

PROCEEDINGS

Carnegie Mellon University
Department of Chemical Engineering



48th ANNUAL CHEMICAL ENGINEERING
GRADUATE STUDENT ASSOCIATION SYMPOSIUM
OCTOBER 15–16, 2026

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Introduction

Welcome to the Carnegie Mellon University Chemical Engineering Graduate Student Association (ChEGSA) 48th Annual Research Symposium. As one of the first student-run research symposia, the ChEGSA Symposium has grown to be one of the largest and most successful among major universities.

The Symposium was initiated in 1979 when Professor Tomlinson Fort suggested it to the governing members of ChEGSA as an opportunity to exchange research ideas within the department and to connect graduate students with industry. Since then, industrial partnerships have become increasingly important each year and have helped the Symposium gain the stature that it holds today. It provides a model for other departments looking to establish similar forums. Without the generous financial support of numerous corporate sponsors and contributors, the continued growth of the Symposium would not be possible.

The ChEGSA Symposium serves many important functions. It provides graduate students the opportunity to present their research work to a diverse audience, fostering an appreciation and awareness for the complexity of research being carried out within the sub-disciplines of chemical engineering. The Symposium also cultivates extensive ties and partnerships between the department and industry. Participating companies and graduate students have enjoyed the ability to meet and connect outside of a formal recruiting context.

This year's 48th Annual ChEGSA Symposium will feature graduate student presentations that highlight research being carried out in the chemical engineering department across a range of research areas. These include bioengineering, process systems engineering and optimization, environmental engineering, solid-state materials, fluid dynamics, and colloids, polymers, and surface science. The two-day program also includes one keynote presentation, a career panel discussion, a poster session, and a luncheon for our industrial guests, presenters, and faculty. At the conclusion of the Symposium, three awards and two honorable mentions will be given to the best student presenters, along with an award for the best student poster. Members of the faculty and our industrial guests will serve as judges and provide feedback on student presentations.

We are excited to have you join us and hope to see you again in future years! Information on both previous and upcoming symposia can always be found on our website at <http://chegsa.cheme.cmu.edu/symposium/>.

Sincerely,

Owen Gerdes
Charlotte Tausche
Anna Witte
2026 ChEGSA Symposium Chairs

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Gold Level Sponsors



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Judging Process and Awards

All student oral presentations will last for no longer than twelve minutes and will be immediately followed by a two-to-three minute question and answer session.

To provide constructive criticism that will enable the students to improve their communication skills, a panel of judges will evaluate the technical content and delivery of each student's presentation. Technical content will be judged on the basis of clarity of objectives, presentation of methodology and results, appropriateness of conclusions, and overall organization of ideas. Delivery will be evaluated on the basis of audience contact, quality and use of visual aids, and responses to questions.

The final standings are based on the scores given by the judges to the students for criteria in both technical content and delivery. The final score for an individual student is calculated as the product of the average of total scores from each judge and a normalized weighing factor. The weighing factor accounts for variations between judges across the sessions.

Five finalists will be chosen based on the final standings. The speaker with the highest final score will receive the Geoffrey D. Parfitt Memorial Award. Two symposium awards and two honorable mention awards will also be given out as well. To continue the tradition of the previous symposium, one oral presenter will be selected based on the choice of first-year Ph.D. students.

In addition to the awards for oral presentations, there is an award for the best student poster. The posters will be judged for their effectiveness in communicating research results through use of visual media. Judging will be based on the dual criteria of technical content (clarity of objective, presentation of theory and results, appropriateness of conclusions, and overall organization of thoughts) and visual impact. Posters will be evaluated by individual judges with the best poster selected by the consensus of the entire judging panel.

All award winners, apart from honorable mentions, will receive money to be used for professional education expenses such as costs incurred while presenting a paper at a national conference or purchases of reference books, computer software, computer hardware. The prize values will be distributed as outlined below.

<i>Geoffrey D. Parfitt Memorial Award (1):</i>	\$300
<i>Symposium Awards (2):</i>	\$150
<i>Honorable Mention Awards (2):</i>	Acknowledgement
<i>Gary Powers Poster Award (1):</i>	\$100
<i>First Year Impression Choice Award (1):</i>	\$40

The Geoffrey D. Parfitt Memorial Award

Dr. Parfitt had been a Professor of Chemical Engineering at Carnegie Mellon University since 1980. He was internationally known for his contributions to the fields of colloid and surface science and powder technology. He was the author or co-author of over 100 publications including 11 books (editor of 8), was a chairman of six conferences, and was a member of five editorial boards.

On July 7, 1985, Dr. Geoffrey D. Parfitt unexpectedly passed away. To honor his memory, ChEGSA established the *Geoffrey D. Parfitt Memorial Award For Excellence in Oral Presentation*. This was an appropriate category for an award in Dr. Parfitt's memory because he always emphasized the importance of good oral communication. The competition for this award is open to all students presenting at the symposium. It will be awarded to the student with the highest presentation score. The winner's name will be engraved on a plaque located in the ChEGSA lounge. The plaque was made possible by the American Chemical Society's Division of Colloid and Surface Chemistry. The student will also receive a certificate of recognition and a cash award of \$300. The award was made possible by an endowment established by the following organizations:

Alcan International, Limited

Alcoa Corporation

Exxon Research and Engineering Company

Glidden Coatings and Resins

International Fine Particles Research Institute

Monsanto Industrial Chemicals Company

PPG Industries

The Gary Powers Poster Award

Dr. Powers was a leading researcher in process systems engineering, specifically in the area of process risk assessment and in process synthesis. He co-authored the text *Process Synthesis*, the first text in this area. Gary's seminal research contributions to safety analysis covered more than three decades. He developed new methods for efficiently generating detailed fault trees for quantitative risk assessment. He applied these methods in industry with great success, and in 1976 he founded the company Design Sciences, Inc. Gary developed theories and models for synthesis and evaluation of high integrity operating procedures. He pioneered novel approaches for the verification of real-time control systems combining chemical engineering models with software engineering techniques. His enthusiasm in the academic setting was appreciated by his students, and he was often awarded the "Kun Li Award for Excellence in Education" by graduating seniors. On July 23, 2007, Gary Powers passed away. This award is intended to continue Professor Powers's strong support of education. The Gary Powers Poster Award will be awarded to the student with the highest poster presentation score.

Keynote Addresses

Since 1984, the Symposium has featured a keynote address from a researcher of international standing to promote excellence in oral presentation. To honor the 48th anniversary of the Symposium, we have one keynote speaker for this year's event.

The **Lubrizol Corporation Keynote Address** will be given by **Dr. Antonio Del Rio Chanona**, Associate Professor, Imperial College London.

Antonio del Río Chanona is Associate Professor in Chemical Engineering at Imperial College London, where he leads the Optimisation and Machine Learning for Process Systems Engineering group. He is Co-Director of the Centre for Doctoral Training in Next Generation Synthesis and Reaction Technology and Associate Director for Education at the Sargent Centre for Process Systems Engineering, and research chair of the European Federation of Chemical Engineering for Artificial Intelligence.

His research develops optimisation and artificial intelligence methods for chemical and biological systems, with particular emphasis on Bayesian optimisation, reinforcement learning, hybrid modelling, and large-language-model and multi-agent systems. These methods are applied to autonomous experimentation, bioprocess development, molecular and process design, industrial control, and sustainable chemical value chains.

Antonio received his degree in Chemical Engineering from UNAM and his PhD from the University of Cambridge, where he was awarded the Danckwerts-Pergamon Prize for the best PhD thesis of his year. His distinctions include the IChemE Junior Sargent and Nicklin Medals, an EPSRC Research Fellowship and recognitions from the International Federation of Automatic Control and the European Operations Research Society. He is actively involved in teaching, mentoring and the organisation of international training programmes in optimisation and machine learning.

Keynote History

1984	Ed Cussler	University of Minnesota
1985	Dan Luss	University of Houston
1986	George Keller	Union Carbide
1987	Alexis Bell	University of California, Berkeley
1988	Eduardo Glandt	University of Pennsylvania
1989	Robert Anderson	Monirex Systems, UOP Inc.
1990	Michael Shuler	Cornell University
1991	Michael F. Doherty	University of Massachusetts, Amherst
1992	John O'Connell	University of Virginia
1993	Elizabeth Dussan	Schlumberger Doll
1994	Joe Pekny	Purdue University
1995	Doug Lauffenberger	Massachusetts Institute of Technology
1996	Mark Barteau	University of Delaware
1997	Alice Gast	Stanford University
1998	John Perkins	Imperial College, London UK
1999	Michael Shuler	Cornell University
2000	Klavs Jensen	Massachusetts Institute of Technology
2001	Ed Cussler	University of Minnesota
2002	Mario Molina	Massachusetts Institute of Technology
2003	John M. Prausnitz	University of California, Berkeley
2004	H. Scott Fogler	University of Michigan
2005	Arthur W. Westerberg	Carnegie Mellon University
2006	Carol K. Hall	North Carolina State University
2007	James Anderson	Harvard University
2008	John Walz	Virginia Polytechnic Institute
2008	Jeffrey J. Sirola	Eastman Chemical Company
2009	Georges Belfort	Rensselaer Polytechnic Institute
2010	Rakesh Agrawal	Purdue University
2010	Karl Jacob	The Dow Chemical Company
2011	Menachem Elimelech	Yale University
2012	George Stephanopoulos	Massachusetts Institute of Technology
2013	Enrique Iglesia	University of California, Berkeley
2014	Kristi S. Anseth	University of Colorado, Boulder
2015	Norman J. Wagner	University of Delaware
2016	Michael F. Doherty	University of California, Santa Barbara
2017	Athanasios Nenes	Georgia Institute of Technology
2018	Linda Broadbelt	Northwestern University
2018	David C. Miller	The National Energy Technology Laboratory
2019	Abraham Stroock	Cornell University
2019	Hari Pujar	Spark Therapeutics
2020	Howard Stone	Princeton University
2021	Susan Soloman	Massachusetts Institute of Technology
2021	Rebecca Liebert	The Lubrizol Corporation
2022	David Scholl	Oak Ridge National Laboratory
2022	Muge Eridrick Dogan	Amazon Fashion
2023	Christos T. Maravelias	Princeton University
2023	Carl Belshauses	Impossible Foods
2024	Victor Zavala	University of Wisconsin-Madison
2024	Celia Cruz	Eli-Lilly and Co.
2025	Jennifer Jackson	Walmart
2025	Lilo Pozzo	University of Washington

The Lubrizol Corporation Keynote Address

Machine Learning for Chemical Engineering: From Automated Experimentation to Intelligent Process Control and Large Language Models

Dr. Antonio Del Rio Chanona

Associate Professor
Imperial College London

Abstract

Machine learning is increasingly changing not only how we model chemical engineering systems, but also how we design experiments, operate processes, and interact with engineering knowledge. In this talk, I will discuss some of the opportunities that arise when machine learning moves from prediction towards decision-making.

I will first introduce Bayesian optimization as a framework for automated design of experiments, where experiments are selected sequentially to learn efficiently while balancing exploration and exploitation. I will discuss how these ideas can be used in chemical engineering and industrial research, particularly when experiments are expensive, data are limited, or operating constraints must be respected. I will then consider reinforcement learning as a data-driven approach to process control, including applications to complex industrial systems and bioprocesses such as microalgae cultivation.

Finally, I will discuss some of the rapidly emerging opportunities created by large language models and agentic AI in chemical engineering, including systems that can interpret engineering information and automatically construct process simulations from flowsheets and images. Throughout the talk, I will use examples from our research and collaborations with industry to highlight both what these methods can already do and some of the challenges that remain.

Thursday, October 15
Morning
Doherty Hall 1212
Keynote Talk Location: Doherty Hall 2210

Session Chairperson

Edwin J. Lebrón Pérez

Judges

Dr. Jim Schneider Carnegie Mellon University

Dr. Sebastian Uribe PPG

Program

- 8:30–9:20 **Breakfast and Registration**
- 9:20–9:30 **Welcome and Opening Remarks**
- 9:30–9:45 **Mechanisms of horizontal gene transfer via lipid nanoparticle recycling**
Samantha Yang · Advised by Dr. Katie Whitehead
- 9:45–10:00 **Graph Neural Networks for Supply Chain Resiliency Mapping**
Arsh Bhatia · Advised by Dr. Carl Laird and Dr. Ignacio Grossmann
- 10:00–10:15 **Interfacial Stress as an Environmental Cue for Adaptive Material Assembly by *Brucella pituitosa***
Shakira Marie Martínez Vásquez · Advised by Dr. Tagbo H.R. Niepa
- 10:15–10:30 **Break**
- 10:30–11:45 **The Lubrizol Corporation Keynote Address (Doherty Hall 2210)**
Dr. Antonio Del Rio Chanona, Associate Professor, Imperial College London
Machine Learning for Chemical Engineering: From Automated Experimentation to Intelligent Process Control and Large Language Models
- 11:45–1:15 **Recruiting and Networking Luncheon**
By invitation: speakers and industry guests

Thursday, October 15
Afternoon I
Doherty Hall 1212

Session Chairperson

Malena Rybacki

Judges

Dr. Bob Tilton Carnegie Mellon University
Dr. Javier Lanauze PPG

Program

- 1:15–1:30 **Mixing oil and water without stirring: a generalized diffusion path theory of spontaneous emulsification**
Emerson Uhlig · Advised by Dr. Aditya Khair
- 1:30–1:45 **Under-oil Microfluidic Platform for Monitoring *Babesia microti* Pathogenesis**
Amy Apgar · Advised by Dr. Tagbo H.R. Niepa
- 1:45–2:00 **Multi-agent Process Design: The role of Game Theory and Reinforcement Learning**
Andres I. Cardenas · Advised by Dr. Ana Torres
- 2:00–2:15 **Break**

Thursday, October 15
Afternoon II
Doherty Hall 1212

Session Chairperson

Naseeha Mohammed

Judges

Dr. Sami Mohammed The Lubrizol Corporation

Dr. Steven Iasella Dow

Program

2:15–2:30 **One Treatment, Four Strains: Electrochemical Therapy
Against Multidrug-Resistant *Candidozyma auris***
Camila Cue · Advised by Dr. Tagbo H.R. Niepa

2:30–2:45 **Designing Dynamic Bicontinuous Thermosets through
Polymerization-Induced Microphase Separation**
Edwin J. Lebrón Pérez · Advised by Dr. Daphne Chan

2:45–3:00 **Influence of electrostatic and non-electrostatic interactions
on the partitioning of colloidal particles in polyelectrolyte
complex coacervates**
Maryam Ali · Advised by Dr. Bob Tilton

3:00–3:15 **Break**

Thursday, October 15
Afternoon III
Doherty Hall 1212

Session Chairperson

Khantey Lim

Judges

Dr. Lorenz T. Biegler Carnegie Mellon University
Dr. Anna Akkus The Lubrizol Corporation

Program

- 3:15–3:30 **Algal-Based Biopolymers: Design and Synthesis of
Spirulina-Derived Cyanophycin Elastomers**
Hannah Elaine Schutte · Advised by Dr. Daphne Chan and Dr. Coty
Jen
- 3:30–3:45 **A Decomposition Approach to Power Grid Capacity
Expansion Planning under Operational Uncertainty**
Sergio Bugosen · Advised by Dr. Carl Laird and Dr. Chrysanthos
Gounaris
- 3:45–4:00 **Protein Corona Engineering Enhances Lipid
Nanoparticle-Mediated RNA Transfection in the Heart**
Naseeha Mohammed · Advised by Dr. Katie Whitehead and Dr. Jim
Schneider
- 4:00–4:15 **Break**
- 4:15–4:30 **Closing Remarks**
- 4:30 **Networking Reception and Mixer**
Graduate Lounge, Doherty Hall A209

Friday, October 16
Morning
Doherty Hall 1212

Session Chairperson

Arsh Bhatia

Judges

Dr. Aisulu Aitbekova Carnegie Mellon University
Dr. Len Gerlowski Gerlowski Consulting

Program

- 8:30–9:20 **Breakfast and Registration**
- 9:20–9:30 **Opening Remarks**
- 9:30–9:45 **Post-translational modifications shape tau aggregation behavior and self-assembly**
Ladan Nikfarjam · Advised by Dr. Anne Robinson and Dr. Daphne Chan
- 9:45–10:00 **Automating Process Synthesis for Critical Minerals with Hierarchical Reinforcement Learning**
Robert Maligon Querimit · Advised by Dr. Ana Torres
- 10:00–10:15 **Processing-Induced Evolution of Protein Secondary Structure and Mechanical Properties in Dynamic Reprocessable Protein-Based Polymer Networks**
Sunny Surprenant · Advised by Dr. Daphne Chan
- 10:15–10:30 **Break**
- 10:30–11:45 **Panel Discussion: Navigating Career Decisions**
Doherty Hall 2210
Moderator: Charlotte Tausche
Panelists: Dr. Antonio Del Rio Chanona (Imperial College London), Jennifer Larimer (Dow), and Dr. David Adrian (Dow)
- 11:45–12:45 **Luncheon**
- 12:45–2:45 **Poster Session**
Doherty Hall A226

Friday, October 16
Afternoon
Doherty Hall 1212

Session Chairperson

Gayatri Moghe

Judges

Dr. Ana Ines Torres Carnegie Mellon University
Dr. David Adrian Dow

Program

- 3:00–3:15 **Multi-Period Robust Optimization for Designing Membrane
Diafiltration Systems Under Operational Disturbances**
Jason Yao · Advised by Dr. Chrysanthos Gounaris
- 3:15–3:30 **Covalent sidechain modifications modulate self-assembly
behavior of amyloid-like fibrils**
Andrew Ashmar · Advised by Dr. Daphne Chan
- 3:30–3:45 **Computational screening of high-internal phase emulsion
stability using physics-informed dataset splitting and
interpretable machine learning**
Peter Cook · Advised by Dr. Bob Tilton
- 3:45–4:00 **Break**
- 4:00–4:15 **Closing Remarks**
- 4:15 **Reception and Awards Ceremony**
Graduate Lounge, Doherty Hall A209 (hors d'oeuvres served)

Poster Session

Doherty Hall A226

12:45–2:45, Friday, October 16

Judges

Jennifer Larimer	Dow
Crystal Azzarello	PPG
Dr. Neslihan Cilek	Carnegie Mellon University
Dr. Suryavarshini Sundar	Carnegie Mellon University
Dr. Yousra Timounay	Carnegie Mellon University

Atmospheric Particle Studies

Malena Rybacki *Seasonal Trends in Coastal New Particle Formation Highlight Highly Localized Marine Influences*
Advised by Dr. Coty Jen

Bioengineering

- Abraham Polanco *Development of an Aptamer-Guided DNA Origami Platform: Nanostructure Fabrication, Cytotoxicity, and Antifungal Interaction in Candidozyma auris*
Advised by Dr. Tagbo H.R. Niepa
- Ann Badia *Adaptive Classification of Pseudomonas aeruginosa Motility in Nanocultures*
Advised by Dr. Tagbo H.R. Niepa
- Charlotte Tausche *Modeling lipid nanoparticle aggregate dissolution in the presence of nonionic surfactant*
Advised by Dr. Jim Schneider
Main listing: Complex Fluids Engineering
- Dhruv Chotaliya *Iterative Optimization of Lipid Nanoparticles for Plasmid DNA Delivery In Vivo*
Advised by Dr. Katie Whitehead
- Edward Onochie *Poloxamer 188 as a cell membrane resealing agent for intracellular delivery*
Advised by Dr. Derin Sevenler
- Hannah Gedde *Interfacial Stress-Induced Restructuring of Pseudomonas aeruginosa Film Networks*
Advised by Dr. Tagbo H.R. Niepa
Main listing: Complex Fluids Engineering
- Lilianna Gutierrez *Temporal Dosing of Triple Transient Transfection Plasmids to Optimize Viral Yield and F/E Ratios of AAV Capsids*
Advised by Dr. Anne Robinson

- Samantha Boczek *Characterizing NISTCHO Growth Across Bench-Scale Bioreactors and Shake Flasks to Inform Mechanistic Model Development*
Advised by Dr. Anne Robinson and Dr. Jim Schneider
- Saurav Padhye *Engineering Lipid Nanoparticles for Pulmonary Gene Delivery*
Advised by Dr. Katie Whitehead
- Warren Callen *Lipid Nanoparticles for Enhanced Brain-Targeted Gene Therapies via Intrathecal Administration*
Advised by Dr. Katie Whitehead

Complex Fluids Engineering

- Charlotte Tausche *Modeling lipid nanoparticle aggregate dissolution in the presence of nonionic surfactant*
Advised by Dr. Jim Schneider
- Edward Onochie *Pluronic 188 as a cell membrane resealing agent for intracellular delivery*
Advised by Dr. Derin Sevenler
Main listing: Bioengineering
- Hannah Gedde *Interfacial Stress-Induced Restructuring of Pseudomonas aeruginosa Film Networks*
Advised by Dr. Tagbo H.R. Niepa
- Harshal Jayesh Mistry *Quincke rotation of a circular cylinder in an alternating electric field*
Advised by Dr. Aditya Khair

Process Systems Engineering

- Florencia Caro Martinez *Trust region filter methods for surrogate-based oil refinery optimization with convergence guarantees*
Advised by Dr. Lorenz T. Biegler
- Lilianna Gutierrez *Temporal Dosing of Triple Transient Transfection Plasmids to Optimize Viral Yield and F/E Ratios of AAV Capsids*
Advised by Dr. Anne Robinson
Main listing: Bioengineering
- Nicolas Smits *RL for Supply Chain Network Design*
Advised by Dr. Carl Laird
- Tirtha Vinchurkar *Reliable Uncertainty Quantification for Machine Learning*
Advised by Dr. John Kitchin
- Xinyu Li *Optimal Bidding Strategy for Financial Transmission Rights Auction*
Advised by Dr. Carl Laird

Materials and Catalysis

- Jarett Ren *Fine-Tuning Generative Models and Machine-Learned Interatomic Potentials for Crystal Structure Prediction*
Advised by Dr. Olexandr Isayev
- Kyle Smith *A Framework to Study Coupled Singlet-Oxygen Generation and Chemistry over Supported Photosensitizers*
Advised by Dr. Aisulu Aitbekova
- Tirtha Vinchurkar *Reliable Uncertainty Quantification for Machine Learning*
Advised by Dr. John Kitchin
Main listing: Process Systems Engineering

Under-oil Microfluidic Platform for Monitoring *Babesia microti* Pathogenesis

Amy Apgar · Dr. Tagbo H.R. Niepa

Babesia microti (*B. microti*), an intraerythrocytic tick-borne parasite, is the primary causative agent of human babesiosis. Despite its increasing clinical impact, the biophysical mechanisms governing host-parasite interactions and pathogenesis remain poorly understood. To overcome these challenges, under-oil microfluidics have been utilized to maintain host-specific whole blood microenvironments for long-term, continuous optical tracking of infection dynamics.

Our microfluidic device helped reveal rapid, parasite-induced hemoglobin reduction and identified an acquired, active motility in a subpopulation ($\sim 10\%$) of infected RBCs moving at speeds up to 4.6 microns per minute. Electron microscopy (SEM/TEM) confirmed structural membrane alterations, including increased nanopore density 8.6 ± 11.2 pores/RBC. However, our early design suffered from low throughput, tedious photolithography-dependent fabrication, dead space formation, and fluidic instabilities including Marangoni flow, Laplace pressure differentials, and Rayleigh-Plateau instabilities.

To address these limitations, we redesigned the under-oil system into higher-throughput platforms featuring expanded chamber arrays that eliminate photolithography, reduce required sample volumes, and overcome non-ideal flow dynamics. Using this optimized system, whole blood from *B. microti*-infected mice was distributed under oil, successfully forming a spontaneous, label-free red blood cell (RBC) monolayer. Confocal fluorescence microscopy enabled precise longitudinal quantification of infection progression over time and tracked various parasite interactions with a variety of host RBCs.

By resolving prior fluid and manufacturing constraints, this enhanced under-oil microfluidic platform provides a robust, high-throughput ex vivo system to elucidate complex host-parasite dynamics, guidance for developing a standardized cultivation method, and support for therapeutic discovery without heavy reliance on animal models.

Multi-agent Process Design: The role of Game Theory and Reinforcement Learning

Andres I. Cardenas · Dr. Ana Torres

Chemical engineering process systems increasingly involve multi-agent networks, where standard optimization approaches fail to capture competing goals and strategic interactions among system members. Classic game-theoretic approaches incorporate agent-centric perspectives, where a variety of agentic behaviors and conditions can be represented as optimization problems with diverse mathematical characterizations; however, they require unrealistic assumptions such as perfect information sharing and pre-specifying agent behavior. We address the limitations of usual optimization practices in multi-agent settings by incorporating game-theoretic models, and then lift the hard assumptions that game theory requires by implementing a decentralized reinforcement learning algorithm to solve multi-agent problems under complete information privacy and without pre-specified agentic behavior. As a case study, we consider the production of sustainable aviation fuel from locally sourced coal and natural gas from the Pittsburgh region. Our game-theoretic results show that collaborative solutions through bargaining allow for a system with a negative carbon footprint in operation and economically attractive for all agents. Meanwhile, competitive behavior disrupts the existence of agents who process the local coal and natural gas, resulting in a system that is both economically and environmentally undesirable. Finally, we model the case study as a price-quantity bidding game and solve it with a decentralized Proximal Policy Optimization routine, achieving the perfect-information competitive solution without disclosing internal agent information or assuming agents' behavior.

Covalent sidechain modifications modulate self-assembly behavior of amyloid-like fibrils

Andrew Ashmar · Dr. Daphne Chan

Inexpensive food proteins such as β -lactoglobulin assemble into amyloid-like nanofibrils only a few nanometers wide but several micrometers long. Their unique aspect ratio and high stiffness have been exploited in many practical applications, such as reinforced composites, fuel-cell membranes, and templates for inorganic nanomaterials. Chemical functionalization of the fibril surface could be advantageous to impart new functionality, but the amino and carboxyl side chains available for conjugation also govern fibril assembly, making it unclear how extensively, and with what chemistry, the β -lactoglobulin monomer can be modified before its assembly behavior changes. Here we show, by covalently modifying amino and carboxyl side chains to vary charge, hydrophobicity, and steric bulk, that net charge on the monomer is the primary determinant of fibril morphology. We find that neutralizing cationic primary amines via acetylation accelerates aggregation and progressively converts rigid fibrils into more amorphous aggregates. Conversely, quaternization of primary amines, which retains their positive charge, preserves the rodlike fibril morphology. Conjugating cationic amines to carboxyl groups likewise promotes formation of rigid fibrils, altering only their diameter. This yields a design rule for functionalizing protein nanofibrils: chemistry that preserves net cationic charge is compatible with fibril assembly, while chemistry that neutralizes charge redirects assembly toward amorphous protein aggregates.

Graph Neural Networks for Supply Chain Resiliency Mapping

Arsh Bhatia · Dr. Carl Laird and Dr. Ignacio Grossmann

Since supply chains have complex dynamics, it is pivotal to understand how disruptions impact resiliency. Previous works have used optimization, simulation, and network theory techniques to understand the bullwhip effect of supply chain disruptions and to topologically evaluate supply chains. One of the challenges industrial practitioners often face is a lack of complete information about their supply chain. In this work, we propose utilizing graph neural networks to map structural and minimal supply chain information to average unmet demand as a measure of supply chain resiliency. We generate 3000 intra-firm graphs where each graph represents the supply chain of one product line. We then develop a supply chain simulator to simulate multiple structural failure scenarios and create synthetic unmet demand data. We train a Graph Attention Network (GAT) to predict the average unmet demand with only 6 features and obtain an R^2 of 0.73 for average unmet demand. We also show that this graph neural network outperforms a baseline of only network theory metrics.

One Treatment, Four Strains: Electrochemical Therapy Against Multidrug-Resistant *Candidozyma auris*

Camila Cue · Dr. Tagbo H.R. Niepa

Candidozyma auris (formerly *Candida auris*) is a multidrug-resistant fungal pathogen whose response to treatment can vary substantially between strains. We first characterized four clinical strains (CA0383, CA0384, CA1104, and CA1105) using electron microscopy, growth kinetics, and colony-forming unit (CFU) assays. The strains differed in cellular structure and in their responses to flucytosine, fluconazole, amphotericin B, and caspofungin; antifungal responses also changed with nutrient availability and growth phase. These findings posed a compelling challenge: could a single treatment remain effective across strains with different resistance profiles? To test this, we exposed each strain to electrochemical therapy (ECT) at $70 \mu\text{A}/\text{cm}^2$ for one hour and quantified surviving cells. ECT produced approximately four- to five-log reductions in CFU across all four strains, despite their distinct responses to conventional antifungals. Post-treatment CFU levels did not differ significantly among strains under the condition tested. Together, these findings show that a single ECT condition can substantially reduce viable *C. auris* across four drug-resistant strains and support further investigation of ECT as a broadly effective antifungal strategy.

Designing Dynamic Bicontinuous Thermosets through Polymerization-Induced Microphase Separation

Edwin J. Lebrón Pérez · Dr. Daphne Chan

Block copolymers (BCPs) are well known for their ability to spontaneously self-assemble into ordered structures, and bicontinuous morphologies have been attractive for applications such as ultrafiltration membranes, high-conductivity nanoparticles and nanocarriers for drug delivery. Polymerization-induced microphase separation (PIMS) is a strategy where bicontinuous morphologies are achieved through RAFT polymerization of monomers and crosslinkers with a macro chain transfer agent (mCTA). As the polymer grows, its inherent immiscibility with the mCTA will drive microphase separation, but rather than achieving long-range ordered structures, the crosslinker kinetically traps the BCP in an intermediate, microphase-separated bicontinuous state. However, due to the presence of crosslinker, the resulting material is a thermoset that cannot be processed either thermally or in solution post-polymerization. To overcome this, we proposed the use of a crosslinker that incorporates a dynamic disulfide bond, such that dynamic covalent bond (DCB) exchange is induced at elevated processing temperatures. In this work, we show that dynamic PIMS materials can be designed to improve their post-polymerization processing without negatively impacting polymerization itself or the final properties.

To do so, we applied PIMS using polylactide-b-poly(isobornyl methacrylate)-based systems, which were crosslinked with static and dynamic crosslinkers. Using small-angle X-ray scattering (SAXS), we found that, regardless of crosslinker selection, the expected bicontinuous PIMS morphology is achieved. Furthermore, dynamic PIMS systems exhibited stress relaxation and improved processability with increasing crosslinker load, due to the increased proportion of disulfide bonds. Additionally, after removal of polylactide (via base-catalyzed hydrolysis), we confirmed the presence of robust porous networks through SAXS, scanning electron microscopy and nitrogen sorption. Together, these results show that incorporating disulfide bonds in PIMS crosslinkers is a feasible approach to design processable thermosets.

Mixing oil and water without stirring: a generalized diffusion path theory of spontaneous emulsification

Emerson Uhlig · Dr. Aditya Khair

Spontaneous emulsification refers to the formation of a metastable (not thermodynamically stable) emulsion without any external energy input (like stirring, e.g.), which typically happens when two multicomponent liquid phases that are not in equilibrium are gently contacted. The diffusion and stranding mechanism proposes that spontaneous emulsification may occur by a purely diffusive means without any hydrodynamic effects, that is, without any fluid flow. The main theoretic development of the diffusion and stranding mechanism of spontaneous emulsification is known as the diffusion path theory, created by Ruschak and Miller in 1972, who solve a representative ternary diffusion problem and hypothesize that when a phase develops a region of supersaturation, then the phase will undergo spontaneous emulsification. We generalize the diffusion path theory to model the phase- and diffusion-behavior of the ternary mixtures in a thermodynamically consistent way, and we unify of this mechanism of spontaneous emulsification with the well-studied “ouzo effect”.

Algal-Based Biopolymers: Design and Synthesis of *Spirulina*-Derived Cyanophycin Elastomers

Hannah Elaine Schutte · Dr. Daphne Chan and Dr. Coty Jen

Conventional plastics derived from fossil fuels persist in the environment for centuries, generating microplastics that accumulate in ecosystems and pose significant human health risks, including lung disease and cancer. While biodegradable alternatives exist, most rely on sugar crop feedstocks that compete directly with resources for food production. This work proposes a novel solution: harnessing biomass from harmful algal blooms (HABs), overgrowths of cyanobacteria and algae, as a sustainable feedstock for biodegradable elastomers. Specifically, we exploit cyanophycin, a natural protein extracted from the cyanobacterium *Spirulina*, as the basis for thermoplastic elastomer (TPE) materials. Cyanophycin is functionalized and copolymerized with a flexible comonomer to produce elastomeric networks architecturally analogous to thermoplastic polyurethane (TPU), a widely used commercial TPE. A key advantage of cyanophycin over TPU is its zwitterionic property that allows for a charge-tunable structure, where mechanical properties can be modulated through simple pH treatment rather than requiring distinct synthetic routes for each target property. Building on established *Spirulina* culturing and cyanophycin extraction protocols developed in our laboratory, we hypothesize that cyanophycin hard domains will function as reinforcing segments within the copolymer network, mimicking the phase-separated morphology responsible for TPU’s elastomeric behavior. The resulting materials will be benchmarked against standard mechanical characterization metrics for commercial TPEs to assess their viability as sustainable replacements. This approach simultaneously addresses plastic pollution, reduces reliance on petrochemical feedstocks, and provides a productive use for ecologically damaging algal blooms.

Multi-Period Robust Optimization for Designing Membrane Diafiltration Systems Under Operational Disturbances

Jason Yao · Dr. Chrysanthos Gounaris

Membrane diafiltration systems, with lower energy requirements and waste generation compared to traditional hydrometallurgical separations, are promising technologies for critical minerals and materials (CMM) recovery. However, they face challenges in uncertain process operating conditions that may severely hamper process efficacy and prevent performance targets from being reached. Thus, multi-period modeling and optimization under uncertainty are needed to better understand how membrane systems may perform in spite of operational variability and uncertainties. To mitigate such risks and improve process reliability, we develop a multi-period modeling framework for diafiltration systems and utilize multi-period, nonlinear robust optimization methodologies to study process design under uncertain, feedstock drift, and disruptions to feedstock availability. We demonstrate significant weaknesses in deterministic cost-optimal diafiltration process design through their infeasibility under changing process conditions, along with the difficulties of traditional ad-hoc overdesign processes in identifying robust solutions. The mathematically rigorous solutions provided by robust optimization provide major insights into process design and operating strategies that consider membrane and diafiltrate usage and are essential for designing membrane diafiltration systems that may reliably perform under realistic variation in operating conditions.

Post-translational modifications shape tau aggregation behavior and self-assembly

Ladan Nikfarjam · Dr. Anne Robinson and Dr. Daphne Chan

Tau is a microtubule-associated protein that supports axonal structure and molecular transport within neurons; however, disease-associated post-translational modifications (PTMs) can disrupt physiological functions and promote pathological aggregation across tauopathies and neurodegenerative diseases, including Alzheimer's disease (AD). Phosphorylation and proteolytic truncation are prominent PTMs associated with tau dysfunction and aggregation, yet how these modifications, individually and in combination, alter tau assembly remains unclear. In particular, the contribution of site-specific phosphorylation at Ser262 and truncation within the microtubule-binding region requires further investigation.

This work examines PTM-dependent tau aggregation using complementary protein and peptide models. Recombinant tau 0N4R and K18, together with GSK3 β -phosphorylated counterparts, were produced from *E. coli* and purified using established methods. We also used synthetic tau-derived R1–R2 peptides, with or without site-specific phosphorylation at Ser262, to determine the effects of phosphorylation and truncation in a controlled in vitro system. We monitored aggregation kinetics and morphology using Thioflavin T (ThT) fluorescence and atomic force microscopy, respectively, and observed distinct changes in aggregation rates and extent among tau, phosphorylated tau, and K18 constructs. Notably, phosphorylated tau exhibited enhanced aggregation relative to unmodified tau, while both full-length constructs displayed greater aggregation than K18 (a truncation containing R1-R4, widely used as a model for tau aggregation studies) under the conditions examined. When R1-R2 synthetic peptides were added to aggregation reactions, we observed both inhibitory and promoting effects, depending on the protein and modification state.

Overall, these studies provide a framework for determining how biochemical modifications influence tau assembly and provide a foundation for future studies examining how physical confinement further regulates these processes.

Influence of electrostatic and non-electrostatic interactions on the partitioning of colloidal particles in polyelectrolyte complex coacervates

Maryam Ali · Dr. Bob Tilton

Complex coacervation is the liquid-liquid phase separation of oppositely charged species into a concentrated coacervate phase and a dilute phase. Emerging applications involve formulating coacervating systems to suspend colloids, both to deliver active ingredients to a surface or remove pollutants from wastewater.

This work considers the partitioning of charged colloids in a coacervating system of two oppositely charged polyelectrolytes, with the goal of determining the relative importance of electrostatic and non-electrostatic driving forces. The relative importance of electrostatic and non-electrostatic interactions, which can be manipulated in the coacervation of weakly charged polyelectrolytes. We experimentally measure the partition coefficient of negatively charged, non-titratable colloidal particles (sulfate-stabilized polystyrene latex) in mixtures of two titratable polyelectrolytes, poly (allyl amine hydrochloride) and poly (acrylic acid sodium salt), undergoing coacervation. The system pH is used to vary the charge density of both polyelectrolytes. NMR spectroscopy and thermogravimetric analysis are used to measure the binodal phase envelope of the polyelectrolyte coacervation. We find that the partitioning of the charged particles tends to mimic the partitioning of the oppositely charged polyelectrolyte, regardless of the behavior of the similarly charged polyelectrolyte: the negatively charged colloid partitions more strongly into the coacervate phase under conditions that favor an excess of polycations in the coacervate. Changes to the composition of the coacervate phase, evident from the binodal envelope, are reflected in changes to the partition coefficient of the particles.

Protein Corona Engineering Enhances Lipid Nanoparticle-Mediated RNA Transfection in the Heart

Naseeha Mohammed · Dr. Katie Whitehead and Dr. Jim Schneider

Cardiovascular disease (CVD) remains the leading cause of death worldwide, partly due to the lack of therapies that target heart tissue. CVD results in the irreversible replacement of functional myocardium with fibrotic scar tissue. Although mRNA delivery has therapeutic potential for reprogramming fibroblasts into cardiomyocytes, mRNA requires encapsulation in carriers for efficient delivery. LNPs are advanced and ideal carriers for this purpose; however, LNP-mediated mRNA delivery to cardiac tissue is physiologically complex. Upon physiological exposure, LNPs interact with endogenous proteins to form a “protein corona” that dictates their biological fate. Notably, Apolipoprotein E (ApoE) is abundant in the protein corona and drives hepatic uptake of LNPs. Even after local injection, LNPs and the encapsulated RNA clear rapidly from the heart to the liver. We therefore pursued a two-part strategy addressing vehicle and cargo optimization.

First, we tested whether pre-forming an engineered protein corona layer around LNPs prior to administration could override default biological outcomes and improve LNP-mediated mRNA transfection in cardiac tissue. The engineered corona layer served as a molecular dial to tune expression up or down following intramyocardial administration in mice: an albumin-corona on LNPs significantly enhanced cardiac mRNA transfection by an additional 2-fold compared to control, non-protein LNPs. Conversely, an engineered ApoE-corona redirected LNP trafficking away from cardiac tissue to the liver. Our findings demonstrate that anatomical localization alone is insufficient to dictate LNP fate. However, localization when coupled with engineered coronas, is a viable strategy to increase LNP delivery to the heart.

Second, mRNA expression is transient while gene therapies in the heart require sustained expression. We began to optimize the cargo via self-amplifying RNA (saRNA). saRNA encodes replication machinery that extends and amplifies expression. In primary cardiac fibroblasts, saRNA produced ~19-fold greater protein expression than conventional mRNA, indicating that intracellular amplification can substantially raise protein output from a limited delivered dose in vitro.

Together, these results define complementary tools for non-viral cardiac delivery. Ongoing work combines albumin-LNPs with saRNA cargo to evaluate reprogramming potential delivery in vivo.

Computational screening of high-internal phase emulsion stability using physics-informed dataset splitting and interpretable machine learning

Peter Cook · Dr. Bob Tilton

The goal of this work is to develop predictive models of water in oil (W/O) high-internal phase emulsion stability for purposes of computational screening of oils and surfactants. This was done by generating a set of available or calculable physicochemical features of oils and surfactants proposed to be influential to emulsion stability, with each feature either being available in literature or calculable, creating an entirely computational workflow for screening purposes. The existence of multiple sets of physical phenomena in the dataset is confounding to modeling; partitioning the dataset by which physical phenomena dominate emulsion stabilization significantly increased model performance without needing additional data or a more complex model architecture. Logistic regression was employed to create interpretable machine learning (ML) classifiers that can be analyzed retrospectively to understand the relative scales of feature values that lead to emulsion stabilization or destabilization and to understand the exact logic followed by the classifiers leading to each decision. The models and their interpretability are demonstrated to be robust to perturbations in available training data and to random initializations. The models are also shown to be well-calibrated, indicating that model outputs correlate with the actual probabilities of each emulsion being stable or not. Preserving only the most confident model predictions further increases model utility, with one implementation of confidence filtering preserving 59-71% of the dataset while increasing the balanced accuracy metric of its cross-validation (CV) predictions to nearly 100% for three unique CV strategies.

Automating Process Synthesis for Critical Minerals with Hierarchical Reinforcement Learning

Robert Maligon Querimit · Dr. Ana Torres

Conceptual process design strongly shapes the economic performance of a chemical process, yet flowsheets are still largely developed through engineering intuition and iterative simulation. For rare earth element (REE) processing from U.S.-based ores, this approach took roughly one year for the chemical extraction step alone, and the result is feasible but not systematically optimized.

This work develops a hierarchical RL framework that reflects the two levels of decision making in process design. A higher-level agent selects the sequence of unit operations using Monte Carlo tree search (MCTS). It balances exploration and exploitation through an upper confidence bound rule and estimates the value of partial flowsheets through rollouts at default operating conditions. A lower-level agent then determines the operating conditions of each selected unit operation (temperature, reagent concentration, and solvent amount) using Bayesian optimization with a Gaussian process surrogate and an expected improvement acquisition function. The environment evaluates each unit operation with a rigorous law-of-mass-action model. The higher-level agent is guided by a global reward, defined as the product of REE recovery, chloride purity, and radioactive material rejection. Each unit operation also receives a local reward tied to its specific function.

We applied the framework to the chemical extraction of xenotime concentrate and compared the result with the manually designed base case. The framework omitted a washing step and selected different operating conditions. The resulting flowsheet achieved a higher global reward (0.9985 versus 0.9900), with REE recovery of 0.9985 and thorium rejection of 0.9999, both at least as good as the base case. It was obtained in 20 minutes of wall-clock time, compared with about one year of manual iteration. Future work will incorporate economic and environmental objectives and extend the framework to solvent extraction, enabling comparison against certified benchmarks.

Mechanisms of horizontal gene transfer via lipid nanoparticle recycling

Samantha Yang · Dr. Katie Whitehead

Lipid nanoparticles (LNPs) are versatile mRNA delivery vehicles, but therapeutic applications have been limited by the propensity of LNPs to accumulate in the liver. To circumvent this, our lab previously developed a unique LNP formulation with pancreatic selectivity. The mechanism was attributed to peritoneal macrophage-mediated horizontal gene transfer via extracellular vesicles (EVs).

Because understanding of this exosome-mediated mRNA delivery is limited, more investigation is warranted to design increasingly effective nanoparticles. In this study, EVs were generated in vitro from mRNA LNP-treated donor cells and used to transfect recipient cells in vitro and in vivo. Multiple donor cell types were tested (fibroblast, epithelial, macrophage), and we found that horizontal gene transfer varied by cell type. In addition to the expected efficacy of macrophage-derived exosomes, placental BeWo cell exosomes induced the highest degree of horizontal gene transfer.

We wanted to determine if mRNA cargo or translated protein was driving exosome horizontal gene transfer. We quantified each through qPCR and Western blot assays and found both associated with exosomes. Since LNP chemistry impacts transfection, we tested different lipids and compared the amount of exosome cargo. Our findings indicated that LNP lipid chemistry influenced the degree of cargo repackaging.

To better understand the exosome repackaging process, we conducted experiments using radioactive LNPs tagged with iodine-125. This enabled tracking of the LNP lipid components throughout the donor cell transfection and exosome production processes. Dosing these radiolabeled LNPs (46% internalized signal) resulted in 43.2% of that signal secreted back into media. Signal measured within the EV fraction after size exclusion chromatography suggested integration of LNP lipids with EVs.

This work aids our understanding of the intracellular fate of LNPs and how their components are repackaged into exosomes. Future work will focus on manipulating LNP chemistry to improve the RNA repackaging process and ultimate therapeutic potential.

A Decomposition Approach to Power Grid Capacity Expansion Planning under Operational Uncertainty

Sergio Bugosen · Dr. Carl Laird and Dr. Chrysanthos Gounaris

This work develops a tailored decomposition algorithm based on dual dynamic programming to inform decision-making for power systems infrastructure planning. Specifically, our goal is to solve a large-scale high-spatial resolution multi-stage power grid capacity expansion planning model that simultaneously optimizes generation, transmission, and energy storage system investments under electricity demand and renewable power availability uncertainty. The model is a challenging mixed-integer linear programming formulation due to inter-temporal coupling created by cumulative investment decisions across investment stages, construction lead times for generation and transmission assets, and the explicit full-scale nodal network representation. When formulated and solved in its full-space form, these features produce large problem instances that are computationally demanding to solve directly. To address this challenge, we reformulate the full-space model as a stage-wise dynamic program in which the vector of cumulative installed assets is carried as the state variable from stage to stage. The resulting algorithm alternates between forward passes that construct feasible incumbent policies and backward passes that refine piecewise-linear value-function approximations via conventional Benders' cuts, while maintaining valid global bounds throughout. Two implementation enhancements are applied: a persistent solver that reuses model structure across iterations to reduce computational overhead, and alternative cut-seeding strategies that warm-start the value-function approximations and improve convergence. We evaluate the framework in three test systems of 24, 300, and 500 buses and demonstrate that it substantially accelerates the discovery of high-quality solutions relative to solving the full-space formulation. These results establish this decomposition as a practical approach for high-fidelity power grid capacity expansion planning at scales that are otherwise computationally prohibitive.

Interfacial Stress as an Environmental Cue for Adaptive Material Assembly by *Brucella pituitosa*

Shakira Marie Martínez Vásquez · Dr. Tagbo H.R. Niepa

Oil–water interfaces provide hydrocarbon-utilizing microorganisms access to carbon substrates while imposing physicochemical stresses that challenge cellular fitness. Yet, how differences in interfacial energy are associated with the physiology, adaptation, and collective behavior of oil-associated microorganisms remains poorly understood. Here, we investigated *Brucella pituitosa* BU72, a non-motile, hydrocarbon-utilizing bacterium isolated from hydrocarbon-polluted sediment that produces exopolysaccharide-based surfactants. We hypothesized that differences in interfacial conditions would be associated with changes in BU72 fitness and extracellular remodeling, with interfacial film formation and mechanics serving as functional phenotypes of hydrocarbon utilization and adaptation. BU72 was exposed to hexadecane–water and squalene–water interfaces representing high and low interfacial stress, respectively. BU72 adsorbed to both interfaces, reduced interfacial tension, and formed stable films that suppressed droplet coalescence. Higher interfacial stress at the hexadecane interface reduced cell viability but promoted more elastic, carbohydrate-enriched films, whereas lower stress at the squalene interface preserved viability and produced softer films with greater carbohydrate partitioning into the aqueous phase. These contrasting responses reveal stress-dependent coping strategies in which extracellular material organization and interfacial mechanics vary with cellular fitness. Collectively, our findings highlight interfacial stress as an important environmental factor associated with BU72 physiology and community-level material assembly and establish BU72 as a model for understanding microbial adaptation at hydrocarbon–water interfaces, with implications for hydrocarbon bioremediation.

Processing-Induced Evolution of Protein Secondary Structure and Mechanical Properties in Dynamic Reprocessable Protein-Based Polymer Networks

Sunny Surprenant · Dr. Daphne Chan

Protein-based polymer networks offer a promising route toward sustainable materials by incorporating renewable protein feedstocks into functional polymer systems. Expanding these materials toward conventional polymer manufacturing requires considering their processability and moldability. Previous studies of static protein-polymer networks show that thermal processing can reorganize protein secondary structure, including formation of β -sheet-rich structures that reinforce physical interactions and alter bulk mechanical properties. However, permanent crosslinks limit subsequent reprocessing. Incorporating dynamic bonds, such as disulfide linkages, enables protein-polymer networks to be reshaped and reprocessed, exposing proteins to additional thermal and mechanical histories. How secondary-structure changes during reprocessing relate to bulk mechanical changes remains unclear. Here, we investigate the evolution of protein secondary structure and mechanical properties during thermal processing of reprocessable protein-polymer networks containing dynamic disulfide bonds.

Protein feedstocks with distinct initial secondary structures were incorporated into polymer networks containing acrylate soft segments and lipoic acid-derived dynamic disulfide bonds. Despite pronounced differences in starting secondary structure, initial bulk mechanical properties are similar across networks. Thermal processing drives substantial secondary-structure rearrangement, generally producing more β -sheet-rich states alongside changes in mechanical behavior. Comparison across feedstocks shows these structural and mechanical changes evolve differently during processing, indicating that reprocessing effects cannot be understood from initial secondary structure alone. To probe how network chemistry influences these changes, small-molecule thiols were introduced to alter the dynamic disulfide environment. Following heat pressing, re-exposure to a thiol-containing solution shifts secondary structure toward its preprocessed state, showing that processing-induced structural changes are at least partially reversible. Together, these results show how protein secondary structure and mechanical properties evolve during thermal processing, and demonstrate that reprocessing behavior emerges from changes within the network rather than from initial secondary structure alone.