Welcome to our Annual Winter Research Review – We are pleased that you can join us. Today's events provide an excellent opportunity to learn about the research of our senior graduate students and their faculty advisors. The focus of the program is the research presentations by our fourth-year graduate students. Throughout the day you can also visit research posters presented by our third-year graduate students.

Our graduate program is one of the key foundations of our principal missions of education and scholarship. We hope that you will enjoy this opportunity to learn more about our department and its activities, as well as to meet the students and faculty.

Eric M. Furst  
Professor and Department Chair  
Department of Chemical and Biomolecular Engineering

Victoria M. Hunt  
President of Colburn Club  
The Graduate Student Organization

Colburn Club is the graduate student organization in the Chemical and Biomolecular Engineering Department, which is comprised of representatives from each year as well as a number of members filling specialized roles. The primary functions of the club are to organize research reviews and social events for the department, in addition to serving as one line of contact between the students and the faculty. We hope you enjoy this event and can join us again in the future.

The Colburn Club  
www/che.udel.edu/cc
Alphabetical List of Talks

Pratyush Agrawal, Advisor: Michael T. Klein
“Molecular-Level Kinetic Modeling of Conventional and Unconventional Hydroprocessing Feedstocks”
Committee: Antony N. Beris and Prasad S. Dhurjati

(Lily) Ziwei Cheng, Advisor: Dionisios G. Vlachos
“Catalytic Hydrotreatment of Humins in Methanol over a Rh/C Catalyst”
Committee: Raul F. Lobo and Bingjun Xu

Chen-Yu Chou, Advisor: Raul F. Lobo
“Direct Conversion of CO\textsubscript{2} into Methanol over Promoted Indium-based Catalysts”
Committee: Michael T. Klein, Dionisios G. Vlachos, and Bingjun Xu

Camil A.C. Diaz, Advisor: Maciek R. Antoniewicz
“Quid pro quo: Engineering Nitrogen Self-sufficient Cocultures”
Committee: Wilfred Chen and Kelvin H. Lee

Glenn M. Ferreira, Advisor: Christopher J. Roberts
“Electrostatically Mediated Protein-Protein Interactions for Monoclonal Antibodies: a Combined Experimental and Coarse-Grained Molecular Modeling Approach”
Committee: Abraham M. Lenhoff, Richard L. Remmele, and Arthi Jayaraman

Thomas E. Gartner, III, Advisor: Arthi Jayaraman
“Solvent Effects on the Structure and Thermodynamics of Polymer Blends of Varying Architecture”
Committee: Eric M. Furst, Michael K. Mackay, and Darrin Pochan

Andrew S. Gaynor, Advisor: Wilfred Chen
“A Tunable, Post-Translational Method for Controlling Prodrug Converting Enzymes in Cancer Cells”
Committee: April M. Kloxin and Millicent O. Sullivan

Nicholas Gould, Advisor: Bingjun Xu
“Spectroscopic Technique Development and Liquid Phase TPD for Understanding Solvent Effects in Biomass Conversion Reactions”
Committee: Raul F. Lobo, Joshua Pacheco, and Dionisios G. Vlachos

Wesley W. Luc, Advisor: Feng Jiao
“Non-precious Copper-based Bimetallic Electrocatalysts for Hydrogen Evolution Reaction in Base”
Committee: Bingjun Xu and Yushan Yan

Brian McConnell, Advisor: Maciek R. Antoniewicz
“Symbiotic Growth of Photoautotrophic and Heterotrophic Microorganisms”
Committee: Wilfred Chen and Kelvin H. Lee

Jared Nash, Advisors: Bingjun Xu and Yushan Yan
“Electrochemical Synthesis of Ammonia Using Proton and Hydroxide Exchange Membrane Electrolysis Cells”
Committee: Raul F. Lobo, Feng Jiao, and Ajay Prasad
Alphabetical List of Talks—Continued

Julia Rohlhill, Advisor: Eleftherios T. Papoutsakis
“Sort-Seq Approach to Engineering a Formaldehyde-Inducible Promoter and Methanol Dehydrogenase for Synthetic Methylotrophy in E. coli”
Committee: Wilfred Chen and Maciek R. Antoniewicz

John Ruano-Salguero, Advisor: Kelvin H. Lee
“Differences in Antibody Transport at the Human Blood-brain Barrier”
Committee: Wilfred Chen and April M. Kloxin

Andrew Swartz, Advisor: Wilfred Chen
“One-step Affinity Capture and Precipitation for Enhanced Purification of Industrial mAbs Using Z-ELP Functionalized Nanocages”
Committee: Abraham M. Lenhoff and Christopher J. Roberts

Hao Wang, Advisor: Yushan Yan
“Conductive, Selective and Stable Polymeric Membranes for Redox Flow Battery”
Committee: Thomas H. Epps, III, Arthi Jayaraman, and Erin Redmond

Katherine L. Wiley, Advisor: April M. Kloxin
“Design of Dynamic Hydrogels to Understand Cell Response to Matrix Remodeling”
Committee: Wilfred Chen and Millicent O. Sullivan
Winter Research Review
John M. Clayton Hall
January 31, 2018

8:30-9:00  Breakfast (Clayton Hall lobby)

9:00-9:10  Welcome / Opening Remarks (Room 101 B)
           *Professor Eric M. Furst, Department Chair*

**Session 1  Room 101 B  9:10 a.m. – 10:30 a.m.**

9:10-9:30  Glenn M. Ferreira
           “Electrostatically Mediated Protein-Protein Interactions for Monoclonal Antibodies: a Combined Experimental and Coarse-Grained Molecular Modeling Approach”
           *Advisor: Christopher J. Roberts / Committee: Abraham M. Lenhoff, Richard L. Remmele, and Arthi Jayaraman*

9:30-9:50  Andrew Gaynor
           “A Tunable, Post-Translational Method for Controlling Prodrug Converting Enzymes in Cancer Cells”
           *Advisor: Wilfred Chen / Committee: April M. Kloxin and Millicent O. Sullivan*

9:50-10:10 John S. Ruano-Salguero
           “Differences in Antibody Transport at the Human Blood-brain Barrier”
           *Advisor: Kelvin H. Lee / Committee: Wilfred Chen and April M. Kloxin*

10:10-10:30 Katherine L. Wiley
            “Design of Dynamic Hydrogels to Understand Cell Response to Matrix Remodeling”
            *Advisor: April M. Kloxin / Committee: Wilfred Chen and Millicent O. Sullivan*

10:30-10:45 Elevator Pitches

10:45-10:55 Short Break

10:55-11:50 Poster Session

11:50-1:30 Lunch (Room 101 A) and Featured Speaker, Bingjun Xu
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<tr>
<th>Time</th>
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8:30-9:00  Breakfast (Clayton Hall lobby)

9:00-9:10  Welcome / Opening Remarks (Room 101 B)
Professor Eric M. Furst, Department Chair

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Advisor: Dionisios G. Vlachos/ Committee: Raul F. Lobo and Bingjun Xu |
| 10:10-10:30 | Chen-Yu Chou | “Direct Conversion of CO₂ into Methanol over Promoted Indium-based Catalysts”
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**Poster Presenters**

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<td>“Enhanced Methane Dehydroaromatization via Coupling with Chemical Looping”</td>
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<td>Kamil Charubin</td>
<td>“Solvent Production using a CO₂-Fixing, Synthetic, Syntrophic Clostridium Co-culture”</td>
<td>Eleftherios T. Papoutsakis</td>
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<td>Kimberly A. Dennis</td>
<td>“High-Pressure Linear Viscoelasticity Measurements of Polymer Solutions and Gels”</td>
<td>Eric M. Furst</td>
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<td>Eden Ford</td>
<td>“Providing Structural Complexity within Hydrogel Biomaterials to Modulate Cellular Response”</td>
<td>April M. Kloxin</td>
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<td>Jiayi Fu</td>
<td>“Selective Hydrodeoxygenation of Tartaric Acid to Succinic Acid”</td>
<td>Dionisios G. Vlachos</td>
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<td>Michaela Gallucci</td>
<td>“Application of Constraint-based Modeling for In Silico Analysis and Prediction of CHO-cell Glycosylation”</td>
<td>Kelvin H. Lee</td>
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<td>Julie B. Hipp</td>
<td>“Structure-property Relationships in Carbon Black Suspensions”</td>
<td>Norman J. Wagner</td>
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<td>Victoria Hunt</td>
<td>“Development of a Novel Temporally-Controlled Gene Regulation Program in Mammalian Cells”</td>
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<tr>
<td>Matthew Jouny</td>
<td>“Electrochemical Reduction of CO to Alcohols at High Current Density”</td>
<td>Feng Jiao</td>
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Poster Presenters

Ohnmar Khanal  “The Mechanisms of Protein Adsorption and DNA Retention on Depth Filters”

Advisor: Abraham M. Lenhoff

Hojin Kim  “Crystallization of Nano-Dicloids by Directed Self-Assembly”

Advisor: Eric M. Furst

Joshua Lansford  “Molecular Vibrations on Transition Metal Surfaces: Applications and Theory”

Advisor: Dionisios G. Vlachos

Paige LeValley  “Design of Photodegradable Hydrogels for the Tunable Release of Immunotherapeutics”

Advisor: April M. Kloxin

Rachael M. Lieser  “Controlled EGFR Ligand Display on Cancer Suicide Enzymes for Targeted Intracellular Delivery”

Advisors: Millicent O. Sullivan and Wilfred Chen

Jonathan Lym  “Understanding the Active Site for Carbon Dioxide Hydrogenation to Methanol”

Advisor: Dionisios G. Vlachos

Alexander A. Mitkas  “Developing a High Affinity, Dynamic Scaffold Toolkit for Control of Intracellular Metabolic Flux”

Advisor: Wilfred Chen

Jannatun Nayem  “Investigating Dynamic Landscape of Therapeutic Monoclonal Antibodies via Neutron Spin Echo”

Advisor: Norman J. Wagner

Angela M. Norton  “Direct Speciation Methods to Quantify Catalytically Active Species of AlCl₃ in Glucose Isomerization”

Advisor: Dionisios G. Vlachos

Eleanor H. Oates  “Towards Engineering a Metabolically Dynamic Co-culture System between Fat and Liver Cells”

Advisor: Maciek Antoniewicz

David D. Phan  “Rheological and Heat Transfer Effects in Fused Filament Fabrication”

Advisor: Michael E. Mackay

Caitlin Wood  “Combined Effects of Temperature and Compression/Dilation of Air-Water Interfaces on Therapeutic Protein Aggregation”

Advisors: Eric M. Furst and Christopher J. Roberts
Molecular-Level Kinetic Modeling of Conventional and Unconventional Hydroprocessing Feedstocks

Pratyush Agarwal
Advisor: Michael T. Klein
Committee Members: Antony N. Beris, Prasad S. Dhurjati

The commercial upgrading of conventional and unconventional hydroprocessing feeds to valuable petrochemicals and fuels usually involves a series of reactors, each of which can contain multiple beds with several different layers of catalysts. A multiphase hydroprocessing reactor system with molecular detail of the feed and products was modeled using an in-house software, the Kinetic Modeler’s Toolbox. A reaction network of vacuum gas oil and triglyceride hydroprocessing feeds with $O(10^3)$ species and $O(10^4)$ reactions that includes the detailed hydroprocessing chemistry (saturation, hydrocracking, ring opening, hydrodesulfurization, hydrodenitrogenation, and hydrodeoxygenation) was generated. Several coke formation pathways and metal deposition reactions were also modeled to account for time-on-stream catalyst site reduction. The initial flow rates of the feed were calculated by defining an attribute, or structural moiety, probability density function tree and optimizing the difference between the feed experimental and simulated properties. A set of catalytic rate law based material balances, one for each species, and an energy balance along with the feed flow rates was used to define the initial value problem to be solved in the kinetic model. Each reactor bed was modeled as a series of plug-flow pseudo-reactors with side-by-side reaction and vapor-liquid equilibrium, where each pseudo-reactor represents a separate catalyst layer. The mixing of the hydrogen quench streams between beds was modeled with a mass balance and an enthalpy balance. Additionally, a complementary selectivity-activity modifier model was used to model the catalyst deactivation on the longer timescale of the catalyst life. Linear free-energy relationships (LFERs) and quantitative structure-property relationships (QSPRs) were used to reduce the parameters of the LHHW rate equations. The LFER concept was extended to catalyst families in order to further minimize the number of parameters and data needed for different catalysts[1]. The final model represents a real refinery reactor simulation over a range of process conditions like space velocity, temperature, pressure, and hydrogen flow. It also allows for scenario studies to test catalyst deactivation for different feed compositions and the impact of changing catalyst layer order, bed height, and quench rates.

Catalytic Hydrotreatment of Humins in Methanol over a Rh/C Catalyst

(Lily) Ziwei Cheng
Advisor: Dionisios G. Vlachos
Committee Members: Raul F. Lobo and Bingjun Xu

Humins are carbonaceous, polymeric by-products that are almost inevitably formed during acid-catalyzed, hydrothermal processing of sugars to bio-based platform molecules, such as 5-hydroxymethylfurfural (HMF).\(^1\) Currently, humins are a low-value product only used for combustion in biorefineries.\(^2\) The process economics of biorefineries can be improved either by inhibiting the formation of humins or by valorizing them. Here, we report one-step valorization of fructose-derived humins in methanol using a Rh/C catalyst. First, we screened four different noble metal catalysts. Aromatic hydrocarbons, phenols and esters were the main liquid products. Rh/C gave the best GC-detectable oil yield and was chosen for a subsequent set of experiments with varying reaction parameters. Up to 12 wt % light, GC-detectable oil yield was achieved at 75 % humins conversion. The light oil yield was shown to be a strong function of hydrogen pressure and temperature. High pressure and intermediate temperature, time and catalyst loadings were found beneficial for the light oil yields. At extremely high temperatures and long times, the total oil yield decreases as a result of enhanced gasification. The product distribution shifts in favor of aromatics and phenols at high temperatures and long reaction times while shifting in favor of esters at short reaction times and high catalyst loadings. Studies are underway to further elucidate the reaction pathways.

\(^2\) Hoang, T. M. C.; Lefferts, L.; Seshan, K. ChemSusChem 2013, 6 (9), 1651–1658.
Direct Conversion of CO\textsubscript{2} into Methanol over Promoted Indium-based Catalysts

Chen-Yu Chou  
Adviser: Raul F. Lobo  
Committee Members: Michael T. Klein, Dionisios G. Vlachos, Bingjun Xu

CO\textsubscript{2} hydrogenation to methanol has received much attention because methanol can be used as fuel or as a precursor to many commodity chemicals. If a green (CO\textsubscript{2}-free) H\textsubscript{2} source is used, the process is sustainable. One of the examples is the George Olah CO\textsubscript{2} to Renewable Methanol Plant in Iceland. The plant uses electricity, which is generated from extra hydro and geothermal energy, to make hydrogen. Although methanol synthesis from CO\textsubscript{2} and H\textsubscript{2} is exothermic, CO\textsubscript{2} conversion to methanol is kinetically limited at low temperatures and thermodynamically limited at high temperatures, resulting in a low theoretical methanol yield \cite{1}\cite{2}. Commercial Cu-ZnO-Al\textsubscript{2}O\textsubscript{3} (CZA) catalysts are currently employed for methanol synthesis from mixed syngas (CO/CO\textsubscript{2}/H\textsubscript{2}) in industry. However, these catalysts have low selectivity because of the competing reverse water–gas shift (RWGS) reaction, and insufficient stability, due to the sintering of the active surface. Recent DFT calculations showed that the key intermediates involved in CH\textsubscript{3}OH synthesis were more stable on a defective In\textsubscript{2}O\textsubscript{3} surface than those on the Cu surface, strongly suppressing the formation of CO \cite{3}. Subsequently, supported indium oxide catalysts have been investigated as they are promising candidates for developing effective and stable catalyst with high selectivity towards methanol.

A number of supported indium oxides with Scandium, Yttrium, or Lanthanum modifiers were synthesized and investigated. It was found that the reducibility of the indium oxide catalysts in a hydrogen atmosphere is correlated to methanol production rates. The Y-promoted catalyst had higher surface reduction temperature compared to the supported indium oxide catalyst. Furthermore, the incorporation of Yttrium and Lanthanum increased the selectivity of methanol from CO\textsubscript{2} conversion significantly (~20% more than the un-promoted catalyst). A selectivity of 100% can be achieved at 528K and 40 bar, which is a mild condition compared to the commercial process (513-533K, 50-100 bar). These results constitute a feasible method for the design of selective catalysts for sustainable methanol economy.

References

\begin{enumerate}
\item J.Ye, C.Liu, D.Me, Q.Ge, Active oxygen vacancy site for methanol synthesis from CO\textsubscript{2} hydrogenation on In\textsubscript{2}O\textsubscript{3}(110): A DFT study, \textit{ACS Catal.} 3 (2013) 1296–1306.
\end{enumerate}
**Quid pro quo: Engineering nitrogen self-sufficient cocultures**

Camil A. C. Diaz  
Advisor: Maciek R. Antoniewicz  
Committee Members: Wilfred Chen and Kelvin H. Lee

Diazotrophs, or organisms capable of converting atmospheric nitrogen into ammonia, are attractive coculture partners, offering a sustainable alternative to the Haber-Bosch process as a source of fixed nitrogen. However, efforts to engineer synthetic consortia are currently impeded by difficulties in predicting metabolic compatibility and achieving long-term stability.

In this contribution, we investigated the performance of an array of fully nitrogen self-sufficient cocultures involving an ammonium-secreting strain of the aerobic diazotroph, *Azotobacter vinelandii*. Coculture pairings were systematically designed to range from pure commensalism (e.g. with wild-type *E. coli*) to fully nitrogen and carbon self-sufficient, mutualist partnerships with engineered cyanobacteria. $^{13}$C labeling studies and metabolic flux analysis (MFA) unexpectedly revealed that the diazotroph shared the majority of its fixed nitrogen, even in commensalistic cocultures. For example, wild-type *E. coli* constituted more than 60-75% of a coculture population with a total OD of $\sim$5, and was maintained as 30-40% of the population in later stages, up to a total OD of $\sim$40. Furthermore, negative interactions could be overcome by introducing metabolic interdependence through genetic manipulation, e.g. by engineering the partner to secrete a carbon source suitable for the diazotroph. Preliminary adaptive evolution studies highlighted the surprising stability of such cocultures, where synthetic cross-feeding persisted over weeks of passaging. Ongoing work dually harnesses deep-sequencing and $^{13}$C-MFA of evolved cocultures to identify additional genetic and metabolic traits that enable enhanced community stability and overall growth. These results shed insight on how bioprocesses can benefit from the modularity, improved sustainability and potential cost reduction offered by diazotrophic cocultures.
Electrostatically Mediated Protein-Protein Interactions for Monoclonal Antibodies: a Combined Experimental and Coarse-Grained Molecular Modeling Approach

Glenn M. Ferreira
Advisor: Christopher J. Roberts
Committee Members: Abraham M. Lenhoff, Richard L. Remmele, Arthi Jayaraman

Electrostatically mediated protein-protein interactions (PPI) can greatly influence key product properties such as solubility, solution viscosity, and aggregation rates as a function of pH and ionic strength. Predictive models for these effects would allow for candidates to be screened with little or no protein material. A series of three monoclonal antibodies (MAbs) that displayed qualitatively different experimental PPI were evaluated at pH and ionic strength conditions that are commonly employed for product formulation. A range of interaction parameters (kD, B22, and G22) were obtained from experimental static and dynamic light scattering measurements. The resulting interaction parameters spanned from strongly repulsive to strongly attractive electrostatic interactions. Coarse-grained (CG) molecular simulations of PPI (specifically, B22) were used to compare against experimental B22, G22, and kD values across multiple pH and TIS conditions, using a model that treats each amino acid explicitly. Predicted B22 values with default model parameters matched experimental B22 values semi-quantitatively for some cases, whereas others required parameter tuning to account for effects such as ion binding. Protein net-charge values determined via membrane-confined electrophoresis (MCE) were compared to those predicted from SLS and coarse-grained simulations. The experimental PPI were also analyzed for each MAb within the context of single-protein properties such as theoretical and experimental net charge, and domain-based and global dipole moments. The results show that PPI are predicted qualitatively and semi-quantitatively by CG molecular modeling, and this can be useful as a computational tool for molecule and/or formulation assessment. PPI correlated with aggregation rates for some but not all antibodies, and in some cases were also indicative of electrostatically-mediated phase separation.
Solvent Effects on the Structure and Thermodynamics of Polymer Blends of Varying Architecture

Thomas E. Gartner III
Advisor: Arthi Jayaraman
Committee Members: Eric Furst, Michael Mackay, Darrin Pochan

Solvent processing techniques (e.g. solvent vapor annealing, flash nanoprecipitation, reverse emulsion assembly, various thin-film casting and coating processes) play a vital role in the fabrication of functional polymer materials. In each of these examples, the presence of solvent alters polymer thermodynamics by screening polymer-polymer and/or polymer-surface interactions, and solvent also tunes polymer dynamics by increasing chain mobility. These combined effects are often exploited to trigger some structural or morphological change in a polymer material. In addition to the tunability imparted by solvent processing, advances in synthesis have unlocked a widening library of nonlinear polymer architectures, such as cyclic, star, hyperbranched, and bottlebrush polymers. Nonlinear polymers exhibit interesting and complex physics, as entropic effects related to the interplay between chain ends and branch points can be leveraged to tune structure and properties such as chain entanglements, segregation to surfaces, rheology, and others. Thus, both solvent processing and altering chain architecture represent powerful and flexible techniques to control the structure of polymeric systems, without changing the polymer chemistry.

In this talk, we will explore the thermodynamic implications of the solvent processing of polymer blends of varying architecture (linear, cyclic, and 4-arm star) using molecular dynamics simulation and polymer reference interaction site model (PRISM) theory in order to provide a mapping between solvent content, chain architecture, and polymer blend structure. We will first present our coarse-grained model for polymer blends swollen by solvents, and describe how we parameterize the model to represent the experimentally-relevant polystyrene-toluene system. We will then discuss the application of the above computational techniques to calculate, both in real and Fourier space, the total intermolecular pair correlation functions, direct pair correlation functions, and effective interactions between polymer(s) and solvent(s) to characterize the blend structure and thermodynamics. In particular, we will show that in solvent-swollen blends of varying architecture, the size and effective hardness of the polymer chains control the structure of the resulting blend, regardless of the specific chain architecture, and discuss how the presence of solvent tunes these macromolecular characteristics of size and hardness.
A Tunable, Post-Translational Method for Controlling Prodrug Converting Enzymes in Cancer Cells

Andrew Gaynor
Advisor: Wilfred Chen
Committee Members: April Kloxin and Millicent Sullivan

Enzyme prodrug therapies, in which an innocuous prodrug is introduced and later enzymatically converted to the potent, active drug by a prodrug converting enzyme (PCE), is a promising direction for treating cancer. Unlike traditional chemotherapies, which offer no ability to target diseased cells specifically, PCEs can be deployed using a variety of targeted delivery mechanisms including cell-specific protein uptake through targeting peptides and transcriptional control through gene therapies. However, these strategies frequently suffer from “leaky” off-target effects which are amplified through the catalytic ability of PCEs. While these strategies have demonstrated potential individually, they often exhibit some off-target background in healthy tissues.

Degradation tags are a post-translational mechanism for controlling cellular protein concentration with much faster response times and lower background levels than transcriptional control. We propose a novel method for modulating degradation tag activity in mammalian cells by sterically blocking endogenous cellular proteins from acting upon the tags. By fusing a small peptide proximal to a degradation tag, the peptide’s corresponding protein-interaction partner is able to effectively conceal the degradation tag from the proteasome. In this manner, a protein of interest can rapidly have its fate altered from degradation to rescued resulting in a several-fold increase in cellular protein concentration. This system is tunable depending on the inherent strength of both the degradation tag and the protein-peptide pair’s interaction. Since this system operates independently of previously described translational or delivery control mechanisms, it could serve in tandem as a second mechanism for controlling PCE activity towards lower off-target consequences. This lends itself toward logic gate architecture, and thus it could expand the current complexity of cellular computing devices. Looking forward, the system can be adapted to detect one or more cancer-specific protein concentrations as a method for autonomously avoiding off-target PCE activity.
Biomass conversion reactions are frequently conducted in a solvent, due to the highly oxygenated nature of the feedstock.\textsuperscript{1,2} Thus, heterogeneous catalytic active sites exist at a solid-liquid interface, where the solvent can modify surface and adsorbate energetics. Even when the solvent does not play a direct role in the reaction mechanism, it can stabilize or destabilize adsorbates, intermediates, and transition states, often leading to markedly different rates and selectivities between solvent choices.\textsuperscript{3–6} However, solvent effects are poorly understood because catalyst characterization techniques, such as probe molecule adsorption in FTIR, are most often conducted under vacuum or in vapor phase.\textsuperscript{7,8} Further, most studies on solvent effects focus on screening solvents via catalytic activity testing, where multiple factors that can influence reactivity exist simultaneously: competitive adsorption, stabilization of reactants and transition states, and phase equilibria differences. Thus, there is currently a need for experimental techniques capable of extracting fundamental thermodynamic properties of solvents in simple systems, with the end goal of decoupling the effects of solvent in catalytic activity tests.\textsuperscript{9}

Attenuated total reflection (ATR) fourier transform infrared spectroscopy (FTIR) was used to characterize zeolites with probe molecules in the presence of solvent. The technique detected that basic probe molecules like pyridine became protonated by a purely Lewis acidic zeolite (Na/Y) in the presence of liquid water.\textsuperscript{10} This example shows that solvent choice has unique interactions with the zeolite framework, and the zeolite micropores can give solvent molecules properties unique from their bulk phase counterparts. The ATR-FTIR was further developed into a quantitative technique, with a procedure for determining extinction coefficients for adsorbed pyridine on zeolites in the presence of solvent.\textsuperscript{11} This allowed for quantitative comparisons of the effect of solvent on probe molecule uptake and protonation in zeolite pores. Ongoing applications of the ATR-FTIR cell include adsorption isotherms and diffusion measurements in porous materials in liquid phase. Further, the effect of solvent on charge stabilization in zeolite pores was studied using a homemade temperature program desorption (TPD) set up under back pressurized, flowing solvent. Preliminary pyridine desorption temperatures from H/ZSM-5 and H/Beta reveal that the ability of a solvent to stabilize pyridinium ions decreases in the order: acetonitrile > water > alcohol > alkane \approx \text{vacuum}.
Non-precious Copper-based Bimetallic Electrocatalysts for Hydrogen Evolution Reaction in Base

Wesley Luc
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The development of highly active non-precious electrocatalysts for hydrogen evolution reaction (HER) is critical for the development of low-cost water-splitting electrolyzers. Herein, a series of non-precious copper-based bimetallic materials was studied for HER in alkaline conditions to identify descriptors that could enable the future development of cost-effective and more efficient catalysts. We showed that alloying copper with small amounts of oxophilic transition metals, such as Ti, Co, and Ni, can significantly enhance HER activities in comparison to pure copper. Combining both density functional theory calculations and experimental investigation, we concluded that the hydrogen binding energy is the dominant descriptor for HER activity in base, whereas the oxygen binding energy is the secondary descriptor that describes the level of activity enhancement due to the synergistic interactions between the copper and the oxophilic metal.
Symbiotic Growth of Photoautotrophic and Heterotrophic Microorganisms

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Climate change due to rising atmospheric greenhouse gas concentrations is one of the most threatening problems facing humanity. Methods for capturing greenhouse gasses and producing biofuels have gained much attention. Microalgae and cyanobacteria can be used to capture carbon dioxide from point-source emitters and produce biofuels at high levels. Open bioreactors are needed to economically grow these photoautotrophs; however, heterotrophs often contaminate open bioreactors. The presence of heterotrophs can be advantageous in some cases, but frequently they are detrimental to the growth of photoautotrophs.

In this work, I show that *Chlorella vulgaris* UTEX #395 (a unicellular, non-motile, photosynthetic microalga) releases significant amounts of polysaccharides and proteins during photoautotrophic growth, termed “photosynthate”. Using *C. vulgaris* spent media, I isolated heterotrophic microorganisms from soil samples that can grow on the released photosynthate and used $^{13}$C-labeled photosynthate to confirm that soil microbes efficiently consumed it. In a co-culture with *C. vulgaris* the soil microbes significantly improved overall biomass production. Using pulse-chase tracer experiments in a co-culture of *C. vulgaris* and soil microbes, I demonstrated that soil microbes efficiently consumed photosynthate while *C. vulgaris* received carbon dioxide in return. The symbiotic exchange between the organisms where each partner benefited from the other was quantified using $^{13}$C-tracers. The increased understanding of photoautotroph-heterotroph interactions obtained in this study may help to improve the possibility of economically viable large scale biofuel production from waste carbon dioxide sources.
Electrochemical Synthesis of Ammonia Using Proton and Hydroxide Exchange Membrane Electrolysis Cells

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With the development of the Haber process and the subsequent work done by Bosch, ammonia production became an industrially and economically viable way to fix nitrogen. This helped increase the global population and estimates put it at about 40% of the global population’s food comes from ammonia made by the Haber-Bosch process[1]. However, the Haber-Bosch process is an energy intensive process requiring high pressure (15-30 MPa) and relatively high temperature (430 °C – 480 °C) and is highly centralized with only about 13 companies and about 29 plants[2, 3]. Renewable energy resources offer a possible alternative way to fix nitrogen at low temperature and low pressure to produce ammonia in a decentralized way. High temperature solid proton conductors have been used to produce ammonia selectively, but the high temperature can degrade the ammonia[5] and the required heating makes distributed production difficult. Low temperature polymer electrolyte membranes can be used which might reduce the overall energy input. The most prevalent polymer electrolyte is an acidic proton exchange membrane (PEM). Platinum group metals (PGMs) are the standard option for electrochemical testing, especially in PEM setups. However, they generally have low Faradaic efficiencies (FE) of less than 1% toward the electrochemical nitrogen reduction reaction (ENRR) with the rest going toward the hydrogen evolution reaction (HER). Hydroxide exchange membrane (HEM) utilize an alkaline environment which has shown to decrease the HER activity of PGMs. We performed a direct comparison and show that there is little to no change in the FE and a lower production rate for HEMs. With HEMs showing lower production rates, we examined other non-PGM catalysts for ammonia production, focusing on metal nitrides because metal nitrides have been predicted, computationally, to be more effective catalysts for ENRR, however, experimental verification has been lacking. We demonstrate that a transition metal nitride (Cr₂N) is an active and selective ENRR catalyst in a PEM electrolyzers. The specific ENRR rate $4.2 \times 10^{-11}$ mol·cm⁻²·s⁻¹) and Faradaic efficiency (1.79%) on Cr₂N are both approximately two orders of magnitude higher than those on Pt at -0.2 V. Overall, the bulk catalyst remains unchanged as confirmed by X-ray diffraction and X-ray absorption spectroscopy. X-ray photoelectron spectroscopy results indicate that chromium nitride species are the likely active phase in ENRR, and the leaching of surface N, which is accelerated at lower potentials, during ENRR causes catalyst deactivation.

References:
Sort-Seq Approach to Engineering a Formaldehyde-Inducible Promoter and Methanol Dehydrogenase for Synthetic Methylotrophy in *E. coli*

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The discovery of large natural gas reserves within the United States has led to increased interest in converting natural gas into liquid fuels and value-added products. Methanol production from methane has been increasing in recent years through chemical and bioconversion processes, and its increasing supply, declining price, and low contamination risk make it an ideal substrate for the production of chemicals and biofuels. Initial attempts to generate a strain of the model organism *Escherichia coli* capable of efficiently utilizing methanol as a substrate have been met with various metabolic bottlenecks.

Formaldehyde is a cytotoxic compound and the product of the first step of methanol assimilation, catalyzed by methanol dehydrogenase (Mdh). Challenges in synthetic methylotrophy include improper pathway balancing and low Mdh selectivity/activity, which can lead to low levels of methanol assimilation and the accumulation of formaldehyde in engineered methylotrophic *E. coli* strains. Here we characterize an *E. coli* transcription factor-based formaldehyde biosensor and engineer its corresponding operator sequence utilizing a robust and rapid sorting and sequencing (sort-seq) approach to achieve tight and tunable gene expression in response to toxic formaldehyde. The resulting analysis identified key mutations for tuning expression levels and were used to engineer formaldehyde-inducible promoters with predictable activities. Engineered variants demonstrated up to 14-fold lower basal expression, 13-fold higher induced expression, and a 3.6-fold stronger response as indicated by relative dynamic range. A similar sort-seq approach was applied to the heterologous *Bacillus stearothermophilus* Mdh and enabled the identification of amino acid positions of interest and mutations capable of achieving higher selectivity and activity towards methanol.
Differences in antibody transport at the human blood-brain barrier

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The blood-brain barrier (BBB) is the generally impermeable network of cerebral capillaries that tightly regulates molecular trafficking between the blood and the brain. As such, the BBB is a formidable barrier limiting the delivery of medicines to the brain. Notably, antibody therapeutics targeting neurodegenerative disease-related antigens demonstrate only 0.1% brain uptake. To help elucidate the transport of such medicines across the BBB, we use a hydrogel-based in vitro model of the BBB comprised of human induced pluripotent stem cell-derived brain microvascular endothelial cells. Time-lapse live-cell microscopy of fluorescent antibody conjugates is used to quantify transport and track intracellular processing. Differences in transport and intracellular processing between various antibody types were observed. Based on the different properties of the antibodies and molecules studied, a hypothesis on antibody transport at the BBB is integrated with current knowledge. In conclusion, these studies demonstrate the utility of a hydrogel-based stem cell-derived BBB model to characterize important attributes of therapeutics interfacing with the BBB.
One-step affinity capture and precipitation for enhanced purification of industrial mAbs using Z-ELP functionalized nanocages

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Protein A chromatography has been identified as a potential bottleneck in the monoclonal antibody (mAb) production platform, generating increased interest in non-chromatographic capture technologies. Affinity precipitation using environmentally responsive, Z-domain-elastin-like polypeptide (Z-ELP) fusion proteins has been shown to be a promising alternative. However, elevated temperature and salt concentrations necessary for precipitation resulted in decreased mAb monomer content and reduced purification capacity. To improve upon the existing technology, a tandem approach was employed to enhance ELP aggregation by enlarging the dimension of the capturing scaffold and by creating antibody-triggered scaffold crosslinking. This was accomplished by covalently conjugating the Z-domain-ELP (Z-ELP) capturing scaffold to a 25-nm diameter, self-assembled E2 protein nanocage (Z-ELP-E2) using enzymatic Sortase A ligation. The enlarged scale of aggregate formation and nanocage crosslinking through multivalent mAb binding resulted in the spontaneous capture and precipitation of mAbs from cell culture at ambient temperature without the addition of salt. After precipitating out of solution, the nanocage-mAb complex remained insoluble until resuspension in an elution buffer at pH < 4, allowing for the dissociation of the mAb from the Z-domain and dissolution of the aggregated complex.

A Z-ELP-E2 nanocage affinity precipitation process capable of purifying industrial mAbs as an alternative to Protein A chromatography was developed through optimization of key parameters. To challenge the capabilities of this technology, nanocage affinity precipitation was investigated using four industrial mAbs (mAbs A-D) and one Fc fusion protein (Fc A) with diverse molecular properties. A 3:1 Z:mAb binding ratio was sufficient to precipitate >95% for all molecules at ambient temperature without added salt. The effect of solution pH on aggregation kinetics was studied to elucidate crosslinking behavior. After pelleting the aggregated nanocage-mAb complex, all molecules remained insoluble and were capable of washing at pH ≥ 5, and were eluted with >90% recovery at pH < 4. The four mAbs and one Fc fusion were purified from clarified cell culture using optimal process conditions and >94% yield and >97% monomer content were obtained. mAbs A-D purification resulted in 3 logs of host cell protein and 4-5+ logs of DNA clearance from the cell culture fluids. Nanocage affinity precipitation was equivalent to or exceeded expected Protein A chromatography performance. Because of the operational flexibility afforded by this one-step affinity capture, the Z-ELP-E2 nanocage based approach has the potential to be a cost-effective alternative to platform mAb purification. Lastly, the Z-ELP-E2 technology was further improved utilizing the Spytag/Spycatcher isopeptide bond system as an alternative conjugation method to Sortase A ligation. Spytag/Spycatcher conjugation resulted in higher Z-ELP nanoparticle surface density, permitted the ligation of longer chain length Z-ELPs, and improved nanocage production and cost efficiency.
Conductive, Selective and Stable Polymeric Membranes for Redox Flow Battery

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Renewable energy sources, such as wind and solar, can help mitigate the issues of air pollution, climate change, and fossil-fuel shortage, but they are intermittent and thus their integration to the grid has to be managed. It has been suggested that if non-dispatchable renewable energy exceeds 20% of the energy-generation capacity without energy storage, electric grid could become destabilized. Thus, the key to the development of large-scale renewable energy is an energy storage system. Currently, redox flow battery technology (RFB) is considered as one of the best energy storage system for renewable power generation. The advantages of RFB include flexible designs, excellent scalability, and long cycle life, making them attractive for large-scale grid storage. Aqueous RFB are also safe compared to flammable lithium-ion batteries and reliable as the redox pairs are separated in different tanks during non-operation times.

Herein, several polymeric membrane developments towards different RFB systems have been conducted. A highly conductive in the acid environment and oxidative stable anion-exchange membrane for 3.08 V aqueous hybrid RFB based on corrosive cerium (IV) electrolyte was developed with grafting tris(2,4,6-trimethoxyphenyl) phosphonium to a hexafluoro-polybenzimidazole backbone. Methylated poly(benzimidazolium) was introduced to widely used all-vanadium redox flow battery (VRFB), and its low area specific resistance, as well as high voltage efficiency, was demonstrated with a detailed investigation of its degradation during VRFB operation. Poly(2,5-benzimidazole), which possesses the highest acid doping potential in the polybenzimidazole family, was synthesized and characterized in VRFB, its low area specific resistance led to a comparable voltage efficiency to Nafion 115 and much higher coulombic efficiency with promising capacity retention during long-term cycling test. In brief, the combination of conductive, selective and stable polymeric materials with advanced RFB designs makes a solid pace for RFB development.
Dynamic reciprocality between cells and their microenvironments during extracellular matrix (ECM) remodeling, such as with aging or injury, is hypothesized to influence cellular function and fate in the progression of various diseases. In order to understand the impact of this remodeling process on cell behavior, our goal is to design a synthetic ECM to mimic key aspects of matrix remodeling and to study its effect on cell fate. Specifically, we aim to test the hypothesis that microenvironment remodeling modulates the dormancy/activation of breast cancer cells in the late stage recurrence of breast cancer at a metastatic site\textsuperscript{1,2}. We have designed a three-dimensional hydrogel cell culture scaffold that can change its mechanical structure and biochemical cue presentation during cell culture. Towards this design, we have demonstrated increasing stiffness post hydrogel polymerization, and have synthesized a molecule that becomes reactive upon irradiation with ultra-violet (UV, 365 nm) light, which we propose for the functionalization of bioactive peptides to promote their temporal incorporation into the synthetic hydrogel. Additionally, we have conducted initial studies to test the incorporation of a UV light cleavable small molecule for the on-demand removal of peptide cues over time. We aim to utilize these approaches to mimic turnover of ECM occurring during aging and injury to probe cell response to these triggered remodeling events.

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