DEPARTMENT OF CHEMICAL & BIOMOLECULAR ENGINEERING

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2021 SUMMER RESEARCH REVIEW

SECOND YEAR TALKS

WEDNESDAY, JUNE 2, 2021

UNIVERSITY OF DELAWARE

GROUP 1

WEDNESDAY, JUNE 2, 2021

TIME	PRESENTER	ADVISOR
10:00 AM	Angyal, Nikolas	Marat Orazov
10:20 AM	Gupta, Yagya	Dion Vlachos
10:40 AM	Hansen, Kentaro	Feng Jiao
11:00 AM	**BREAK**	
11:20 AM	Kim, Quentin	Marat Orazov
11:40 AM	Yu, Kewei	Dion Vlachos
12:00 PM	**LUNCH BREAK**	
1:30 PM	Oliveira, Alexandra	Yushan Yan
1:50 PM	Selvam, Esun	Dion Vlachos
2:10 PM	Vance, Brandon	Dion Vlachos
2:30 PM	**BREAK**	
2:50 PM	Wu, Yurong	Dion Vlachos
3:10 PM	Kuo, Mi Jen	Raul Lobo
3:30 PM	Zhou, Jiahua	Dion Vlachos

GROUP 2

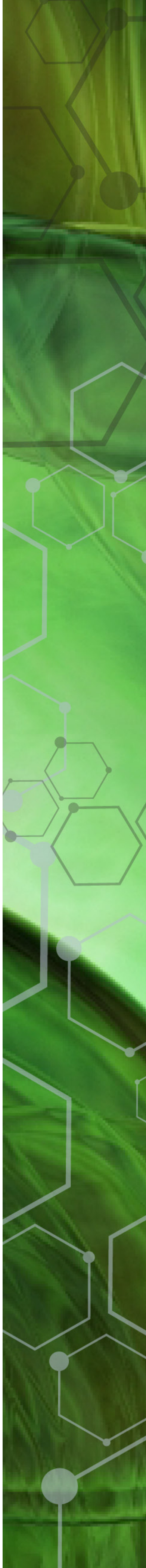
WEDNESDAY, JUNE 2, 2021

TIME	PRESENTER	ADVISOR
10:00 AM	Liao, Vinson	Dion Vlachos
10:20 AM	Ding, Chaoying	Marianthi Ierapetritou
10:40 AM	Srinivas, Sanjana	Dion Vlachos
11:00 AM	**BREAK**	
11:20 AM	Lu, Shizhao	Arthi Jayaraman
11:40 AM	Luo, Yuqing	Marianthi Ierapetritou
12:00 PM	**LUNCH BREAK**	
1:30 PM	Shoemaker, Terrance	Chris Roberts
1:50 PM	Tian, Huayu	Marianthi Ierapetritou
2:10 PM	Venkatarama Reddy, Jayanth	Marianthi Ierapetritou Terry Papoutsakis
2:30 PM	**BREAK**	
2:50 PM	Badejo, Oluwadare Abiodun	Marianthi Ieraptetriou
3:10 PM	Yang, Piaoping	Dion Vlachos

GROUP 3

WEDNESDAY, JUNE 2, 2021

TIME	PRESENTER	ADVISOR
10:00 AM	Becker, Matthew	Bramie Lenhoff
10:20 AM	Bhoyar, Soumitra Shrikant	Bramie Lenhoff
10:40 AM	Goncalves, Antonio	Millie Sullivan Wilfred Chen
11:00 AM	**BREAK**	
11:20 AM	Jachuck, Joshua	Terry Papoutsakis
11:40 AM	Kim, Jihyuk	Norm Wagner
12:00 PM	**LUNCH BREAK**	
1:30 PM	Naqi, Ahmad E A Y A	Michael Mackay
1:50 PM	Paul, Brian	Bramie Lenhoff Norm Wagner Eric Furst
2:10 PM	Rammohan, Mruthula	Millie Sullivan Thomas Epps
2:30 PM	**BREAK**	
2:50 PM	Willis, Noah	Terry Papoutsakis
3:10 PM	Wong, Yu Tai	LaShanda Korley



Valorization of Plastic Waste via Low Temperature Oxyfunctionalization

Nikolas Angyal
Advisor: Marat Orazov
Committee Members: Raul Lobo, Dionisios Vlachos

The widespread use of plastic in the modern world has been beneficial in many ways, but it has come at the expense of placing a massive burden on society in the form of an environmental crisis as plastic waste is dumped into landfills and the environment. Current plastic recycling methods are not equipped to handle the overwhelming load of plastic waste generation and the technology remains stagnant as plastic production increases. One of the major reasons for this is that current plastic recycling technologies are not viable for large-scale, efficient recycling of plastic waste, making it more economical to dump it in landfills instead. Chemical recycling of plastic waste provides a potential alternative to current recycling methods by turning the waste plastic into other valuable chemicals. This has proven easier for some polymers than others due to the level of functionalization present that makes it possible to perform selective chemistry. Some of the most challenging polymers to work with are the polyolefins – polypropylene and polyethylene – which lack almost all functionality along their carbon backbone. Although the technology is still in its infancy, there are a few chemical recycling methods for polyolefins that have received some attention from researchers such as pyrolysis, hydrogenolysis, and metathesis. All of these methods, however, require either high temperatures and pressures, or a low-value product that makes the economics of process scale-up challenging.

We have proposed a new method of chemical recycling for polyolefins called low temperature oxyfunctionalization. In the process, waste plastic is oxyfunctionalized via autoxidation to generate a polymer with oxygen-containing functional groups which permits subsequent chemistry to be performed targeting these functional groups to cause chain scission and the generation of value-added chemicals. For the purposes of our research we have used decane as a model molecule to perform initial experiments due to its ease of use relative to waste plastic. We have been able to successfully autoxidize decane at low temperatures (150 °C) to generate the desired oxygenates. The rate of formation of these oxygenates has also been improved via the use of initiators and system design.

Once the waste plastic undergoes autoxidation, additional chemistry will be needed to cause chain scission and break the polymer chain into more valuable products. Numerous reactions exist for this type of chemistry, and one of the well-known strategies for breaking carbon-carbon bonds is the Baeyer-Villiger reaction. We have begun exploring the use of the reaction in our system to oxidize the autoxidation products into shorter chain, value-added compounds. Work continues in this area with the future goal of combining these two reactions into one connected system that can take waste plastic and generate value-added chemicals.

Integration of Planning and Scheduling using Data-Driven Feasibility Analysis

Oluwadare A. Badejo
Advisor: Marianthi G. Ierapetritou
Committee Members: Antony N. Beris; Babatunde A. Ogunnaike

The economic success of a process industry is largely determined by its supply chain design, planning, and operation decisions. These decisions include the design of a robust supply chain network, and the deployment of supply chain resources to maximize profit while maintaining high customer service level. Optimal decisions necessitate the use of integrated models, which capture multi-level dynamics. Although integrated models improve accuracy of solution by leveraging the interconnection between decision making levels, they can become computationally intractable as problem's dimensions increase.

Operational planning and scheduling are concerned with allocating available resources over time to perform a set of tasks required to complete several customer orders for finished products. Integrating the planning and scheduling model improves the feasibility and optimality of the planning decisions by taking into consideration detailed scheduling constraints. The integration is achieved either using a simultaneous or hierarchical (sequential) approach[1]. Although the simultaneous approach can reach a coordinated and global solution, the resulting model can quickly become computationally intractable. Sequential approaches, on the other hand, needs to be refined appropriately to avoid infeasible solution. Therefore, additional coordinating constraints should be incorporated in the different decision levels to avoid the infeasibility issue. For the scheduling and planning problem, these coordinating constraints are resource limitations and the production cost evaluation. Surrogate models can be used to capture these coordinating constraints, hence reducing the computational complexity of the integrated approach.

In this work, we exploit three surrogate modeling strategies to capture the planning relevant information from the scheduling level. Support vectors method, linear models, and radial basis linear expansion. The last surrogate model exploits the radial basis function (RBF) kernel of support vector classifier by mapping the input data to randomized feature space and applying existing linear methods to this transformed predictor. Once the surrogate models were generated, their accuracy were tested using feasibility metrics[2]. Then, the integrated planning and scheduling problem is solved using the surrogates as aggregates of the feasible space. Solution to the integrated models were compared with that of the simultaneous method and results shows great accuracy while reducing drastically the computational time. This method offers potential advantage in considering large sized problems which are intractable using the simultaneous approach, further it can readily be extended to consider uncertainty.

References

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Measurement of Binding Affinity of CHO Host-Cell Proteins to Monoclonal Antibodies

Matthew L. Becker
Advisor: Abraham M. Lenhoff
Committee Members: Christopher J. Roberts, Kelvin H. Lee

Host-cell proteins (HCPs) are process-related impurities generated by Chinese hamster ovary (CHO) cells during upstream monoclonal antibody (mAb) processing. Although most HCPs are removed during downstream processing, a certain few can elude removal and persist even into the drug substance. One mechanism thought to enable this persistence is HCP product-association, wherein the HCPs bind to the mAb and then are not removed in subsequent chromatographic steps. In this study, three HCPs that have been previously shown to product-associate to mAbs were studied at three pH values using a seven-member library of industrial mAbs from two companies. Each of the combinations of pH, HCP, and mAb were analyzed via fluorescence polarization in order to determine the binding strength of HCP to mAb via the dissociation constant K_D. Results for K_D in both the nanomolar and micromolar range were seen, and the implications of these binding strength measurements for the removal of problematic HCPs will be discussed, as will the structure of the complexes formed by these HCP-mAb interactions.

Determinants of mAb capacity in protein A chromatography

Soumitra Bhoyar
Advisor: Dr. Abraham Lenhoff
Committee Members: Dr. Christopher J. Roberts, Dr. Eric M. Furst

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Protein A (PrA) affinity chromatography is widely used in the manufacture of monoclonal antibodies (mAbs) due to the high affinity and selectivity of the PrA ligands to the Fc fragment, a principal subunit of mAbs. Despite its ubiquitous use, the mechanistic details of PrA chromatography have not yet been characterized fully, and some factors may help in achieving an optimal balance between mAb yield and purity. The investigation here was prompted by a significant reduction in mAb yield during a high-pH wash to improve clearance of host-cell proteins. This loss of yield was found to result from an appreciable dependence of resin capacity on pH, including a significant decrease at high pH. We investigated further by seeking to distinguish the effects of pH on mAb affinity to the PrA ligand from effects that altered the capacity directly. We prepared Fc fragments by papain digestion and measured the dependence of their static capacity on pH. Similarly to the intact mAb, the capacity of the Fc fragment also drops at high pH, indicating that the high pH yield loss is a property intrinsic to the Fc fragment. Next, we fitted a chromatography model to the breakthrough and elution data generated using the intact mAb and the Fc fragments. We used the model to identify and distinguish between possible changes in mAb-PrA (or Fc-PrA) interactions and mAb-mAb (or Fc-Fc) interactions. The model parameters for the intact mAb and its Fc fragment will be compared, and possible mechanistic interpretations will be discussed.

Surrogate-based Feasibility Analysis for the Identification of Design Space of Multicolumn Continuous Chromatography for Antibody Capture

Chaoying Ding
Advisor: Prof. Marianthi Ierapetritou
Committee Members: Prof. Abraham Lenhoff, Prof. Babatunde Ogunnaike

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Monoclonal antibodies (mAbs) are the most widely used biopharmaceutical products. However, due to the fast expansion of market demand, continuous production becomes a promising alternative to produce mAbs, which has various advantages including higher and constant product quality, increased productivity and yield, smaller footprint, and rapid capacity adjustment [1]. With rapid improvements in continuous upstream processes like the development of perfusion bioreactors, continuous downstream processes have become the technical bottleneck in achieving the integrated continuous bioprocess, especially for primary capture. Protein A affinity chromatography is a benchmark tool for primary capture because of its high selectivity and efficiency, but its development is mainly impeded by the high resin costs. To address this issue, continuous chromatography like multi-column periodic counter-current chromatography (PCC) has been developed, which can efficiently improve productivity, increase resin capacity utilization, and lower buffer consumption [2]. In order to gain an insightful process understanding, design space can be identified to help determine the operational ranges and understand the main effects and interactions of process variables on product quality. Besides using design of experiments (DOE) to identify design space, modeling can be also employed to reduce the experimental cost and explore the impact of critical process parameters (CPPs) on the critical quality attributes (CQAs) [3], but mechanistic models would result in a tradeoff between model accuracy and computational cost.

In this work, surrogate-based feasibility analysis with adaptive sampling approach is proposed to identify the design space of multi-column PCC in an effort to balance model accuracy and computational complexity. To validate the applicability of this proposed methodology, twin-column CaptureSMB and three-column PCC are regarded as two case studies. Mechanistic models are first built, following by establishing the surrogate models based on the relationship between the inputs (process variables including interconnected loading time, interconnected flowrate, and batch flowrate) and the outputs (the maximum value among productivity, yield, and capacity utilization constraints) obtained from the developed mechanistic models. Using this approach, the change of design space with respect to different process variables is investigated based on active set strategy to thoroughly characterize the variations in column performance. In addition, the impacts of recovery-regeneration time, product quality constraints, and design variables on the design space are also studied.

References

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Modular Assembly and Delivery of a Worm-like Protein Nanoparticle

Antonio Goncalves
Advisor: Wilfred Chen, Millicent Sullivan
Committee Members: April Kloxin, Catherine Fromen

Biologics comprise a rapidly growing class of therapeutics, as evidenced by an increasing proportion of FDA approvals being for biologics in the recent years. However, looking at the composition of clinically-approved biologics, almost all are restricted to being cellular surface-targeted or vascular-targeted antibodies and antibody-drug conjugates. Delivery challenges such as membrane impermeability place limits on the accessible target space of biologics, preventing the current therapeutic use of additional proteins that have intracellular activity. To address these problems, nanoparticles have been investigated for their use as carriers in protein delivery. Their high capacity for surface-functionalized targeting ligands and size-scales imparts the potential for nanoparticles to overcome the delivery challenges seen in intracellular protein delivery. Yet nanoparticles have seen very limited translation to clinical use, which is primarily due to the low passive accumulation of many nanoparticle formulations to the diseased tissue site. Some strategies have been developed to try to counteract this by improving on the circulation half-life of nanoparticles, either by altering the physical parameters to allow for higher aspect ratios or by coating the surface of the nanoparticle with stealth ligands. However, these strategies have still yet to be effectively combined while still maintaining effective surface densities of targeting ligands for the intracellular delivery of proteins.

In our work, a targeted high aspect ratio nanoparticle is established by utilizing SpyCatcher-SpyTag isopeptide-ligating protein-peptide pairs to initiate linear assembly while simultaneously incorporating a yeast cytosine deaminase prodrug-converting enzyme therapeutic cargo as a building block to the development of a worm-like structure. Then by utilizing SpyCatcher variants with enhanced reaction rates towards the SpyTag peptide, tight control of the length of the worm-like nanoparticle can be established with the addition of a capping module. Further inclusion of stealth and targeting ligands onto the worm-like nanostructure can be facilitated through the incorporation of unnatural amino acids containing bioorthogonally reactive functional handles with controlled valency and spacing as to maximize circulation half-life and specificity in uptake. Currently, we have successfully shown the potential for our design strategy to create higher molecular weight ligated structures by utilizing a fluorescent protein as a model protein cargo. Future work will look to demonstrate control of the worm-like nanoparticle's physical parameters such as length and ligand valency with therapeutically relevant protein cargo, and optimize these parameters for maximization of circulation half-life and specificity in uptake to inflammatory breast cancer cells.

Upgrading Food Waste (FW) to High Commercial Value Chemicals

Yagya Gupta
Advisor: Dionisios G. Vlachos
Committee Members: Yushan Yan, Abraham M. Lenhoff, Souryadeep Bhattacharyya

The global challenge of food waste (FW) is evidenced by the fact that approximately a third of global food production (*i.e.*, 1.3 billion tons) ends up as waste. Traditional FW treatment methods, such as disposal into landfills and composting, are environmentally unfriendly. Intensive exploration of other methods that selectively utilize the diverse composition of FW to high commercial value chemicals is a key to alleviating this challenge. Extraction of antioxidant and antimicrobial activity providing chemicals (flavonoids, phenolic acids, etc.) from FW feedstocks is one such economically lucrative option to valorize FW. The choice of the solvent has been identified as a critical parameter affecting the efficiency of extraction. However, there is an insufficient fundamental understanding of the solvent selection process for FW extraction applications, with ethanol and methanol being a common choice. This study directly addresses this issue by focusing on solvent selection for enhancing the extraction efficiency of various phenolic compounds from FW. *In silic*o screening using ADF-COSMO-RS is conducted to identify solvents providing high solubilities for the target compounds. These predictions reveal more than 150 possible solvents provide higher solubilities than ethanol and methanol, with up to 15-fold enhancements. Analysis of sigma profiles reveals the underlying physicochemical interactions behind the enhanced solubility. Nine promising environmentally “green” solvents are then shortlisted. Experimental investigations of the solubility of representative phenolics in the selected solvents via HPLC show reasonable agreement with model predictions. Further, we also propose the replacement of high solubility, toxic solvents with green solvents. Furthermore, we investigate these solvents for microwave (MW) assisted extraction of the key compounds from potato peel waste and olive pomace. We optimize the process for independent extraction of target compounds and find correlations between MW reaction parameters and extracted compounds from diverse FW. This comprehensive study provides a general methodology for solvent selection and generates new insights into FW extraction.

Determination of mass transport/conductivity/active area tradeoffs for CO_2 electrolysis gas diffusion electrodes at high single-pass conversion

Kentaro U. Hansen
Advisor: Prof. Feng Jiao
Committee Members: Prof. Yushan Yan, Prof. Dionisios G. Vlachos

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Mitigating greenhouse gas emissions to a meaningful degree requires a simultaneous effort in many different sectors to electrify transportation, reduce emissions with electricity generation, and capture (and subsequently utilize or sequester) CO_2. In this mosaic of possibilities, the utilization of carbon dioxide as a feedstock in the production of chemicals and fuels can provide an economic on-ramp for more extensive CO_2 capture and sequestration. One CO_2 utilization technology, electrochemical CO_2 reduction, can leverage the rapid increase in cheap renewable electricity to add economic value to CO_2 capture. However, to make economic sense, electrolyzers will need to be stable on the order of years, operate at high single-pass conversion, operate at high current density, and be energetically efficient.

A key electrolyzer component that must be improved to meet all of these criteria is the CO_2 reduction cathode. Notably, since the feedstock is a gas, optimization of the cathode hydrophobicity is critical: too dry and you reduce the active catalyst area and instigate instability for any ionically conductive binder employed; too wet and the mass transport limit of the electrolyzer lowers the maximum possible current density. Furthermore, the high consumption rate of CO_2 (from conversion and other parasitic losses) will exacerbate technical issues from local CO_2 starvation, such as higher overpotentials to drive the reaction and a lower mass transport limit. Moreover, salt accumulation at high current densities can catastrophically lower electrode hydrophobicity. Therefore, there is a need to evaluate parameters that relate catalyst layer properties to the optimization and stability challenges. Using electrochemical impedance spectroscopy coupled with a four-point probe measurement system, a generalized mass transport resistance is experimentally derived for the CO_2 gas diffusion electrode. Then, preliminary results of modelling to use the derived resistance term is used to estimate the limiting current density and single pass conversion based on the design of the CO2 catalyst layer, temperature, and humidification. Furthermore, the rational design of CO2 catalyst layers may aid in the development of other similar technologies such as electrochemical CO reduction.

Megakaryocytic Microparticles as Efficient Gene Therapy Vectors Targeting Blood Stem Cells

Joshua R. Jachuck

Advisor: Professor Eleftherios T. Papoutsakis
Committee Members: Professor Catherine Fromen, Professor April Kloxin,
Professor Emily Day

A number of genetic disorders exist that can affect a person's hematopoietic (blood) cells, leading to hemoglobinopathies, immune deficiencies, bleeding problems and other serious health consequences. Gene therapy has the potential to cure these previously intractable diseases by correcting gene and protein expression in the afflicted cells. Previous gene therapy strategies have primarily focused on *ex vivo* manipulation of hematopoietic stem and progenitor cells (HSPCs), the precursors to all hematopoietic cells. However, to date, such strategies have suffered from safety concerns and logistical/economic challenges associated with *ex vivo* cell manipulation.

Megakaryocyte microparticles (MkMPs) could serve as a novel gene therapy vector and alleviate such concerns regarding the manipulation of HSPCs. MkMPs are a type of extracellular vesicle naturally secreted by megakaryocytes (platelet-producing cells) in the body, and can be produced by the *ex vivo* culture and differentiation of HSPCs to megakaryocytes. Through receptor-mediated interactions, MkMPs uniquely target and deliver nucleic acid cargo to HSPCs both *in vitro* and *in vivo*. It has been demonstrated that MkMPs can be exogenously loaded with pDNA via electroporation, and can deliver that pDNA to HSPCs *in vitro*, resulting in gene expression at levels of up to 6% of cells.

The present work aims to continue development of MkMPs as a gene therapy vector for pDNA delivery to HSPCs. Emphasis will be placed on improving the level of gene expression via the MkMP delivery method. Strategies such as plasmid and dose optimization, as well as the loading of additional cargo will be explored. A mechanistic understanding of the MkMP uptake and cargo delivery process will also be examined, with the expectation that findings could be applied to the engineering of MkMPs for further improvement of gene expression. Finally, performance of the MkMP vector will be explored in a murine model to evaluate clinical relevance.

Microscopic Structure and Dynamics of Attractive Polymer Nanocomposites

Jihyuk Kim
Advisor: Norman J. Wagner, Arthi Jayaraman, Antonio Faraone
Committee Members: Eric M. Furst, Lashanda Korley

Polymer nanocomposites (PNC), in which the addition of nanoparticle (NP) into a polymer matrix changes the overall system properties such as the mechanical, optical, and electrical properties relative to the host polymer, are already widely applied and studied because of their potentials in tunability, responsiveness, and functionality. However, sufficient understanding of the structure-dynamics-property relationship of these materials are lacking. This work seeks to quantify molecular level physicochemical properties, such as the nanoscopic structure and dynamics, of PNC and their relationship to the macroscopic rheological behavior. The fundamental understanding of this relationship will aid in developing a map of the effects of the vast parameter space of PNC on its bulk properties.

Here, silica nanoparticles (SiO2) in polyethylene oxide (PEO) in various sizes (10 nm and 50 nm in diameter) are investigated as model attractive PNC using scattering methods and rheology to connect the molecular level structure and dynamics to the macroscopic property. Small angle scattering techniques provide information on the dispersion of the nanoparticles as well as the conformation of the polymer chains via contrast matching SiO_2 with hydrogenated and deuterated PEO. The Gaussian nature of the structure of PEO has been confirmed independent of the loading of SiO_2. Dynamic neutron scattering techniques, such as backscattering and spin echo, are used to measure the effect of the different nanoparticles on the Rouse dynamics and reptation tube diameter. Data are interpreted in terms of standard theories developed for bulk polymers providing a mean to connect the microscopic dynamics to the observed rheological behavior. Raising the loading of the SiO_2 slows down the Rouse dynamics of PEO, this effect being enhanced with smaller NP which increase the interfacial surface for the same particle loading. The results provide insights into the role of surface, volume and nanoparticle dispersion in polymer matrix and shed light on how polymer dynamics is related to mechanical reinforcement of PNC.

Low Temperature Oxyfunctionalization of Propane

Quentin Kim
Advisor: Dr. Marat Orazov
Committee Members: Dr. Raul Lobo, Dr. Dionisios Vlachos

Over the last two decades, increases in proven reserves of natural gas and the shale gas revolution has led to a drastic rise in natural gas production from the United States[1]. While shale gas is primarily composed of methane, propane is also present in lower quantities and can be easily separated from the methane. The abundance of propane has generated interest in new and improved ways of processing propane. Industrially, propane is primarily used in propane non-oxidative dehydrogenation (PDH) for on-purpose propylene production. However, commercial PDH processes suffer from high temperatures, endothermic reactions, and catalyst deactivation[2]. There is currently no effective low temperature process for directly converting propane into products other than propylene, such as oxygenated species like isopropanol or acetone. Both isopropanol and acetone require expensive propylene processing methods and hazardous materials. It would be valuable to be able to produce oxyfunctionalized species from propane without extensive processing steps or dangerous catalysts.

We have observed that CeO_2 is capable of low temperature propane activation in oxidative dehydrogenation conditions. The reaction reaches nearly full oxygen conversion by 250 °C but does not produce appreciable amounts of propylene until 300 °C and higher. We hypothesize that propylene and other three carbon intermediates are present on the CeO_2 surface at low temperatures and are desorbed at higher temperatures. Desorbing partially oxidized species from the catalyst surface prior to over-oxidation could produce oxyfunctionalized species such as isopropanol at lower temperatures than other propane processes. In this work, we explored the effect of active site isolation, various catalyst morphologies, and liquid co-feeds on propane oxidation.

References

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Selective Synthesis of 4,4'-Dimethylbiphenyl from 2-Methylfuran

Mi Jen Kuo
Advisor: Raul F. Lobo
Committee Members: Mary P. Watson, Christopher J. Kloxin, Marianthi Ierapetritou

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4,4'-dimethylbiphenyl (DMBP) has been identified as one of the most valuable chemical platforms to the production of polymers, plasticizers, and metal-organic frameworks. For instance, 4,4'-biphenyldicarboxylic acid (BDA), which could be derived from the oxidation of DMBP, is an important precursor to engineering plastics, and in particular, it has been shown that incorporating BDA into polyethylene-terephthalate (PET) as a co-monomer greatly enhances the mechanical properties, such as glass transition temperature, strength, modulus and barrier properties. However, DMBP is difficult to produce from petroleum sources with significant selectivity given that there are six possible isomers of similar thermodynamic properties. In addition, it is completely derived from petroleum-based feedstocks. It would be desirable to have a biomass-derived substitute that could turn non-edible sugars into advanced materials.

In this talk I will present a two-step pathway to produce DMBP selectively using biomass-derived molecular precursors such as a 2-methylfuran (MF) and ethylene (Scheme 1). The first step consists of the oxidative coupling of MF to form 5,5'-dimethyl-2,2'-bifuran (DMBF) through Pd(II)-based homogeneous catalysis, and the second step consists of the addition of ethylene to DMBF via a tandem Diels-Alder cycloaddition-dehydration reaction using heterogeneous acid catalysts. A modified protocol for the oxidative coupling of MF to DMBF with $Pd(OAc)_2$ as catalyst is described. STY of the reaction ($6.99\ h^{-1}$) is improved by a factor of ~20 in presence of trifluoroacetic acid (TFA), compared with the previously reported STY value ($0.35\ h^{-1}$). High O_2 pressure and high TFA concentration are necessary to improve the DMBF formation rate. More importantly, phosphoric-on-silica ($P\text{-}SiO_2$) catalyzes the Diels-Alder dehydration tandem reactions of DMBF with ethylene to generate DMBP (83% yield), with a carbon balance of ~93%. The moderate Brønsted acidity of $P\text{-}SiO_2$ leads to the high conversion and selectivity, which catalyzes the dehydration of furan-ethylene cycloadducts selectively. No major coke formation, which is caused by the side reactions such as the alkylation or oligomerization of the cycloadducts, is observed. This alternative provides a completely renewable path to DMBP synthesis with a combined yield of 49% and selectivity of 78%. This result could enable multiple possibilities for the production of promising sustainable polymer-based industry and chemical products.

Characterization of Supported Subnanometer Clusters via Computational Infrared Spectroscopy

Vinson Liao
Advisor: Dionisios G. Vlachos
Committee Members: Antony N. Beris, Raul F. Lobo

Heterogenous single-atom catalysts (SACs) have been extensively studied due to their potential for high performance catalytic activity, while simultaneously minimizing noble metal usage. Determining experimentally the stability and morphology of single atoms and subnanometer clusters of few atoms remains a challenge, especially under working conditions. Adsorbate vibrational excitations are often used to determine structural properties, as they are selective to adsorbate/metal interactions. Infrared (IR) spectra associated with activating adsorbate vibrational modes are accurate and can be obtained quickly in situ or operando. Experimental infrared peaks are often assigned heuristically and are often the gold standards for well-defined single crystals, but they provide few details on structural characterization of subnanometer catalysts.

Here, we present a computational framework to characterize supported single-atoms and subnanometer clusters from adsorbate vibrational excitations determined from IR spectroscopy. We combine data-based approaches with physics-driven surrogate models to generate realistic synthetic IR spectra from first-principles vibrational calculations of carbon monoxide on palladium clusters supported on ceria. Due to the relative expense of first-principles vibrational calculations, their direct use for exploring the vast combinatorial space to directly match experimental spectra is beyond our current computational capabilities. Rather, we utilize calculations of energetically viable structures and apply realistic peak broadening to generate single-cluster primary spectra, analogous to pure component spectra in gas-phase IR spectroscopy. Finally, we perform peak deconvolution of complex synthetic and experimental spectra under the Bayesian Inference framework to predict cluster size distributions and quantify uncertainty. We discuss extensions of this computational methodology for characterization of other complex materials under realistic working conditions.

Modeling and simulations of polymer nanocomposites containing nanorods

Shizhao Lu
Advisor: Arthi Jayaraman
Committee Members: April Kloxin, Eric Furst

Polymer nanocomposites (PNCs) with nanorods as fillers have gathered considerable attention in the past decade because the anisotropic shape of these fillers imparts unique mechanical, optical, electronic and transport properties to the PNC. Even though past studies using theory, molecular simulation and experiment have provided strong fundamental understanding on how the isotropic interactions between the various components of the PNC affect the PNC morphology, studies focused on effects of directional interactions within the PNC (e.g., through hydrogen bonding between the nanorod and matrix polymer) are still lacking.

In the first part of this talk, we will address this knowledge gap. we will present coarse-grained molecular simulations of PNCs with nanorods as fillers with either isotropic interactions between all components of the PNC or with directional interactions between some/all components of the PNC. Through a systematic variation of the parameters (e.g., nanorod size, matrix chain length, strength of pair-wise interaction) in both systems, we are able to compare and contrast the morphological implications of isotropic and anisotropic/directional interactions between the various components of the PNC. Short nanorods with isotropic attraction phase separate and form randomly oriented aggregates, while short nanorods with directional attraction form percolating network in multi-dimensions. Long nanorods form parallelly aligned aggregates due to depletion interaction regardless of the type of chemistry.

The second part of the talk will focus on how the physical roughness affect the morphology and phase behavior of PNCs with nanorods under purely entropic interactions. We observe that at a fixed nanorod aspect ratio and nanorod volume fraction in PNCs, nanorod roughness reduces aggregation and promotes percolation. We will also discuss how the chain length of the polymer matrix affect nanorods of different roughness differently.

Sustainable Process Design, Techno-economic Analysis and Life Cycle Assessment of Biomass-based Chemical Production

Yuqing Luo
Advisor: Marianthi Ierapetritou
Committee Members: Dionisios Vlachos, Raul Lobo

Using biomass as feedstock for chemical production provides opportunities to reduce greenhouse gas emissions in chemical industry. However, biomass feedstock itself does not guarantee better environmental performance since other raw materials and utility usage may contribute significantly. It is of vital importance to improve the technologies and design sustainable processes to make them competitive with the incumbent oil-based production. Techno-economic analysis (TEA) and life cycle assessment (LCA) are essential tools to evaluate the economic viability and sustainability of new processes and guide their development at the early stage.

In the first part of this talk, different LCA methodologies will be reviewed and applied to a biomass-based p-xylene production. Two commonly used LCA methods are the bottom-up process LCA and the top-down economic input-output LCA (EIO-LCA). Currently, most LCA research follows the process LCA approach, which is inevitably subject to missing flows and truncation errors. Hybridization methods have been developed to reduce truncation error by incorporating EIO-LCA information and the practitioner's knowledge of the upstream production. Tiered hybrid LCA and integrated hybrid LCA with different double-counting elimination methods are presented in the comparison of concentrated acid (CA) and two p-xylene processes. The result shows that the integrated hybrid LCA is a flexible and effective method to account for chemicals that are not in the commercial process LCA database (e.g., Ecoinvent database and Gabi database).

The second part of the talk will focus on the process design and technoeconomic analysis of the pressure-sensitive adhesive production from different technical lignin feedstocks. Lignin is commonly used as the heat source in biorefinery or paper mill because of its complex structure and composition. Recently, reductive catalytic fractionation (RCF) of lignin has been developed to convert lignin into valuable phenolic monomers. It is further functionalized with methacrylic anhydride and copolymerized with butyl acrylate (BA) to synthesize the block copolymer used in the pressure-sensitive adhesive (PSA). This work compares the potential economic performance of the conventional RCF that operates under 80 bar and the intensified reactive distillation reductive catalytic fractionation (RD-RCF) under ambient pressure. The lignin depolymerization yields and product distributions obtained from the conventional and RD-RCF experiments were used to design two lignin-based PSA production processes in Aspen Plus V11. Although the minimum selling prices (MSP) are very sensitive to different lignin feedstocks, RD-RCF technology outperforms the RCF process in all scenarios considered due to its reduced capital investment and the additional revenue from valuable byproducts. Effective process improvements include producing MAAH in the plant to save feedstock cost and reducing the depolymerization reactor size by decreasing the solvent usage or reaction time using optimized reaction conditions. Our future work will perform systematic uncertainty analysis on the parameters and incorporate this information in the optimization framework for rational biorefinery designs.

Multi-material Fused Filament Fabrication via Core-Shell Die Design

Ahmad Naqi
Advisor: Michael Mackay
Committee Members: Antony N. Beris, Christopher J. Kloxin

Additive manufacturing (AM), commonly referred to as 3D printing, promises avenues of rapid prototyping with enormous customization and cost savings in the development of new designs. Fused filament fabrication (FFF), also known as material extrusion (ME), is one of the emerging AM technologies that creates three dimensional objects by adding a melted polymer in a layer-by-layer manner based on computer-aided design (CAD) models. Despite the substantial advancement in FFF, a key limitation for practical applications of FFF parts is the weak interlayer strength (aka, bond strength) due to the intrinsic layer-wise mechanism. More specifically, the poor interlayer strength is caused by insufficient interlayer polymer contact and diffusion during FFF. The use of composite core-shell filaments in FFF has demonstrated a promising approach for increasing the extensibility and impact strength of printed objects.

While much of the progress on trying to improve the mechanical properties of FFF 3D printed objects has focused on optimizing the processing conditions and developing new plastics, this coextrusion design aims to address poor mechanical performance using the first of its kind FFF extruder with a core-shell configuration. This novel design has been implemented as a means to improve the mechanical performance of printed objects by attaching a custom-made coextrusion system to the FFF machine. This new method advances the capability of FFF to extrude two different polymer melts simultaneously, using commercially available filaments, offering the advantage of producing composite filaments in a single step, which would otherwise necessitate multi-step operations.

In addition, thermal and rheological analyses are conducted to obtain an understanding of the temperature-dependent molecular processes during the FFF process due to its highly nonisothermal nature. A nonisothermal heat transfer model with embedded temperature-dependent rheological properties and a nonisothermal healing model were utilized to predict the inter-laminar fracture toughness degree of healing (DOH). In this study polyethylene terephthalate glycol (PETG) and acrylonitrile butadiene styrene (ABS) will be used as the shell and core polymers, respectively, as a preliminary example. Polymers that are more mechanically dissimilar will also be studied in the future.

Self-Supported Ni Foam Electrodes for Hydroxide Exchange Membrane Water Electrolysis

Alexandra Oliveira
Advisor: Prof. Yushan Yan
Committee Members: Prof. Feng Jiao, Prof. Marat Orazov

Green hydrogen has the unique ability to decarbonize energy-related sectors, such as chemical synthesis and long-range and heavy-duty transport, that currently have no economically viable zero-emissions alternatives. Water electrolysis is an environmentally clean technology that uses renewable electricity to split water into hydrogen and oxygen gas with no emissions, but production costs and electrolyzer efficiency must be improved if this technology is to compete with hydrogen derived from fossil fuels. Hydroxide exchange membrane electrolyzers (HEMELs) are a promising new technology that have the potential to achieve the high current densities and voltage efficiencies of their proton exchange membrane counterparts, without the harsh acidic environment, which requires the use of expensive platinum-group metal (PGM) catalysts and materials. Instead, the alkaline environment of HEMELs allows for the use of inexpensive PGM-free alternatives such as nickel and iron, but the slower kinetics of the hydrogen (HER) and oxygen (OER) evolution reactions in basic conditions requires improved utilization of the catalysts to achieve comparable performance.

Nickel foams show promise for use as electrode substrates to increase catalyst utilization due to their electrical conductivity and high surface area brought about by microscopic pores. The high surface area increases the number of active sites where water, catalyst, and a conductive polymer electrolyte come in contact, while the conductivity allows for catalyst layers to be grown directly on the nickel foams through electrochemical methods. In this work, we use spontaneous galvanic corrosion mechanisms to deposit nickel iron oxyhydroxide and platinum catalyst layers onto self-supported anodes and cathodes, respectively. These corroded nickel foams contain the kinetic active sites for the HER and OER while simultaneously facilitating the transport of liquid water and gaseous products to and from the catalyst, and they provide an opportunity for easily scalable commercial synthesis. By altering the platinum and acid content under synthesis conditions, we can increase the surface area to improve electrode activity and electrolyzer performance. We find that an electrolyzer with self-supported nickel foams at both electrodes achieves comparable performance in DI water to a commercial alkaline electrolyzer with concentrated potassium hydroxide electrolyte.

Structure and Rheology of Biopolymers Under High Pressure

Brian Paul
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Committee Members: Dr. Christopher Roberts, Dr. April Kloxin

The phase behavior of protein dense phases is not well understood, despite their presence both *in vivo* and during solution processing. The physical nature of the dense phase, whether crystal, dense liquid, or a non-equilibrium phase such as a gel, depends strongly on the solution conditions. Finding desired phase behavior, such as protein crystallization, gelation, or solubilization, can require extensive empirical exploration. We hypothesize that careful high-pressure (HP) control while holding temperature and pH constant can allow for biopolymer formulation steps without disrupting key properties, or for the successful manipulation of properties in a development step[1]. A novel high-pressure sample environment for simultaneous structural and rheological measurements is being developed to generate 4D structuration information (spatiotemporal structure-property relationships). Greene et al. showed for the first time that macroscopically amorphous salted-out protein dense phases can contain nanocrystalline regimes[2]. Further structural investigations of salted-out ovalbumin under ambient conditions are performed to validate the novel sample environment with a well-characterized protein dense phase. Small-angle neutron scattering (SANS), static light scattering (SLS), and small-angle x-ray scattering (SAXS) data are combined to provide a structural profile. Rheological information is to be obtained at HP using diffusing wave spectroscopy (DWS) microrheology. The results provide insights into the kinetics of nanocrystallite formation and resultant gelation within amorphous protein dense phases and provide a basis for my doctoral dissertation on the effects of pressure on biopolymer materials.

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Controlled release of nucleic acids into skin using photo-responsive polymers

Mruthula Rammohan
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Nucleic acids are potential therapeutics for various dermatological diseases such as skin cancer and psoriasis. However, current topical formulations, including polymer-based nanocarriers that encapsulate nucleic acids, are limited by (1) low penetration depth through the epidermis and into the dermis, and (2) lack of controlled release of cargo in the skin. Here, photo-responsive polymers encapsulating short-interfering ribonucleic acids (siRNAs) were designed for topical penetration and on-demand release of cargo in the skin. It was hypothesized that modifying the formulation of polymer nanoparticles of small sizes (~30 nm) with skin-penetrating components would enhance the accumulation of the polymer nanoparticles in hair follicles and enable the subsequent delivery of the particles to the dermis. To test this hypothesis, the formulations containing siRNA encapsulated by polymers were modified by addition of nanoparticles to ethanol. The hydrodynamic diameter of the particles after the modification was measured *via* dynamic light scattering. The stability of the nanoparticles against sodium dodecyl sulfate (SDS) was analyzed using gel electrophoresis, and the light-induced release of siRNA was probed *via* fluorescence correlation spectroscopy. The results of gel electrophoresis suggested that addition of ethanol led to improved stability of the particles against SDS, indicating that the nanocarriers will be stable in the anionic lipid-rich environment within cells. Future work will focus on the investigation of rate, depth, and mechanisms of nanoparticle penetration in porcine skin, with the goal of optimizing the formulation for non-invasive delivery of nanoparticles into the dermis.

Microwave-Assisted Glycolytic Depolymerization of Polyethylene Terephthalate using ZnO as catalyst

Esun Selvam
Advisor: Dionisios Vlachos
Committee Members: Raul Lobo, Yushan Yan, Marat Orazov

Plastics are extremely versatile materials and have become ubiquitous. However, due to the same reasons, these materials are very hard to degrade naturally and are overwhelmingly landfilled or leaked into the environment at their end-of-life posing a huge threat to the environment. Polyethylene Terephthalate or PET, which is used mainly for the production of single-use bottles, accounts for a significant fraction of the global plastic waste, and the currently employed recycling strategies are not adequate to deal with the global plastic waste problem. Over the years several chemical recycling strategies have been developed for plastic recycling, and glycolysis is one such method that has proven to be a promising solution for the depolymerization of PET. However, there are still several challenges that need to be addressed, especially in terms of finding active sustainable catalysts and making the processes more energetically efficient for them to compete with the current recycling technologies. The use of microwave heating in PET glycolysis offers many advantages over conventional heating is one way that could help us overcome the later issue. With the demonstrated ability to heat both more efficiently and more effectively, the technology seems well-suited for the fast and compact heating that would be necessary for the depolymerization of PET. In this work, we implement microwave technology to study glycolytic depolymerization of PET. We utilize different Lewis-acid metal salts to study the catalytic properties of these catalysts for the reaction and use the insights gained from this to identify Zinc Oxide (ZnO) as a very promising heterogenous catalyst for this reaction. We further study the morphological effects on the catalytic activity via controlled synthesis of ZnO of different morphologies. Lastly, we study the kinetics of the glycolysis reaction with ZnO using different microscopy techniques.

Analyzing the Predictive Capability of Coarse-Grained Simulation for the Viscosity of Antibody Solutions

Terrance William Shoemaker III
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Monoclonal antibodies (mAbs) are a unique class of protein therapeutics that assist immune systems target foreign or diseased species. The high interest in mAbs is due to the high binding affinity, high specificity, and the ability to target a diverse range of molecules. However, the unique chemistry that gives rise to its diverse application gives it unpredictable solution behavior. Properties such as increased viscosity or reduced shelf life influences the developablity of the mAb. Simulation provides a low-cost method for early prediction of these drug properties. The focus of this work is on analyzing mechanisms of interaction through a coarse grained simulation of antibodies and attempting find predictive models for the viscosity using the modes of interaction.

Virial coefficients measure multi-body interactions that can be useful for determine net protein-protein interactions (PPI) of mAbs at different solution conditions. Increased PPI between mAbs can lead to increase aggregation or reversible self-association clusters which could lead to higher viscosity. Simulations that are used to predict virial coefficients explore the energy landscape of the multi-body interaction explore and the configurations of the interacting mAbs. The energy landscapes of the configurations also show the mechanisms of interaction between the proteins in solution. These insights are a unique way to analyze the interaction at a molecular level and the specific amino acid's chemistry that contributes to the increase in viscosity in a variety of mAbs. This talk will characterize results found from the influence of two body interactions on the viscosity.

Patterns of the compactness of the configurations and energy of interaction did not show a direct effect on the measured viscosity. Additionally, the simulated virial coefficients for two body interactions as a function of solution conditions were used in a machine learning algorithm to find predictive model for viscosity. The accuracy and correlation of models using simulated osmotic virial coefficients as predictors are positive, but dependent on the training set used to generate the model.

Mechanistic understanding of the effect of active site size in the dehydrogenation of ethane on Co/SiO_2 catalyst

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Owing to the recent shale gas boom in the US, production of ethylene via catalytic dehydrogenation of ethane is a viable alternative to steam cracking. Earth-abundant 3d and 4d metals dispersed on oxide supports have been recently garnering attention as alternative dehydrogenation catalysts, owing to their non-toxicity and high selectivity. In particular, highly dispersed Co(II) on SiO_2 support has demonstrated high selectivity for ethylene (>95%) and good conversion. Two types of active sites have been experimentally investigated: sub-nanometer Co(II) oxide clusters; and monomeric Co(II) species in a tetrahedral coordination environment[1,2].

This paper investigates differences in catalytic activity of the two types of sites and attempts to uncover unexplored theoretical efficiencies in earth-abundant 3d and 4d metals for small alkane dehydrogenation. We map out catalytic pathways using density-functional theory (DFT) calculations, rank them in kinetic importance using micro-kinetic analysis and validate them by comparing with experimental data. We show that, contrary to what has been suggested in literature, the rate-limiting step on the catalytically dominant pathway on sub-nanometer Co(II) oxide clusters is the second C-H bond activation. Informed by this development, we explore modulation of the reaction rate by varying the metal center. We argue that on the dominant pathway on atomically dispersed Co(II) sites, the second C-H activation step entails a spin crossover. We use the Landau Zener model and non-adiabatic transition state theory to evaluate rate constants. Finally, we will present a comparison between the mechanisms (and corresponding barriers) on the two types of active sites and discuss implications for related metal ions with partially filled d-orbitals (Fe, Ni) and fully filled d-orbitals (Zn/SiO_2).

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RTD-Based Modeling and Uncertainty Characterization for Continuous Solid-Based Drug Manufacturing

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Over the last few years, there has been a trend in pharmaceutical industry to commercialize continuous manufacturing (CM) for the production of solid-based drug products, given its potential to reduce production costs while improving product quality[1]. To fully utilize the benefits of CM, it is important to properly design the process to guarantee the production of qualified drug products. Process design relies heavily on detailed understanding of the process characteristics, which gives rise to the need for developing process models. A variety of modeling techniques have been developed in the literature, including discrete-element method, population balance modeling, residence time distribution (RTD) modeling, and semi-empirical modeling. We focus on RTD modeling in this study because it is well-suited for building integrated flowsheet models with low computational cost while maintaining sufficient degree of characterization of the process behavior, particularly from a process dynamics point of view. This implies that given an upstream disturbance, the system’s response can be predicted using convolution of the developed RTD models with the disturbance. Consequently, the disturbance propagation can be tracked downstream to quantify its effects on final drug product quality[2].

RTD model parameters are determined based on RTD experiments conducted under steady-state operation. However, maintaining a steady state during manufacturing can be difficult due to numerous unpredictable events including fluctuation of flowrates, changes in flow patterns within unit operations, environmental changes and human-based variabilities. Thus, there is a certain degree of uncertainty inherently associated with the system and corresponding RTD models. This uncertainty can lead to significant implications for RTD flowsheet model applications like material traceability and diversion of out-of-specification (OOS) material. So, it is important to consider the process uncertainty and properly characterize its range and implications on drug product quality. To this end, we aim to develop an RTD-based flowsheet model encompassing quantification of the degree of uncertainty. The developed RTD flowsheet model can then be used to demonstrate its ability for disturbance propagation and precise determination of OOS products. The proposed methodology would pave the way for robust and efficient solid-based drug production as it provides a unique strategy to incorporate the effects of process uncertainty in maintaining drug product quality for CM applications.

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Bridging the Gap Between Model Alkane and Polyolefin Hydrocracking

Brandon C. Vance
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Plastics have become ubiquitous in modern society. Unfortunately, the current management of plastic waste (PW), based mainly on landfill disposal, is unsustainable. Chemical recycling of PW, particularly of polyolefins (PO), to liquid fuels and lubricants, is promising for generating value while diverting it from landfills.

Hydrocracking is widely exploited in refineries to valorize waxes and heavy oils (C_{20}-C_{50+}) and is attractive for the chemical recycling of PO. Hydrocracking catalysis is well understood for small alkanes (C_6-C_{12}). However, it is unclear if these model compounds' mechanistic concepts can be directly applied to PO systems.

Platinum on select oxides has been demonstrated to be active and selective hydrocracking catalyst. Moreover, its physicochemical properties are well established, making it an ideal candidate for fundamental studies.

The current work establishes a mechanistic framework for PO hydrocracking and identifies reactivity descriptors to close the gap between model alkanes and PO. We assessed the effects of each catalyst component loading on low-density polyethylene (LDPE) as a function of reaction conditions. Our results show that the catalyst composition and structure play a significant role in LDPE hydrocracking. We demonstrate that we can control the distribution to larger alkanes and enhance the branching in the residual polymer. Moreover, we identify key similarities and differences between the hydrocracking behavior of small alkanes and LDPE and propose a new macromolecular hydrocracking mechanism that departs from small alkanes. We perform extensive characterization of the catalyst, the products, and the residual polymer to provide structure-reactivity relations.

Modeling the effect of pH and Temperature on Chinese Hamster Ovary cell metabolism and glycosylation to optimize the production of monoclonal antibodies

Jayanth Venkatarama Reddy
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Committee Members: Professor Kelvin Lee and Professor Abraham Lenhoff

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Monoclonal antibodies (mAbs) based treatments have been established as one of the most successful strategies to treat various diseases. The number of mAbs that are approved by the FDA has been increasing every year and the number of mAbs that are falling off patents is leading to a rise in the biosimilar market. The increase in demand of mAbs, the large cost of mAbs and the rise of the biosimilar market leads to an increasing need to optimize the production to meet demand at reduced costs. Chinese Hamster Ovary (CHO) cells are the preferred choice for production of mAbs. Optimal bioreactor operation requires optimizing the pH, temperature, dissolved oxygen, media composition and feeding schedule. It has been demonstrated in the literature that the use of models can optimize the process while minimizing expensive experimental effort [1]. However, it is difficult to use currently available models to optimize the overall process as the majority of models in the literature do not incorporate the effects of pH, temperature and dissolved oxygen. The work performed here aims to incorporate the effects of pH on a model of CHO cell metabolism and glycosylation. VRC01 producing CHO cells were grown at various pH values in a bioreactor to develop a database for model regression. The model for metabolism and glycosylation was developed by integrating a combined kinetic and stoichiometric model for cell metabolism with a kinetic model for glycosylation [2,3]. The effects of pH were incorporated into the kinetic expressions of both the cell culture model and the model for glycosylation. Through the experimental data it is evident that changes in pH led to either accumulation or depletion of specific metabolites depending on examined conditions. This leads to suboptimal media performance. The proposed model will be used to determine the effect of pH on nutrient requirements as well as product quality, providing a platform to optimize bioreactor pH and media formulation as well as determining product quality. The subsequent goal is to perform similar experiments to incorporate the effect of temperature into the integrated model.

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Exploring Clostridial Co-culture Transcriptional Profiles Towards Engineering Microbial Syntrophy

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Microbial biotechnology breakthroughs have primarily relied on engineering individual species grown in monoculture. However, in most cases, microbes evolved specifically to function within a larger community. Although many modern biotechnological examples use sterile mono-cultures, industrial examples such as wastewater treatment and the fermented foods industry have already proven that co-cultures can succeed where mono-cultures fail. When grown in coculture, *Clostridium acetobutylicum* (*Cac*) and *Clostridium ljungdahlii* (*Clj*) have been demonstrated to increase carbon conversion via CO_2 capture, improve electron utilization via H_2 capture, and expand the metabolic space, producing valuable products, such as isopropanol and 2,3-butanediol, that neither monoculture produces independently. Recent work has shown that these unique metabolic outcomes seem to be due to cellular fusion events that lead to cytoplasmic exchange of RNA and protein. Further study of these events has the potential not just to improve biotechnological processes but to deepen our understanding of microbial community ecology and evolution.

The first part of this talk will discuss characterization of the genes and corresponding proteins involved in these cross-species cellular fusion events via transcriptomics. RNA sequencing (RNAseq) was performed on RNA samples extracted from *Cac*-*Clj* cocultures at three different timepoints, and differential expression analysis was performed using monoculture samples as controls. Preliminary analysis of these results shows changes in amino acid and cofactor transport and metabolism in both organisms, which, in some cases, appear complementary across the two species.

The second part of this talk will discuss exploration of a new coculture system combining *Clj* and an *Escherichia coli* (*E. coli*) strain engineered to express the *Cac* acetone production operon. In anaerobic monoculture, this *E. coli* strain accumulates approximately 20mM acetone, primarily due to conversion of acetate already present in the culture medium. However, in anaerobic coculture with *Clj*, this same strain produces approximately 100mM of net acetone that is either excreted or converted to isopropanol, suggesting that *Clj* substantially alters *E. coli*'s metabolism. Preliminary exploration also suggests that *E. coli* can shield *Clj* from oxygen in static aerobic cocultures.

Exploring the Relationship Between Architecture and Mechanics in Lignin-Derived Networks

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Lignin, the second most abundant biopolymer and the most abundant aromatic-based polymer in nature, is a promising precursor for the development of sustainable, performance-advanced polymers with the potential for lower toxicity compared to petroleum-based analogs. The inherent aromaticity of lignin-phenols derived from selective catalytic depolymerization aids in the generation of materials with tunable thermal and mechanical properties comparable to those of commercial plastics. One relatively unexplored area in lignin-derivable polymeric materials is the design of tailored crosslinked systems that incorporate not only the chemical tunability of the phenolic building blocks, but also the architectural flexibility driven by network design.

To this end, we have envisioned a comprehensive investigation to probe structure-property relationships in lignin-derivable networks that encompasses both chemical and structural diversity. Initial studies have focused on the design of single networks photopolymerized from lignin-derivable diacrylates with variations in chemical structure and aromaticity. To identify the network architecture and reaction kinetics, infrared spectroscopy was employed to monitor the conversion of the acrylate end groups, as the presence of unreacted groups indicates the bulky architecture. Next, thermomechanical properties, including glass transition temperature (T_g), storage modulus (G'), and the width of tanδ peak, were determined to gain the insights into the mechanics of the temperature dependent mobility of polymer chains, revealing that a more heterogeneous network occurs with the increasing number of aromatic rings per monomer. Preliminary study of tensile behavior further corroborates the mechanical strength brought by the aromatic structure without showing the yielding point on the stress-strain curve. Understanding the thermomechanical behavior of these single networks facilitates the development of design strategies to maintain high T_g and mechanical strength, while enhancing network flexibility and toughness. Potential approaches to meet this design challenge include the formation of (semi)interpenetrating polymer networks with a more extensible, bio-based second phase, the copolymerization with small quantities of aliphatic diacrylate monomer, and also the modification of the lignin-derivable phenolic precursors with flexible segments.

The dynamics of Brønsted acidity over tungsten-oxide modified platinum silica catalyst

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Metal-metal oxide (M-MO) paired bifunctional catalysts have been widely studied in biomass upgrading reactions. Promoted by multiple active sites, including metallic sites, acid sites, redox sites, and interfacial sites, M-MO catalysts show unique properties. Among the sites, metal oxide provides Brønsted acid sites crucial for isomerization and C-O bond cleavage via dehydration. However, because of the complexity of the co-existing site and metal-metal oxide interactions, nature-revealing and rational control of Brønsted acid sites remain challenging. Pt-WO_x supported catalyst, one typical M-MO pair, was chosen as a model catalyst to illustrate how the Brønsted acidity changes dynamically and why it changes from a structural viewpoint.

In this work, we use SiO_2 as a support for the convenience of characterization. To investigate the dynamics of Brønsted acidity derived by WO_x, we use *tert*-butanol dehydration reaction and pyridine chemisorbed FT-IR under several pretreatment conditions. Through Raman and FT-IR characterizations, we further explain the different acidity by structural changes. Results from this study provide insights into understanding, predicting the Brønsted acidity and structure of supported M-MO catalysts under working conditions, which are the prerequisites for universally developing M-MO catalysts with desired properties.

Highly Active Single-Atom Iron Catalysts towards Catalytic Transfer Hydrogenation of Furfural

Piaoping Yang
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Committee Members: Marianthi G. Ierapetritou, Raul F. Lobo

To reduce the dependence on fossil fuels and mitigate environmental issues, various methods and processes have been explored to covert abundant lignocellulosic biomass into fuels and value-added chemicals. The catalytic transfer hydrogenation (CTH) is a potential approach for the hydrogenation of lignocellulosic biomass to valuable chemicals, using organic molecules as the hydrogen donor. Atomic-dispersed metal-nitrogen-carbon (M-N-C) catalysts are promising candidates for this reaction in terms of cost-effective metal sites, high stability, and reactivity. However, the CTH reaction over M-N-C catalysts has rarely been explored, making the underlying relationship between local structures of M-N-C catalysts and reaction activity unclear.

Herein, by investigating the CTH of furfural (FF) to furfural alcohol (FA) over Fe-N-C and Zn-N-C catalysts using computational and experimental methods, we unravel the nature of metal center and coordination number (CN) of metal-N sites on the adsorption strength of FF and the reaction activity. For example, Zn-N-C catalysts show weak binding of FF and low activity owing to the weak oxygen affinity of the Zn center. In contrast, the Fe-N-C catalysts possess high affinity of oxygen, bind FF much stronger, and can exhibit high activity but also be susceptible to deactivation. This work provides important insights into the design of highly active M-N-C catalysts with specific active centers.

Ethane dehydrogenation over Co/SiO_2 and its high-temperature treatment effect

Kewei Yu
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Committee Members: Yushan Yan, Raul F. Lobo

Light olefins such as ethylene and propylene are important building blocks for modern chemical industries. With the increasing demand over the past decades and recent shale gas revolution, direct dehydrogenation of alkanes to olefins has become an economically viable choice to produce light olefins. Co/SiO_2 is a highly active and selective catalyst for light olefin dehydrogenation, which is also low-cost and environmentally friendly. However, the active site structure and reaction mechanism remain unclear and catalyst activity requires further improvement.

In this study, we synthesized Co/SiO_2 with a facile electrostatic adsorption method and optimized the catalyst activity by varying cobalt loadings and pretreatment conditions. A facile high temperature pretreatment method was found to increase the initial activity of the catalyst up to 4 times. Extensive spectroscopic characterizations such as FTIR, XAS, and XPS were conducted to investigate the structure-function correlations of Co/SiO_2. In addition, kinetics experiments were conducted and compared with micro kinetic modeling results, which reveals the active site structure. Post characterization indicates that hydrogen generated by the reaction plays a key role in catalyst deactivation by reduction and sintering of Co species.

The Role of Oxygen-Containing Functional Groups of Carbon Surfaces

Jiahua Zhou
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Oxygen-containing functional groups (OCFGs) on carbon surfaces impact catalytic performance in ways that are not well understood. For example, the hydrophilicity and acidity-basicity of carbon materials could be controlled and these can change reactivity. Notably, some of the acidic OCFGs could act as Brønsted acid sites. Currently, the identification of the nature and the characterization of the amount of OCFGs remains a challenge due to their complexity. FTIR is normally used to characterize OCFGs, but carbon appears dark black powders make IR rays absorbed, causing weak signals that are difficult to analyze. TPD-MS can detect all OCFGs over a temperature range from 500 to 1200 K. Still, multiple OCFGs may decompose at similar temperatures and cannot be confidently correlated to specific OCFGs. Furthermore, the effect of the microenvironment of carbon-based catalysts on catalytic performance in hydrodeoxygenation (HDO) of biomass upgrading remains poorly understood.

In this study, we apply probe molecules to conduct alcohol dehydration reaction and investigate the acidic OCFGs (Brønsted acid sites) of a diverse library of materials we synthesize. Those probe molecules undergo acid-catalyzed elimination reactions and are sensitive to the acidic OCFGs on carbon surfaces. Comprehensive XPS characterization, machine learning (principal component analysis), as well as operando XPS characterization are coupled with kinetics to identify the acidic OCFGs on carbon surfaces and correlate structure and specifically OCFGs with the observed reactivity.

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