylene glycol" Advisor: **Marat Orazov** Committee Members: Raul F. Lobo, Dionisios G. Vlachos
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
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CLAYTON HALL | JANUARY 26, 2022

ROOM 101B

SCHEDULE OF TALKS

8:00 – 8:50 AM	**BREAKFAST** (Lobby)
8:50 – 9:00 AM	**WELCOME/Opening Remarks:** Colburn Club (Room 101B)
9:00 – 9:10 AM	**REMARKS:** Dr. Eric Furst (Room 101B)

SESSION I — 9:20 AM – 10:40 AM — ROOM 101B

9:20 – 9:40 AM	**Sophia Kurdziel** "Theory and Applications of Transition-State Vibrational and Thermochemical Scaling Relationships for AHx (A = C, N, O) Species" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Marat Orazov
9:40 – 10:00 AM	**Himaghna Bhattacharjee** "Interpretable Machine Learning for Unvertainty Quantification in Computation Catalysis" Advisor: **Dionisios G. Vlachos** Committee Members: Antony N. Beris, Marianthi G. Ierapetritou, Xi Peng
10:00 – 10:20 AM	**Seungyeon Lee** "Theoretical insights into the heterogeneous hydroformylation of ethylene on atomically dispersed Rh-oxide promoter pairs" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Marat Orazov
10:20 – 10:40 AM	**Xue Zong** "Statistical-learning-aided Multiscale Modeling of Structure-sensitive Catalytic Reactions" Advisor: **Dionisios G. Vlachos** Committee Members: Antony N. Beris, Feng Jiao

10:40 – 10:45 AM	**BREAK**
10:45 – 11:45 AM	**POSTER SESSION**
11:45 AM – 1:00 PM	**LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

UNIVERSITY OF DELAWARE
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CLAYTON HALL | JANUARY 26, 2022

ROOM 101B

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 101B

1:10 – 1:30 PM	**Tso-Hsuan Chen** "Computational Study of the Solvent Effects in Biphasic Systems for Fructose Dehydration" Advisor: **Dionisios G. Vlachos** Committee Members: Marat Orazov, Raul F. Lobo
1:30 – 1:50 PM	**Sai Preneet Batchu** "Theoretical insights into the selective conversion of cyclic ethers to conjugated dienes on ZrO2" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Marat Orazov, Stavros Caratzoulas
1:50 – 2:10 PM	**Yung-Wei Hsiao** "Cost and Energy Efficient Cyclic Separation and Upgrade of 5-Hydroxymethyl Furfural in a Microfixed Bed" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Marianthi G. Ierapetritou
2:10 – 2:30 PM	**Montgomery Baker Fales** "Microwave Heating of Liquid-Liquid Biphasic Systems" Advisor: **Dionisios G. Vlachos** Committee Members: Abraham M. Lenhoff, Raul F. Lobo, Marat Orazov

2:30 – 2:50 PM **BREAK**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 101B

SCHEDULE OF TALKS

SESSION III	2:50 PM – 5:15 PM	ROOM 101B

2:50 – 3:10 PM	**Zhaoxing Wang** "Selective Extraction of Furfural and 5-Hydroxymethylfurfural from Mixed Lignocellulosic Biomass-Derived Feedstocks in Biphasic Solvent Systems" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Marat Orazov
3:10 – 3:30 PM	**Maximilian Cohen** "A Data Driven Investigation of Catalytic Upgrading of Ethane to Ethylene over Ga/Al2O3" Advisor: **Dionisios G. Vlachos** Committee Members: Raul F. Lobo, Babatunde A. Ogunnaike, Markos Katsoulakis
3:30 – 3:50 PM	**Yingjie Chen** "A Framework of Surrogate-based Multi-objective Optimization for Continuous Pharmaceutical Manufacturing Processes" Advisor: **Marianthi G. Ierapetritou** Committee Members: Babatunde A. Ogunnaike, Bertrum Diemer
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 119

SCHEDULE OF TALKS

8:00 – 8:50 AM **BREAKFAST** (Lobby)

8:50 – 9:00 AM **WELCOME/Opening Remarks:** Colburn Club (Room 101B)

9:00 – 9:10 AM **REMARKS:** Dr. Eric Furst (Room 101B)

SESSION I 9:20 AM – 10:40 AM ROOM 119

9:20 – 9:40 AM	**DoYoung Kim** "Molecular Redistribution of Alkanes and the Chemical Upcycling of Low-Density Polyethylene" Advisor: **Raul F. Lobo** Committee Members: Bingjun Xu, Marat Orazov
9:40 – 10:00 AM	**Yong Yuan** "Ga+ in Chabazite Zeolite as Highly Selective Catalyst for Non-Oxidative Propane Dehydrogenation" Advisor: **Raul F. Lobo** Committee Members: Dionisios G. Vlachos, Feng Jiao, Antony N. Beris
10:00 – 10:20 AM	**Mingchun Ye** "Novel and Valuable Chemicals from Renewable Feedstocks through Catalysis" Advisor: **Raul F. Lobo** Committee Members: Dionisios G. Vlachos, Christopher J. Kloxin, Donald Watson, Hari Sunkara
10:20 – 10:40 AM	**Jason Lee** "Mechanistic Understanding of Hydrocarbon Dehydrogenation and Cyclization in Zeolites" Advisor: **Raul F. Lobo** Committee Members: Feng Jiao, Marat Orazov, Stavros Caratzoulas

10:40 – 10:45 AM **BREAK**

10:45 – 11:45 AM **POSTER SESSION**

11:45 AM – 1:00 PM **LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 119

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 119

1:10 – 1:30 PM	**Mark LaFollette** "Olefin Methylation Reactions over Iron Zeolites: Increasing Reaction Rates and Shifting the Selectivity" Advisor: **Raul F. Lobo** Committee Members: Douglas J. Buttrey, Marat Orazov, Anibal Boscoboinik
1:30 – 1:50 PM	**Samantha Cassel** "Lentiviral reporters for temporal characterization of cell activation in response to dynamic stimuli" Advisor: **April M. Kloxin** Committee Members: Catherine A. Fromen, Wilfred Chen
1:50 – 2:10 PM	**Xutao Shi** "Design of PLGA-based drug delivery systems through a molar mass-dependent sustained release model" Advisors: **Abraham M. Lenhoff, Norman J. Wagner** Committee Members: Christopher J. Roberts, Antony N. Beris, Aditya M. Kunjapur, Arthi Jayaraman
2:10 – 2:30 PM	**Tai-Ying Chen** "Data-driven modeling and process intensification for distributed biomass processing" Advisor: **Dionisios G. Vlachos** Committee Members: Antony N. Beris, Raul F. Lobo
2:30 – 2:50 PM	**BREAK**
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 125

SCHEDULE OF TALKS

8:00 – 8:50 AM	**BREAKFAST** (Lobby)
8:50 – 9:00 AM	**WELCOME/Opening Remarks:** Colburn Club (Room 101B)
9:00 – 9:10 AM	**REMARKS:** Dr. Eric Furst (Room 101B)

SESSION I — 9:20 AM – 10:40 AM — ROOM 125

9:20 – 9:40 AM	**Mukund Kabra** "Photo-CuAAC-Methacrylate Interpenetrating Polymer Networks: Manipulating Formation Trajectory with Light" Advisor: **Christopher J. Kloxin** Committee Members: Thomas H. Epps III, LaShanda T. Korley, Darrin J. Pochan
9:40 – 10:00 AM	**Joshua Meisenhelter** "Coiled-Coil Peptides as a Building Block for Material Design" Advisor: **Christopher J. Kloxin** Committee Members: April M. Kloxin, Darrin J. Pochan, LaShanda T. Korley
10:00 – 10:20 AM	**Jennifer Mills** "Structure-property relationships of alkali-activated aluminosilcate gels for design of sustainable construction materials" Advisors: **Norman J. Wagner, Paramita Mondal** Committee Members: Eric M. Furst, Christopher J. Kloxin
10:20 – 10:40 AM	**Soham Jariwala** "Rheology of aggregating colloidal suspensions: perspectives from population balances and non-equilibrium thermodynamics" Advisors: **Antony N. Beris, Norman J. Wagner** Committee Members: Bertrum Diemer, Eric M. Furst

10:40 – 10:45 AM	**BREAK**
10:45 – 11:45 AM	**POSTER SESSION**
11:45 AM – 1:00 PM	**LUNCH** (Room 101A) **and Featured Speaker, Dr. Kevin V. Solomon.**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 125

SCHEDULE OF TALKS

SESSION II	1:10 PM – 2:30 PM	ROOM 125

1:10 – 1:30 PM	**Haesoo Lee** "Visualizing the gelation of highly concentrated hollow nanorod suspension via small-angle neutron scattering and complex rheology" Advisor: **Norman J. Wagner** Committee Members: Eric M. Furst, Arthi Jayaraman, LaShanda T. Korley, Wilfred Chen, Ryan Murphy
1:30 – 1:50 PM	**Yu-Fan Lee** "Microstructure, Rheology and Tribology Study for Shear Thickening in Colloidal Suspensions and Applications" Advisor: **Norman J. Wagner** Committee Members: Scott Brown, Eric M. Furst, Abraham M. Lenhoff
1:50 – 2:10 PM	**Esther Roh** "Kinetic modeling to accelerate the development of nucleic acid formulations" Advisor: **Thomas H. Epps III, Millicent O. Sullivan** Committee Members: Catherine A. Fromen, Wilfred Chen
2:10 – 2:30 PM	**Arjita Kulshreshtha** "Theory and Simulation Studies of Structure and Thermodynamics in Polymer Blends and Polymer Nanocomposites" Advisor: **Arthi Jayaraman** Committee Members: LaShanda T. Korley, Norman J. Wagner, Laure Kayser

2:30 – 2:50 PM **BREAK**

UNIVERSITY OF DELAWARE
ENGINEERING

CLAYTON HALL | JANUARY 26, 2022

ROOM 125

SCHEDULE OF TALKS

SESSION III	2:50 PM – 3:50 PM	ROOM 125

2:50 – 3:10 PM	**Phillip Taylor** "Computational studies of the phase transitions and self-assembly of peptide-based biomaterials" Advisors: **April M. Kloxin, Arthi Jayaraman** Committee Members: Millicent O. Sullivan, Christopher J. Roberts, and Kristi Kiick
3:10 – 3:30 PM	**Zijie Wu** "Computational studies of macromolecular materials with directional and specific interactions" Advisor: **Arthi Jayaraman** Committee Members: April M. Kloxin, and LaShanda T. Korley
3:30 – 3:50 PM	**Christian Heil** "Computational Study of Structure, Self-Assembly, and Optics of Bio-Inspired Nanoparticles" Advisor: **Arthi Jayaraman** Committee Members: Catherine A. Fromen, Eric M. Furst, and Ali Dhinojwala
4:00 – 5:15 PM	**INDUSTRY MIXER (Room 101A)**
5:15 PM	**END**

UNIVERSITY OF DELAWARE
ENGINEERING
DEPARTMENT OF CHEMICAL AND BIOMOLECULAR ENGINEERING

GRADUATE RECRUITING AGENDA

February 17-19, 2022

ABSTRACTS

Microwave Heating of Liquid-Liquid Biphasic Systems

Montgomery Baker-Fales
Advisor: Dionisios G. Vlachos
Committee Members: Abraham Lenhoff, Raul Lobo, Marat Orazov

Microwaves (MWs) can enable the electrification and intensification of chemical manufacturing. They have been applied to various unit separations, such as drying, distillation, and extraction, entailing gas-liquid and solid-liquid systems. However, a limited quantitative understanding of MW-heated liquid-liquid biphasic systems related to extraction exists. This work measures the temporal and spatial temperature difference between an aqueous and an organic phase in batch and continuous microfluidic modes. We demonstrate permanent temperature differences between phases in excess of 35 °C and spatiotemporal periodic and quasiperiodic oscillations modulated by the flow patterns. We establish a multiphysics model to predict the temperature difference in a batch system. The model is in good agreement with experiments. We observe a strong effect of input power, dielectric properties of organic solvents, volume of solvents, and volume ratio between phases on the temperature difference. The temperature differences with varying conditions are primarily driven by the fast absorption rate of microwave irradiation by the aqueous phase vs. the slow heat transfer from the aqueous phase to the organic phase. They are amplified by low specific interfacial area and secondary by modifications of the electromagnetic field. We develop a simple analytical model to describe the temperature difference and provide design principles for significant temperature differences. The combined approach offers new insights into the design and optimization of the MW-heated biphasic systems.

Theoretical insights into the selective conversion of cyclic ethers to conjugated dienes on ZrO_2

Sai Praneet Batchu
Advisor: Dionisios G. Vlachos
Committee Members: Raul F. Lobo, Marat Orazov, Stavros Caratzoulas

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Conjugated dienes such as 1,3-butadiene and pipyrelene (1,3-pentadiene) are important industrial chemicals. 1,3-Butadiene is used in the manufacture of automobile tires, and pipyrelene is used in the production of certain plastics, resins, and modern adhesives such as envelopes, parcel tapes, and diaper fastenings. The current production methods, mainly steam cracking of naphtha and shale gas, are energy-intensive, less selective, and produce large amounts of CO_2.[1-2] Renewable biomass-based production of conjugated dienes could potentially be a sustainable and energy-efficient alternative due to lower reaction temperatures and green-house gas emissions.[1-2] Out of the various possible catalytic chemical routes, the conversion of biomass to butadiene via ethanol and four-carbon alcohols has been widely explored.[1-2]

Recent methods, which have emerged as alternatives, convert tetrahydrofuran (THF) and 2-methyl tetrahydrofuran (2-MTHF) into 1,3-butadiene and pentadienes, respectively, by dehydra-decyclization over Brønsted acid zeolites.[3-6] Recently, an experimental work has been published that shows a remarkable performance of ZrO_2, a catalyst not typically thought of as Brønsted acidic, over other metal oxides in selectively converting THF to butadiene (selectivity over 90%).[7] Also, another recent study (under review)[8] shows ZrO_2 catalyst facilitating a highly selective conversion of 2-MTHF and tetrahydropyran (THP) to 1,3-pentadiene. Thus, ZrO_2 shows potential for its industrial use in diene production since its catalytic usage can significantly lower the downstream separation costs of dienes, which are typically energy-intensive processes due to similar volatilities of different diene isomers. This high selectivity towards ZrO_2, compared to other metal oxide catalysts, has intrigued us the most.

In this work, we perform Density-Functional Theory calculations and microkinetic modeling to gain mechanistic insights into the high performance of ZrO_2. We investigate the conversion of THF to *(a)* the main reaction to butadiene; and *(b)* the retro-Prins condensation to propene and formaldehyde, the dominant side reaction on dry and hydroxylated surfaces of the (101) facet of tetragonal ZrO_2. In addition, we also investigate the conversion of THP to 1,3-pentadiene(major product) and 1,4-pentadiene(minor product) on the dry surface of the tetragonal ZrO_2(101).

References:

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Extracellular Vesicles Generated by Chinese Hamster Ovary Cells Under Normal and Stressed Conditions Facilitate Large-Scale, Dynamic Exchange of Proteins and RNA

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Cells in culture are viewed as unique individuals in a large population communicating with each other through extracellular molecules and, more recently, also through extracellular vesicles (EVs). Chinese Hamster Ovary (CHO) cells dynamically produce and uptake EVs, and through these EVs, they exchange proteins and RNAs at a large scale. To visualize the dynamic production and cellular uptake of CHO EVs, and the associated protein and RNA exchange, correlative confocal microscopy and scanning electron microscopy (SEM) was used, as well as flow cytometry to interrogate labeled CHO cells. CHO cells expressed fluorescent proteins (GFP, miRFP703) and CHO cells were tagged with protein dyes (CFDA-SE and CellTracker Deep Red) or an RNA green fluorescent cell stain (SYTO RNASelect). Correlative confocal/SEM images identified localization of exchanged CHO EVs on high-resolution SEM images of CHO cells. Using flow cytometry and the SYTO RNASelect green fluorescent cell stain, we tracked and quantified the exchange of cellular RNA between CHO cells through EV exchange. This hitherto underappreciated native cell communication and protein/RNA material exchange mechanism mediated by EVs in suspension culture suggests that the close proximity of cells may result in prolific cellular exchange.

The widespread exchange of EVs, and the associated exchange of proteins and RNAs, among cells in culture is hypothesized to result in a collective regulation of the cellular state. EVs are highly enriched in small regulatory RNAs, notably microRNA (miRNA), relative to the parent cell. To understand how the miRNA content in CHO EVs changes with stress (ammonia or osmotic stress) compared to non-stressed, exponential phase cultures, we used RNA sequencing of the parent cells, MPs, and exosomes. The miRNA landscape in cultures (cells, MPs, exosomes) exposed to ammonia or osmotic stress was highly enriched in the let-7 family of miRNAs. Of the total detected miRNAs in the MPs from the ammonia-stressed cultures, let-7c accounted for 19% and let-7b accounted for 17% of the total miRNA content. In the osmotic-stressed MPs, let-7c accounted for 17% and let-7b accounted for 22% of the total miRNA content. In the non-stressed MPs, let-7c accounted for 4% and let-7b accounted for 2% of the total miRNA content. The changing miRNA landscape of EVs exposed to stress (ammonia, osmolarity) conditions indicates a dynamic gene regulation mechanism for cells in culture to homogenize cellular state and behave as a community in response to environmental stressors. Gene ontology analysis of the genes and pathways targeted by these highly enriched miRNAs suggest their profound physiological role in regards to cell proliferation and survival, and their potential to be used for strain engineering.

Protein Unfolding and Aggregation at High Pressure and Low Temperature: Role of a Fragment

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Non-native protein aggregation is a common issue that can occur during multiple steps of manufacturing and storage. Experimental models of aggregation under cold (sub-zero °C) storage conditions are often confounded because of the presence of ice, which is also a potential denaturing agent via adsorption of proteins to the ice-water interface. Hydrostatic pressure can be used to prevent water from crystallizing at sub-zero temperatures, allowing for the characterization of protein structural perturbations leading to aggregation in solution, and separating those effects from aggregation at bulk interfaces.

The effects of high pressure (up to 350 MPa) and low temperature (0 to -20 °C) on the stability of two different monoclonal antibodies (MAb) were examined in this work. Intrinsic fluorescence and small-angle neutron scattering (SANS) were used to observe the *in situ* effects in an effort to not only characterize tertiary structure at these conditions, but also to detect aggregation prone intermediates that are often difficult to characterize. In both cases but to varying extents, partial unfolding of the MAbs was observed under a range of pressure/ temperature conditions. Several pressure and temperature conditions were also used to discern the respective contributions of the isolated MAb fragments (Fab and Fc) to unfolding and aggregation. The fragments for each antibody showed unique partial unfolding profiles and reversibility, indicating a complex relationship to full MAb unfolding and aggregation behavior in the case of both antibodies.

In situ effects of pressure on protein interactions were also measured with a specially developed high-pressure static light scattering apparatus. This technique quantified the osmotic second virial coefficient (B_{22}) versus protein concentration and pressure. Net protein-protein interactions ranged from strongly repulsive to attractive interactions across pressure, ionic strength, and selected MAb. The combined use of spectroscopic and scattering techniques provides insights into MAb conformational and colloidal stability in high-pressure, low-temperature environments. In advancing mechanistic understanding of protein behavior at these conditions, this work may ultimately lead to better prediction of aggregation propensity during long term storage and faster screening of new stabilization strategies for MAb therapeutics.

Interpretable Machine Learning for Uncertainty Quantification in Computation Catalysis

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Due to their tractable computational cost and relatively high accuracy, Density Functional Theory (DFT) calculated electronic energies combined with statistical mechanical temperature corrections are used to parametrize microkinetic models of reaction pathways. Such models have had notable successes, for example in identifying dominant reaction pathways. However, a common source of error in such models stems from the error in DFT calculated energies. One way to improve ab-initio energy parameters is to introduce systematic corrections. Several such ad-hoc methods have been proposed in the literature. We develop a graph theoretical framework to systematically study these errors and use machine learning methods to develop predictive corrections on DFT calculated thermochemistry.

We extend this conceptual approach to 'merge' thermochemical databases from various sources at varying degrees of accuracies. Specifically, we show that it can be used to predict different thermochemical quantities at a higher level of theory using a quantity at a lower level of theory. The generalizability of the model is investigated, and rigorous statistical tests are used to guarantee bounds in model predictions. Two important aspects of machine learnt models are addressed: domain knowledge and interpretability. We show how our model draws from chemical knowledge and thus provides an interpretable mapping across levels of theory and quantities of interest. These help us to draw physical insight from the learning process. The approach is illustrated with multiple mapping tasks, and levels of quantum theory for a dataset of ~12k molecules. Chemical accuracy (1 kcal/mol) is attained for all tasks. Our approach provides a blueprint of how to merge disparate and incomplete literature datasets, built using different levels of theory, to create a more comprehensive thermochemical database for applications such as Big Data analysis.

Utilizing mechanically and biochemically tunable synthetic culture platforms to investigate and modulate immune cell response

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The immune system, consisting of innate and adaptive immunity, acts as the body's defense mechanism to protect against disease-causing pathogens. Innate immune cells (such as macrophages and dendritic cells) act as an initial line of defense in the human body to protect against pathogens non-specifically. Adaptive immune cells (such as B and T-cells) are a part of acquired immunity that specifically targets the disease-causing agent. In a healthy body, innate and adaptive immune cells work together to protect the body against pathogens. However, innate and adaptive immune cells respond to remove the disease-causing agent in a diseased state and maintain homeostasis. Synthetic culture platforms (such as hydrogels) present opportunities to mimic more complex tissue microenvironments in both fundamental studies of immune cell responses to specific extracellular stimuli (e.g., microenvironment changes during disease progression) and applied studies that utilize these extracellular cues to direct immune cell phenotype and enable their engineering and expansion.

First, to investigate how innate immune cells respond to microenvironment changes in disease progression, we utilized mechanically and biochemically tunable hydrogels to mimic aspects of lung tissue microenvironments in Idiopathic Pulmonary Fibrosis (IPF). IPF is a chronic fibrotic disease with unknown etiology thought to be initiated by repeated micro-injuries to the alveolar epithelium. Increased tissue stiffness and presence of profibrotic stimuli such as IL-13 have been observed in the fibrotic microenvironment, which has been hypothesized to promote profibrotic phenotype in macrophages (M2 phenotype); however, it is unclear if the presence of profibrotic cytokines or changes in ECM stiffness is the main drivers in accelerating fibrosis or if there is a synergistic effect that aids in fibrosis progression. To investigate that, we prepared hydrogels with moduli ranging from healthy (Young's modulus (E) ~ 1.5 kPa) to fibrotic lung tissue (E~23 kPa) and established relevant conditions to assess the macrophage response in fibrosis. The presence of IL-13 and increased substrate stiffness (*in-vitro* fibrotic mimic) independently and synergistically resulted in an increased profibrotic phenotype of macrophages that could drive fibrosis progression. Second, to further demonstrate the ability of biomaterials to modulate immune cell response, we optimized a manufacturing platform that combines existing flow-based membrane technology with biomaterial approaches to manipulate cell populations toward maximizing the production efficiency for T-cell therapies. Using biocompatible synthetic hydrogel materials, we created thin hydrogel films on microfiltration membranes and quantified height (~40–80 μm) and mechanical properties (E ~100–300 kPa) of the resulting composites. Hydrogels were then modified with anti-CD3 and anti-CD28 antibodies through biotin-avidin chemistry to regulate T-cell activation. These hydrogel-membrane composites were introduced into a tangential flow filtration (TFF) cell. Further, we investigated the activation of T-cells on anti-CD3 and anti-CD28 modified hydrogel-membrane composites within the device and their transduction with a model lentiviral system under flow. Together, these results demonstrate our ability to utilize biomaterials to investigate disease mechanisms by accurately mimicking disease progression and modulating immune cell responses to manufacture cell-based therapies.

De Novo Biosynthesis and Site-Selective Ribosomal Incorporation of a Nitroaromatic Non-Standard Amino Acid

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Nitroaromatic functional groups can impart valuable properties to chemicals and to biological macromolecules including polypeptides. The nitroaromatic amino acid p*ara*-nitro-L-phenylalanine (pN-Phe) in particular has been applied in proteins as an immune stimulating and fluorescence quenching residue. Currently, nitroaromatic chemical synthesis methods, including that of pN-Phe, do not follow green chemistry principles and limit the use of pN-Phe in engineered bacterial cells for *in situ* applications. To this point, metabolic engineering efforts toward *de novo* nitro-product biosynthesis and investigation into nitro-forming enzymes has been limited. Through the development of metabolic synthesis pathways for pN-Phe paired with orthogonal translational machinery, bacteria can be engineered to autonomously utilize an expanded genetic code with nonnative chemistries.

In this work, I present an integrated *de novo* heterologous pathway for the production of pN-Phe in *Escherichia coli*. Here, I utilized previously characterized genes for the biosynthesis of an amine precursor (*para*-aminophenylalanine) with a newly discovered nitro-synthesizing enzyme identified through screening of putative diiron monooxygenases from nature. Further optimization of the chassis, plasmid constructs, and media conditions, enabled me to improve pN-Phe biosynthesis to near millimolar levels in relevant culture conditions. Then, through fluorescence-based screening, I identified orthogonal translational machinery capable of selective incorporation of pN-Phe within proteins. Integration of the metabolic pathway with orthogonal translational machinery will result in a microbe capable of *in situ* use of an expanded, nitroaromatic amino acid-containing genetic code.

Lentiviral reporters for temporal characterization of cell activation in response to dynamic stimuli

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Fibrosis, a class of diseases characterized by accumulation of scar tissue, is driven by the differentiation of fibroblasts, among other cell types, into activated myofibroblasts. This activation is crucial to healthy healing after injury, where myofibroblasts facilitate wound contraction and secrete matrix proteins for tissue regeneration. However, when activation persists after complete wound healing, excessive protein deposition leads to increased tissue stiffness and eventual organ failure. This persistence is multifaceted and thought to be driven by mechanical feedback loops that continually activate fibroblasts, as well as through crosstalk that encourages myofibroblastic differentiation of surrounding cell types such as epithelial cells. Activation is often assessed by characterizing the expression of a cytoskeletal protein called alpha smooth muscle actin (αSMA), traditionally quantified through destructive end-point techniques that provide population averages. These methods (RT-qPCR, western blot, immunostaining) are often limited by large error owing to the inherent heterogeneity of myofibroblast populations and highlight the need for more sophisticated tools to capture these dynamics. In this work, we establish and utilize lentiviral reporters to assess individual and collective activation of human fibroblasts for characterizing real-time cell response to mechanical and biochemical cues.

The reporter system provides low-level constitutive expression of DsRed fluorescent protein, while ZsGreen fluorescent protein is conditionally expressed as the cell produces αSMA. Three versions of the virus were tested: two with a destabilized ZsGreen, where fluorescence dissipates over short or moderate time scales after expression, and a stable ZsGreen, where fluorescent protein accumulates and fluorescence persists over longer timescales. With emphasis on different timescales of interest (e.g., hours to days), each system provides unique insights into dynamic activation behavior not captured with static assessment of αSMA protein expression. This reporter system can be utilized across a wide array of cell types and is further being applied to patient-derived human cells, providing a complementary approach to transgenic reporter animal models. Work is ongoing to implement these reporters in dynamically modulated systems for more insights into fibroblast activation and persistence, aiming to understand the role of extrinsic and intrinsic factors in these complex processes and move towards developing more representative *in vitro* disease models. With tools like these, we can improve our understanding of fibrosis progression and motivate new approaches for treatment.

Computational Study of the Solvent Effects in Biphasic Systems for Fructose Dehydration

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The partial deoxygenation of fructose to platform molecules, 5-hydroxymethylfurfural (HMF), is critical for the economic production of biofuels and chemicals from non-edible lignocellulosic biomass. Efforts have been made over the past few decades to identifying solvents, catalysts, and reaction conditions that could enable the selective production of such intermediate. Previous study from Román-Leshkov et al. has initiated the exploration of biphasic reactive extraction systems for fructose dehydration, reporting unprecedented improvements in the selectivity to HMF. In such biphasic system, HMF is continuously extracted into a non-polar organic phase, allowing the separation between the products and the catalysts and suppressing further side reactions. Despite the significant enhancement in the yield of HMF, the mechanistic understanding of fructose dehydration in the biphasic system remains lacking. Even the well-studied effects of polar aprotic co-solvents on the rate and selectivity of the monophasic fructose dehydration are difficult to extrapolate to the non-polar solvents used in biphasic systems.

In this work, we investigated the nature of the enhanced dehydration of fructose to HMF in the water and methyl isobutyl ketone (MIBK) biphasic microfluidic system computationally. Classical molecular dynamics simulations (MD) were performed to understand the partition of water between fructose and HMF in the mixture of organic solvents and water. Hybrid quantum mechanics/molecular mechanics (QM/MM) MD was applied to study the proton-fructose and proton-HMF interactions in the organic solvents. Finally, we applied the linear response theory to estimate the relative solvation free energy ($\Delta\Delta G_{sol}$) between the reactant and product states and further understand the change of their relative stability in different solvents. Among the major conclusion from our simulations are: (a) When both fructose and HMF co-exist in non-polar organic solvents, water preferably coordinates near the highly hydrophilic fructose substrate, limiting the water available for HMF rehydration. (b) The formation of a tight hydrophilic domain around the substrate enables strong proton-substrate interactions in the organic solvent-rich environment and further enhance the reaction rates. (c) In the aqueous mixture of the non-polar organic solvents, the formation of the side product (levulinic acid) is suppressed and thus increases the selectivity towards HMF.

Data-driven modeling and process intensification for distributed biomass processing

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Modular and green manufacturing has received growing interest to improve energy efficiency and reduce operating costs and waste in various areas, such as biomass processing and natural gas upgrading. For example, distributed compact reactors enable processing high-volume biomass within a short distance from the source and promote economic feasibility. Electrification of such processes using renewable energy enables carbon-neutral production. However, the design principles for these complex and intensified reactors are lacking. Development of a fundamental understanding and optimization workflow is necessary to design modular and compact reactors of enhanced productivity and efficiency.

Here, we discuss modeling of a microreactor under microwave radiation. Microwaves (MWs) can heat rapidly, volumetrically, and selectively to overcome the heat transfer limitations of conventional reactors and enable process intensification of chemical manufacturing. It has been applied to a range of chemical processes, such as microfluidic processes and catalytic reactors. Yet, it is challenging to optimally design and construct MW-heated systems due to the resonance nature and complex spatial distribution of the electromagnetic field in the reactor cavity and the overall lack of fundamental understanding. In this work, we develop a multi-physics model to investigate the effects of various processing parameters on the outlet temperature. We employ machine learning to optimize the microfluidic channel dimensions and the processing conditions in consideration of both heating performance and energy efficiency.

A Framework of Surrogate-based Multi-objective Optimization for Continuous Pharmaceutical Manufacturing Processes

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Incentivized by increasing competition and encouragement from regulatory agencies to develop agile, flexible, and robust manufacturing lines, pharmaceutical manufacturing processes are experiencing a shift from batch to continuous operations [1]. With considerable research efforts, progress has been made in modeling solid-based continuous manufacturing processes, which supports the design, analysis, and optimization of these lines. However, with better understandings of the processes, the complexity of models and constraints increase, leading to a rise in computational burden. In addition, there are still some unknown analytical relationships between process variables, posing a challenge for solving optimization problems efficiently. To address the problem, a surrogate-based optimization strategy has been proposed, where a surrogate model is iteratively updated with the adaptive sampling step that searches for new promising points based on certain expected improvement (EI) function, and the final surrogate with low approximation error is used for optimization [2]. Previous work has applied this approach in pharmaceutical manufacturing by using a weighted EI on feasibility to guide the search of new points towards feasible regions with low objective values, followed by a modified EI on the objective to search for global optimum within the feasible region [3]. Although the work demonstrates high accuracy in obtaining optima, it is limited to single-objective problems.

In this work, an updated surrogate-based, feasibility-driven, multi-objective optimization framework is proposed. Each objective function is approximated using a surrogate, and the constraints are grouped into a feasibility function based on maximum constraint violation, which is also substituted with a surrogate. The two EI functions used in the single-objective case are changed to expected hypervolume improvement (EHVI) functions that seek for Pareto solutions based on the difference of hypervolumes between the current and the next updated sample set. With the identified Pareto front, a goal programming approach is implemented to decide for the best solution. The effectiveness of the framework is demonstrated with an example benchmark problem and a case study from the continuous pharmaceutical manufacturing process via the wet granulation route. Such framework enables the industry to effectively investigate multiple objectives (e.g., cost, waste, energy consumption, environmental impacts, etc.) under quality constraints, allowing for a better decision-making strategy.

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A Data Driven Investigation of Catalytic Upgrading of Ethane to Ethylene Over Ga/Al_2O_3

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The recent shale gas revolution offers exciting opportunities to meet global demands with new solutions. Increasing demand for ethylene, one of the world's most produced chemicals, presents such an opportunity. While traditionally generated through naphtha cracking, ethylene may also be produced through the dehydrogenation of ethane present in shale gas. To enable the economic feasibility of this process, studies[1] screened numerous candidate catalysts and discovered alumina-supported gallium (Ga/Al_2O_3) as a highly promising material. However, its impressive catalytic activity is inhibited by deactivation due to coking. Attempting to prevent this deactivation while retaining dehydrogenation activity, multiple investigations[2,3] explored coking mitigation strategies, such as CO_2 co-feeding, but we have yet to understand the complete, underlying kinetics and unlock the potential of this exciting catalyst.

In this work, we investigate the kinetics of ethane dehydrogenation over Ga/Al_2O_3 and the associated deactivation. Analyzing our micro gas chromatography data with novel Bayesian techniques, we ascertain a layered reaction network and associated kinetic parameters. We discover a fundamental change stemming from the water produced that selectively affects ethane dehydrogenation but not the unwanted side reaction of hydrogenolysis. This water effect also applies to the deactivation kinetics and explains CO_2 co-feeding inhibiting coking through the surprising lens of the reverse water-gas shift reaction. Applying these findings alongside additional experiments exploring water co-feeding, we identify a promising path towards substantial conversion, improved selectivity, and negligible coking. These discoveries offer novel insights into this promising catalyst and general applicability to similar oxide materials.

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Case Studies in Coculture Metabolic Flux Analysis

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Engineering microbial consortia for fermentation allows for pathway compartmentalization, broadened metabolic capability, and improved robustness. However, tools for modeling consortia are underdeveloped, limiting predictability compared to monocultures. Identifying and quantifying interspecies cross-feeding and its effect on each species' metabolism is crucial to understanding cooperation and exploitation in consortia. In this work, we develop techniques for conducting ^{13}C metabolic flux analysis on consortia using a range of model cocultures.

In one model coculture, a methionine-auxotrophic *E. coli* cleaves lactose, providing glucose and galactose to *S. enterica*. In turn, *S. enterica* excretes excess methionine that is taken up by *E. coli*. Knowing only the biomass composition of each species and the combined biomass ^{13}C-labeling, we used our recently developed methodology to simultaneously resolve the ratio of *S. enterica* to *E. coli* and each species' full metabolic profile, both in isolation and in coculture. We discovered that *S. enterica* feeds on pyruvate produced from *E. coli*. In another coculture system, a complementary pair of Keio collection *E. coli* were grown. One strain cannot consume glucose (ΔptsIΔglK) and the other strain cannot consume galactose (ΔgalK). When the LacZ operon was reintroduced to the galactose-consuming strain, the coculture's growth was limited by the slower-growing strain's ability to cleave lactose into glucose and galactose. In a pair of coculture transwell experiments with either [U-^{13}C-galactose]-lactose or [U-^{13}C-glucose]-lactose, we discovered widespread exchange of carbon via acetate, and Krebs cycle dicarboxylic acids.

In the final project, we study cocultures of *C. acetobutylicum* (*Cac*) and *C. ljungdahlii (Clj);* coculturing with *Clj* has been shown to increase *Cac*'s carbon efficiency. In the process, we develop techniques to study metabolism in complex media, including: a) calculations to differentiate biomass derived from yeast extract or derived from hexose; b) co-culture ^{13}C-MFA to discretize monoculture metabolism into distinct phases; and c) isotopomer spectral analysis (ISA) on cell membrane lipids to calculate marginal growth during stationary phase. We show from ISA analysis of fatty acids that *Cac* has irreversible excretion of acetate. In *Clj* we use ISA on fatty acids to discern two distinct acetyl-CoA labeling phases, suggesting that media acetate freely exchanges with intracellular metabolite pools. We found that 30% of *Cac* biomass derived from glucose and the remainder was derived from yeast extract, limited only by the complete consumption of every yeast extract component except alanine and glutamate. For *Cac*, most yeast extract components flowed directly into protein synthesis. Only aspartate and glycine entered central carbon metabolism. These new methods were then applied to the CO_2-fixing bacterium *Clj*. Using ^{13}C-tracers, we discovered that *Clj* is methionine auxotrophic, allowing us to formulate defined media for *Clj*. Despite the availability of fructose, externally supplied CO_2 was the primary carbon substrate for growth (47% of total carbon-moles consumed). Asparagine was a major carbon source via deamination to fumarate, or via cleavage of threonine to acetaldehyde and glycine to feed the Wood-Ljungdahl pathway. In both species, we discover significant alanine excretion.

In vivo Biological Function, Biodistribution and Targeted Gene Editing and Modulation of Hematopoietic Stem Cells Using Endogenous and Engineered Cas9 and siRNA-loaded Megakaryocytic Membrane Vesicles

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There is a large spectrum of highly pervasive hematological disorders affecting red blood cells (erythrocytes), white blood cells (granulocytes), platelets (megakaryocytes) and lymphocytes. Hematopoietic stem and progenitor cells (HSPCs) can differentiate into these blood cell types, and gene editing of HSPCs can provide therapeutic benefits to patients for a variety of genetic hematological disorders, ranging from immunodeficiencies to thrombocytopenia[1-3]. For more transient gene therapy, gene expression can be modulated epigenetically using RNA interference through administration small RNAs into the target HSPCs[4, 5]. Thus, by directly administering gene therapeutics into HSPCs, a significant proportion of hematological diseases can potentially be ameliorated.

Previously, it has been demonstrated that microparticles derived from platelet-producing megakaryocytes (MkMPs) can readily interact with and deliver cargo to HSPCs *in vitro*[6]. In our current study, we have demonstrated that these MkMPs also have the propensity to localize within murine bone marrow *in vivo* roughly 24-hrs after intravenous administration[7]. We also discovered that these infused MkMPs spur murine *de novo* platelet biogenesis via MkMP-induced megakaryopoiesis of HSPCs *in vivo*[7]. Furthermore, through histology, we determined that these MkMPs also interact discriminately with HSPCs and other blood cells in the bone marrow and lungs *in vivo*, thus enabling microparticles to serve as efficacious drug delivery vehicles. Thus, it is hypothesized that CRISPR Cas9 and siRNA can be delivered specifically to HSPCs through receptor-mediated endocytic pathways to HSPCs using both natural (microparticles) and semi-synthetic membrane vesicles.

We have successfully loaded cell membrane-wrapped PLGA nanoparticles with siRNA for delivery to HSPCs *in vitro* and subsequently observed effective downregulation of an HSPC-specific gene. Likewise, CRISPR Cas9, a sequence-specific nuclease, can be encapsulated by cationic polymers and further wrapped with membranes for cell-specific delivery to HSPCs *in vitro*, which provides efficient gene knockout and reduced cytotoxicity in comparison to traditional plasmid-based Cas9 systems and exogenous transfection methods. Blood cell-derived membrane vesicles minimize the immunogenic risk associated with other vehicles, potentially establishing cargo-loaded membrane vesicles as a safe and effective method for cell-specific *in vivo* gene therapies of various hematological diseases.

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Electrochemical Generation of Reactive Intermediates as a Tool for Aromatics Upgrading

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Functionalization of simple aromatics such as benzene, toluene, xylenes, ethylbenzene, and styrene substantially expand the utility of such commonly available building blocks. Traditional upgrading methods include electrophilic aromatic substitution, partial oxidation, and halogenation of side chains. Such reactions often require harsh conditions like elevated temperature and pressure, corrosive solutions and vapors, and reactive reagents such as halogens. Electrosynthesis employs electrochemical potential as the driving force of reactions, allowing operation near ambient temperatures, with conventionally unreactive reagents, thus providing alternative pathways to aromatic functionalization that avoid harsh conditions.

The electrochemical upgrading of aromatics often involves reactive intermediates such as radicals or carbocations, which can be produced by Kolbe electrolysis of carboxylic acids or direct activation of aromatics. Reactive carbon-centered radicals are produced in Kolbe electrolysis of carboxylic acids [1]. While simple, symmetric radical coupling products have limited commercial interest, directing such radicals towards addition to C=C double bonds in styrene is a promising approach to extend electrosynthesis to complicated upgraded aromatic products. Such reactions have been reported in several studies [2-3], but the undesired side reactions, such as self-coupling and radical-initiated polymerization, often led to low selectivity and rapid catalyst deactivation. We developed a current-pulse technique to mitigate deactivation of the electrodes caused by deposition of insulating oligomers, improving the carbon balance and reducing the energy input. Several parameters such as the concentration of substrates, current density, temperature, pulse length and frequency were investigated and optimized. The reaction mechanism was confirmed to involve a radical intermediate using a radical trap. Direct oxidation of aromatic substrates is another way to generate reactive intermediates electrochemically. The electrooxidation of alkylbenzenes is believed to proceed via a radical carbocation intermediate [4]. We showed that performing such electrooxidations in anhydrous carboxylic acid solvents lead to the formation of corresponding aromatic esters without substantial solvent oxidation under high oxidation potentials. With p-xylene as substrate and acetic acid as solvent, the major product, p-methyl benzyl acetate was produced at 65% Faradaic efficiency and 70% selectivity. Further oxidation produced a mixture of partially oxidized products, including substantial quantities of aromatics functionalized on both alkyl groups.

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Quantitative Prediction of MAb Interactions with Experimental and Computational Approaches

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Monoclonal antibodies (MAbs) are a prominent sector of the biopharmaceutical industry, with dozens of FDA-approved therapies for treating diseases including a range of cancers and autoimmune disorders. Many challenges remain in the process of developing MAb therapies including candidate selection and formulation development, which are both multiparameter optimization problems that span an intractable space of possibilities. Rational and efficient workflows are essential for choosing a developable candidate (i.e., one that can be developed into a drug product free from debilitating issues in manufacturing, stability, or efficacy), and successfully determining the formulation conditions (e.g., pH, co-solutes and ionic strength) of the final drug product. There is a demand for tools that can be used to predict experimental properties relevant to developability of a given protein candidate, with less time- and material-intensive methods. Of particular concern is irreversible aggregation, a common but not well-understood form of MAb degradation that reduces shelf life and can lead to a detrimental immunogenic response in patients. MAb self-interactions at low and high protein concentrations are of interest as they are at least phenomenologically related to the mechanisms of aggregation and other problematic behaviors such as phase separation and high viscosity.

Recent work used low-concentration self-interaction experimental data in the form of static light scattering (SLS) to parameterize low-resolution coarse-grained simulations that can quantitatively predict high-concentration self-interactions for a subset of behaviors. Additionally, prior experimental work has semi-quantitatively connected SLS to aggregation rates for formulations as a function of pH and salt concentration. Each of these studies motivates further investigation that captures a broader range of MAbs, especially those with net attractive self-interactions. This presentation will focus on coarse-grained molecular simulations at low and intermediate resolution that provide quantitative predictions of high-concentration MAb self-interactions. Experimental low- to high-concentration SLS measurements are used to parameterize the models and validate the computational predictions, while dynamic light scattering measurements provide an independent measurement of self-interactions that also includes hydrodynamic interactions.

High-yielding processes for transient and stable expression of the SARS-CoV-2 receptor binding domain in HEK293 cells

Erica A. Green
Advisor: Kelvin H. Lee
Committee Members: April M. Kloxin and Millicent O. Sullivan

Human embryonic kidney 293 (HEK293) cells are an important host platform for production of therapeutic proteins and viral vectors. While other mammalian cell lines such as Chinese hamster ovary (CHO) and murine myeloma (NS0) cells generally can produce therapeutics at higher titer, the use of HEK293 cells is advantageous when proteins with humanized post-translational modifications are desired. Over the last few decades, HEK293 cells have been more widely used in scalable, serum-free protein expression systems, but further work in vector engineering and cell line development is needed to improve transient and stable protein production processes.

We established transient and stable process development workflows for production of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) spike protein receptor binding domain (RBD). HEK293 was selected as the expression system because of the need to produce recombinant RBD (rRBD) protein with human characteristics. Transient process development involved screening of vector elements, transfection conditions, and process parameters to identify the most productive rRBD expression workflow. Stable cell line development involved the generation of a rRBD-expressing pool and generation of clonal cell lines that were screened for rRBD titer. A bio-layer interferometry method used to measure RBD titer on unpurified supernatant samples enabled efficient comparison of the titers from different processes and clones. Ultimately, these methods can be used to develop transient and stable production processes for other proteins expressed in HEK293 cells.

Computational Study of Structure, Self-Assembly, and Optics of Bio-Inspired Nanoparticles

Christian Heil
Advisor: Arthi Jayaraman
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Nanoparticle self-assembly is relevant to engineering materials for a wide array of applications including optics, catalysis, biomedicine, sensing, and electronics. Directed self-assembly of nanoparticles near surfaces/interfaces (e.g., in thin films, droplets in emulsion assembly) enables formation of 3-dimensional "supraparticle" assemblies that are used in optics and photonics applications. Such supraparticle assemblies produce structural colors by constructive interference of specific wavelengths of light as it moves through the assembled structure. The direct relationship between the assembled supraparticle structure and resulting optical properties requires structural characterization as a necessary step during the design of materials with tailored optical or photonic properties. Structural characterization of assembled nanoparticles is performed primarily using microscopy and scattering techniques. While microscopy is beneficial for visualizing the nanoparticle assemblies, both transmission electron microscope**,** TEM, and scanning electron microscope, SEM, suffer from limited sample area and probe limited length scales. In contrast, small angle scattering techniques characterize structures over a broader range of length scales and present ensemble averaged information from the sample. Interpreting the small angle scattering output data, $I(q)$ vs. q, typically requires fitting the scattering data with an appropriate analytical model that is relevant for the material under consideration; however, for some supraparticle assemblies (e.g., high packing fraction, amorphous structure) the existing analytical models may be too approximate. One part of my thesis work has been focused on development of a computational method called CREASE (computational reverse-engineering analysis for scattering experiments) for interpreting supraparticles' structure from small-angle scattering without relying on analytical models. In the first part of my talk, I will describe the genetic algorithm (GA) based optimization used in CREASE to analyze the $I(q)$ from structural arrangement of the assembled spherical nanoparticles within a supraparticle. I will demonstrate how we validate our approach using *in silico* experimental scattering profiles from prior simulations of supraparticles composed of binary mixtures of spherical nanoparticles by comparing the output of our GA approach to the known structure. In the second part of my talk, I will present our recent extensions of CREASE to interpret small angle scattering profiles from systems (e.g., concentrated solution of micelles) where both the form factor of the particle (i.e., micelle) and the assembled structure of the particles are unknown to the experimentalist and determined by CREASE.

Modeling weakly adsorbing impurities in flow-through ion-exchange chromatography

Chase Herman
Advisor: Abraham Lenhoff
Committee Members: Eric Furst and Kelvin Lee

Downstream bioprocess development relies primarily on empirical methods, despite incentives to adopt more first-principles approaches. This is the case for flow-through ion-exchange chromatography, which is often used as a polishing operation following product capture. A large number of physicochemically diverse impurities may be encountered in this step, and it would be beneficial to better understand their behavior. To this end, we report insights into the factors that contribute to the clearance of weakly adsorbing impurities. Transport contributions are analyzed with column simulations, revealing that dilute impurity breakthrough volumes depend on an effective Graetz number for mass transfer. This dependence is validated experimentally, and the implications are examined. Thermodynamic information in the form of retention factor–ionic strength data are also compiled from experiments and literature, providing data for over 200 protein-pH-resin combinations. Fitting these data reveals a correlation between retention strength and the protein characteristic charge, which may prove useful in the *a priori* estimation of impurity behavior and in testing the validity of molecular adsorption models.

Identifying stable hotspots of transcriptional activity in the CHO genome

William Hilliard
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Committee Members: Eleftherios T. Papoutsakis, Wilfred Chen

The Chinese hamster ovary (CHO) cell lines that are used to produce commercial quantities of therapeutic proteins commonly exhibit a decrease in productivity over time in culture, a phenomenon termed production instability. Random integration of the transgenes encoding the protein of interest into locations in the CHO genome that are vulnerable to genetic and epigenetic instability often causes production instability through copy number loss and silencing of expression. These cell line development challenges can be overcome by using site-specific integration (SSI) technology to insert the transgenes at genomic loci, often called "hotspots," that are transcriptionally permissive and have enhanced stability relative to the rest of the genome. Extensive characterization of the CHO genome is needed to identify hotspots that maintain their desirable epigenetic properties in an industrial bioprocess environment and maximize transcription from a single integrated transgene copy. To address this need, we first used high-throughput chromosome conformation capture (Hi-C) to construct a chromosome-scale reference genome assembly suitable for genome-scale comparative analysis of different CHO-K1 cell lines. Large "safe harbor" regions of the CHO genome containing transcriptionally permissive three-dimensional chromatin structures with enhanced genetic and epigenetic stability were then identified by analyzing the epigenomes and transcriptomes of two industrially relevant CHO-K1 cell lines and several other cell lines used throughout the CHO research community. These safe harbor regions significantly reduce the genomic search space when looking for CHO hotspots with widespread applicability. Ongoing efforts to characterize these regions at higher resolution include the development of low- and high-throughput methods to directly interrogate transgene transcription at candidate hotspots. These methods will pinpoint stable transgene integration sites with maximal production potential that can be retargeted using CRISPR/Cas9 genome editing technology.

Cost and Energy Efficient Cyclic Separation and Upgrade of 5-Hydroxymethyl Furfural in a Microfixed Bed

Yung Wei Hsiao
Advisor: Dionisios G. Vlachos
Committee Members: Raul Lobo and Marianthi Ierapetritou

The efficient separation of 5-hydroxymethyl furfural (HMF) – a platform chemical in biomass valorization – from the reactive aqueous mixture of sugars is key to improving its economic production. Here we demonstrate a cyclic fixed-bed process that selectively adsorbs HMF from the aqueous phase, purifies the solute, and enables its subsequent desorption using a suitable solvent for downstream applications. This intensified process bypasses the traditional energy-intensive recovery of HMF via vacuum distillation. The adsorption and desorption performances of a commercially available polymer-based spherical activated carbon (PBSAC) are quantified in batch and continuous systems. The effects of temperature (25 – 90 °C) and the co-existence of other components from the fructose dehydration reaction (fructose, formic acid, and levulinic acid) on adsorption are evaluated. It is demonstrated that HMF can be selectively purified and recovered, and the adsorption column can be reused for at least seven cycles tested here. Model predictions based on parameters extracted from batch isotherms describe the continuous experimental breakthrough curve well with suitable transport parameters. A simple economic analysis further showcases nearly tenfold cost and energy savings for HMF separation. The cyclic mechanism promotes flexible solvent choice. An intensified downstream hydrodeoxygenation (HDO) reaction using the desorbed HMF is demonstrated using an inexpensive copper-based catalyst, achieving a high >95% yield under continuous operation. The framework outlined here highlights the potential for modular biorefineries and can be applied to other biomass solutes.

Inert Nanoparticles for Enhancing the Survival of Primary Macrophages

Bader M. Jarai
Advisor: Prof. Catherine A. Fromen
Committee Members: Prof. April M. Kloxin, Prof. Millicent O. Sullivan, Prof. Jason P. Gleghorn

Macrophage-based cell therapy has been identified as a promising therapeutic approach to treat chronic immune dysfunctions, owing to the functionality and phenotype plasticity of macrophages. However, current attempts of macrophage activation for autologous cell therapy fail to elicit effective therapeutic responses because of low cell survival ex vivo following macrophage isolation from tissue and upon reintroduction. Therefore, there is a need to develop approaches to regulate primary macrophage survival in both in vivo and ex vivo environments. We have discovered that ex vivo cultured primary bone marrow-derived macrophages (BMMs), which typically undergo apoptosis within 2 weeks under appropriate culture conditions, can persist and maintain functionality for several months after being treated with a single dose of inert polyethylene glycol (PEG)-based nanoparticles. This enhanced survival phenomenon is also applicable to ex vivo cultures of terminally differentiated macrophages isolated from tissue. Our results indicate that nanoparticle uptake significantly delays primary macrophage cell death through the downregulation of caspase-dependent apoptosis pathways and the expression of antiapoptotic proteins. Furthermore, nanoparticle-induced longevity does not influence macrophage polarization into pro-inflammatory or anti-inflammatory phenotypes. Overall, this work demonstrates for the first time the ability of inert nanoparticles to suppress apoptotic signaling and prolong viability in primary macrophages extracted from different tissues and could eliminate a major obstacle standing in the way of developing macrophage-based cell therapies.

Rheology of aggregating colloidal suspensions: perspectives from population balances and non-equilibrium thermodynamics

Soham Jariwala
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Committee Members: R. Bertrum Diemer, Eric M. Furst

Aggregating colloidal suspensions can be encountered in a large number of materials; examples include food products, and biological fluids to printer inks, paints, and slurries [1]. A consistent description of these suspensions remains challenging as their rheology directly connects to the mesoscale structure and aggregation kinetics. Transient flows in such suspensions show complex dynamics due to yield stress, viscoelasticity, and flow history dependence, i.e., thixotropy. Numerous models have been proposed over the years to address these rheological features, predominantly for shear flows. Among these, a popular class of models, known as structure kinetics, uses a scalar parameter to track changes in mesoscale structure and empirically relates it to rheological properties. Mwasame et al. [2, 3] have shown that one can more accurately capture the aggregation and breakage kinetics using population balances, taking advantage of rigorously derived aggregation kernels for shear flow and Brownian motion, and more physically based relations for rheology. This approach provides a bottom-up particle level description; however, it is limited only to shear flows and cannot be generalized for any arbitrary flow.

In this work, we show that one can incorporate the principles of population balances in the framework of non-equilibrium thermodynamics such that the flow descriptions are generalizable to a three-dimensional system. We offer a top-down approach and show how the entropy associated with the aggregate formation is related to the evolution equations of the distribution of aggregate sizes. Through a consistent tensor description from non-equilibrium thermodynamics, we also explore how this modeling approach can capture phenomena such as inhomogeneities and stress-induced migration commonly observed in these systems.

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Characterization and expansion of synthetic auxotrophy for microbial biocontainment

Michaela Jones
Advisor: Dr. Aditya Kunjapur
Committee Members: Dr. Wilfred Chen, Dr. Millicent Sullivan, Dr. Ethan Garner (Harvard)

Thus far the innovations of synthetic biology and genetically modified organisms (GMOs) have mostly remained confined to laboratory settings despite the broad and promising potential they offer in medicine, agriculture, and bioremediation. Deployment of engineered microbes requires safeguards to prevent their uncontrolled proliferation in natural environments; fortunately, biocontainment methods, like synthetic auxotrophy, offer a strategy for secure environmental release of GMOs. Synthetic auxotrophs are microbes engineered to depend on a synthetic nutrient, typically a non-standard amino acid (nsAA), for growth. Successful synthetic auxotrophs have undetectable escape in laboratory settings under evolutionary pressure. However, further characterization and development of synthetic auxotrophs are necessary before their widespread deployment. Following a study on the long term biocontainment of an *E. coli* synthetic auxotroph, we characterized the persistence of the strain in the absence and subsequent re-addition of the synthetic nutrient. We found that the strain could persist in laboratory conditions with a tunable lag phase based on time of nutrient re-addition.

While further characterization of *E. coli* synthetic auxotrophs is ongoing, there is a broad array of engineered bacterial species with natural plant and human probiotic properties that will also need to be biocontained. We are working to expand synthetic auxotrophy to other hosts, such as *Bacillus subtilis,* which will require selection of essential protein markers and robust nsAA incorporation. To establish best practices for marker selection, we are determining required expression levels for different essential proteins. Despite the recent expansion of nsAA incorporation to *B. subtilis*, we are investigating the significant limitations to this technology, such as low incorporation in rich media conditions. To study these limits, we have generated an nsAA-dependent strain based on nsAA incorporation in an antibiotic resistance marker.

Photo-CuAAC-Methacrylate Interpenetrating Polymer Networks: Manipulating Formation Trajectory with Light

Mukund Kabra
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Committee Members: Professor Thomas H. Epps III, Professor LaShanda T. J. Korley, Professor Darrin J. Pochan

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Light can be utilized to create soft, polymeric materials that can be used for molecular separations, sensors, fuel cell operation, and mechanical support. Advanced materials require a macromolecular organization within the polymer- generally a part of the material that is engaged in the action of separating, sensing, conducting, etc. and the other part which gives the material the chemical and structural integrity to withstand the conditions within which it must operate. Incorporating multiple different types of polymers and macromolecules into the same material can lend it such a portfolio of properties. Using light has the inherent advantage of choosing when and where functional structures begin to form within the system space, lending organizational control over the final form of the material. To construct hybrid materials with light, orthogonal photochemistries have been combined into the same pot. In the work to be presented, the photo-initiated Cu(I) catalyzed azide alkyne cycloaddition (CuAAC) polymerization and photo-initiated free radical polymerization of methacrylates have been combined to produce interpenetrating polymer networks, or IPNs. IPNs are multiple crosslinked polymers that are topologically constrained together at the nano and micron length scales, bringing together multiple functions into a single material. The final behavior of the material depends greatly on how the distinct networks interpenetrate (mix) or phase separate from one another. The drive for phase separation and interpenetration depends on the miscibility of the monomers and growing polymers, the number of potential topological constraints (covalent crosslinks and entanglements), and the formation trajectory of both networks. The final phase separation in the IPNs is evaluated by dynamic mechanical analysis and atomic force microscopy. The bulk properties of the IPNs are compared to those of the constituent networks and the phase separated morphologies are evaluated in phase images via AFM. In this presentation, the effects of varying light intensity on the formation trajectory, thermomechanical properties, and morphology of the photo-CuAAC-methacrylate IPNs will be discussed.

Molecular Redistribution of Alkanes and the Chemical Upcycling of Low-Density Polyethylene

Doyoung Kim
Advisor: Raul F. Lobo
Committee Members: Bingjun Xu, Marat Orazov

The negative environmental impact of plastic waste requires the urgent development of effective and economic plastic recycling and upcycling processes. Polyethylene (PE) is the largest portion of the plastic waste stream and presents major challenges to chemical recycling due to the stability of the polymer C-C bonds. Numerous investigations utilizing various catalytic reactions for PE upcycling have been recently reported. Catalytic alkane metathesis chemistry—comprising tandem (de)hydrogenation and olefin metathesis—has been explored as an alternative to these catalytic processes due to its molecular redistribution capability at moderate operating temperature (~200 °C) and in absence of reactive gases (*i.e.*, H_2) in the process, two favorable factors for economic viability of this chemical recycling/upcycling process.

While alkane metathesis-based PE deconstruction processes have been demonstrated in the literature, these works rely on a rhenium oxide catalyst for the olefin metathesis reaction. Rhenium oxide is expensive, cannot be applied at the high temperatures where reaction kinetics are most favorable (due to its high volatility), and is difficult to regenerate. We sought to substitute this catalyst with a silica-supported tungsten oxide (WO_x/SiO_2), a relatively inexpensive material that addresses the adverse features of rhenium oxide. Olefin/Alkane metathesis using WO_x/SiO_2 has been previously applied in PFR-type flow systems and is generally known as a molecular weight redistribution process; however, there have been no reports of the application of this catalyst for either olefin or alkane metathesis reactions in a batch reactor system nor for PE upcycling. A batch reactor may be preferable to a flow reactor for PE upgrading to address challenges of conveying mixed plastics waste; understanding the conditions needed for catalyst operation in a closed system is then key to developing successful upcycling processes.

Herein, we develop model reactions of catalytic olefin and alkane metathesis using a WO_x/SiO_2 catalyst in a batch system. Using these model reactions, we evaluate the role of zeolite 4A absorbent in facilitating catalyst activation and reaction in a closed batch system. We demonstrate that because WO_x/SiO_2 can operate in the range of temperatures that are inaccessible to rhenium oxide, shorter reaction times can achieve high conversion of the surrogate reactant. High conversion of 1-hexadecene (96 %) and n-hexadecane (92 %)—surrogates of long-chain molecules—demonstrate the high reactivity of WO_x/SiO_2 metathesis catalyst for olefin and alkane metathesis reactions, respectively, at moderate reaction temperatures of 300 °C for 2 to 3 h. Pretreatment temperature and length of short alkane chain solvent have significant effects on metathesis reactivity and selectivity. The WO_x/SiO_2-driven alkane metathesis system demonstrates remarkable potential for the chemical upcycling of PE at short reaction time (3 hours) using short chain alkane (6 g) required to convert the unit mass of LDPE, and the capacity to produce solid products of homogenous molecular weight distributions with the greatest reduction in the average molecular weight (Mw) by 99 % and polydispersity over 6-fold.

Impact of nitrogen oxides on electrochemical carbon dioxide reduction

Byung Hee (Brian) Ko
Advisor: Feng Jiao
Committee Members: Raul F. Lobo, Yushan Yan

The electroreduction of carbon dioxide (CO_2) offers a promising avenue to produce valuable fuels and chemicals using greenhouse gas CO_2 as the carbon feedstock. Because industrial CO_2 point sources often contain numerous contaminants, such as nitrogen oxides (NO_x), understanding the potential impact of contaminants on CO_2 electrolysis is crucial for practical applications. Herein, we investigate the impact of various NO_x, including nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O), on CO_2 electroreduction on three model electrocatalysts (i.e., Cu, Ag, and Sn). We demonstrate that the presence of NO_x in the CO_2 feed leads to a considerable Faradaic efficiency loss in CO_2 electroreduction, which is caused by the preferential electroreduction of NO_x over CO_2. The primary products of NO_x electroreduction include nitrous oxide, nitrogen, hydroxylamine, and ammonia. Despite the loss in Faradaic efficiency, the electrocatalysts exhibit similar CO_2 reduction performances once a pure CO_2 feed is restored, indicating a negligible long-term impact of NO_x on the catalytic properties of the model catalysts.

Anatomical and Geometric Variations Between Adult and Pediatric Airways and Resultant Aerosol Deposition Differences

Emily L. Kolewe
Advisor: Catherine A. Fromen
Committee Members: Prof. Millicent Sullivan and Prof. Abraham Lenhoff

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Fluid flow patterns and aerosol deposition are intricately linked to the geometry through which they are moving; a tapered or turning pipe will have more particles depositing than a steadily straight pipe. This is analogous in the study of airway geometry where it is widely known that the pediatric airways and adult airways differ in their anatomical and geometric structures as well as aerosol deposition patterns. However, limited data sets from pediatric patients and overuse of idealized models have made studying this phenomenon difficult. For example, the narrowest part of the adult airways is the vocal cords while for pediatric patients it is in a region below the vocal cords. Pediatric variations and the degree of development from a "pediatric-like" to "adult-like" throats has led to debate on the physical features of pediatric throats, their variations from adult throats, and the resultant influence on aerosol deposition. Thus, it is our goal to identify the anatomical and geometric variations in models, assess their "adult-like" and "pediatric-like" features, and quantify the correlation to aerosol deposition.

Access to a library pediatric CT scans has enabled our lab to study 3D rendered replicas in computational fluid-particle dynamics (CFPD) modeling. In addition, we compare results of CT scan replicas to the pediatric Alberta Idealized Throat (AIT), which is the industry standard representative idealized pediatric airway created by scaling down the analogous adult version of the model. By varying flow rate through the model across a range from 10 – 120 Lpm and water droplet aerosols from 100nm – 10 μm in diameter, a range of relevant parameters has been studied. An in-house analysis method utilizing open source softwares quantified the centerline and aerosol deposition as a function of distance along said centerline. Anatomical regions were identified by an otolaryngologist and correlated to the models and centerlines. This novel centerline and anatomical analysis correlated to CFPD deposition has allowed a rigorous study of a previously underrepresented group in aerosol research.

To date, our results indicate that there are indeed a range of "adult-like" and "pediatric-like" features, even within the same patient, indicating developmental variations happening in a nonuniform order. There are similarities to the idealized models, such as a statistically significant increase in deposition for aerosols >= 3 μm, which suggest that the idealized model is able to capture phenomena of realistic model. However, differences were also observed between the idealized model and the realistic models, especially between the models with more "pediatric-like" features, observed by the aerosol deposition parameter d^2Q. The comparison to the idealized model for these metrics is a warning that while the idealized models may be appropriate for some studies, there are studies for which it is best to use realistic models. This is critical insight for our future work on understanding and targeting deposition in pediatric patients with the disease Juvenile Onset Recurrent Respiratory Papillomatosis (JORRP).

Theory and Simulation Studies of Structure and Thermodynamics in Polymer Blends and Polymer Nanocomposites

Arjita Kulshreshtha
Advisor: Prof. Arthi Jayaraman
Committee Members: Prof. LaShanda Korley, Prof. Norman Wagner & Prof. Laure Kayser

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Blending two or more polymers or nanoparticles and polymers leads to enhanced macroscopic properties compared to neat polymers making these macromolecular materials suitable for a variety of applications ranging from automobile parts, insulating materials, optical fiber cables, batteries, etc. In all these applications, the macroscopic properties are linked to the blend or nanocomposite morphology. One way to tune morphology in these materials is by introducing favorable interactions between components of the blend/nanocomposite. In polymer nanocomposites (PNCs), this can be achieved by tethering the nanoparticle surface with graft polymers, thus allowing graft-matrix monomer interactions to tune effective particle-particle interactions. The graft-matrix monomer interactions in PNCs or monomer-monomer interactions in a polymer blend can be either isotropic (i.e., van der Waals) or directional (e.g., hydrogen bonds). Although, directional interactions like hydrogen bonding (H-bonding) offer a promising potential route to precisely tune structure and morphology within polymeric materials, computational studies on polymers with directional interactions have been largely limited to atomistic simulations that explicitly represent H-bonding atoms and their interactions making them expensive for simulation of large length and time scale assembly in polymers. Conversely, simulations with coarse-grained (CG) models are able to capture the large length and time scales associated with polymer chains but cannot capture the effects arising due to the specificity and directionality of interactions without using complex anisotropic interaction potentials to model directional interactions. In this talk, I will be highlighting our efforts towards the development of a CG model[1] that captures the short length and time scales of directional and specific interactions as well as the large length and time scales of polymer chains in polymer blends and PNCs. I will also present our work involving molecular dynamics (MD) simulations and the CG model for polymers with directional interactions to predict polymer blends' morphology for varying composition (*i.e.,* fraction of monomers with H-bonding acceptor/donor groups along polymer chains) and placement of H-bonding acceptor/donor groups along polymer chains. We first validate our CGMD simulation approach by reproducing previously published theoretical phase diagrams for end-associating polymers at varying H-bonding strength vs. polymer segregation strength. We then use the validated CGMD approach to elucidate how blends' morphology varies with random and regular placement of multiple H-bonding groups along the polymer chains. For these varying placements of multiple H-bonding groups, we characterize the blend morphology (e.g., two-phase, lamellar, bicontinuous microemulsion, disordered and disordered microphase) and domain sizes as a function of varying H-bonding attraction vs. polymer segregation strength. Through the results from this study, we establish design rules for incorporating H-bonding functional groups along polymer chains to achieve precisely tuned blend morphology.

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Theory and Application of Transition-State Vibrational and Thermochemical Scaling Relationships for AH_X (A = C, N, O) Species

Sophia Kurdziel
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Committee Members: Dr. Raul F. Lobo, Dr. Marat Orazov

Semi-empirical energy correlations, such as linear scaling relationships (LSRs) and transition-state scaling (TSS) / Brønsted-Evans-Polanyi (BEP) relationships, are often used to circumvent expensive density functional theory (DFT) computations of electronic energies. These models are well established for AH_X (A = C, N, O) adsorbates and reactions across transition-metal surfaces; however, other Arrhenius parameters are often taken as constants to avoid quantum calculations. Our group developed vibrational scaling relationships (VSRs) which correlate metal-adsorbate driven vibrational modes between AH_X species across metal surfaces, and recently expanded to transition-state VSRs (TSVSRs) which scale metal-adsorbate driven modes between local minima and transition states for AH_X reactions. (TS)VSRs, and by extension, thermochemical property scaling relations, offer a pathway to estimate vibrational thermochemical contributions for larger species or at transition states.

Using *d*-band theory and linear muffin tin orbital theory, we discuss the derivation of the TSVSR slopes from the corresponding TSS relations and pertinent geometric data for AH_X diffusions and dehydrogenations. For AH_X diffusions, we incorporate variation between binding sites into TSVSR slope predictions. For bond breaking reactions, namely for AH_X dehydrogenations, we examine changes in relevant adsorbate orbital overlap with metal atomic *d* orbitals between local minima and transition states, and predict both the slopes of the TSSs and TSVSRs. Finally, we demonstrate thermochemical property scaling across metal surfaces and a homologous series as an application of TSVSRs to estimate pre-exponentials and temperature corrections to DFT energies.

Olefin Methylation Reactions over Iron Zeolites: Increasing Reaction Rates and Shifting the Selectivity

Mark R. LaFollette
Advisor: Raul F. Lobo
Committee Members: Douglas J. Buttrey, Marat Orazov, J. Anibal Boscoboinik

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The methanol to hydrocarbons (MTH) reaction is a pathway for converting methanol or dimethyl ether (DME) into fuels and chemicals driven by homologation of methanol. The reaction is catalyzed by a variety of acidic zeolites and depends on pore structure: with the large-pore zeolite H-[Al]beta, the products are predominantly isobutane and triptane, for example. The alkanes are formed via hydrogen transfer reactions of the isostructural olefins formed through successive methylation of small olefins. The hydride donors (other olefins) undergo further reactions to give aromatic products such as n-methylbenzenes; these side products are not valuable as a fuel and lead to catalyst deactivation.

Zeolite catalysts containing framework iron reduce the rate of hydrogen transfer reactions due to their weaker Brønsted acid strength greatly reducing alkane and aromatics production. However, at the same time, the methylation rates on Fe-zeolites also decrease: for example, at 400 °C, the conversion for H-[Fe]ZSM-5 is 60% lower than the conversion for H-[Al]ZSM-5 under otherwise similar conditions. To mitigate the lower reaction rates, olefins can be added to the reactor feed.

This talk will describe research on the kinetics and selectivity effects of olefin additives on Fe-zeolites for the MTH reaction. Over H-[Fe]beta adding isobutene at a 6.3% isobutene co-feed more than doubles the DME consumption rate while shifting the carbon selectivity towards C5, C6, and C7 olefins. These trends continue as the isobutene content is decreased; however, further addition of isobutene leads to surface poisoning by the alkenes with reduction in DME consumption rates. When a medium-pore zeolite H-[Fe]ZSM-5 is used, the DME consumption rate increases—relative to H-[Fe]-beta—and the selectivity to smaller olefin cracking products decreases while the selectivity to C5 through C8 increases. We show that co-feeding isobutene overcomes low catalytic rates by increasing the DME consumption rate at lower reaction temperatures. The results of methylation of other molecules including C5-C8 olefins over Fe-zeolites is also reported

Mechanistic Understanding of Hydrocarbon Dehydrogenation and Cyclization in Zeolites

Jason Lee
Advisor: Raul F. Lobo
Committee Members: Feng Jiao, Marat Orazov, Stavros Caratzoulas

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Detailed reaction mechanisms with elementary steps are essential for understanding how to improve upon the reactivity and selectivity of current generation catalysts while reducing costs. Acid zeolites have long been robust, cost effective heterogeneous catalysts capable of converting light alkanes and methanol into important platform chemicals, such as aromatic hydrocarbons and light olefins. Despite the ubiquity of both zeolites and associated processes to produce these valuable chemicals, unresolved questions remain about the mechanism by which the structure and surface chemistry of these microporous catalysts drive the formation of either aromatics or alkenes.

In particular, it is generally accepted that conversion of methanol and light hydrocarbons proceed via complex "carbon pool" reaction networks, whose key intermediates have been posited based largely on *in situ* spectroscopy or analysis of product distributions. In some industrially relevant zeolites, many believe that an "olefin pool" coexists with an "aromatic pool". Produced from the initial dehydrogenation of methanol or light alkanes, light olefins grow through sequential methylation steps. Eventually, a sufficiently large olefin cyclizes and converts to an aromatic ring. Recent *in situ* IR and UV-Vis studies suggest that conjugated trienes are prevalent during aromatization and are likely the necessary class of higher olefin. Prior to this work, no proposed reaction mechanisms satisfactorily explained the elementary steps of such a triene cyclization pathway. Using 1,3,5-hexatriene as a model triene and Faujasite (FAU) as a model zeolite, density functional theory (DFT) calculations were used to propose a new cyclization mechanism. Catalysis of this pathway over zeolite Brønsted acid sites (BAS) was compared to the reaction occurring in the gas phase.

It is also generally accepted that zeolite pore size and structure influences product selectivity by limiting the size of hydrocarbon products that can diffuse from the micropores. Hence, small pore zeolites, such as chabazite (CHA), have been the subject of renewed interest in catalytic non-oxidative alkane dehydrogenation as a more energy efficient and lower carbon-footprint alternative to thermal cracking. The few existing experimental studies show that Ga- and In-CHA are potentially less costly and more robust alternatives to existing industrial platinum catalysts, while still being highly selective for smaller alkene products. These experiments also show that Ga-CHA has higher reactivity and selectivity than In-CHA, but it is unknown why. DFT calculations were used to elucidate the elementary steps of alkane dehydrogenation over these catalysts, with a particular focus on ethylene formation. From both thermodynamics and kinetics calculations, the higher selectivity and reactivity of ethane in Ga- over In-CHA can be surmised.

Microstructure, Rheology and Tribology Study for Shear Thickening in Colloidal Suspensions and Applications

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Committee Members: Scott C. Brown, Eric M. Furst, and Abraham M. Lenhoff

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The shear thickening of dense colloidal suspensions is an active area of research aimed to understand the non-linear flow response under various processing conditions, relevant to high-speed coating, spraying, printing, pumping and other industrial applications [1]. Efforts in theoretical models and simulations seek to examine the underlying physics thought to be controlled by nanometric inter-particle forces, including lubrication hydrodynamics [2,3] and frictional contact forces [4-6], whereas experimental tests of these latest theories are lacking. In this work, we first present rheological measurements for a variety of colloidal dispersions varying from model systems to industrially commercial dispersions where both shear and first normal stress differences are available [7]. Particle-scale measurements of friction coefficients are used then to test a recent frictional contact model derived from correlation of simulation results [8]. It is found the sign of first normal stress differences highlight the fundamental physical difference governed shear thickening in various systems. To gain a deeper understanding of the relationship between particle-level micromechanics and bulk suspension rheology, measurements of the microstructure on two model suspensions of bare and coated silica spheres under shear with very different levels of interparticle friction are measured via small angle neutron scattering [9]. Difference in microstructure symmetry is found between the two model systems, indicating nanoscale interaction on particles surface can be reflected by microstructures. Future research proposes to study the relationship between rheology and particle topology by measuring surface roughness via atomic force microscopy and SANS. Investigation of rheology, microstructure, tribology and topology provide quantitative information valuable for those modeling suspensions to understand the mechanistic role of lubrication hydrodynamics and frictional contact in shear thickening. The comparisons presented in this work provide quantitative suggestions for further simulation improvement and formulation improvement at industrial level.

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Visualizing the gelation of highly concentrated hollow nanorod suspension via small-angle neutron scattering and complex rheology

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Tunable hollow silica rods with thermoreversible attractions have been shown to be more effective in minimizing gravitational settling than solid rods due to its hollow interior and nanoscale length. We hypothesize that these octadecyl-coated hollow adhesive hard rods (AHR) suspended in tetradecane have superior colloidal stability comparable to that of ~30 nm adhesive hard spheres and could be used to better map out the dynamic arrest boundaries of anisotropic colloidal suspensions. Small-angle neutron scattering (SANS) characterization of the microstructure is linked to complex rheology of AHR gels by quantifying the strength of interparticle short-range attractions in terms of Baxter sticky parameter, τ. Our recent study of newly synthesized hollow AHR system with reduced dimensions of 30-300 nm shows very pronounced structural effects in low q scattering regions, with a presence of softening turnover peaks that occur at high concentrations ($\phi \sim 0.40$) nearing the glassy regime. SANS model of core-shell cylinder form factor and sticky hard sphere structure factor is used to capture the structural changes as the system undergoes thermoreversible gel transitions. While this temperature-driven change visually appears like a liquid-solid transition, we investigate the precise microstructure responsible for the soft solid state. We also study the flow behavior of AHR gels under deformation via SAOS rheology and correlate it with the local microstructural changes. The gelation behavior is studied at higher volume fractions ($\phi = 0.01$-0.40) to demonstrate a systematic increase in gel temperatures with increasing volume fractions. The results of this study will provide a clearer basis for understanding the behavior of much more complex particulate gels which are ubiquitous in industrial and biological systems.

Theoretical insights into the heterogeneous hydroformylation of ethylene on atomically dispersed Rh-oxide promoter pairs

Seungyeon (aka Lina) Lee
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Committee Members: Raul Lobo, Marat Orazov

Atomically dispersed late-transition state metals on oxide supports have emerged as a new frontier in catalysis as they combine the advantages of both homogeneous and heterogeneous catalysts.[1] Successful heterogenization of the hydroformylation reaction, an industrially significant process for aldehyde production conventionally performed on homogeneous Rh or Co complexes,[2] has been reported recently for atomically dispersed Rh on oxide supports.[3-4] Interestingly, the presence of oxide promoters on the support seems to enhance the catalyst's selectivity for hydroformylation versus hydrogenation of the olefin. Ro et al.[3] have demonstrated that Rh-ReO_x pairs atomically dispersed on γ-Al_2O_3 are more selective for the hydroformylation of ethylene than Rh alone.

I present a theoretical study of ethylene hydroformylation by Rh atomically dispersed on γ-Al_2O_3(110) in the absence and presence of two oxide promoters, ReO_x and WO_x, and evaluate the developed mechanisms by comparing the predicted kinetic observables (selectivity, apparent activation energies, and reaction orders) with experimental values. I analyze how the promoters modify the electronic properties of the Rh(I) active site and elucidate their role in the catalyst's enhanced selectivity for the hydroformylation pathway. The Re(VII) promoter seems to induce no electronic changes to Rh that are related to the latter's catalytic function, and it only blocks the dehydrogenation pathway by posing a steric hindrance. On the other, the W(VI) promoter have a more profound electronic effect as it must be reduced to the W(V) state before it is activated.

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Electrochemically-Driven CO_2 Separation from Ambient Air using Hydroxide Exchange Membranes

Stephanie Matz
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In a hydroxide exchange membrane fuel cell (HEMFC), hydroxide produced at the cathode readily reacts with CO_2 in air due to its acid-base reaction. The CO_2 in (bi)carbonate form then transports across the hydroxide exchange membrane to the anode where bicarbonates build up lowering the local pH until CO_2 evolution reactions become favorable. The pH gradient across the cell results in lower voltage output, decreasing fuel cell efficiency; however, this cell can effectively separate CO_2 from air. By focusing on CO_2 separation, rather than power production, an electrochemically-driven CO_2 separator (EDCS) was developed using a poly(aryl piperidinium) membrane. The EDCS only requires a small hydrogen stream to power separation of ambient levels of CO_2 from air at moderate temperatures. The EDCS product streams are a CO_2-depleted air stream and a CO_2-concentrated stream contaminated with a small amount of unreacted hydrogen and pure water. Compact, efficient, and continuous CO_2 separation technologies, like the EDCS, are needed for various applications such as direct air capture, air pretreatment for HEMFC stacks in vehicles, and life support systems in submarines and manned spacecrafts.

This work will demonstrate the ability of the EDCS to effectively and continuously remove CO_2 from air at ambient levels while minimizing hydrogen consumption. The effect of various operating conditions on CO_2 separation performance of the innovative EDCS will be explored, such as flow rates and current density. A carbon-ionomer interlayer added between the catalyst layer and membrane will be shown to improve CO_2 capture by creating an accessible volume for hydroxide and CO_2 gas to react. Additionally, various design features of the cell will be investigated to reduce gas-phase mass transport resistance such as flow fields and gas diffusion layers. An optimized single-cell 25 cm^2 EDCS achieves > 99% CO_2 removal from 3.2 sLpm air containing 400 ppm CO_2 for over 150 h while maintaining a hydrogen consumption of 0.05% of air processed. The EDCS operating conditions and design is also evaluated for different applications as their requirements for air flow requirements, CO_2 concentrations, operating conditions, hydrogen availability, and size restraints differ and must be taken into account.

Coiled-Coil Peptides as a Building Block for Material Design

Joshua Meisenhelter
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Proteins are capable of achieving incredibly complex tasks which we cannot hope to mimic with modern materials. These intricate functions arise from the hierarchical structure of proteins and the location of various chemical handles in exact locations based on the folding of the protein; however, proteins are limited in their materials applications due to strict limitations on their stability in solution which generally limits them to only being viable in aqueous conditions, and difficulty in using a peptide for an application that it does not naturally achieve. This work aims to capture the best aspects of a proteins, being molecular monodispersity and exact locations of functional groups in the particle, while also allowing them to be used in a wide variety of non-native applications through chemical modification. This was achieved by using a protein sub-domain called a coiled-coil as a stable nanoparticle that can be used as a building block for complex hierarchical structures. To develop a coiled-coil into such a versatile particle, the peptide has been computationally designed to be stable as an individual particle and of varying sizes. By altering the size of the coiled-coil, the thermal stability of the structure can be tuned where larger coiled-coils lead to more stable particles while also greatly impacting the speed and ease of synthesis. To further expand upon the diversity of applications that these peptides are useful for a set of heterogeneous coiled-coils were also developed which allow for the mixing of multiple functionalities into a single particle. This work focuses on the synthesis and characterization of these unique coiled-coils. Confirmation of coiled-coil structure was done through circular dichroism, while further characterization into the configuration of the coiled-coil was done through gel electrophoresis and the use of fluorescent resonance energy transfer (FRET) tags.

Structure-property relationships of alkali-activated aluminosilicate gels for design of sustainable construction materials

Jennifer Mills
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Traditional cement production and usage has an incredibly large carbon footprint- the annual production of 30 billion tons of concrete for global use is responsible for 8% of anthropogenic CO_2 emissions and consumes 2-3% of global energy supply, and demand for this material continues to rise[1]. Alkali-activated binders present opportunities for significant reduction in CO_2 emissions, as well as for locally sourced materials and in-situ resource utilization for lunar and Martian construction in support of human space exploration. However, key challenges preventing the widespread adoption of this solution are variability in the composition of alternate aluminosilicate-based source materials and lack of understanding how the chemical composition and reaction mechanism affect the internal structure formed during set and the resultant workability and strength of the material. The rheological development with time and concentration is crucial for applications including traditional construction processes (pumping, pouring, setting) as well as additive manufacturing. A mechanistic and quantitative understanding of the chemical kinetics and dynamics of microstructure formation and associated rheology development in model geopolymer binders will facilitate the universal engineering of construction materials from a variety of aluminosilicate materials.

The current work focuses on structural characterization of aluminosilicate gel hydrates by relating chemical composition to phase behavior. Small amplitude oscillatory shear (SAOS) experiments were used to identify the gel percolation point and characterize the growth of the storage modulus with increasing aluminum concentration. The storage modulus growth is fit to two kinetic regimes whose behavior is consistent across complementary neutron scattering and NMR data. Additionally, the evolution of the storage modulus over time is fit to kinetic models which give insight to the reaction mechanism and quantify the kinetics with respect to the chemical composition. The scattering data is fit to a mass-surface fractal model which yields key insight to the structure development as a function of composition. A pseudo-ternary state diagram is proposed that successfully demarcates the states of gels from both formulations as well as other N-A-S-H gel and geopolymer reports in literature. These model system studies provide insight into the more complex rheological behavior of geopolymer cements.

Straightforward incorporation of tailorable stromal compartments into microfluidic microphysiological systems

Katherine Nelson
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Committee Members: Dr. April Kloxin and Dr. Catherine Fromen

The extracellular matrix (ECM) is well appreciated to impact cellular function, morphology, and phenotype. In recent years advances in *in vitro* models have included the incorporation of spatial and temporal control of the biochemical and biophysical properties of 3D hydrogels to recapitulate the native microenvironment of a tissue. However, these methods are difficult to incorporate into microfluidic fabrication techniques for organ-on-a-chip microphysiological systems. These microfluidic models of organs and tissues allow for the incorporation of dynamic fluid forces and relevant transport kinetics and length scales which are also well appreciated to impact cellular function. To merge these two powerful approaches, we have developed simple, cleanroom-free methods to incorporate microfluidic fabrication with a tailorable stromal compartment into microphysiological systems.

For this work, we created a placenta-on-a-chip as an exemplar microphysiological model for the validation of transplacental drug transport kinetics. Fibroblasts were embedded within a thin collagen-I hydrogel fabricated on a silicon support. Placental epithelial cells (BeWo) and endothelial cells (HUVECs) were seeded on either side of the collagen-I hydrogel and cultured for at least four days to ensure monolayer formation. The seeded gel and support were incorporated into a microfluidic device by clamping the support between two laser-etched, acrylic sheets containing microfluidic channels. The resulting construct creates a maternal fluid channel lined with BeWo cells and a fetal fluid channel lined with HUVECs on either side of a hydrogel stromal compartment with embedded fibroblasts.

To test the function or this assembled system, we used immunostaining and fluorescent microscopy to observe confluent epithelial and endothelial cell layers were formed on the obverse and reverse of the collagen gel. Fibroblasts were successfully cultured within the hydrated stromal layer as validated with live-dead staining over the week-long culture period. Barrier formation was confirmed with transepithelial electrical resistance (TEER). Following seven days of culture, antipyrine, sodium-fluorescein, and glucose were used to validate transport dynamics in static and dynamic conditions. In addition to the functional tests for this placenta-on-a-chip model, we validated that these fabrication methods are compatible with a range of native and synthetic hydrogels as well as reconstituted decellularized ECM scaffolds.

In this work we have developed methods to generate microphysiological systems with tailorable stromal compartments using a placenta-on-a-chip as a model. These methods integrate an extensive biomaterials toolbox into these fluidic 3D multicell *in vitro* models, significantly expanding the ability to investigate how cell-ECM interactions regulate disease processes and homeostasis. Our simple fabrication approach, with the ability to include stromal cells, such as fibroblasts and tissue-resident immune cells, will enable more complex *in vitro* models of complex organs such as the small intestine, kidney, lung, or placenta.

Alternative mechanisms for persistence of host-cell proteins in monoclonal antibody bioprocessing

Younghoon Oh
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Committee Members: Kelvin H. Lee, Christopher J. Roberts, Steven M. Cramer

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In the manufacture of monoclonal antibodies (mAbs), host-cell proteins (HCPs) generated by host-cells may elude multiple purification steps that are, in general, composed of mAb capture or protein A chromatography, viral filtration and polishing chromatography steps. Certain HCPs that are present in the final drug product may bring in specific challenges as they have potential to cause product degradation or an immune response in patients. Two mechanisms are widely thought to make such HCPs difficult to remove, namely mAb-HCP association and co-elution of HCPs in the chromatography steps. In addition, chromatin-derived complexes have been suggested as another possible cause of HCP persistence by forming larger heterogeneous clusters with mAbs and HCPs, which can then bind to stationary phases such as cation exchangers.

In this study, HCPs present in the eluate pools of protein A chromatography of seven mAbs were identified. Further analysis based on a literature review and a protein database search revealed that more than a quarter of the HCPs that were identified in all seven samples are known to be associated into protein aggregates. To understand the origins of those HCPs and to determine possible effects on their persistence through the protein A step, size-exclusion chromatography (SEC) fractions were collected from harvested cell culture fluid (HCCF) and protein A pools and analyzed by LC-MS/MS, which enabled identification of HCPs that may be incorporated into aggregates or clusters.

This study aims to understand the origins of certain HCPs that are incorporated into aggregates or clusters and the possible mechanisms that make them difficult to remove. Such association may help explain the persistence of those HCPs in the mAb process stream even in the absence of product association, co-elution or generation of chromatin-derived complexes.

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Evidence for the Lack of Caffeine Specific Adsorption and its Impact on Water Structure to Increase HOR/HER Activity on Pt

Nicholas Oliveira
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As the cornerstone for much of our electrochemical knowledge, the inexplicable 2 orders of magnitude decrease in the hydrogen oxidation and evolution reactions (HOR/HER) in moving from pH 1 to 14 on precious metals continues to undermine our understanding of and ability to better design electrochemical systems. Several theories have been proposed for this anomalous change, from electric field effects, the influence of cations, co-adsorption of H and OH, and the orientation of interfacial water, driving innovations in *in situ* electrochemical techniques, such as potential changes with Fourier Transform Infrared Spectroscopy (FTIR) or X-ray Absorption Spectroscopy (XAS). Recently, it was found that including small concentrations of caffeine in pH 13 was able to drastically increase the HOR/HER catalytic activity of platinum through what was postulated as surface specific adsorption. In this work, we identify the imidazole ring of caffeine as the HOR promoting group and challenge the notion of specific adsorption through an *in situ* surface sensitive technique, termed Attenuated Total Reflection-Surface Enhanced Infrared Reflection Absorption Spectroscopy (ATR-SEIRAS) while simultaneously analyzing the underlying theory of water reorganization. Due to SEIRAS' s surface sensitivity, we can distinguish between specific electrochemical surface adsorption and molecules merely located in the outer Helmholtz plane (OHP) through stark tuning, where species located in the inner Helmholtz plane (IHP) experience the strongest electric fields, and demonstrate a potential dependence of their vibrational frequency. Further, trends in caffeine induced water structure changes support our hypothesis that surface bound water layer changes observed in our *in situ* spectra are responsible for the "apparent pH dependence" of HOR/HER.

The electrochemical interface is traditionally viewed as a double layer model, with specific electrochemical adsorbates existing in the Inner Helmholtz Plane and the first layer of non-adsorbates at the Outer Helmholtz Plane. ATR-SEIRAS enhanced surface sensitivity allows for strong signals to be obtained within 5 nm of the surface, selectively capturing both the IHP and OHP with decreasing strength into the diffuse layer and bulk electrolyte. In situ surface sensitive IR shows strong peaks corresponding to caffeine/imidazole on addition of 10^{-4} M to basic electrolyte, but a lack of stark tuning suggests no specific adsorption of caffeine on the Pt surface. Furthermore, SEIRAS spectra reveal subtle changes to the interfacial water with addition of caffeine, namely losses of certain types of interfacial water and changes in the water-water hydrogen bonding network. These spectra compared with similar samples collected in traditional 0.1 M $HClO_4$ electrolyte point toward the "apparent pH dependence" being a function of pH induced changes to the interfacial water structure.

Syntrophic Co-Cultures of *Clostridium* Organisms to Produce C6-C8 Alcohols and Carboxylic Acids

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Synthetic syntrophic co-cultures provide several advantages for the renewable production of target biofuels and chemicals. Engineering all desired metabolic pathways into one organism is difficult, but in a co-culture, each organism can specialize according to their natural and engineered capabilities while sharing metabolites and proteins. This project explores co-cultures of *C. acetobutylicum* (*Cac*), an industrial solventogen that produces ethanol, butanol, and acetate; *C. kluyveri* (*Ckl*), which can elongate acetate into longer-chain carboxylic acids; *C. ljungdahlii* (*Clj*), an acetogen that can capture carbon dioxide to produce ethanol and acetate; and *C. saccharolyticum* (*Csac*), which can quickly produce large amounts of ethanol and acetate. Butanol, hexanol, and octanol, as well as their respective carboxylic acids, are common industrial chemicals, but they are currently produced from petroleum-based processes. Syntrophic co-cultures of *Clostridia* promise a sustainable and green replacement.

In these co-cultures, an engineered high-ethanol-producing strain of *Cac* consumes glucose and produces ethanol, acetate, carbon dioxide, butyrate, and butanol. The ethanol and acetate are elongated by *Ckl* to create valuable hexanoate and octanoate, which can be converted by either *Cac* or *Clj* into their respective alcohols, which are easier to extract from the media. Co-cultures of *Cac* and *Ckl* and *Csac* and *Ckl* have been studied. *Clj* can be added to these co-cultures to capture the carbon dioxide produced by the co-culture organisms, which raises carbon efficiency and lowers costs. Notably, this work has resulted in the highest-observed hexanoate production from *Ckl* without concurrent in-reactor capture. Co-cultures of *Csac* and *Ckl* produce more hexanoate more quickly than any published co-culture. This work also provides more insight into co-culture biology, as both flow cytometry and fluorescent microscopy have provided evidence of cell contact and protein sharing between co-culture members of different species. Altogether, this work elucidates how co-cultures can expand the metabolic space by unlocking and better utilizing the capabilities of all co-culture members so that we can deploy more environmentally sustainable means of chemical production.

Electrochemical conversion of carbon monoxide to acetate and ethylene

Sean Overa
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The electrochemical conversion of CO_2 to value-added products is a promising approach for mitigating rapidly rising CO_2 levels. Direct CO_2 conversion to high-value multi-carbon (C_{2+}) products, such as ethylene, alcohols, and acetate, still lacks in development and suffers in selectivity and durability. However, electrochemical CO_2 conversion to CO has been shown to be both durable and highly selective in both low- and high-temperature reactors. As a result, significant interest has been invested in the electrochemical conversion of CO to valuable C_{2+} products. Here we present our work on designing and scaling a CO electrolyzer capable of producing acetate and ethylene at >90% selectivities. We first demonstrate the system's feasibility through the construction of a 5 cm^2 membrane electrode assembly (MEA) electrolyzer. Through reactor, membrane, and catalyst design, this reactor demonstrated state of the art acetate production from CO, producing >3 M acetate at a purity of 98% for >100 hours. The system's feasibility was demonstrated through selective acetate production directly from CO_2 via a two-step electrolysis method, where >25% of fed CO_2 was converted to acetate. Lastly, this work highlights our future efforts in scaling the CO reactor system from the bench scale to the pilot scale. We will highlight our work developing a 25 cm^2 reactor and designing more stable catalysts to achieve a total current of 7.5 A with >130 hour durability. This system is then further scaled to 100 cm^2 in preparation for developing a CO MEA stack operating at the kW scale.

Catalytic Dehydrogenation of Ethane over Metal Exchanged Chabazite Zeolite

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Ethylene is a very important building block in chemical industry with a worldwide consumption of over 150 million tons per year. For now, the most used approach of producing ethylene is steam cracking of ethane and naphtha which needs high temperature (>750 °C) and emits large amount of CO_2. Catalytic non-oxidative ethane dehydrogenation (EDH) is one of the most promising candidates to produce ethylene in a way that minimizes energy consumption and greenhouse gas emissions[1]. Metal-exchanged zeolites have been widely investigated for alkane dehydrogenation reactions[2] and other zeotypes may help tunning the catalytic reactivity of metal species. Among this group, the chabazite (CHA) zeolite is a representative example[3]. We have prepared and investigated a series of metal exchange CHA zeolites for EDH, including indium, gallium, and manganese.

In this present work, I will focus on the catalytic and mechanistic differences between In- and Ga-CHA for EDH. The metal-exchanged CHA samples showed high ethylene selectivity and high stability compared to that of the acid H-CHA. Ga-CHA with lower activation energy delivers higher reaction rates but lower selectivity and carbon balance than that of In-CHA. Among Ga-CHA with different compositions, the higher Ga/Al ratio and Si/Al lead to higher reaction rate. Due to the zeolite micropore structure of CHA and the resultant unique active sites, Ga-CHA also shows higher reaction rate than Ga-Al_2O_3 and Ga-SiO_2 for EDH. Besides, the micropores of CHA zeolite also limits the movement of the aromatics moieties which are generated from the oligomerization and polymerization of C_2H_4, leading to coke accumulation and catalyst deactivation during the reaction. However, after coke combustion, the catalytic activity of Ga-CHA can be regenerated. An alkyl mechanism was proposed for DFT calculations, based on which potential intermediates of Z[In] and Z[Ga] for In- and Ga-CHA were compared. The much lower Gibbs free energy of oxidative addition over Z[Ga] is consistent with the higher reactivity of Ga-CHA, which combined with the lower activation energy and higher reaction rate from experimental data, indicates that the thermodynamics of oxidative addition are more important than that of elimination steps.

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Kinetic modeling to accelerate the development of nucleic acid formulations

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One of the most prominent bottlenecks in the clinical translation of nucleic acid drugs is the inefficiency in testing the therapeutic potential of formulations. The inability to evaluate these drugs in an expedient manner is mostly due to the lack of predictive capacity especially transitioning between *in vitro* studies to more complex *in vivo* studies and ultimately clinical trials. We designed a mathematical framework that can accurately predict siRNA-mediated gene silencing with as few as one experimental data point as an input. The model was streamlined to consist of only essential rate-limiting steps and parameters with easily characterizable values, enabling the elucidation of which kinetic experimental parameters play dominant roles in determining the potency of siRNA formulations. Model predictions were in close agreement to both *in vitro* and *in vivo* results reported in multiple published data sets. Specifically, critical information needed when designing efficient dosing regimens, including maximum gene silencing efficiency, when this maximum gene silencing occurs, and the duration of silencing, were accurately captured by our mathematical framework. Retrospective analysis using our kinetic model suggested that siRNA dilution is the primary determinant of gene-silencing kinetics, and the dilution rate is governed by different parameters *in vitro* (cell division) and *in vivo* (clearance from target tissue). This discrepancy highlights a key for the traditional lack of *in vitro-in vivo* correlation. Our current effort focuses on siRNA, but we anticipate that the framework can be modified and applied to other nucleic acid therapeutics, such as mRNA, that rely on similar biological pathways.

Engineering the *Escherichia coli* N-degron pathway for enhanced control of intracellular protein accumulation

Sabyasachi Sen
Advisor: Aditya Kunjapur
Committee Members: Wilfred Chen & Kelvin Lee

Advances in genetic circuit design allow for enhanced cellular control through use of standardized parts in synthetic biological systems. To develop circuits with the tight protein stoichiometries and transient protein behaviors found in nature, there is a need for genetic tools that can better monitor and control protein accumulation within the cell. To accomplish this type of protein regulation, a careful consideration of the balance between expression and degradation is crucial. While protein expression tools have rapidly grown in scope and function, there remains a need for protein degradation tools that are modular in strength, minimally invasive to the protein of interest's function, and conditionally activated to initiate proteolysis.

To that end, we seek to characterize and expand the capabilities of the *Escherichia coli* N-degron proteolysis pathway to generate a reliable controller of protein accumulation. We focus on the relationship between short, conditionally destabilizing N-terminus motifs (N-degrons) and the proteins that modify, enhance, and initiate proteolysis (N-recognins) within a model organism. We have developed a dual fluorescent reporter system for kinetically monitoring degron-dependent accumulation of model proteins. In tandem, we introduced a series of eukaryotic and novel N-degrons utilizing the Arg/N-degron pathway and arginyltransferase ATE1 towards the creation of logic gates for protein accumulation control. Finally, we optimized expression of key proteins to enable conditional stabilization or destabilization of proteins of interest. Ongoing efforts will further develop this technology for use in next-generation biosensors and genetic circuits.

Design of PLGA-based drug delivery systems through a molar mass-dependent sustained release model

Xutao Shi
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Committee Members: Christopher Roberts, Antony Beris, Aditya Kunjapur, Arthi Jayaraman

Improvements to a drug-release model are validated by comparing model prediction to in vitro experiments on a novel, industrially relevant PLGA controlled release system from Genentech. Combining parameter estimations from literature and comparisons to an extensive data base, this study enables a priori design of controlled drug release from a model PLGA system. Model predictions were validated against formulations of FITC-labeled dextran, a model surrogate for biopharmaceutical drugs, in PLGA rods with a broad range of parameters. While successful, deviations were noted for several model formulations with significant first-phase drug release. Supported by cross-sectional florescence microscopy images of the FITC-dextran distribution within the rods, this first-phase release was attributed to a combination of factors: (1) percolation of the drug particles and (2) swelling and pore formation due to water uptake. These observations indicate the importance of careful selection of the PLGA polymer grade when designing drug release systems. Adapting model parameters, without modifying the physical processes included in the model, enabled accurate fitting of the experimental data for all formulations, highlighting the wide applicability of the model. Areas for model improvement were identified and supplemented by X-ray computed tomography images of the PLGA spatial distribution. Correlation between early-stage release behavior and polymer porosities was addressed and modeled via population balance model of the pore space network within system.

The local mass transport of ketene and acetate selectivity in electrochemical CO reduction

Haeun Shin
Advisor: Feng Jiao
Committee Members: Dr. Dionisios Vlachos and Dr. Yushan Yan

Electrochemical carbon monoxide (CO) reduction is one of the fast-growing technologies in carbon capture, utilization, and storage (CCUS) to convert carbon dioxide to valuable chemicals. However, tuning selectivity towards desirable products of electrochemical CO reduction, for example, acetate needs to be addressed to maximize the energy and cost efficiency. Hence, the understanding of the reaction mechanism is crucial to rationally engineer the selectivity towards the target products. Previous studies discovered that acetate formation was promoted in a highly alkaline environment with an increase in hydroxide concentration on the reaction surface highlighting the local transport impact on the selectivity. [1,2] Furthermore, high acetate selectivity was achieved on the 2-dimensional Cu{111} facet surface drawing attention to how the intrinsic activity of the catalyst can shift the selectivity. [2] However, there is no comprehensive understanding of the reaction mechanism of acetate production addressing both transport and intrinsic activity.

In this work, we propose a new reaction mechanism of acetate formation among multi-carbon (C_{2+}) products, ethylene, ethanol, and acetate supported by a transport model and a series of electrochemical CO reduction in different conditions. 1) Varying electrolyte pH: The acetate formation was dependent on pH on all Cu morphology. 2) Varying Cu catalysts with different roughness: The acetate formation tended to be promoted on the catalyst surface where it has lower roughness. The results provided evidence that the acetate formation is determined by the transport of ketene intermediate from the catalyst surface to a solution phase where a nucleophilic attack of hydroxide on ketene occurs to form acetate. The rate of (re-)adsorption of a ketene intermediate on the catalyst surface was determined by the roughness factor, which then controled the selectivity rather than the change in the intrinsic activity of the Cu catalyst. Moreover, over 70% of acetate selectivity among C_{2+} products was achieved by engineering the catalyst and reaction conditions.

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Ethylbenzene via Consecutive Oxidative Dehydrogenation of Ethane and Benzene Alkylation

Eric Steinman
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Committee Members: Douglas Buttrey and Yushan Yan

While vapor-phase zeolite-catalyzed benzene alkylation is a mature industrial process, current methods produce ethylene through energy intensive processes and require expensive intermediate separations before benzene alkylation. Ethylene can be produced via oxygen-oxidized oxidative dehydrogenation of ethane (ODHE) to reduce external energy needs, enable operation at lower temperatures, remove significant thermodynamic limitations, and mitigate coking compared to ethylene production via ethane cracking. One can envision consecutive reactors for ODHE and benzene alkylation to convert from ethane to ethylene and ethylene to ethylbenzene, respectively. Operating ODHE as a standalone process for the production of ethylene below full ethane conversion at scale would require cryogenic distillation or advanced membranes to separate product ethylene from unreacted ethane similar to those used for ethane cracking. Separation costs can be mitigated in the consecutive process if benzene alkylation can operate at high ethylene conversion and be agnostic toward feed ethane. Thereby, the ethane-ethylene separations can be replaced with much easier ethane-BTEX separations.

In an ideal embodiment, the downstream alkylation process would be compatible with all reactants and products of the upstream ODHE process. Unfortunately, the presence of oxygen leads to deactivation of the parent zeolite for the standard alkylation catalyst. Since industrial alkylation catalysts are already highly efficient and optimized, it is desirable to avoid making major alterations to the alkylation catalyst. Thus, ODHE needs to be operated at high oxygen conversion which can hurt the performance and longevity of ODHE catalysts. ODHE catalyst selection and reaction engineering is needed to overcome these hurdles. In this presentation, we will show a proof of concept for our novel consecutive process.

Utilizing Metal-Organic Framework (MOF) Nanoparticles for Applications in Pulmonary Drug Delivery and Synthetic Vaccines

Zachary Stillman
Advisor: Professor Catherine Fromen
Committee Members: Professors Eric Bloch, Thomas Epps III, and Christopher Kloxin

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Pulmonary administration offers many advantages for the delivery of therapeutics and vaccines because of the ability to deliver cargo locally and systemically. For drug delivery, the pulmonary route of administration generally has high bioavailability of delivered therapeutics. Furthermore, nanomedical approaches to pulmonary drug delivery using biomaterials have risen in prominence because of the ability to have ready cellular internalization of nanomaterials and high loading capacity of therapeutic cargo. Though rarely used for pulmonary applications, metal-organic frameworks (MOFs) have recently been explored as materials for drug delivery because of their high porosity, variable chemistry in their organic linkers and metal clusters, and tunable physiochemical properties. Here, we explore the use of UiO-66, a zirconium-based MOF, as a pulmonary drug delivery vehicle. We determined that the aerodynamic properties of UiO-66 lend to characteristics leading to efficient aerosol delivery and that they are biocompatible both *in vitro* and *in vivo*. The UiO-66 nanoparticles also remain localized to the lung when delivered orotracheally to mice and can successfully be loaded with cargo that is selectively released in environments mimicking intracellular pH. These results collectively demonstrate that MOFs, UiO-66 in particular, have great potential as pulmonary drug delivery vehicles with high loading capacity, advantageous aerodynamic properties, and desirable stability until internalized. We also utilized other, aluminum-based MOFs for synthetic vaccine applications as stimulants for the immune system and as carriers for antigens to have co-delivery of antigen with immune stimulating particles. Our results have shown promise for aluminum-based MOFs to stimulate the immune system *in vitro* and *in vivo*, which often outperform alum, the clinical standard for vaccine immune stimulation.

Developing an encapsulated catalyst for the direct conversion of glucose to ethylene glycol

Roshaan Surendhran
Advisor: Dr. Marat Orazov
Committee Members: Dr. Raul Lobo, Dr. Dionisios G. Vlachos

With a global production capacity of 42 million tons in 2019 and a global market value of 30.4 billion USD in 2018[1], ethylene glycol (EG) is a high-volume chemical used primarily as a reagent in the synthesis of polymers, as a solvent, and as a heat-transfer fluid. The most prevalent process for the production of EG currently involves epoxidation of ethylene, followed by the hydration of the ethylene oxide intermediate, which requires multiple reactors and separation units[2]. Over 95% of the global EG supply is produced through this method utilizing ethylene sourced predominantly from non-renewable natural gas, naphtha, and coal[1]. More recently, ethylene has been sourced from renewable biomass feedstocks[1]. The overall financial and environmental cost for sourcing the ethylene and subsequently converting it to EG incentivizes the development of a technology that can directly convert the feedstock to EG. To this end, the direct conversion of cellulose or glucose to EG has been the subject of research in the recent years, with a sequential retro-aldol–hydrogenation strategy being particularly appealing.

The retro-aldol reaction required for this strategy is equilibrium limited and favors the hexose (glucose) over the smaller fragments (glycolaldehyde and erythrose). To overcome this limitation, we propose a tandem strategy that irreversibly transforms the glycolaldehyde to EG via hydrogenation. Such a strategy requires the simultaneous use of two catalysts, one for the retro-aldol reaction, and one for the selective hydrogenation of glycolaldehyde. However, typical hydrogenation catalysts like Ni/SiO_2 are not selective and catalyze the reduction of both glucose and glycolaldehyde. By encapsulating the active Ni nanoparticles inside zeolitic frameworks, we can achieve size-selective hydrogenation of glycolaldehyde without hydrogenating glucose. MFI framework type materials with 5.5 Å pores can exclude glucose due to its larger size and provide the necessary selectivity for glycolaldehyde reduction to EG. In this work, we have explored the preparation and application of such MFI encapsulated Ni catalysts for size-selective hydrogenation.

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Identification of "Difficult-to-Express" mAb Frameworks to Alleviate Expression Bottlenecks in CHO Cells

Alana C. Szkodny
Advisor: Kelvin H. Lee
Committee Members: Abraham M. Lenhoff, April M. Kloxin, Christopher J. Roberts

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Candidate therapeutic monoclonal antibodies (mAbs) are often engineered for increased affinity to the target antigen or for improved thermostability, yet they are rarely evaluated prior to candidate selection for their expression in production host cell lines, such as Chinese hamster ovary (CHO) cells. Cases of "difficult-to-express" (DTE) antibodies exist where even single amino acid differences between mAb candidates result in titers differing by up to an order of magnitude, which can impact development timelines and manufacturability. Previous studies have shown that these DTE phenotypes are driven by post-translational bottlenecks in antibody folding, assembly, and secretion processes which are due to the biophysical changes that arise from differences in primary sequence. However, these bottlenecks and the types of sequence variation that can create them have only been studied in a small number of cases. To investigate the primary sequence trends that lead to low mAb expression on a larger scale, we generated an extensive mAb variant expression dataset by measuring the expression of 178 systematically chosen single amino acid mutations of a model IgG1 mAb in an industrially-relevant CHO cell line. The tested variants showed a wide range of expression compared to the wild type mAb. The expression levels of each variant, when combined with physical and chemical characteristics, reveal distinct combinations of primary sequence mutations and molecular contexts that impact mAb expression. Studying mAb variants on this scale can provide a framework for improving the developability of therapeutic mAbs through primary sequence optimization, potentially leading to accelerated process development timelines.

Computational studies of the phase transitions and self-assembly of peptide-based biomaterials

Phillip A. Taylor
Advisors: April M. Kloxin and Arthi Jayaraman
Committee Members: Millicent O. Sullivan, Christopher J. Roberts, and Kristi L. Kiick

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Recent advances in materials design, synthesis, and simulation have allowed the creation of biomimetic materials with responsive and controllable physicochemical properties. Such materials self-assemble into desired morphologies such as vesicles, fibrils and gels, and their ability to self-assemble can be tuned by applying external stimuli such as heat, light, pH, and salt for applications including drug delivery and tissue engineering. While experimental synthesis and characterization of biomaterials are often time consuming and limited in terms of resolution, simulations allow for efficient screening of broad design spaces while also giving insight into the molecular mechanisms and driving forces governing the complex phase behavior and assembly of responsive biomaterials. Therefore, there is a need to develop molecular models that can capture the thermodynamics and self-assembly of biopolymers in order to simulate large enough length scales and time scales which are applicable to experiments. The overarching goal of my thesis is to use atomistic (AA) and coarse-grained (CG) molecular dynamics simulations to study and design responsive, peptide-based materials such as elastin-like peptides (ELP), collagen-like peptides (CLP), and ELP-CLP bioconjugates. First, I will briefly highlight our studies on the lower critical solution temperature (LCST)-like phase behavior of ELPs and ELP-CLP conjugates, the melting transitions of CLPs with natural and non-natural amino acids, and the self-assembly of CLPs which form triple helices, fibrils, and supramolecular networks. Next, I will discuss our recent AA and CG simulation work on the impact of substitutions of phenylalanine (F) with Tyrosine (Y) guest residues on the transition temperatures of short ELPs when ELPs are conjugated to CLPs. I will also discuss the molecular interactions that drive the experimentally observed shifts in the transition and present some general design rules for future synthesis of ELP-based biomaterials. Overall, our work highlights the predictive capabilities of molecular dynamics simulations in guiding experiments, as these complex peptide systems with unique molecular insights can inform new system designs and streamline the discovery of new, biomimetic platforms.

The Nature and Physiological Impact of Small RNA Cargo in Microparticles from Megakaryocytes and Chinese Hamster Ovary Cells

Will Thompson
Advisor: Eleftherios Papoutsakis
Committee Members: Catherine Fromen, April Kloxin

Extracellular vesicles—lipid bilayer-bound particles of less than one micron in diameter—are produced by every cell type and increasingly recognized as key to intercellular communication. Subcategorized as "exosomes" (derived from late endosomes) and "microparticles" (derived from the plasma membrane), these vesicles transport proteins, lipids, and nucleic acids between cells. Small RNA cargo—thought to be most responsible for inducing phenotypic change in target cells—is of particular note.

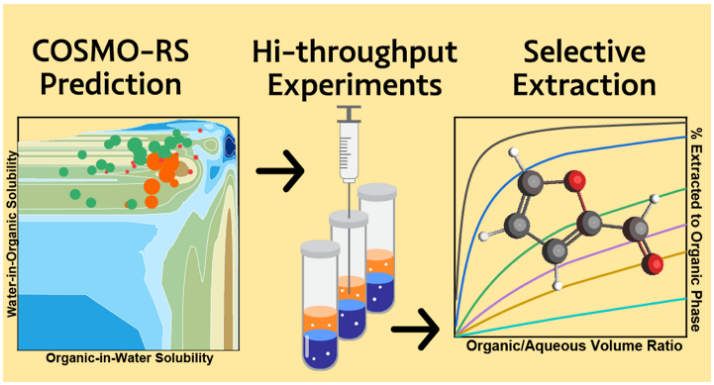
The properties of microparticles derived from megakaryocytes (platelet-producing cells) are well-defined. These vesicles promote the proliferation and subsequent megakaryopoiesis of hematopoietic stem and progenitor cells, even in the absence of thrombopoietin, an important finding for both *in vitro* and *in vivo* platelet production efforts. This function is primarily due to the action of two small RNAs: hsa-miR-486-5p and hsa-miR-22-3p. However, while increased shear stress (similar to that experienced by megakaryocytes *in vivo*) is known to promote microparticle production by megakaryocytes, the impact of this stress—and additional relevant factors, such as culture age—on the microparticles' small RNA levels has never been studied. To this end, we investigate and contrast methods for shear-induced megakaryocytic microparticle production, giving special attention to variation in the particles' small RNA profiles. The collective findings suggest a synchronicity between microparticle loading and release machinery which changes over time and becomes disturbed by various culture stresses, including shear stress. We observe a similar dynamic in microparticles released from Chinese hamster ovary cells, themselves the workhorses of the biopharmaceutical industry. The way forward, then, involves manipulating culture stressors and other microparticle harvest conditions such that the particles' cargo can be selectively enriched or depleted in a scalable process. Enriched megakaryocytic microparticles offer promise as ultra-powerful inducers of stem cell growth and megakaryopoiesis, which, as described previously, is crucial for platelet production. Meanwhile, depleted such particles offer excellent unsullied vehicles for targeted delivery of choice exogenous cargo to stem cells.

Selective Extraction of Furfural and 5-Hydroxymethylfurfural from Mixed Lignocellulosic Biomass-Derived Feedstocks in Biphasic Solvent Systems

Zhaoxing Wang
Advisor: Dionisios Vlachos
Committee Members: Raul Lobo and Marat Orazov

Broad utilization of carbon-neutral feedstocks as carbon sources is one answer to accomplishing carbon neutrality by mid-21st century. Furfural and 5-hydroxymethylfurfural (HMF) are two major lignocellulose-based platform chemicals capable of such goals. In the biphasic water-organic production of furfural and HMF, simultaneous reaction and product separation are essential for process intensification to improve selectivities. However, common solvents are often selected *via* heuristic methods, resulting in suboptimal yields due to poor extraction of the furanic compounds to the organic phase and the subsequent aqueous degradation of the furanic compounds. In this work, we provide a systematic framework for solvent selection in biphasic systems for HMF and furfural, which are reactive intermediates in the dehydration of pentose and hexose sugars.

The initial screening step in this framework identifies high-performing furfural and HMF extractants using the multiscale COSMO-RS predictive model. Solute distribution (partition coefficients, P_{HMF} and $P_{furfural}$) between an aqueous phase and an organic solvent are predicted. Interestingly, the model predicts higher furfural partitioning to the organic phase compared to HMF (*i.e.,* $P_{furfural} > P_{HMF}$) for all 2500+ solvents in the database. 670 solvents are predicted to form biphasic systems that favorably extract both HMF and furfural at 298 K (*i.e.,* $P_{furfural}$ and $P_{HMF} > 1$), while solvents selective for furfural but not HMF (*i.e.,* $P_{HMF} < 1 < P_{furfural}$) number 775 at 298 K. This *in silico* screening was followed by experimental validation for selected solvents, and solvents with order-of-magnitude increase in $P_{furfural}$ and P_{HMF} were identified. Using a high-throughput *in situ* phase sampling and subsequent sample handling process, solute partitioning at the relevant reaction temperature of 423 K was experimentally determined. These results were supplemented by solvent stability and solute compatibility experiments. Furthermore, we demonstrate that it is possible to selectively separate furfural from aqueous mixtures of furfural and HMF, commonly found in processed lignocellulosic streams.

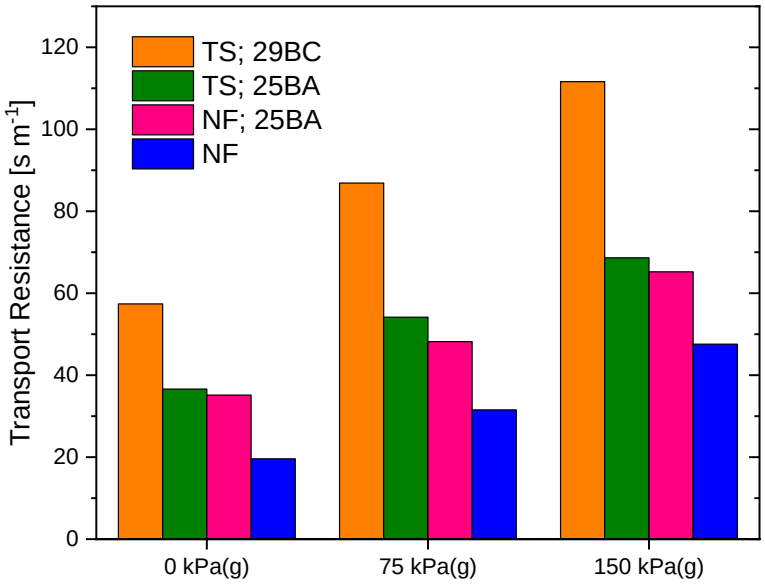


Study of Cell Architecture for Improved Oxygen Transport in Hydroxide Exchange Membrane Fuel Cells

Catherine M. Weiss
Advisor: Yushan Yan
Committee Members: Antony N. Beris and Marat Orazov

Hydroxide Exchange Membrane Fuel Cells (HEMFC) have a potentially significantly lower module cost compared to Proton Exchange Membrane Fuel Cells (PEMFC). When switching from the low pH environment to the high pH environment, from PEMFCs to HEMFCs, more cost-effective materials become stable reducing the overall module cost[1]. A key difference between these two environments is the water management. In PEMFCs water is produced on the cathode creating O_2 transport limitations when excess water is present. In HEMFCs water is produced on the anode and consumed on the cathode[2]. Since water is produced on the anode, where pure hydrogen is being fed, O_2 transport in the cathode can be optimized without the presence of excess liquid water. Minimizing the oxygen transport resistance is critical for maximizing fuel cell performance and reducing costs.

An advantage of both PEMFCs and HEMFCs for vehicle application is that only one fuel, hydrogen, is stored, while the other fuel, oxygen, is used from the air. The diluted oxygen in nitrogen from air must diffuse from the channels of the flow field through the gas diffusion layer (GDL), microporous layer (MPL), and catalyst layer decreasing the concentration of oxygen on the cathode catalyst surface. Through limiting current analysis, the total oxygen transport resistance is measured and separated into two types of oxygen transport resistance depending on the type of diffusion[3]. The elimination of the traditional gas diffusion architecture, triple serpentine flow field, GDL, and MPL, and the creation of a new gas diffusion architecture consisting of nickel foam decreases the total oxygen transport resistance from 112 s m^{-1} to 48 s m^{-1} at 80 °C cell temperature and 150 kPa(g) back pressure. The new gas diffusion architecture can be implemented in HEMFCs due to water consumption on the cathode, contrary to PEMFCs. The optimal cell configuration for performance is the nickel foam acting as the flow field with a GDL without an MPL due to vastly improved oxygen transport while maintaining adequate electrical contact with the catalyst layer.



Total transport resistances for cells with triple serpentine flow field and 29BC (orange), triple serpentine and 25BA (green), Ni foam and 25BA (pink), and Ni foam (blue) at difference back pressures. All tests were done at cell temperature of 80 °C with inlet streams at 90% RH. The cells with cathode triple serpentine flow field used flowrates of 1000 sccm of H_2 and 2000 sccm of O_2 diluted in N_2. The cell with Ni foam only cathode had anode flow of 1000 sccm H_2 and 500 sccm of O_2 diluted in N_2. All cells were fabricated with 0.4 mg_{Pt} cm^{-2} with TP-85 ionomer at ionomer to carbon ratio of 0.4 for both anode (60wt% PtRu/C) and cathode (40wt% Pt/C).

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Insights into Surface Charge Effects on the Volmer Step on Pt (111) through Controlled-Potential Anderson-Newns Molecular Dynamics

Jon Wilson
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Committee Members: Stavros Caratzoulas, Arthi Jayaraman, Marat Orazov

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The mechanism of pH-dependent hydrogen oxidation and evolution (HOR, HER) kinetics is still debated, and the lack of a definitive explanation has made the design of active alkaline HOR/HER catalysts challenging. To make progress, we have employed molecular dynamics including controlled electrode potential and an Anderson-Newns model for electrocatalysis to study Volmer step kinetics on Pt (111). As pH is increased, the metal surface charge at the equilibrium potential for HOR/HER is more negative. We study varying surface charge as a proxy for pH effects and investigate its relationship with solvent reorganization, hydrogen binding energy, and the free energy to move the proton to and from the surface. Close to the surface where the Volmer step transition state is located, the solvent reorganization is insensitive to changes in surface charge. Hydrogen binding energy increases due to electrostatic interactions between adsorbed hydrogen and the negatively charged surface. Additionally, the negative surface charge significantly stabilizes the proton relative to adsorbed H, promoting oxidation. However, the energy to move the proton from the double layer both to the surface and to the bulk is greatly increased, suggesting the proton motion, not the redox event, is the rate limiting process in alkaline HOR/HER.

3D Printed Lattices for Next-Gen Pulmonary Therapeutics

Ian R. Woodward
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Committee Members: April M. Kloxin, Abraham M. Lenhoff, and Jason P. Gleghorn

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3D printing and additive manufacturing have seen rapid development in recent history, making the technology relevant across a variety of research and industrial sectors. In addition to on-demand manufacturing and reduced waste, 3D printing facilitates the realization of highly intricate structures like periodic lattices. These structures are accessible through a wide range of design parameters, which has made them useful in the contexts of catalysis, thermal management, structural support, biomedical devices, and even consumer products. Simultaneously, the COVID-19 pandemic has highlighted the difficulties of treating respiratory illnesses, which have been the leading causes of death worldwide, for over 30 years. This is due in part to the complexity of the lungs, which exhibit a range of length scales, transport phenomena, and biological responses–all of which are difficult to characterize *in vivo* and prohibitively challenging to fully replicate *in vitro*. As a result, modern inhalable therapeutics stem from *in vitro-in vivo* correlations (IVIVCs) developed in the mid-to-late 20th century. Here, we will showcase the ways in which we are leveraging 3D printing to drive innovation in inhalable therapeutics, to develop not just devices for administration but also platforms to approximate the full lung space.

In this talk, we demonstrate a method for generating lattice structures capable of conforming to an arbitrary configuration. Using a Carbon M1 3D printer, we assessed printability at unit cell length scales ranging from 0.5 to 3.5 mm and strut diameters ranging from 0.11 to 1.05 mm. Upon characterization, we identified trends in dimensional deviations that depend on length scale and resin chemistry, and we implemented a method to compensate for these defects at the design stage. We further investigated the fluid properties of two common lattice geometries in pipes ranging from 12 to 52 mm in diameter and compared the measured pressure gradient to published correlations. Finally, we will discuss the performance of these lattice structures in heterogeneous systems and how they can be combined with 3D printed anatomical features to model the lungs. Through these continued developments, this work supports the promise of 3D printing to bring tailored solutions to any application and the potential to design the next generation of IVIVCs based on patient-specific metrics and dynamics.

Computational studies of macromolecular materials with directional and specific interactions

Zijie Wu
Advisor: Prof. Arthi Jayaraman
Committee Members: Prof. April Kloxin, Prof. LaShanda Korley

Hydrogen bonding interaction is an important inter-molecular interaction that drives assembly in many families of polymer chemistries (e.g., polysaccharides, polysulfamides, polypeptides, oligonucleic acids). Researchers using molecular modeling and simulations to study these macromolecules face the challenge of simultaneously capturing the localized directionality induced by hydrogen bonding at monomer-scale and the larger length and time scales associated with polymer relaxation and ordering/assembly. The overarching goal of my thesis is to develop appropriate multiscale models and computational methods to probe assembly and structure formation in macromolecules driven primarily by hydrogen-bonding interactions. In this talk, I will highlight my recent work aimed at thermoresponsive self-assembly of methylcellulose (MC) solutions, widely used in food, medical and biological industries, where hydrogen bonding interactions stabilize various observed structures in experiments. MC chains in aqueous solutions remain soluble at room temperature and assemble into fibrils at elevated temperatures. Experiments [e.g., *Macromolecules,* 2018, **51**, 7767-7775] show constant average fibril diameters upon varying MC molecular weight and concentration. Using a combination of recently developed coarse-grained models [*J. Chem. Theory Comput*. 2020, **16**, 7, 4599-4614] and a recently developed computational method called CREASE [*J. Am. Chem. Soc*. 2019, **141**, 14916−14930], my work is focused on unraveling the molecular mechanism of the assembly and the packing of individual MC chains within the fibrils, both of which remain unclear. In this talk I will describe how we apply genetic algorithm (GA) part of CREASE to extract MC fibril dimension (diameter, flexibility, dispersity) from small-angle X-ray scattering (SAXS) profiles for MC fibrils obtained experimentally by Bates, Lodge and coworkers [*Macromolecules,* 2018, **51**, 7767-7775] without the need for *a priori* analytical models. Using the molecular reconstruction part of CREASE, I will show our prediction of chain packing driven by both directional hydrogen bonding effects and isotropic hydrophobic effects within the fibril contour. Our work provides insight into the self-assembly of MC chains in solution and generally, fibrillar network formation of semiflexible polymers with a combination of directional and isotropic molecular interactions.

Developing a Highly Specific, Modular Platform for Conditional Protein Degradation

Hopen Yang
Advisor: Wilfred Chen
Committee Members: April M. Kloxin, Abraham M. Lenhoff

Current approaches to balancing dysregulated protein levels focus on either RNA or protein level control schemes. Protein level control mechanisms can deplete both pre-existing targets and those that will continue to be produced. In nature, intracellular proteolysis is either promiscuous (lysosomal), or selective (ubiquitin-dependent proteasomal targeting). The selectivity of proteasomal degradation makes it an attractive choice for synthetic applications. Recent advances, such as proteolysis-targeting chimeric molecules (PROTACs), have expanded the scope of potential treatments for protein disease targets. PROTACS repurpose native ubiquitination machinery to tag specific target proteins for destruction. This approach is particularly useful in treatments where diseased cell death is desirable. Unfortunately, total ablation of essential proteins in diseased cells that need to be restored is not useful. Thus, the uncontrolled destruction effected by existing approaches has proven to be a roadblock to adaption for such use-cases.

To address this challenge, we are developing a new synthetic biology framework to elicit dynamic fine-tuning of target protein levels based on intracellular information (proteins and/or miRNAs) for restoration of basal, healthy protein levels. I have identified several promising systems that utilize highly specific nanobodies to repurpose cellular E3 ligases to tag targets for degradation. Notably, the Affinity Directed Protein Missile (AdPROM) retargets the CUL2 E3 Ligase. Insertion of the Tobacco Etch Virus protease (TEVp) cleavage site produces a novel turn OFF control mechanism that exhibits similar knockdown to the original AdPROM, and no significant protein degradation when turned OFF. This addition of TEVp control allows us to readily adapt the platform to various input mechanisms using activatable split TEVp assembly.

Various lock and key devices can be used to directed mechanistic control of the split TEVp: small molecules, light activation, or even RNA level markers. We first demonstrated the suitability of our Turn OFF system for modulating target proteins using small molecule and light inputs. Next, we have demonstrated ON/OFF switchable control using blue light activation. We also layered multiple control inputs to build gated logic circuits. Future work includes tuning system responsiveness to various inputs, notably the RNA level markers, and further logic-gate circuit design.

Novel and Valuable Chemicals from Renewable Feedstocks through Catalysis

Mingchun Ye
Advisor: Dr. Raul F. Lobo
Committee Members: Dr. Dionisios G. Vlachos, Dr. Christopher J. Kloxin, Dr. Donald A. Watson and Dr. Hari B. Sunkara (DuPont)

To mitigate the environmental impact of plastic waste and reduce our dependence on fossil fuels, we must find renewable alternatives with desirable combinations of physical and chemical properties. Recent reports have shown that bifuran-based polyesters could afford such materials: poly(ethylene bifuroate), for example, has attractive UV blocking and gas barrier properties. This bifuroate can be prepared by the selective C-C homocoupling of methyl furoate via the Heck reaction, but this requires halide substitution and inert reaction atmosphere. To prepare the bifuroate from less expensive ingredients alternatives to the C-C homocoupling need to be found. Here we investigate the feasibility of oxidative coupling of furoate using homogeneous Pd(II) catalysts. We have simplified the reaction composition, determined important steps of the reaction mechanism and optimization of the oxidative coupling of the methyl furoate. Using homogeneous Pd(II) catalysts we have obtained acceptable yields (11.4%), good selectivity (85%) and very high turn-over-frequency (TOF) (544 h^{-1}). Kinetic analyses revealed that the mechanism fitted the so-called bimetallic mechanism of oxidative coupling. It was found that the solubility of the product, Dimethyl 2,2'-bifuran-5,5'-dicarboxylate (DMBF), was greatly temperature dependent and shown that this property can be used for effective scale up of the reaction.

Ga^+ in Chabazite Zeolite as Highly Selective Catalyst for Non-Oxidative Propane Dehydrogenation

Yong Yuan
Advisor: Raul F. Lobo
Committee Members: Dionisios G. Vlachos; Feng Jiao; Antony N. Beris

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Propane dehydrogenation (PDH) has attracted increasing attention due to the growing demand for propylene and the large availability of shale gas. Ga-based catalyst was widely investigated as a promising catalyst for non-oxidative propane dehydrogenation in addition to the commercial Pt-based and Cr-based catalysts. However, the small pore size (such as CHA) supported Ga has less been investigated for propane dehydrogenation. In this work, Ga-CHA catalyst has been discovered as an effective catalyst for propane dehydrogenation with high propylene selectivity (96%). In-situ FTIR spectroscopy results show the displacement of Brønsted acid sites (BAS) upon reducing Ga-CHA catalysts. GaH_x centered at 2034 cm^{-1} appear when introducing H_2 (1 atm) at 150 °C and the intensity grows as the contact time with H_2 increases. The intensity of GaH_x on reduced Ga-CHA (Si/Al = 12) increases as the Ga/Al ratio rises to 0.7 and decreases slightly with further addition of Ga/Al ratio to 1.0, suggesting that isolated Ga^+ dominantly forms in the low range of Ga/Al ratios and further addition of Ga loading led to the formation of GaO_x. The initial C_3H_6 yield of Ga-CHA catalyst dropped rapidly during the first 100 min and declined slowly in the later part of the test, while the C_3H_6 selectivity is stable at approximately 96%, showing that the deactivation of the Ga-CHA catalyst is possibly due to the formation of coke without changing the active site. The correlation between GaH_x vs Ga/Al ratio and PDH rates vs Ga/Al ratio suggested that isolated Ga^+ is the active center catalyzing propane dehydrogenation. Additionally, the same tendency of Ga-CHA deactivation and polycyclic aromatics formation indicated that the accumulation of polycyclic aromatics is the cause of the deactivation. This work provides an in-depth understanding of the Ga-CHA for propane dehydrogenation.

Statistical-learning-aided Multiscale Modeling of Structure-sensitive Catalytic Reactions

Xue Zong
Advisor: Dionisios G. Vlachos
Committee Members: Antony N. Beris, Feng Jiao

Heterogeneous catalytic reactions are commonly structure sensitive and dependent on the size and shape of catalyst particles. However, the structure sensitivity of surface reactions has been a long-studied problem, and often debated experimentally even for a simple chemical reaction due to the difficulty in identifying catalyst surface structures in situ. The ability to predict a priori which reactions are structure sensitive and under what conditions has not been in general possible. This challenge arises from being difficult to make materials with arbitrary and stable structures and the need to perform numerous first principles calculations on various facets, build kinetic models, and compare the rates. To our knowledge, while in principle possible, structure dependent models have not been achieved yet because the effort of building a first-principles kinetic model is already significant. Recently published work either chooses several common facets [1] or develops a structure-dependent model for archetypical simple reactions, such as CO oxidation [2]. There is a need to create suitable kinetic models for describing structure sensitivity of complicated reactions.

In this work, we introduce statistical learning tools to develop a novel structure-descriptor-based kinetic model for complete methane oxidation based on first-principles calculations. Structure-reactivity scaling relationships, reminiscent of the generalized coordination number (GCN) [3], are developed using statistical learning techniques. By incorporating these correlations into kinetic models leveraging our in-house developed software, we predict the experimental observables, such as turnover frequencies (TOF) and apparent activation energies, at a dramatically reduced computational cost compared to first-principles calculations. Additionally, uncertainty quantification is applied for exploring the effects of errors in structure-reactivity scaling relations on variable catalyst facets. This methodology enables the rapid prediction of kinetics on arbitrary structures for complicated catalytic reactions and quantifies the uncertainties due to the catalyst structure for the first time.

References

1. Wang, Y. et al. *J. Phys. Chem. C* 124, 2501 (2020).
2. Jørgensen, M. and Grönbeck, H. *ACS Catal.* 7, 5054 (2017).
3. Calle-Vallejo, F., Sautet, P. and Loffreda, D., *Angew. Chem. Int. Ed.* 53, 8316 (2014).

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GRADUATE RECRUITING AGENDA

February 17-19, 2022

POSTER PRESENTERS

UNIVERSITY OF DELAWARE
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POSTER PRESENTERS

Nikolas Angyal	"Valorization of Plastic Waste via Low Temperature Oxyfunctionalization" **Advisor: Marat Orazov**
Oluwadare Badejo	"Integration of Tactical Supply Chain and Process Operations using Data-driven Feasibility Analysis" **Advisor: Marianthi G. Ierapetritou**
Matthew Becker	"Determination of the Binding Behavior of Problematic Host Cell Proteins to Industrial Monoclonal Antibodies" **Advisor: Abraham M. Lenhoff**
Soumitra Bhoyar	"Determinants of capacity in protein A chromatography" **Advisor: Abraham M. Lenhoff**
Chaoying Ding	"A Novel Framework of Surrogate-based Feasibility Analysis for Establishing Design Space of Twin-column Continuous Chromatography" **Advisor: Marianthi G. Ierapetritou**
Antonio Goncalves	"Progress Towards the Modular Assembly of a Worm-like Protein Nanoparticle" **Advisors: Wilfred Chen and Millicent O. Sullivan**
Yagya Gupta	"Upgrading Food Waste to High Commercial Value Chemicals" **Advisor: Dionisios G. Vlachos**
Kentaro Hansen	"Operando Breakdown of CO2 Reduction Electrolyzer Performance by Component and Timescale" **Advisor: Feng Jiao**
Jihyuk Kim	"Microscopic Structure and Dynamics of Attractive Polymer Nanocomposites" **Advisors: Norman J. Wagner, Arthi Jayaraman, and Antonio Faraone**
Quentin Kim	"Low Temperature Oxyfunctionalization of Propane" **Advisor: Marat Orazov**
Mi Jen Kuo	"Selective Synthesis of 4, 4′-Dimethylbiphenyl from 2-Methylfuran" **Advisor: Raul F. Lobo**
Vinson Liao	"Characterization of Supported Subnanometer Clusters via Computational Infrared Spectroscopy" **Advisor: Dionisios G. Vlachos**

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POSTER PRESENTERS

Shizhao Lu	"Modeling and simulation of polymer nanocomposites containing nanorods" **Advisor: Arthi Jayaraman**
Yuqing Luo	"Biorefinery process and supply chain design optimization under Uncertainty" **Advisor: Marianthi G. Ierapetritou**
Ahmad Naqi	"Multi-material Fused Filament Fabrication via Core-Shell Die Design" **Advisor: Michael E. Mackay**
Alexandra Oliveira	"Studies of Water Management in Hydroxide Exchange Membrane Electrolyzers for Green Hydrogen Generation" **Advisor: Yushan Yan**
Brian Paul	"Crystal, Liquid, or Gel: A Thermodynamic Framework for Phase Behavior in Dilute Protein Solutions with Increasing Salt Concentration" **Advisors: Norman J. Wagner, Eric M. Furst, Abraham M. Lenhoff, Susana C.M. Teixeira**
Mruthula Rammohan	"Stabilizing lipid nanoparticles using photo-responsive polymers for mRNA delivery" **Advisors: Thomas H. Epps and Millicent O. Sullivan**
Sanjana Srinivas	"Spin-Crossing in Heterogeneous Catalysis By Atomically Dispersed Transition Metals: Ethane Dehydrogenation By Co/SiO2" **Advisors: Dionisios G. Vlachos and Stavros Caratzoulas**
Terrance Shoemaker	"How well do low-concentration models of protein-protein interactions predict high-concentration solution properties?" **Advisor: Christopher J. Roberts**
Esun Selvam	"Shape and size-controlled ZnO for the microwave-assisted depolymerization of PET" **Advisor: Dionisios G. Vlachos**
Huayu Tian	"Characterization and Propagation of RTD uncertainty for Continuous Solid-Based Drug Manufacturing Process" **Advisor: Marianthi G. Ierapetritou**
Brandon Vance	"Developing a Mechanistic Framework for Polyolefin Hydrocracking" **Advisor: Dionisios G. Vlachos**

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POSTER PRESENTERS

Jayanth Venkatarama Reddy	"Modeling the effect of pH on Chinese Hamster Ovary cell metabolism and N-linked glycosylation" **Advisors: Marianthi G. Ierapetritou and Eleftherios T. Papoutsakis**
Noah Willis	"Mechanistic Understanding of Syntrophic Clostridium Coculture Using Transcriptomic and Metabolic Analyses" **Advisor: Eleftherios T. Papoutsakis**
Yu-Tai Wong	"Exploring the Relationship Between Architecture and Mechanics in Lignin-Derivable Polymer Networks" **Advisor: LaShanda T. Korley**
Yurong Wu	"Intrinsic Dynamics of Brønsted Acidity over Pt-WOx Inverse Structure" **Advisor: Dionisios G. Vlachos**
Piaoping Yang	"Structure Sensitivity of Catalytic Transfer Hydrogenation of Furfural over Single-Atom Catalysts: A Computational Study" **Advisor: Dionisios G. Vlachos**
Kewei Yu	"Ethane Non-oxidative Dehydrogenation over Co/SiO2 – Pretreatment and Regeneration" **Advisor: Dionisios G. Vlachos**
Jiahua Zhou	"The Role of Oxygen-Containing Functional Groups of Carbon Surfaces" **Advisor: Dionisios G. Vlachos**