Innovation Day Posters

September 9, 2024

In-Person Poster Session, 10:15 AM – 11:15 AM

Innovation Day 2024 features 23 posters. The themes of this year's event explore Energy Storage and Advanced Mobility as well as Regulatory Needs Driving the Chemical Industry.

The posters in this document are organized alphabetically by poster presenter last name. For full poster citations, please contact the poster presenter(s) during Innovation Day 2024. To review poster abstracts, refer to the *Poster Session Guide* on the Innovation Day homepage.

Poster Listing in order of appearance:

1. Gabriela Alvez, Katie Barta, Aromax® Technology
2. Clayton Cuddington, Next Generation Polymerized Hemoglobins for Use in Transfusion Medicine
3. Martin Deetz, Water Treatment for Hydrogen Production
4. Theresa Feltes, Jeremy Praetorius, A History of Innovating Differentiated Products for a More Sustainable Future
5. Rishi Gupta, Advanced Recycling: Supporting a More Circular Economy
6. Chihhung Ko, Development of Ultra High Purity and Sustainable Solvents for Semiconductor Processes
7. Julia Kozhukh, Design and Synthesis of Copolymer Adhesives for Advanced Medical Applications
8. Conor Kulczytzky, Advancements in Sustainable Manufacturing of Lithium-Ion Batteries
9. Sam Lim, James Padaguan, Innovative Approaches to Road Safety: Enhancing Traffic Lane Markings through Digital Technology
10. Stephanie F. Marxsen, Tuning Processability of Isotactic Polypropylene (iPP) Through Blending with iPP Ionomers
11. Shannon McGee, Metal-Working Fluid Performance Metrics for Sustainability
12. Abigail Meyer, Use of Keyence VHX Digital Microscope to Determine Composition and Microstructure Changes in Polymer Quenched AISI 1060
13. Ellen Qin, DuPont™ Vespel® for Hydrogen and Electric Vehicle Industries and Applications
14. Sara Reynaud, Applications of Coupled Rheology – FT-IR to Polymer Analyses
15. Ian Robertson, Liquid applied sound damping coatings optimized for next-generation vehicles
16. Michael Rodig, Eastman AventaTM Renew Compostable Materials

17. Arun Sridharan, Controlling metal complex speciation with ligand sterics: Synthesis of monomeric iron(II) and cobalt(II) chloride/methyl complexes using the bulky ligand ITr
18. Abby Van Wassen, A New Low-GWP Dielectric Fluid for Immersion Cooling of Data Centers
19. Jeffrey Wilbur, Nanofiltration in Direct Lithium Extraction: Component and System Design Innovation
20. Susie Wu, Shyamal Saha, and Jesse Hellums, Enabling Sustainable Technology Deployment, High Performance Anode Binder
21. Susie Wu, Shyamal Saha, and Jesse Hellums, The Sustainable Wax Revolution
22. Hunter Ye, High Performance Anode Binder
23. Hannah Zeitler, Kalrez® perfluoroelastomer parts - improving circularity in specialty sealing

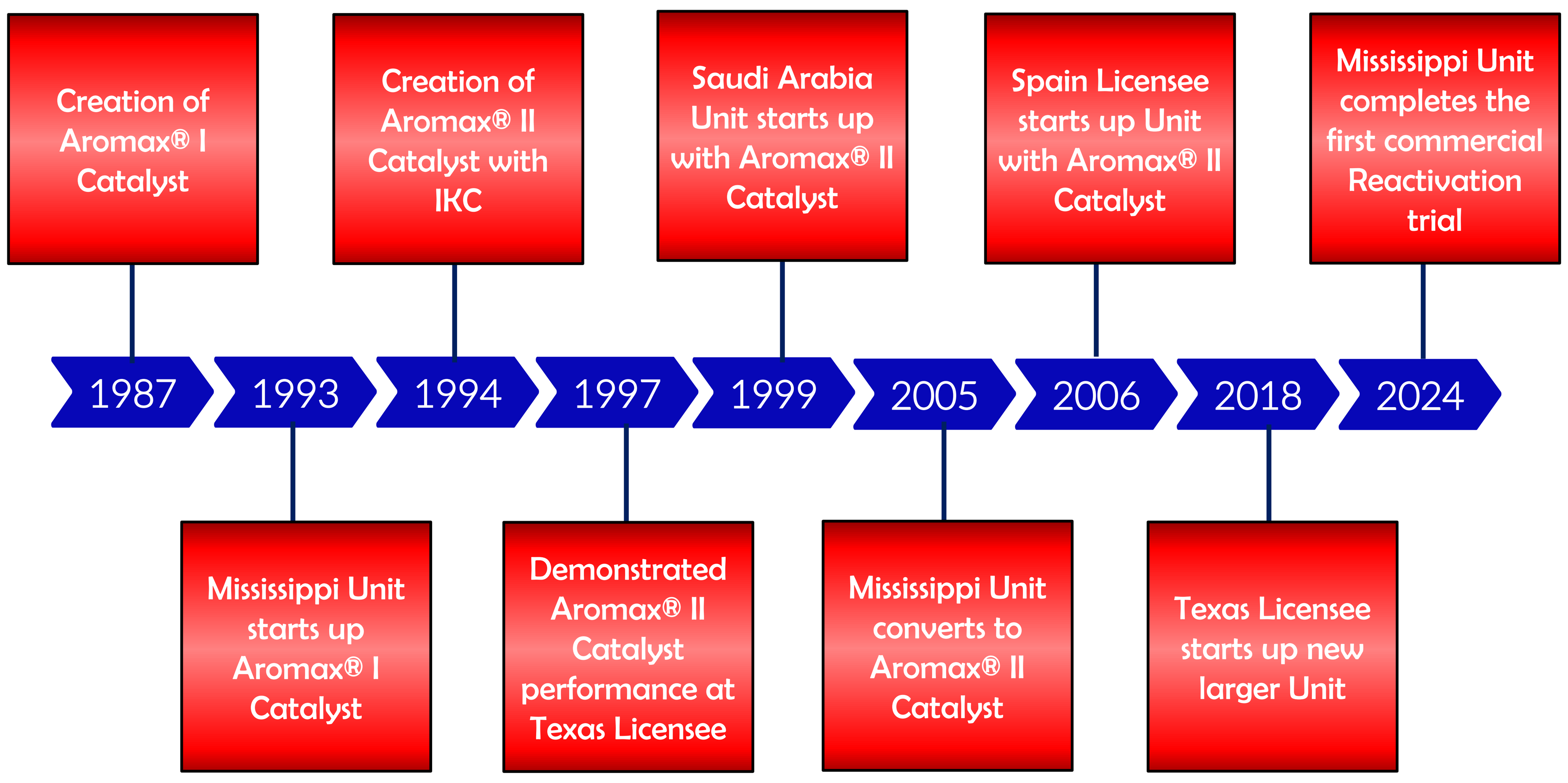
Aromax® Technology

PREMIER ON-PURPOSE BENZENE PRODUCTION TECHNOLOGY

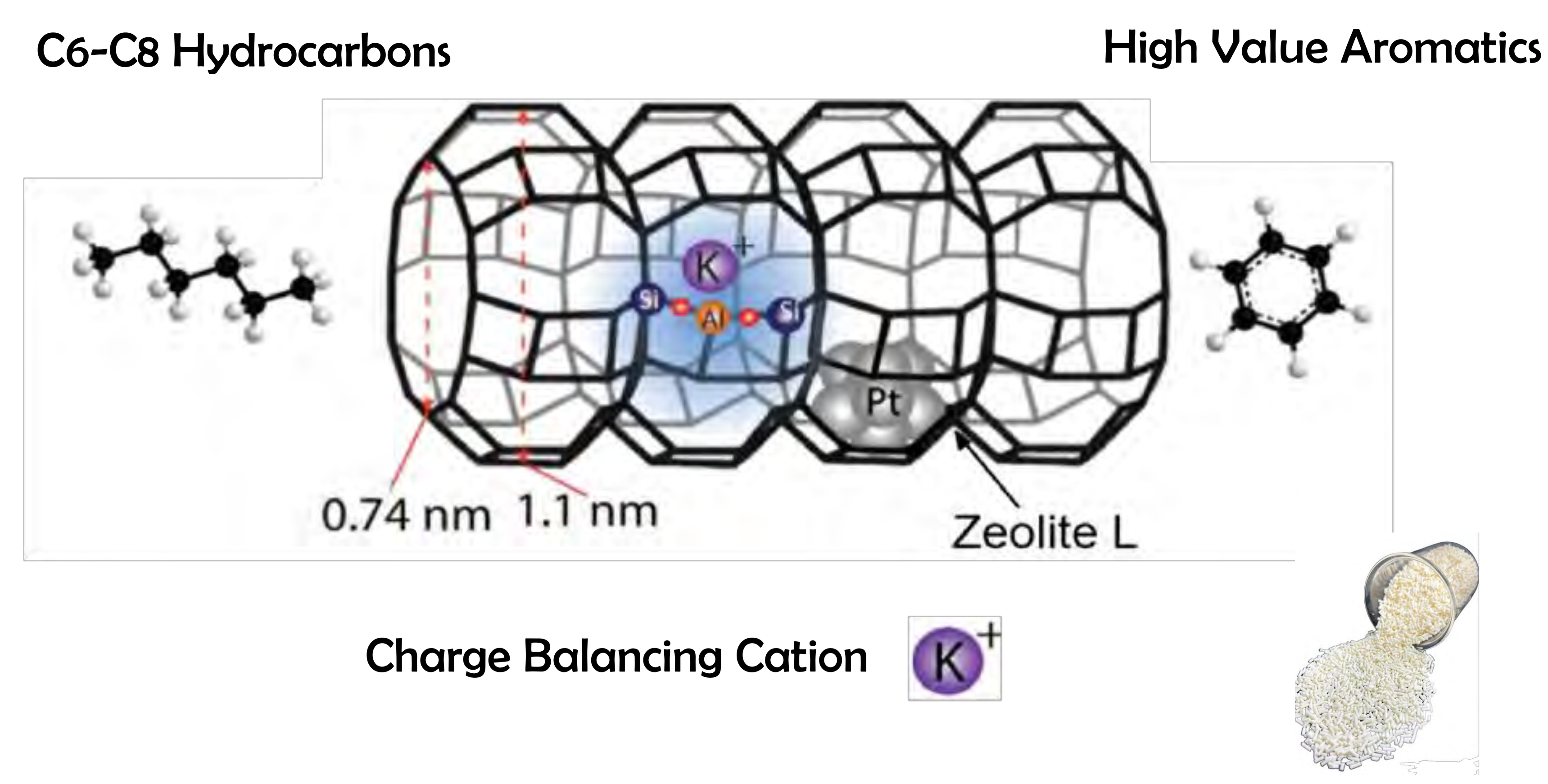
Gabriela Alvez
Senior Research Chemist

Katie Barta
Process Engineer - Aromatics

Aromax® Technology History

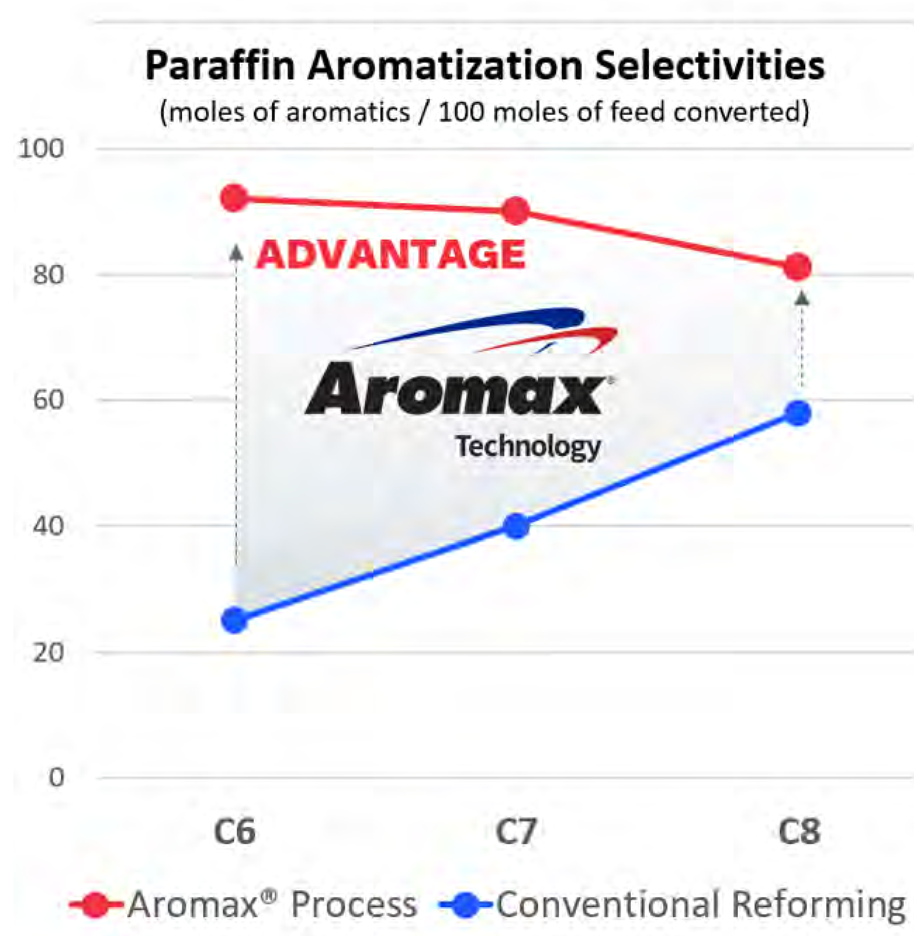


Aromax® Catalyst

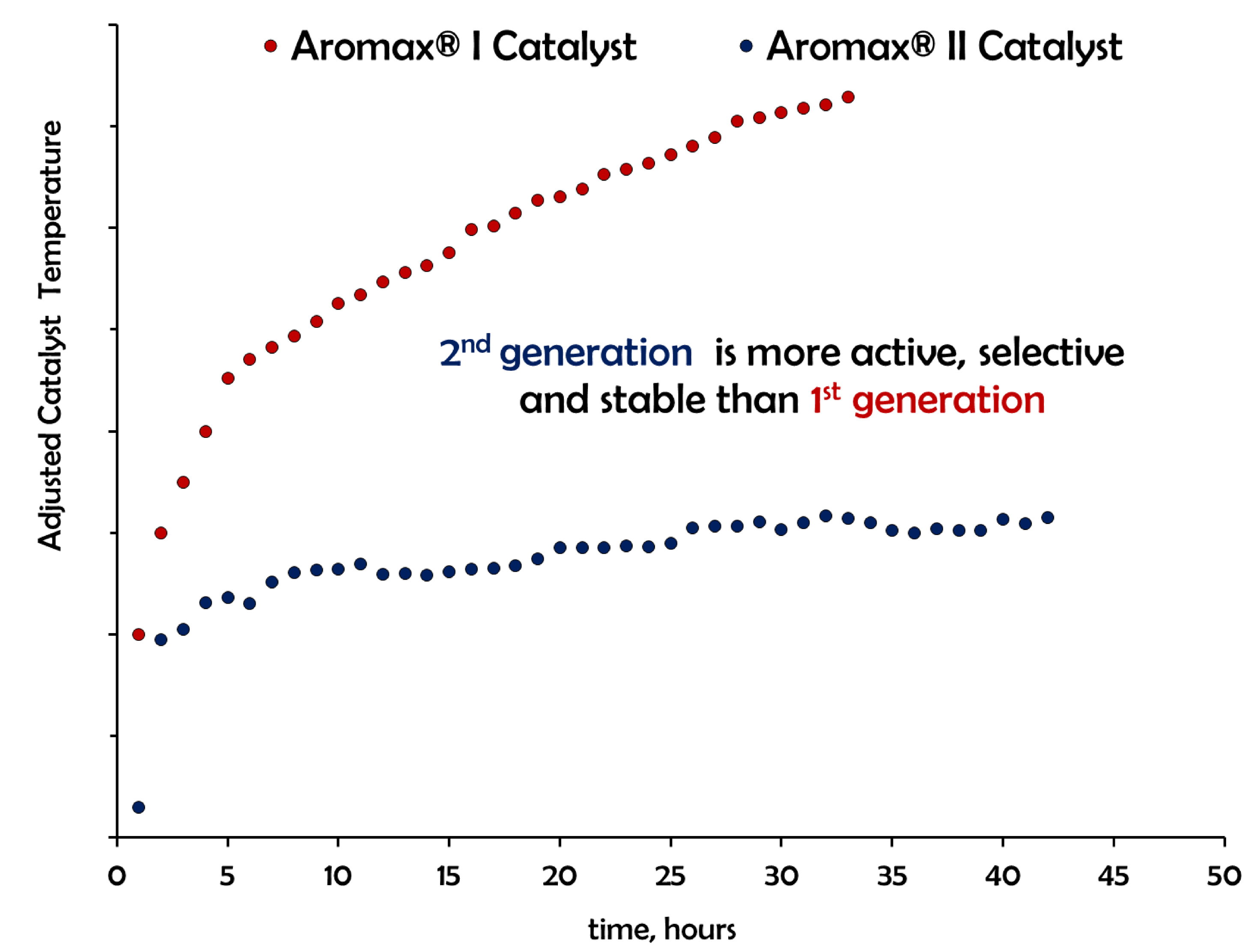


Aromax® Technology

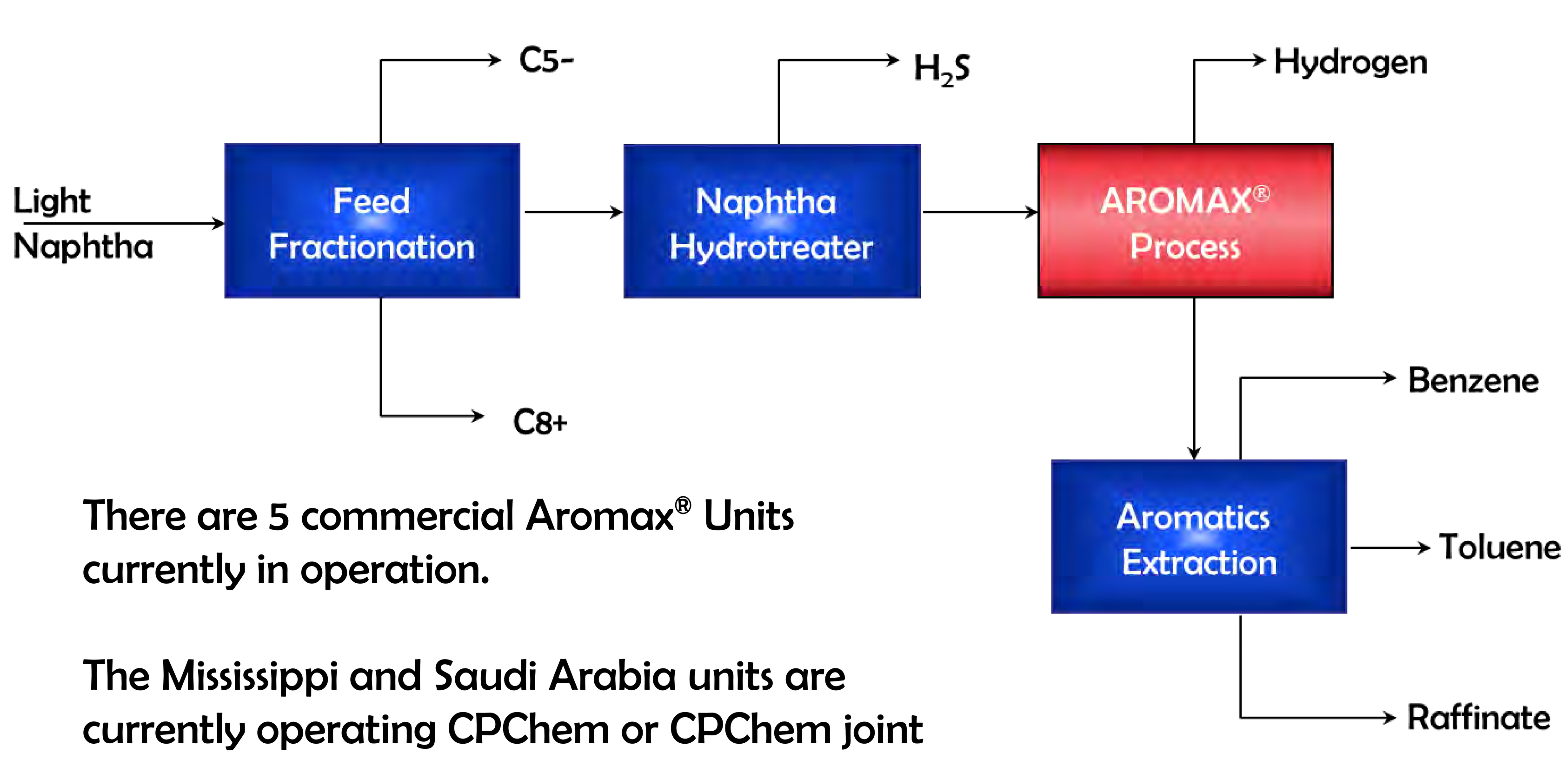
- First reforming process based on a zeolitic catalyst
- Best suited for converting C6-C8 hydrocarbons
- Exceptional selectivity for converting C6 and C7 paraffins & naphthenes to benzene, toluene and hydrogen
- Process includes a high efficiency sulfur control system to eliminate catalyst poisoning by sulfur
- Proprietary catalyst technology
- Includes Metal Protection Technology for metal carburization control



Aromax® Catalyst Performance



Aromax® Process

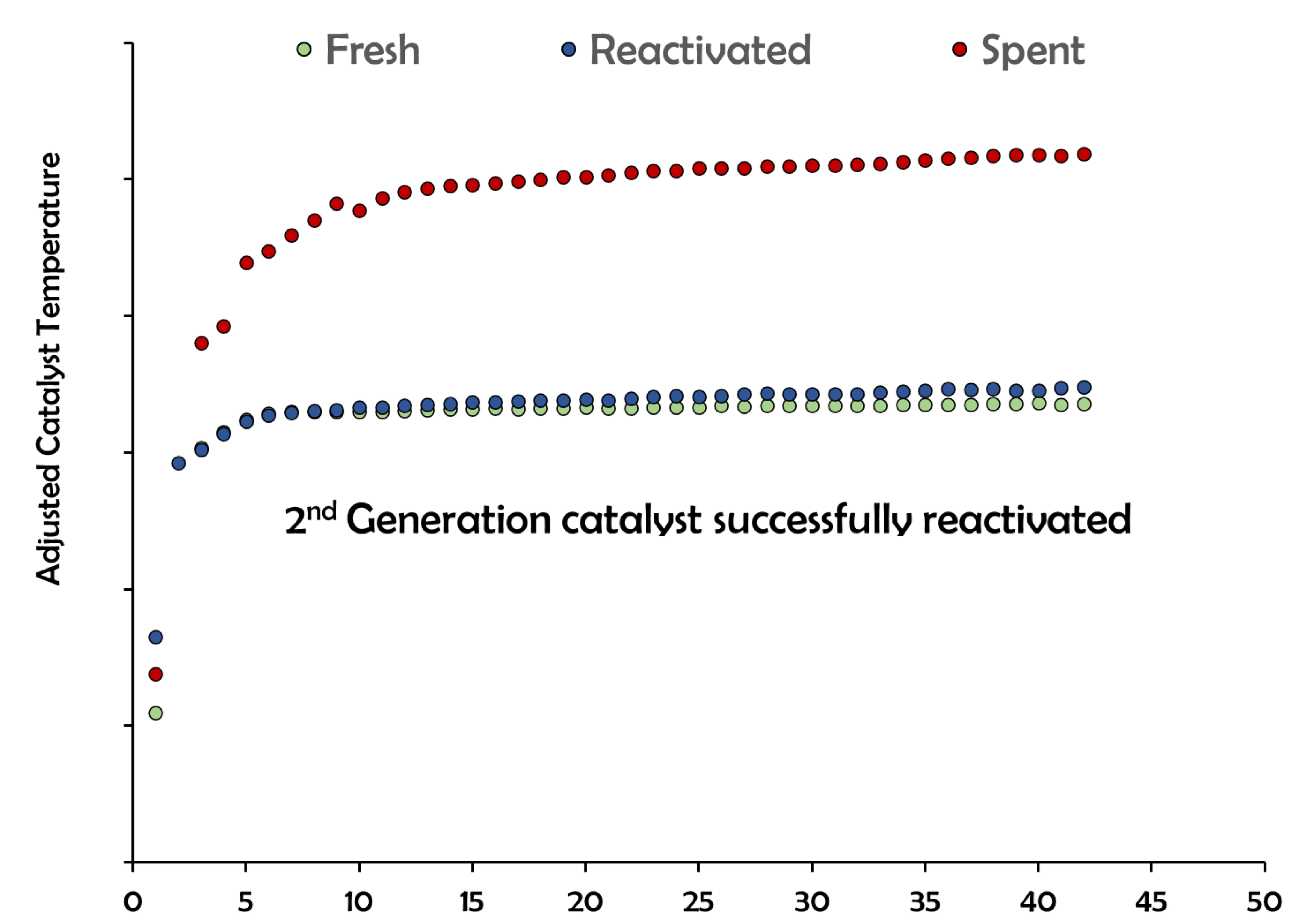


There are 5 commercial Aromax® Units currently in operation.

The Mississippi and Saudi Arabia units are currently operating CPChem or CPChem joint venture units.

The Japan, Spain and Texas units are licensed.

Aromax® Catalyst Reactivation



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Aromax® Technology

NEXT-GENERATION **POLYMERIZED HUMAN HEMOGLOBINS** FOR USE IN **TRANSFUSION MEDICINE**

THE OHIO STATE UNIVERSITY

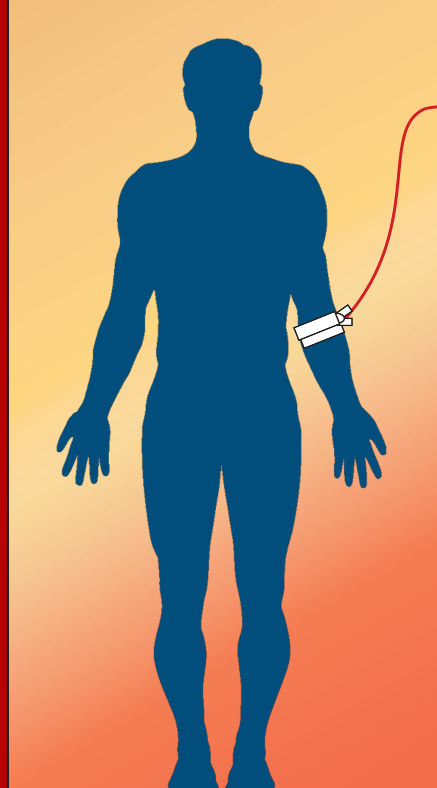
Clayton Cuddington, Savannah Wolfe, and Andre Palmer

Contact: clayton.t.cuddington@exxonmobill.com

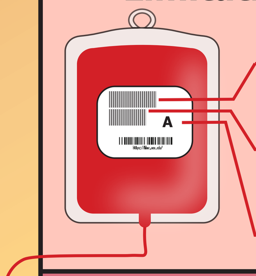
ExxonMobil Technology & Engineering Company
5200 Bayway Drive, Baytown TX 77520
BTEC-WEST 2131

PURPOSE & MOTIVATION

Emergency Transfusion After Traumatic Injury



Limitations of RBC Transfusion



- Limited ex vivo shelf life of 42 days
- Require refrigeration at 4 ºC
- Type compatability with patient

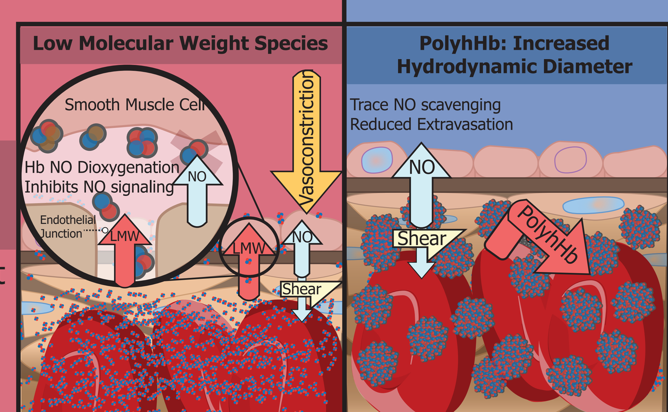
Commercial HBOCs: Problems in this Solution

Advantages of Hemoglobin-Based Oxygen Carriers (HBOCs):

- Stable at ambient conditions
- Reduced storage constraints

Challenges of commercial HBOCs:

- Low Molecular Weight
- Extravasation
- Vasoconstriction
- Tissue injury



Polymerized Human Hemoglobin (PolyhHb): Effective Extension of the Golden Hour of Care

Tunable Hydrodynamic Radius:

Reduced extravasation → decreased toxicity

Tense-State (T-State) Configuration:

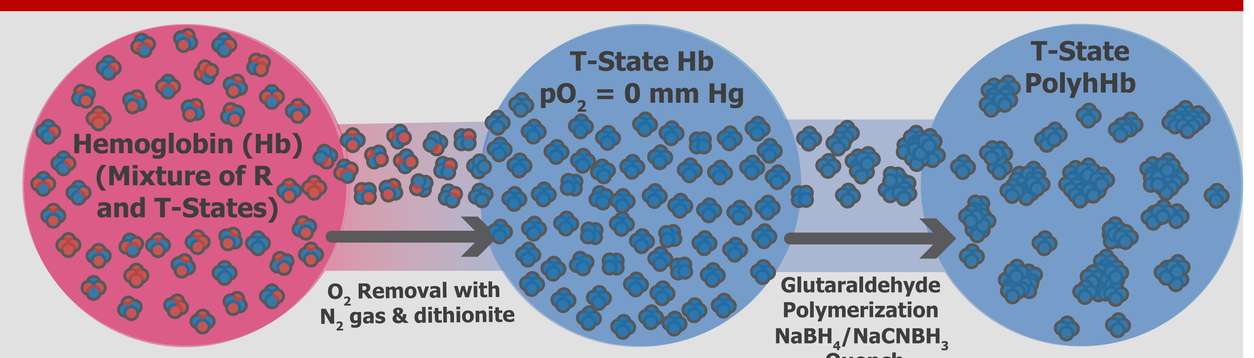
Optimal O_2 offloading to tissue

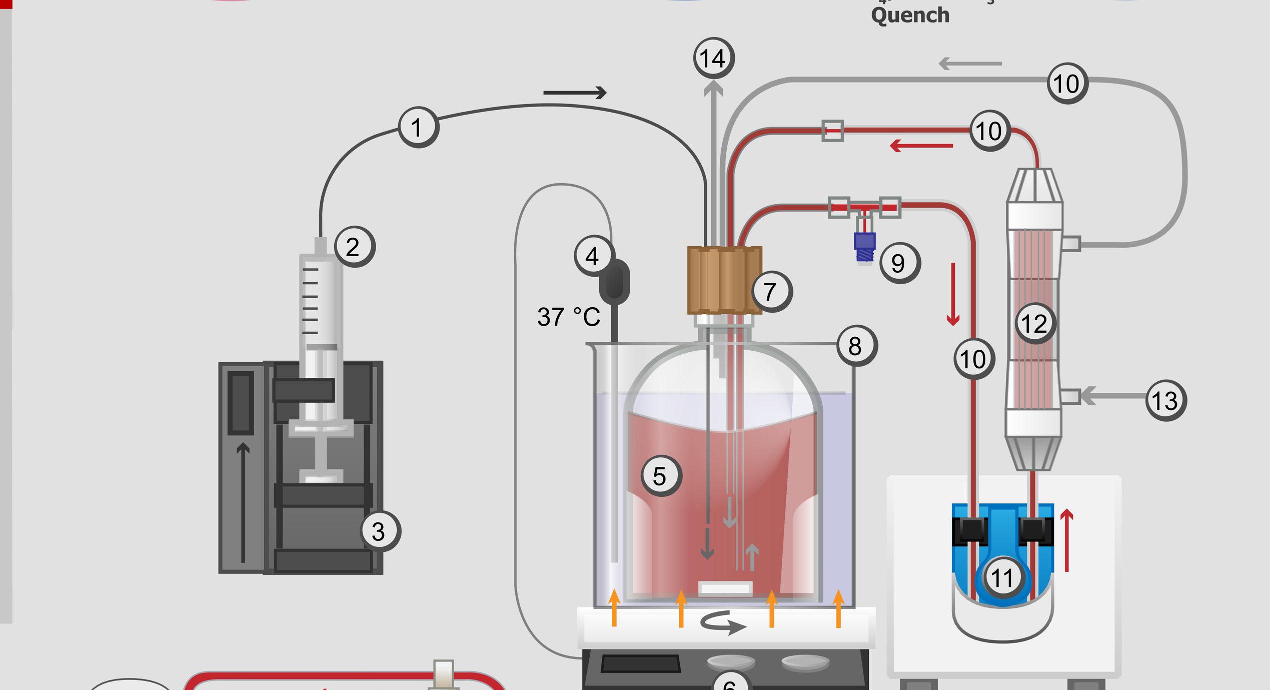
T-state PolyhHbs: A **safe** and **viable** alternative to RBC transfusion in the event of traumatic blood loss.

POLYMERIZED HEMOGLOBIN SYNTHESIS

T-state PolyhHb possesses low amounts of small molecular weight polymers

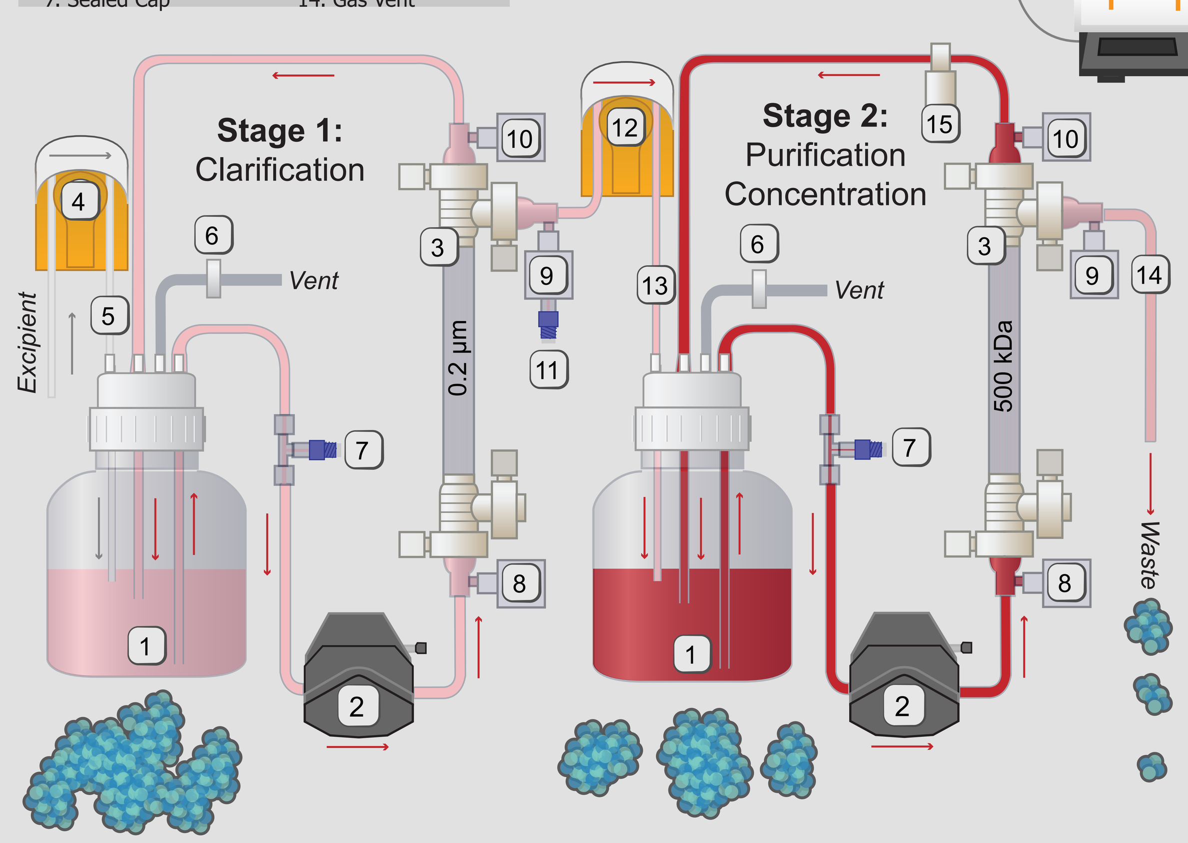
- More than 90% of final T-State PolyhHb product is > 500 kDa
- Reduced levels of small molecular weight species poses a lower risk of extravasation and reduced side-effects [1]





Polymerized Hemoglobin Reactor Components

1. Stainless Steel Needle
2. Reagent Syringe
3. Syringe Pump
4. Thermocouple
5. Glass Reactor Vessel
6. Hot/Stir Plate
7. Sealed Cap
8. Water Bath
9. Sample Port
10. O2 Impermeable Tubing
11. Peristaltic Pump
12. Membrane Contactor
13. Sweep Gas Inlet
14. Gas Vent



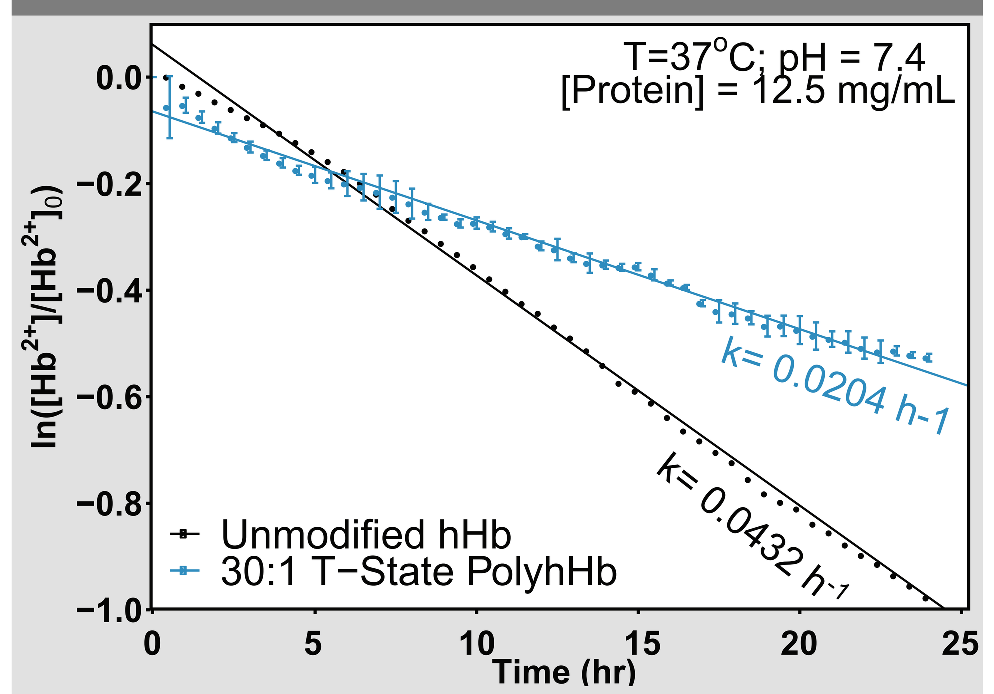
Purification Methods

- **Stage 1**
  - PolyhHb clarified on 0.2μm TFF filter module
  - Retained material > 0.2μm waste
- **Stage 2**
  - Stage 1 permeate difiltered on 500 kDa TFF module
  - Species <500 kDa removed via Ringer's lactate buffer exchange
  - PolyhHb stored at 10 g/dl, -80 °C

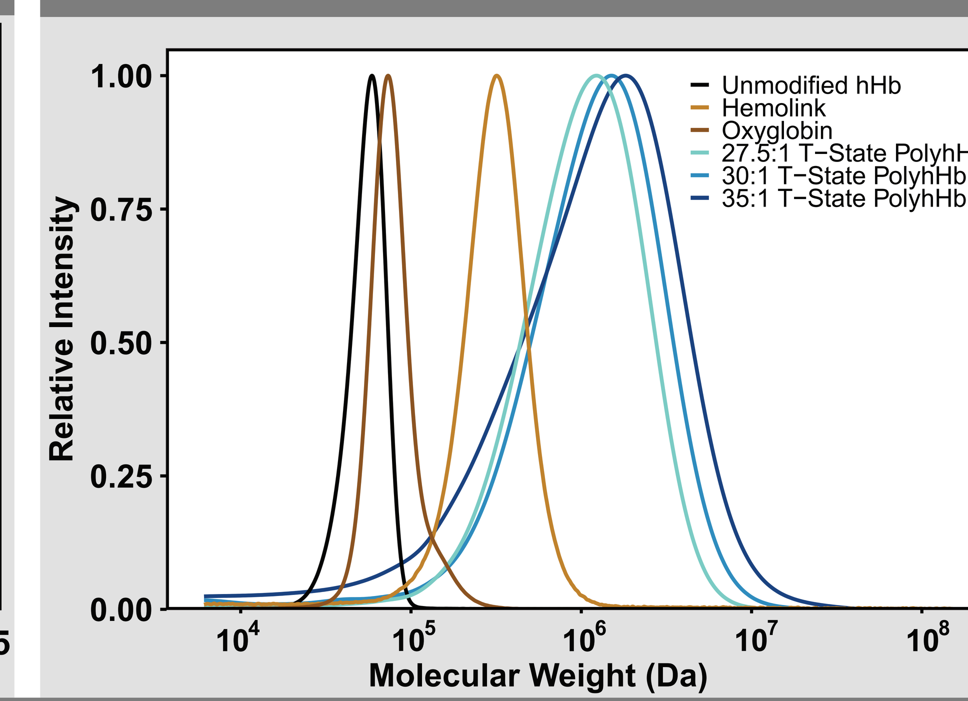
1. Retention Vessel
2. Recirculation Pump
3. Tangential Flow Filter
4. Diafiltration Pump
5. Excipient Solution
6. Air Vent Filter
7. Retentate Sample Port
8. Inlet Pressure Sensor
9. Permeate Pressure Sensor
10. Retentate Pressure Sensor
11. Permeate Sample Port
12. Interstage Diafiltratio Pump
13. Permate to Stage 2
14. Permeate to Waste
15. Backpressure Valve

POLYMERIZED HUMAN HEMOGLOBIN BIOPHYSICAL PROPERTIES

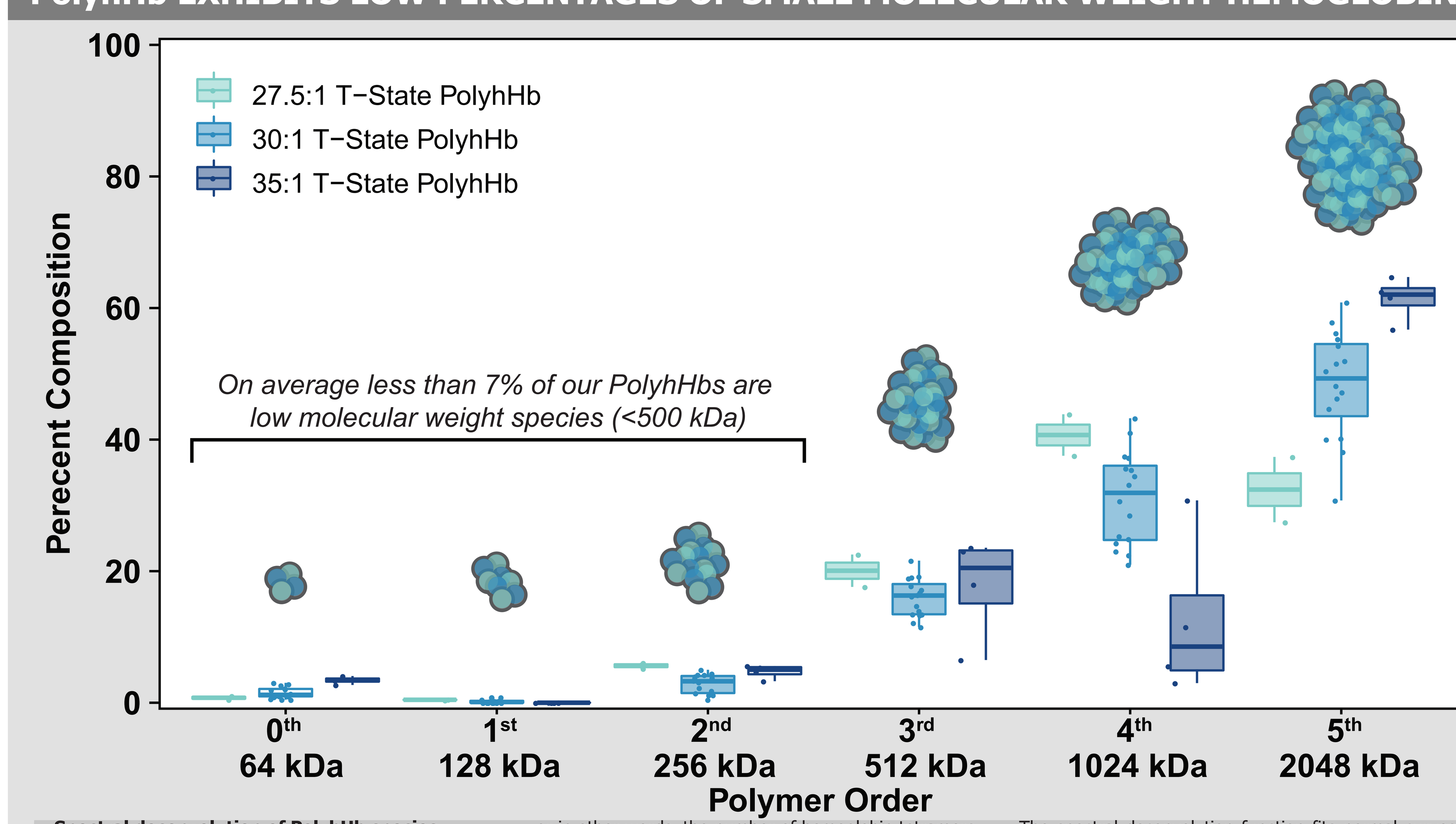
AUTOXIDATION RATE AT NORMOTHERMIC TEMPERATURE IS SLOWED



SIZE EXCLUSION CHROMATOGRAPHY SHOWS SIZE IS DRASTICALLY INCREASED

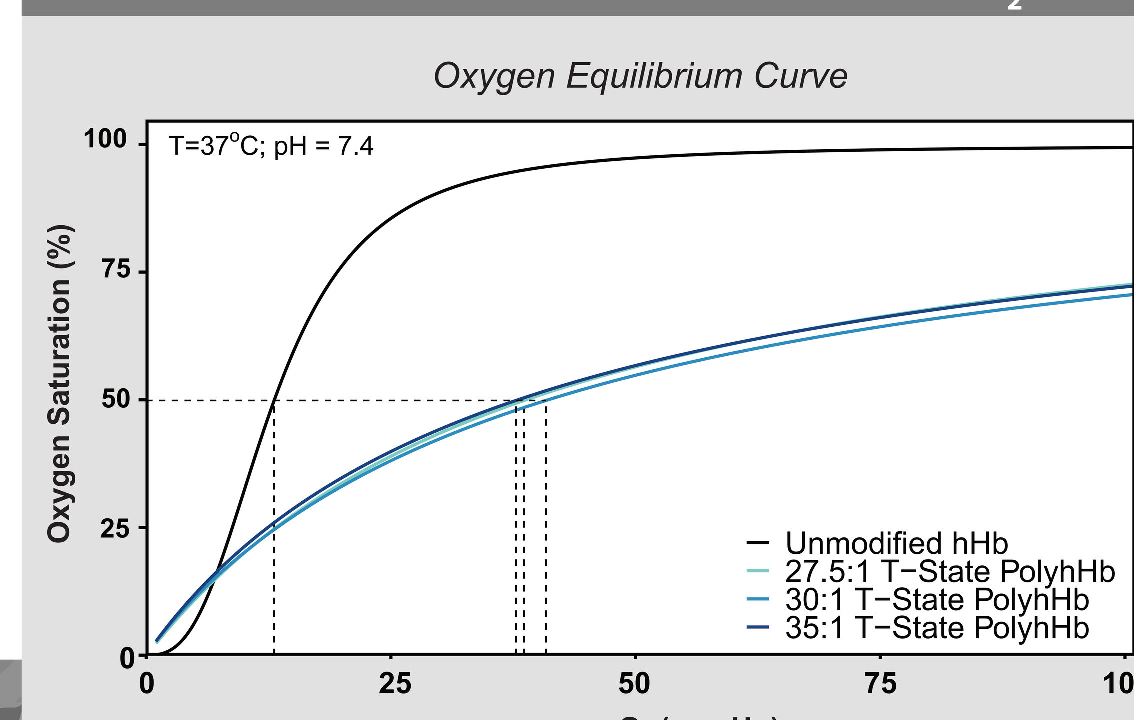


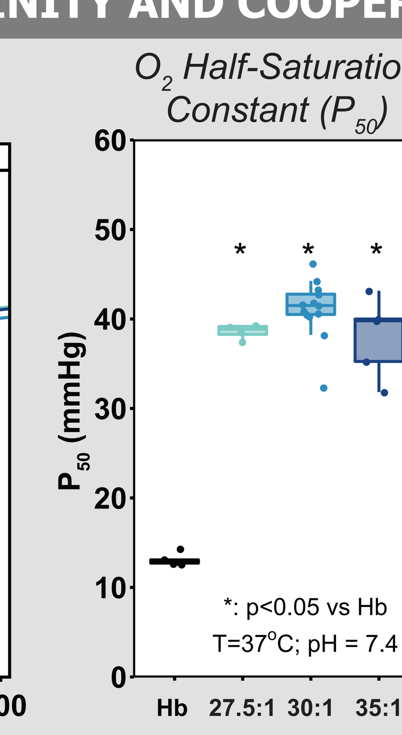
PolyhHb EXHIBITS LOW PERCENTAGES OF SMALL MOLECULAR WEIGHT HEMOGLOBINS

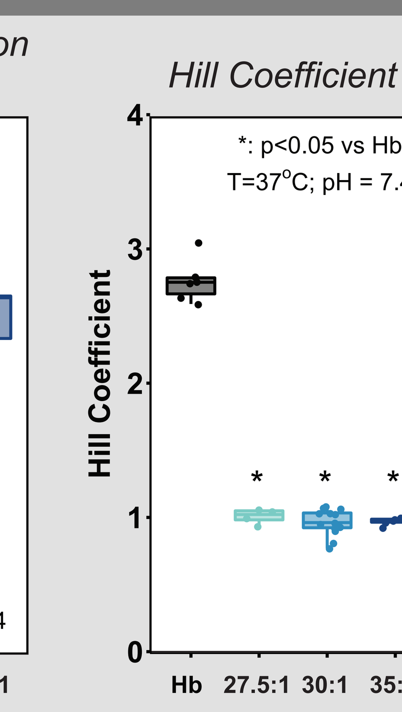


Spectral deconvolution of PolyhHb species. Using a spectral deconvolution function, SEC-HPLC data was broken down into different polymer fractions. The polymer order is defined as the number of pairs of hHb molecules that come together to form the PolyhHb, or in other words, the number of hemoglobin tetramers in the PolyhHb molecule = 2n where n is the polymer order. The results show a breakdown of both the grand averages for each of the polymer orders, and the size to scale of each of the respective polymer orders. The spectral deconvolution function fits normal curves with means at their respective molecular weights such that the individual order curves sum to the total HPLC distribution curve. 6th order polymers are not shown because they are 4096 kDa in size and are retained on

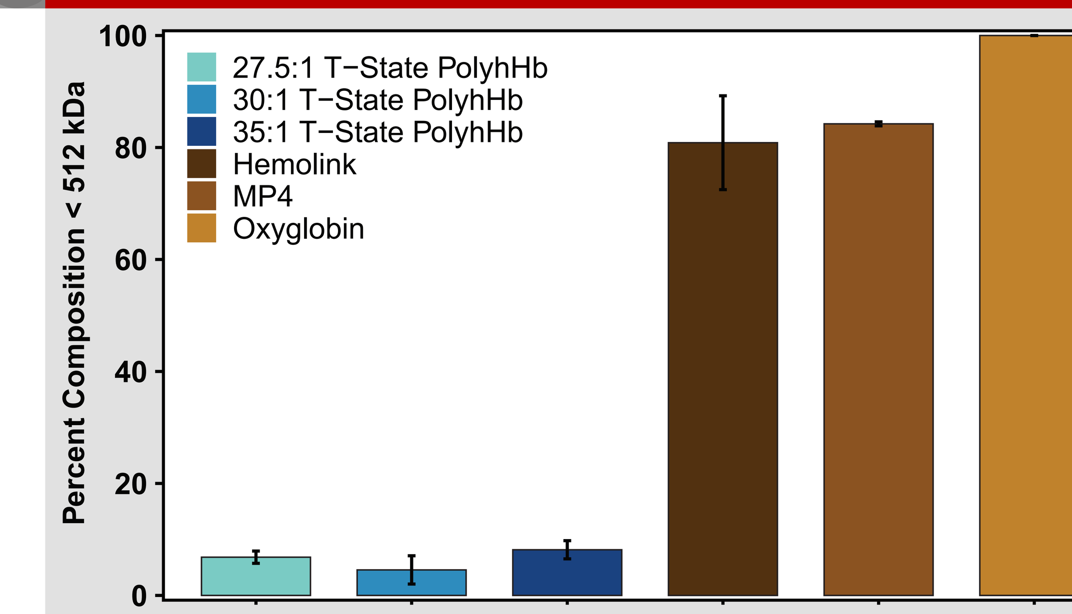
POLYMERIZATION DECREASES O_2 AFFINITY AND COOPERATIVITY







DISCUSSION & COMPARISON



T-state PolyhHb possesses low amounts of small molecular weight polymers

- More than 90% of final T-State PolyhHb product is > 500 kDa
- Reduced levels of small molecular weight species poses a lower risk of extravasation and reduced side-effects [1]

T-state PolyhHb possesses low amounts of small molecular weight polymers

- Larger diameter (~68 nm) compared to Oxyglobin® and Hemolink®.
- MetHb levels (~5.7%) are comparable to HBOC-201®, Polyheme®, Hemolink®, and Oxyglobin®
- P50 values (41 mm Hg) are similar to that of HBOC-201® and Oxyglobin®
- Cooperativity (0.97) comparable to HBOC-201® and Hemolink®

FUTURE WORK

Further Analysis

- Stop-flow kinetics of gaseuos ligands (Nitric oxide, carbon monoxide, oxygen)
- Bohr effect (Carbon dioxide effect on P_{50})
- Haptoglobin binding kinetics

Organ Perfusions

- Extend viable *ex vivo* window for donated grafts
- Faster path to clincal trials compared to transfusion

Storage Studies

- Lyophilization and dry storage
- Storage stability in aqueous and powdered state

WORKS REFERENCED

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6. Buehler PW, et. al. Analytical Chem. 2005;77: 3466–3478.
7. Jia Y et. al. Biochem J. 2004;384: 367–375.

ACKNOWLEDGMENTS

Wexner Medical Center Transfusion Services, The Ohio State University for generously donating expired human RBC units. Pedro Cabrales for generously donating commercial HBOCs. Our coworkers in the Palmer Lab for their collaboration and support.

Water Treatment for Hydrogen Production

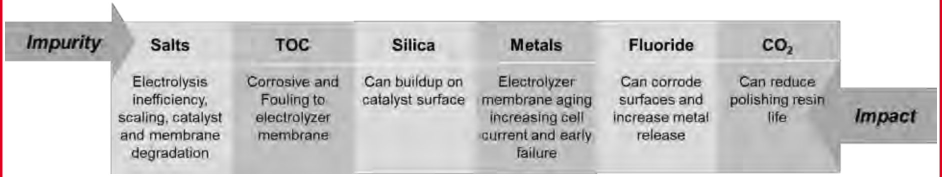
Marc Slagt, Matt Roth, Jordi Bacardit and Martin Deetz - DuPont Water Solutions

Challenge

Green Hydrogen has emerged as a key technology to enable global decarbonization. Proton exchange membrane (PEM) electrolysis requires a constant supply of ultrapure water for robust operation. The electrolyzer stack is the most expensive capital cost of the system and water impurities can limit its lifetime and efficiency and increase the cost of H_2.

The makeup water that feeds the system can come from a variety sources and robust treatment schemes need to be designed for each type of source water.

Within the electrolyzer system, a water loop recirculates to carry the gases and cool the electrolyzer stack. The loops currently run with a water temperature of ~60°C, with the industry target to go >80°C to boost electrolyzer efficiency. This is a real challenge, since higher temperature leads to more impurities leaching into the water and makes them harder to remove, especially silica.

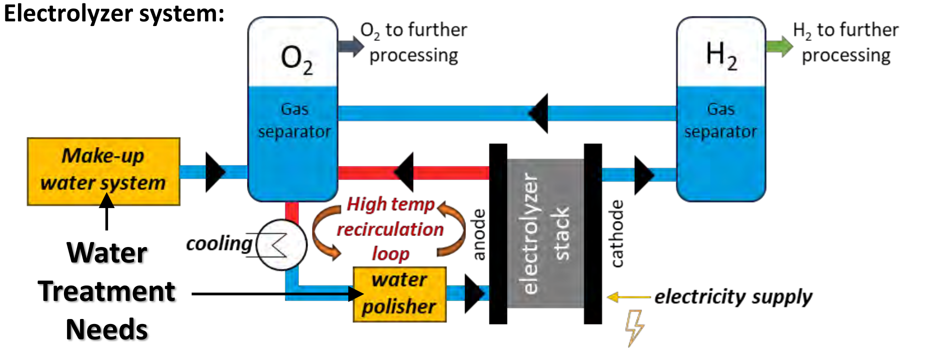


90% of electrolyzer failures are caused by water quality issues!

Approach

To address these challenges, DuPont Water Solutions has treatment technologies for all types of feed waters and recently launched the first-of-its-kind ion exchange resin designed specifically to remove the unique types of impurities within the water polishing loop allowing producers to push past current system limits to boost electrolyzer efficiency.

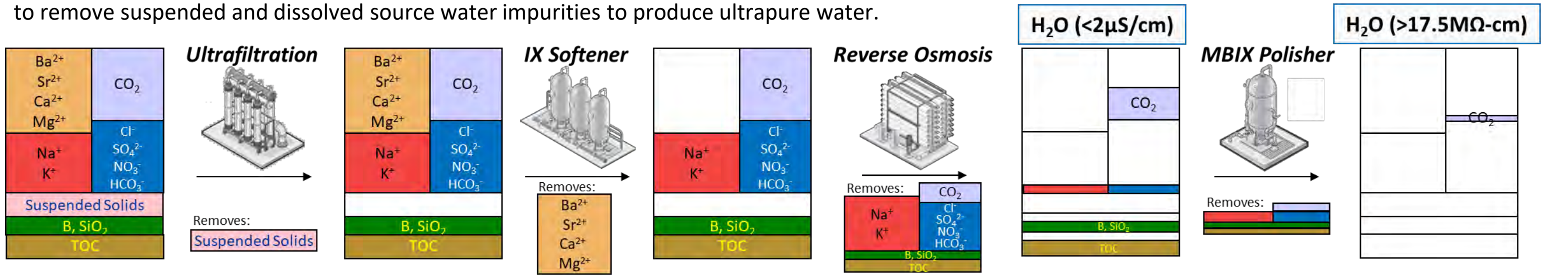
Electrolyzer system:



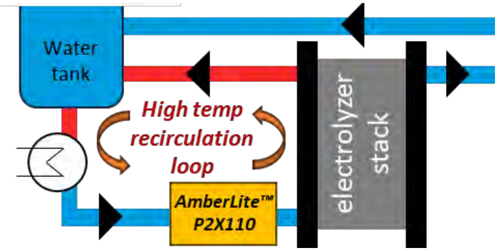
IX = ion exchange, MB = mixed bed, RO = reverse osmosis, UF = ultrafiltration, TOC = total organic carbon

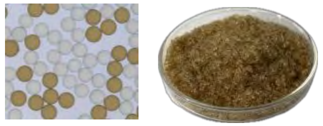
Solutions

Make-up water treatment: While designs will vary from one source water to another, the scheme below shows how each technology works together to remove suspended and dissolved source water impurities to produce ultrapure water.



Recirculation loop water polishing:





AmberLite™ P2X110

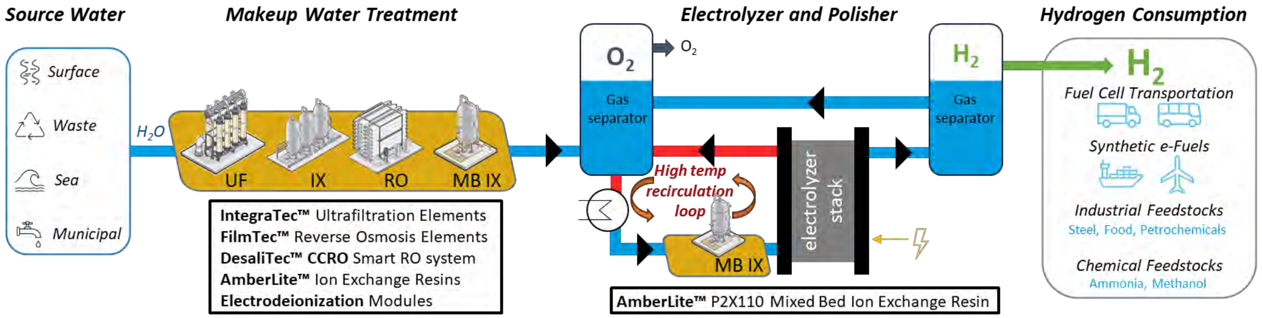
System components leach trace impurities into the high temperature recirculation loop which can impact the performance of the electrolyzer unit if not removed.

Our new **AmberLite™ P2X110** ion exchange resin is specially designed for electrolyzer polishing, with:

- **Robust performance at high temperature operation, up to 70°C**
- **High capacity, up to 40% longer run time than std mixed beds**
- **Enhanced silica removal capacity, >60% more**
- **18MΩ-cm water quality**
- **Very low TOC leachables, <5ppb**
- **Uniform particle size for ease of use and high mechanical strength**

2024 Business Intelligence Group: Sustainability Product of the Year

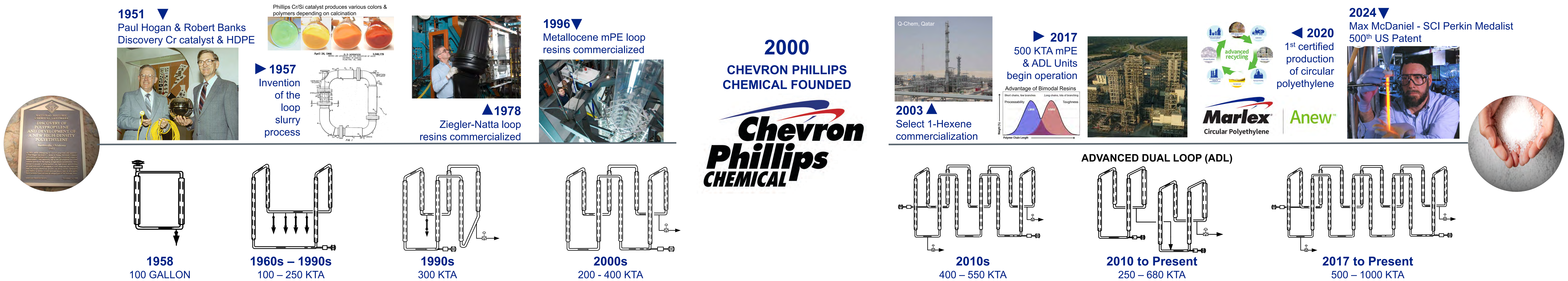
Summary



Hydrogen production relies on reliably maintaining high purity water for the electrolyzer. DuPont technologies offers robust performance under the challenging conditions to improve system cost, efficiency and lifetime.

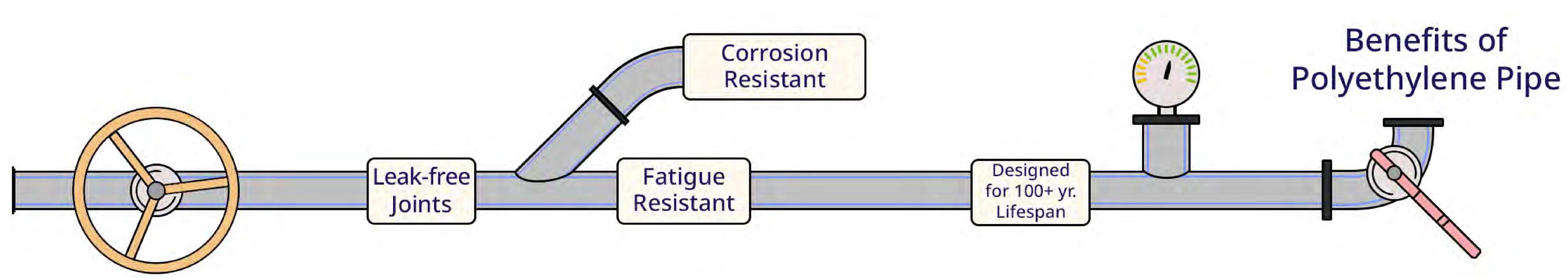
A History of Innovating Differentiated Products for a More Sustainable Future

Jeremy Praetorius, PhD, Metallocene Platform Team Leader and **Theresa Feltes, PhD,** Licensing Manager



Chevron Phillips Proprietary Bimodal Technology

Our high-density polyethylene **Pipes** provide clean drinking water, safely transport natural resources and protect sensitive electrical cables that keep the world connected.



PE100 Pressure Applications

These PE100 rated pipes are tailored for demanding requirements:

Excellent long-term hoop strength

Superb resistance to slow crack & rapid crack growth

Outstanding low-temperature toughness

Our low slump resin has excellent melt strength for large applications

Marlex® TRB-432 HDPE

Marlex® TRB-437LS HDPE

Municipal • Industrial • Energy • Mining • Potable Water

Non-Pressure Applications

Marlex® TRB-223 HDPE

A ***new*** conduit pipe resin that delivers enhanced properties critical to dependable performance in the demanding trenchless installation processes

Electrical • Telecommunications • Data Transmission

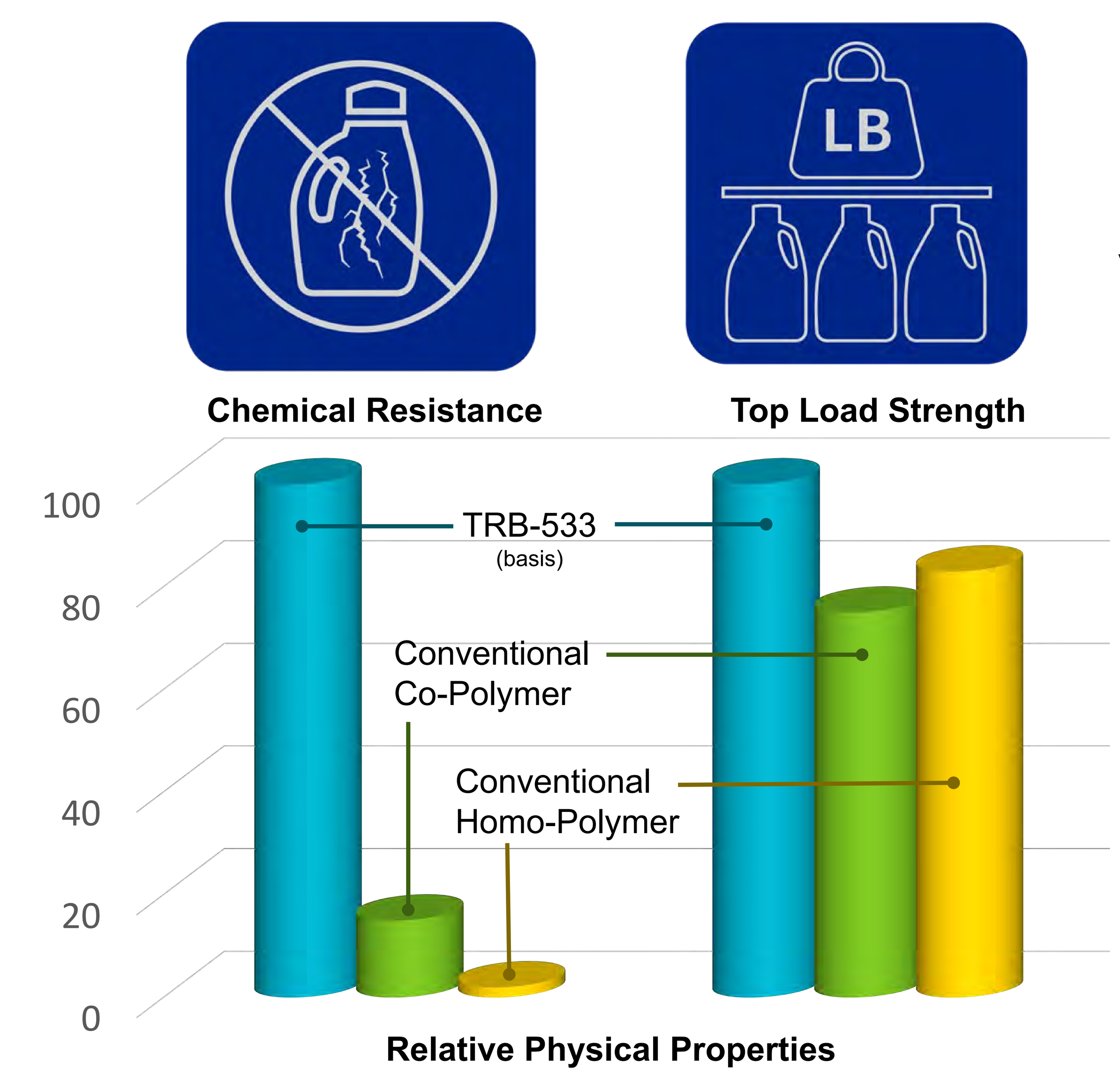
Marlex® TRB-490 HDPE

A bimodal blend component taking corrugated pipe applications to the next level

Roadway Culverts • Storm Sewers • Land Drainage

Introducing our new high-performance **Blow Molding** product: ***Marlex® TRB-533 HDPE***

Designed for small part blow molding, Marlex® TRB-533 HDPE provides a superior combination of stiffness and chemical resistance, making it ideal for a variety of end-use packaging applications.



Versus conventional Cr HIC resins in continuous blow molding processes:

- Increases melt strength performance
- Produces lighter weight bottles
- Improves extruder performance and polymer output
- Provides brilliant white containers with a matte surface

These outstanding physical properties provide our customers with sustainability advantages:

- Light-weighting potential
- Retain bottle properties with higher PCR loading

Agricultural Chemicals • Household Industrial Chemicals (HIC) • UN/DOT Containers • FDA Food Contact Containers

Performance by design.
Caring by choice.™

2 ZERO HUNGER · 3 GOOD HEALTH AND WELL-BEING · 6 CLEAN WATER AND SANITATION · 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE · 12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Aligning with the UN's Sustainable Development Goals allows us to leverage our product portfolio, value chain and industry leadership to advance these important goals while also helping to address potential areas of concern.

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ExxonMobil

Rishi Gupta & Sara Yacob
Process Innovation & Scale-Up
ExxonMobil Technology and Engineering Company
rishi.r.gupta@exxonmobil.com

Advanced Recycling: Supporting A More Circular Economy

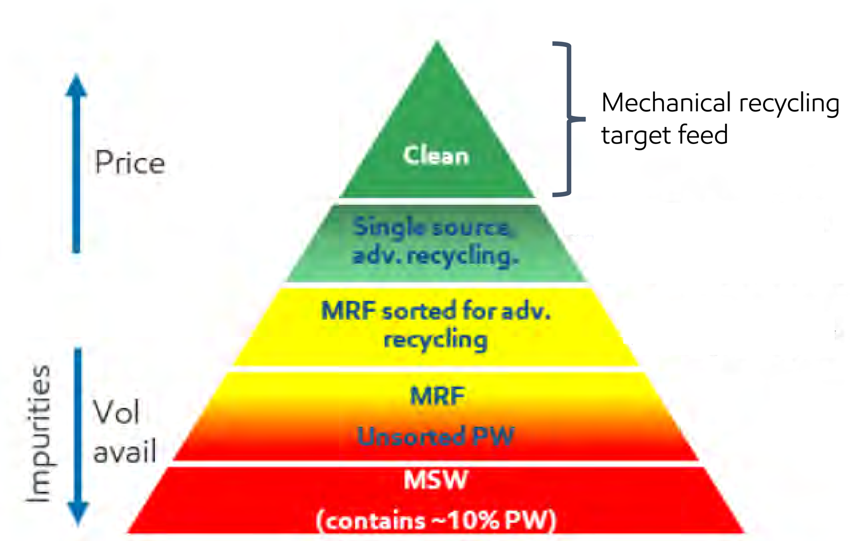
SCI Innovation Day, 9 September 2024

The Global Waste Management Challenge

- ~3 billion people worldwide are estimated to lack access to controlled waste disposal facilities[1]
- ~12% of the global municipal solid waste stream is plastic[2]
- Right now, less than 10% of plastic waste is recycled[3]
- Solutions will require innovation and global collaboration among the plastics value chain, governments, NGOs, and consumers

[1] United Nations - https://unhabitat.org/news/10-feb-2020/un-habitat-partners-with-wwf-to-tackle-global-challenge-of-waste-management-in
[2] World Bank, What a waste 2.0
[3] Source: (National Overview: Facts & Figures on Materials, Wastes and Recycling) EPA.com

Understanding the post-Consumer Landscape



- Advanced recycling target feedstocks Single Source & MRF Sorted to manage impurity content
- Driving for innovation to push AR feedstock lower in the pyramid

Estimates based on internal ExxonMobil analysis

ExxonMobil Advanced Recycling Projected Capacity

U.S. National Challenges

- Limited access to recycling programs
- Lack of recycling standards and fragmentation across current programs
- Confusing consumer education
- Films, flexibles, and other mixed-polymer feedstock too often not accepted
- Lack of sorting capacity

Meeting ExxonMobil's Advanced Recycling Capacity Ambitions

Scaling technology demonstrated in Baytown, Texas

- *Baytown advanced recycling facility started up in December 2022*
- *Technology widens the range of plastic waste that can be recycled*
- *Utilizes existing facilities to scale-up quickly*

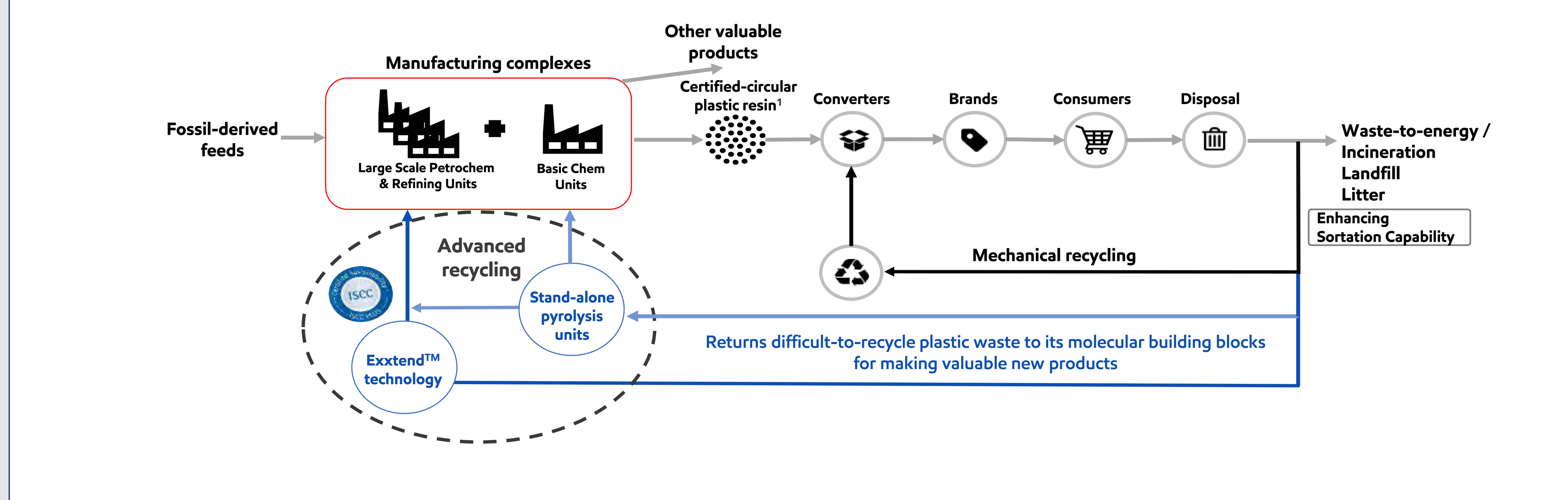
Widening the Range of Recyclable Plastics[1]

Material type	Single-stream plastics recovered for mechanical recycling[2,3]		Mixed-plastics desirable for Exxtend™ technology[4]	
1 PET	Target	•Monomaterial, easy to sort •Polymer properties amenable to M/R and food contact qualification	Tolerated in feed mix	•Acceptable in quantities up to oxygen contaminant limit
2 HDPE	Target	•Monomaterial, single source more common •Polymer properties amenable to M/R	Target	
3 PVC	Challenge	•Limited single source collection •Lack of monomaterial (additives)	Challenge	•Capable of taking small amounts
4 LDPE	Challenge	•Film collection & sortation more challenged •Polymer properties not amenable to M/R	Target	
5 PP	Tolerated in feed mix	•Sortation improving •Polymer properties less amenable to M/R	Target	
6 PS	Challenge	•Expanded PS foam collection, cleaning, densification is challenged	Tolerated in feed mix	•Acceptable in quantities up to contaminant limits
7	Challenge	•Not a monomaterial	Tolerated in feed mix	•Acceptable in quantities up to contaminant limits (e.g., high nitrogen content from nylon and polyamides)

Legend: Target; Tolerated in feed mix; Challenge

[1] In communities with programs and facilities in place that collect and recycle the resulting product.
[2] Plastics Recyclers Europe: PET Market in Europe: State of Play – Production, Collection and Recycling Data 2018
[3] Prepared for ACC by More Recycling, US PCR 2020
[4] ExxonMobil data

Exxtend™ aims to accelerate progress towards a more circular plastic economy



1 ISCC PLUS mass balance approach using the "determined by mass" option with "certified free attribution" applied. Does not represent GHG emissions or recycled content.
For illustrative purposes only.

Examples of Waste Plastic Processed in Baytown

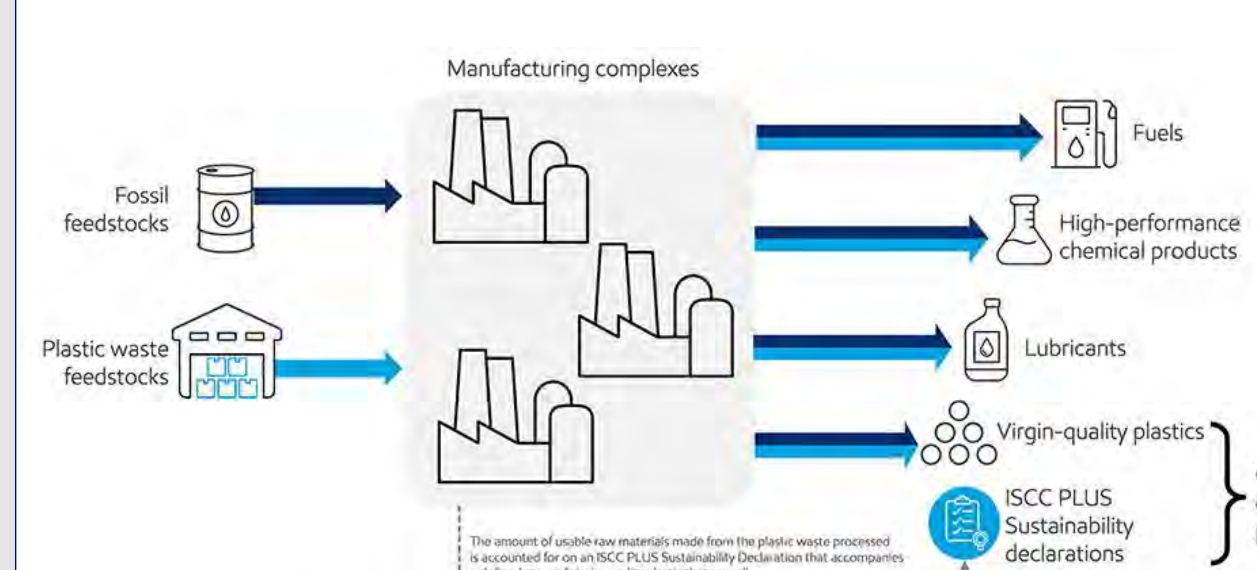
- Targeting plastic waste that is otherwise going to landfill or incineration, such as plastic films, cross-linked PE tubing, motor oil bottles, artificial turf
- Plastic films, cross-linked PE tubing, motor oil bottles, artificial turf
- Work with multiple parties to supply waste to Baytown facility, including Cyclyx JV

ISCC PLUS Certification

- ExxonMobil uses a concept called mass balance attribution in combination with ExxonMobil's Exxtend™ technology for advanced recycling
- Under this independently certified, auditable methodology, the mass of plastic waste that we process through our advanced recycling process- less manufacturing losses- is attributed to the mass of virgin-quality plastics that we sell as "certified-circular plastic"
- Our advanced recycling facilities and processes are certified via a third-party certification system called International Sustainability and Carbon Certification (ISCC) PLUS

ISCC PLUS Criteria for Certification

Site-specific	Operational Data	Process Feasibility	Physical Output	Transparency
Mass balancing must be site-specific	Determination of the conversion factor based on operational data	Chemically/technically possible, that the input molecular/atoms are included in the attributed output	Attributed sustainable output cannot be higher than the physical output in a mass balance period	Information on the used option for mass balance attribution and on multi-site mass balance must be provided via sustainability declaration



To learn more, please visit https://cutt.ly/qwSqDjqt.
For illustrative purposes only

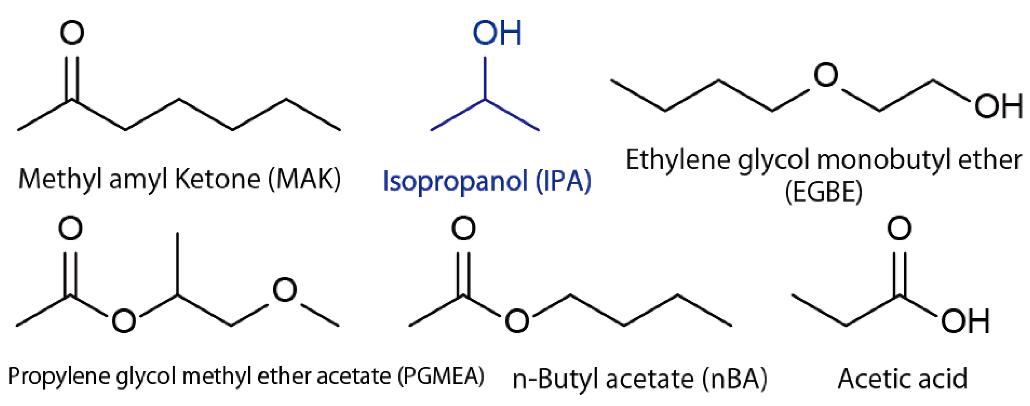
Development of Ultra High Purity and Sustainable Solvents for Semiconductor Processes

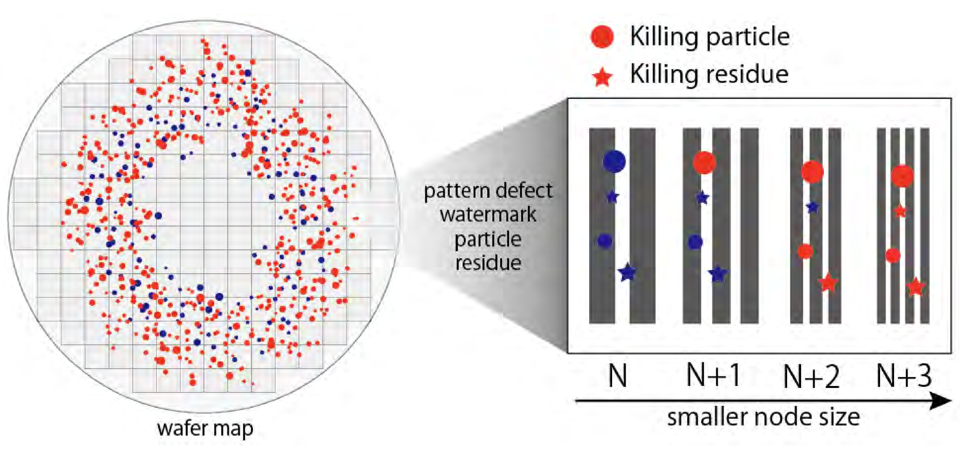
Eastman EastaPure™
electronic chemicals

Chih-Hung Ko, Jeff Powell, and Ken Hampton
100 Eastman Road Kingsport, TN 37660, and 300 Kodak Blvd. Longview, TX 75602
chihhung.ko@eastman.com | 919-590-9008

Driving Force for Ultra High Purity Solvents

Originating from small molecules like methanol, Eastman has manufacturing oxygenated and amino solvents for a long time. These solvents support various industries, including adhesives, coatings, inks, personal care, and electronics. Particularly, in semiconductor manufacturing processes, Wet chemicals play a critical role in resist coating, developing etching, stripping, and cleaning steps. Among these organic solvents, isopropanol (IPA) is widely used in the final stage of the standard cleaning process to remove organic compounds, water residue, and particles. The ultra-high purity of IPA ensures pristine surface quality during hundreds of process steps . As die sizes diminish, more cleaning steps are required, where the reduction of killer particles or residue in IPA plays a critical role in reducing wafer defects, according to 2022 IEEE IRDS Yield Enhancement."





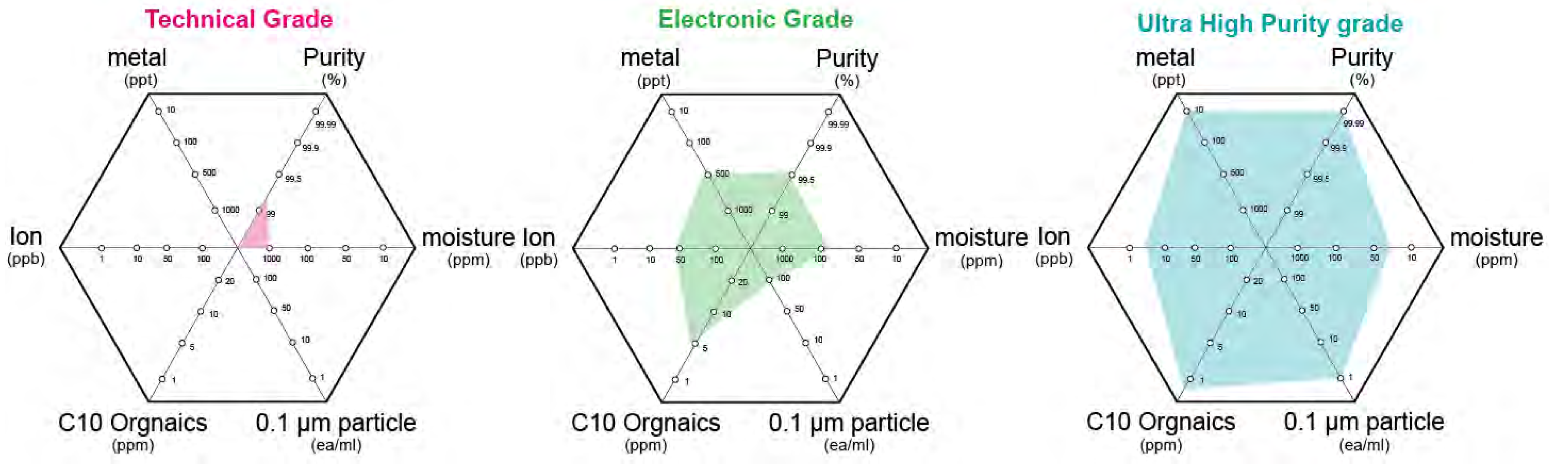
Year	2021	2023	2025	2027
"Node Range" (nm)	"5"	"3"	"2.1"	"2.1"
High MW organics (ppb)	150	50	30	10
Assay (±%)	99.94±0.02	99.95±0.02	99.97±0.02	99.99±0.02
Particle Count (10 nm /ml)	<60	<60	<60	<60
General Metal content (ppt)	<10	<1	<0.09	<0.07

On-shoring Semiconductor Supply Chain

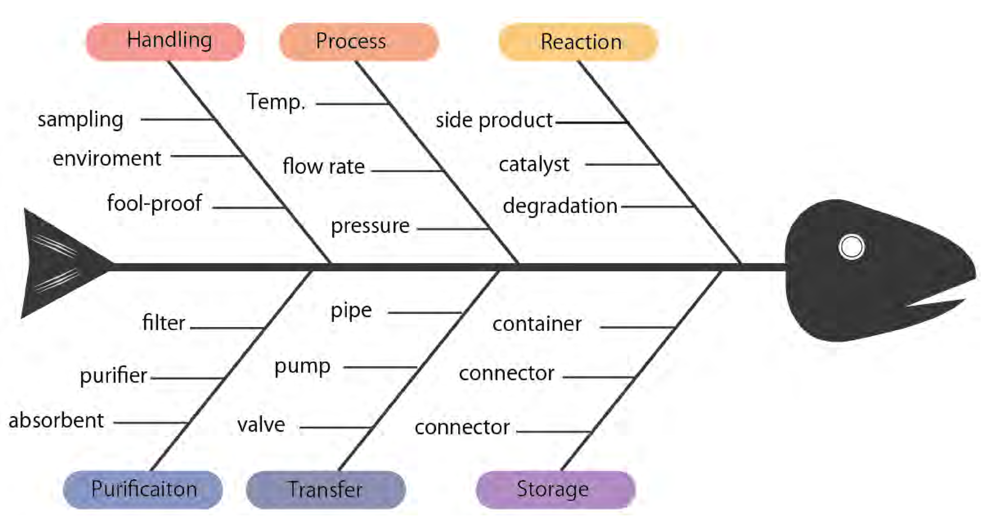
Compared with chemicals imported from other regions, the domestically produced solvent supports U.S. semiconductor manufacturers by providing a reliable and high-quality supply, mitigating supply chain issues for U.S.-based technology brands and manufacturers. Along with stable production plan to meet the growing demand, lead time can be shortened with less concern about blockages.

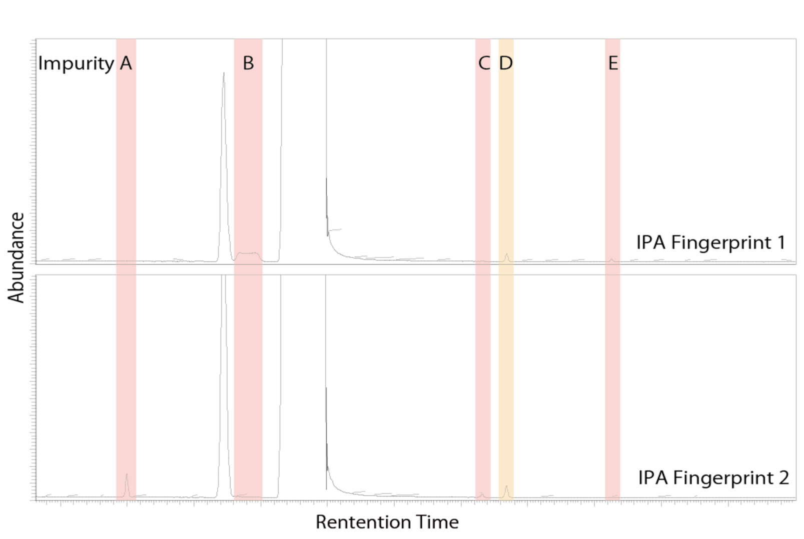
Advancing Quality in Fitness for Use

Eastman has introduced a new electronic grade isopropyl alcohol (IPA) to its EastaPure™ solvents portfolio, designed to meet the high purity and reliability standards required by the semiconductor industry. EastaPure™ IPA is effective in various stages of semiconductor production, including wafer fabrication and advanced packaging processes. Schematic diagram to compare three grades of IPA is provided to better visualize the quality control parameters. Notably, except for particles, most parameters are easier to handle in the upstream process rather than with costly advance purifiers located at the CDU (chemical dispense unit) or POU (point of use).



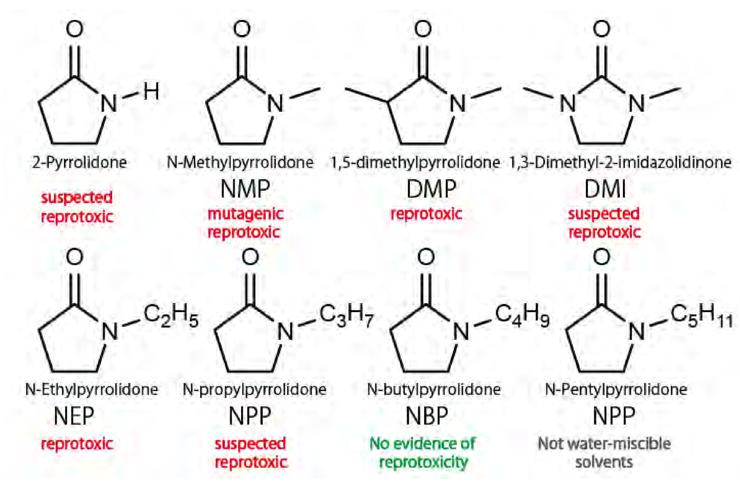
Backed by more than 70 years of experience, the Eastman team of specialists stands behind electronic grade IPA and can help to continuously improve products to fulfill advancing technology. Manufactured in world-class facilities equipped with dedicated equipment to prevent contamination, EastaPure™ IPA ensures 99.99% purity and consistent quality. The reduction of impurity levels is achieved through chemical engineering design and stringent quality control from processing to material handling. Additionally, metrology techniques such as mass spectrometry are crucial for tracing the sources of even the smallest quantities of contamination in the solvent."





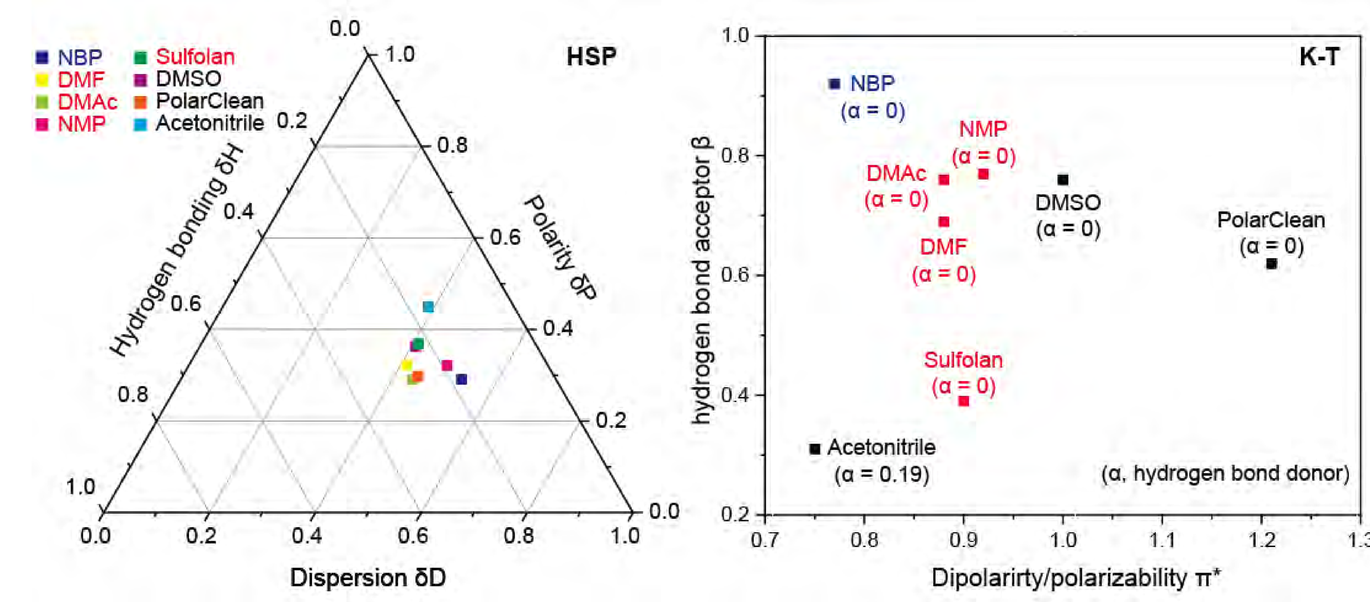
Searching of Sustainable Dipolar Aprotic Solvent

Specialty chemicals formulated with dipolar aprotic solvents such as NMP, NEP, DMF, DMAc and 2-Pyrrolidinone are widely utilized for stripping and cleaning processes due to their high polarity and solvation. Yet, these solvents raise environmental concerns and pose health risks. For instance, NMP is classified as a substance of very high concern (SVHC) by the European Chemicals Agency (ECHA) because of reproductive toxicity, initiating Notice of Proposed Rulemaking (NPRM) under Toxic Substances Control Act (TSCA) by Environmental Protection Agency (EPA). In response, major technology firms have committed to managing hazardous substances by reducing or eliminating undesired solvents. A significant challenge in the search for sustainable solvents results from time-consuming reproductive toxicity studies in which NEP and DMP were initially defined as green solvents, and eventually categorized as reprotoxic category 2 by ECHA. N-butylpyrrolidinone (NBP) emerges as a promising candidate which is identified as non-reproductively toxic (OECD 414 and 421), non-mutagenic (OECD 471) and inherently biodegradable (OECD 302B).



Solvent	b.p / °C	m.p / °C	viscosity / cp	E_T	Issue
NBP	241	< - 75	4.0	0.323	
NMP	202	-24	1.9	0.355	H360
DMF	153	-60	0.8	0.386	H360
DMAc	163	-20	1.9	0.377	H360
Sulfolan	285	26	10.3	0.410	H360, high cp
DMSO	189	18	2.0	0.444	skin penetration
Acetonitrile	82	-44	0.3	0.460	class 3 flammable
PolarClean	280	-60	9.8	-	high cp

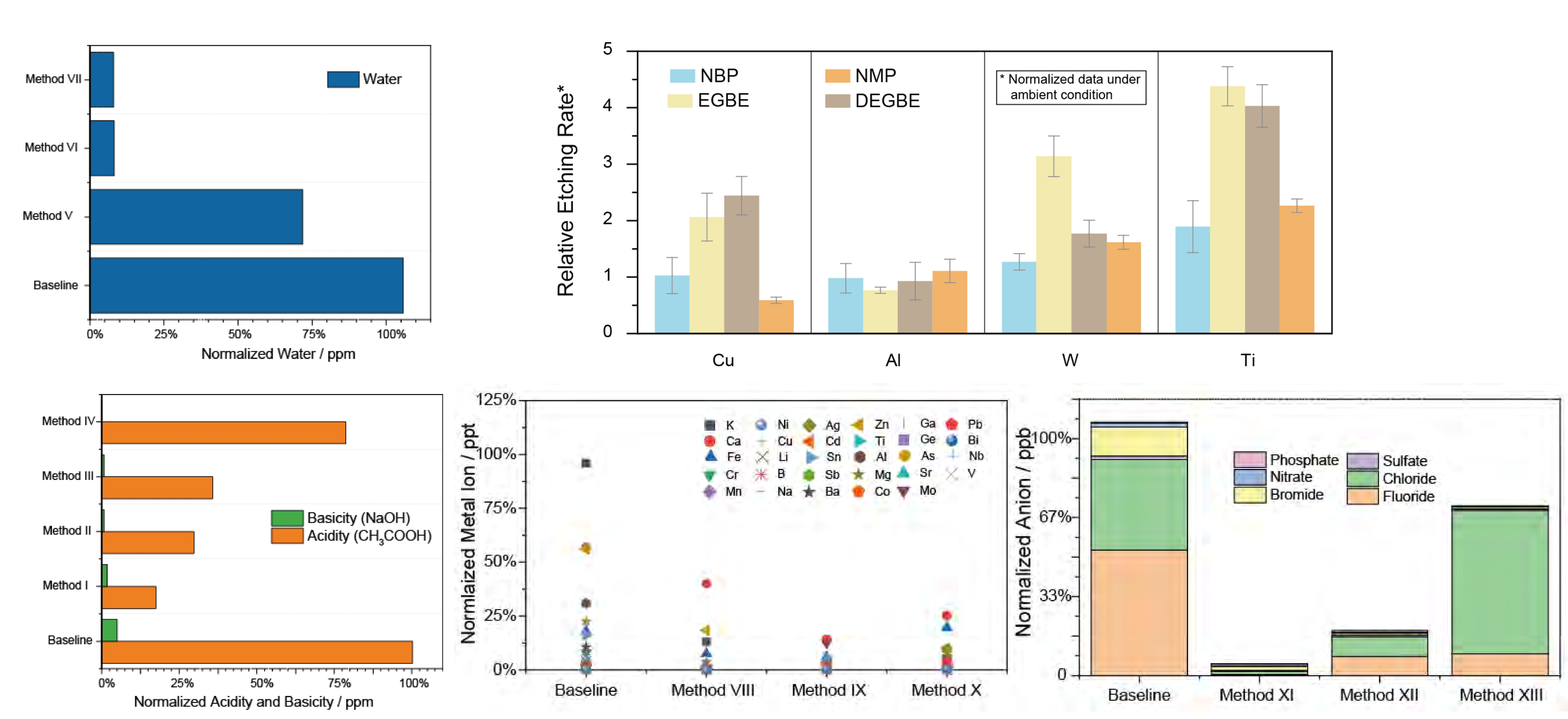
The longer alkyl chain of NBP leads to slightly higher boiling point and viscosity while reducing polarity. Hansen Solubility Parameters (HSP) and Kamlet-Taft (K-T) parameters estimating the type of interactive forces responsible for solvent–polymer compatibility and synthesis process indicate the adaptation of NBP may require refinement of raw materials, reformulation of specialty chemicals.



Solubility Test and Refinement Process

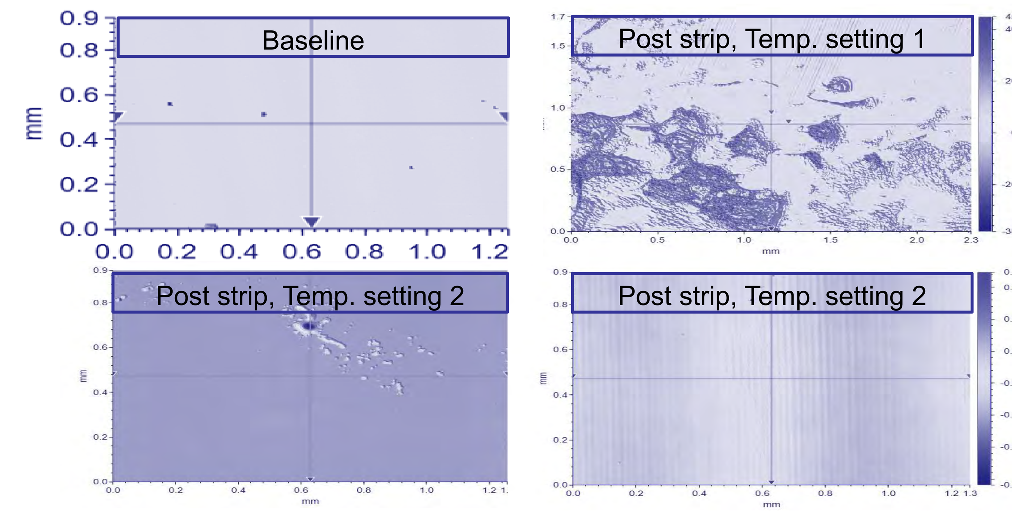
To fulfill the expected purity level, various NBP polishing methods are selected to effectively reduce water, acidity, basicity, metal ions, and anions, minimize the surface contamination or prevent unwanted side reactions of reactants. Noteworthy, NBP etching rate is very close to NMP on Al, Cu, Ti and W substrate.

Polymer	Solubility	Polymer	Solubility	Polymer	Solubility
PE	Not soluble	PTFE	Not soluble	PC	Soluble
PP	Not soluble	PFA	Not soluble	PET	Partially soluble
PS	Soluble	PMMA	Soluble	PVDF	Not solube
PVC	Solube	CPVC	Solube	PI	solube



Polymer Stripping

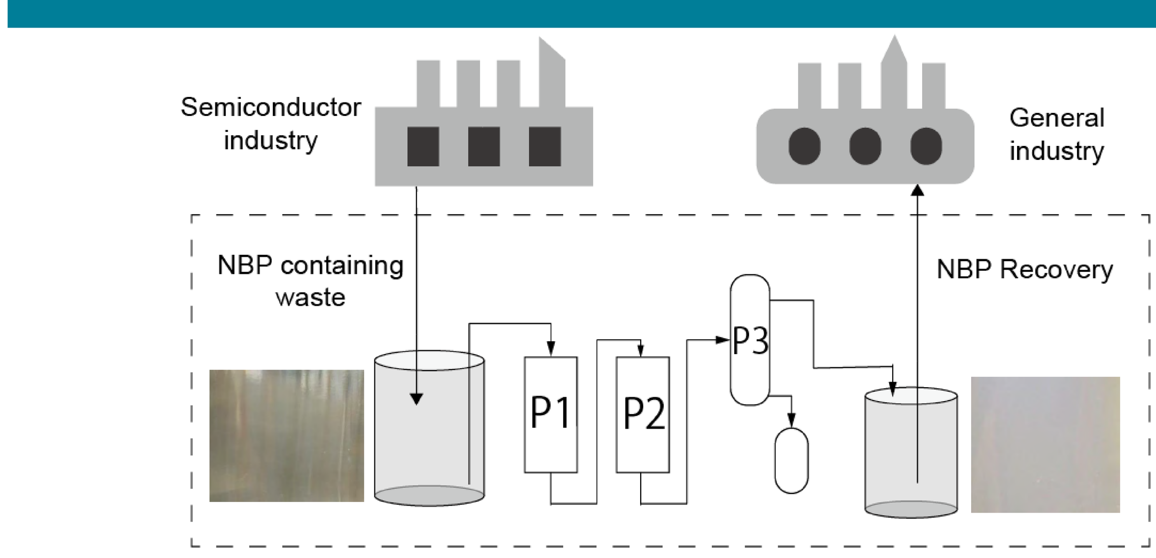
An exemplary film deposited on a 1.2 x 1.2 mm area was selected to observe the stripping behavior. As the process temperature increased, the removal capability was enhanced. Several blend systems were also examined to demonstrate nanometer-scale surface roughness at lower temperatures by adjusting HSP and ratio.



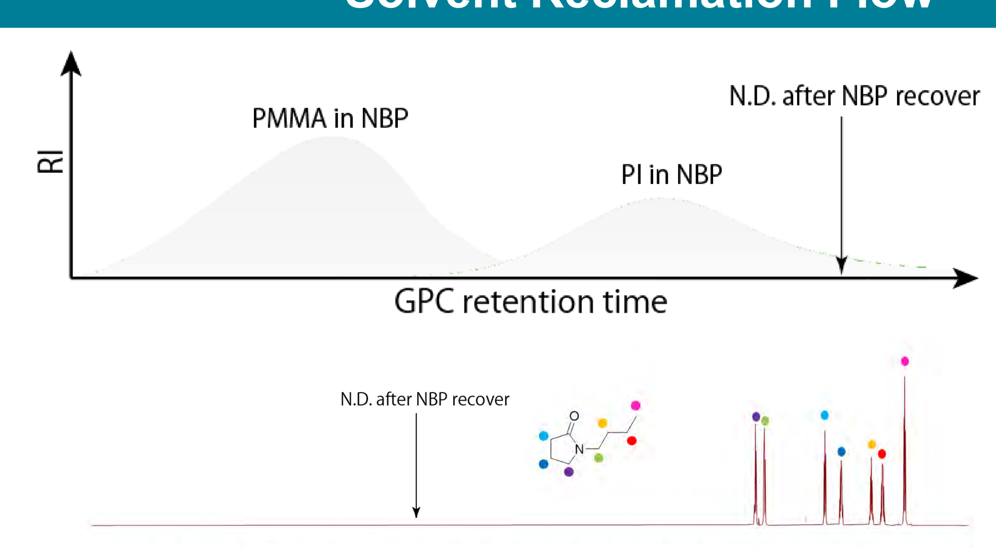
Blend	NBP	+AB	+BC	+CF	+DF	+AF
δH	5.8	<5.8	<5.8	>5.8	<5.8	<5.8
δD	17.5	<17.5	<17.5	<17.5	<17.5	<17.5
δP	9.9	<9.9	<9.9	<9.9	<9.9	<9.9
Polymer A	×	×	×	⊗	×	○
Polymer C	○	×	×	⊗	○	⊗
Polymer B	◎	⊗	×	○	◎	○

◎: low roughess, ○: medium roughess, ⊗: high roughess, ×: significant residue

Solvent Reclamation Flow



Proposed NBP Recovery Flow



A proposed solvent recovery flow, as a representative scheme, may include stripping, distillation, and post-treatment to demonstrate the customizable feasibility of reclaiming a mixture of NBP with selected resin, where the removal of yellowish polyimide (PI) and PMMA is verified by GPC and 1H NMR to renew NBP for general industry usage. The "cradle to cradle" ecosystem makes it possible to recover bulk organic solvent (e.g., NBP, IPA, PGMEA), and will help industry

- *Eliminating incineration cost*
- *Creating sustainable manufacturing*
- *Reduction of green house gas emission*

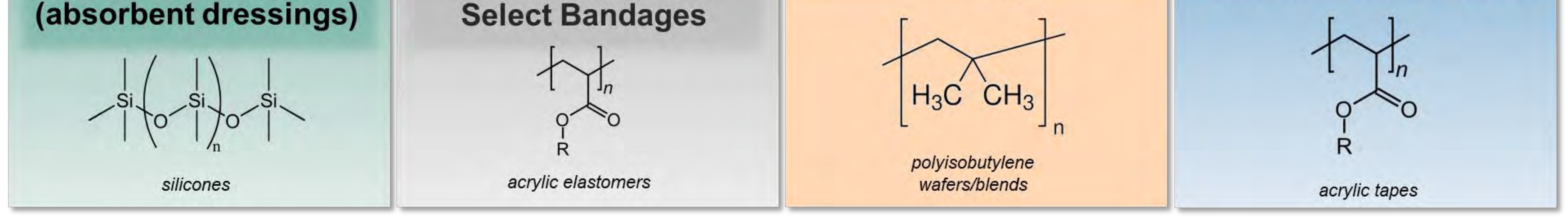
EASTMAN

Polymer Design of Polyester-Based Medical Adhesives

Julia Kozhukh, Christina Older, Margaret Gerthoffer, Bolun Hu, Mark Guidry, Audrey Wipret, Guy Mommens, Jessica Klinkenberg, Todd Pangburn, Michele Vigliotti, Xavier Thomas, Heidi Burch, Marios Avgousti, Jeff Meth

Medical Adhesive Applications Related to Wear Time

Advanced Wound Care (absorbent dressings)	Surgical Drapes & Select Bandages	Ostomy	Advanced Wearables



Application Specific Desirables:

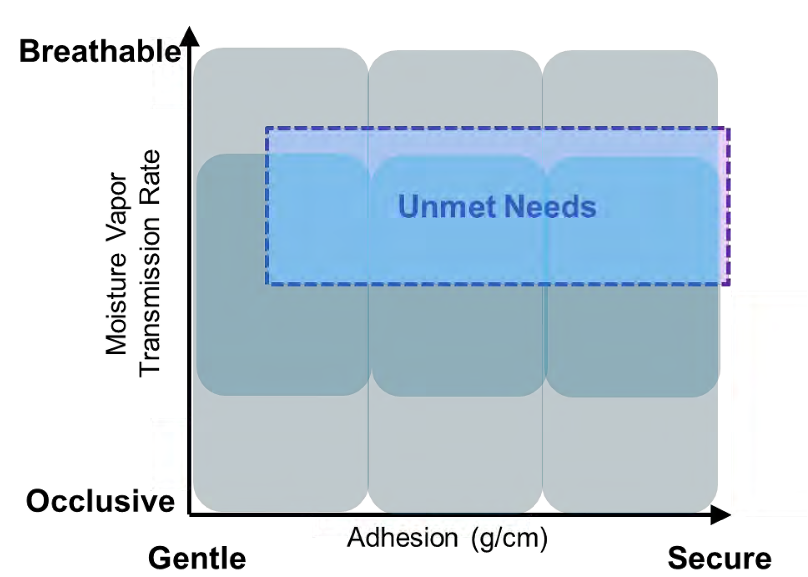
- ✓ Facile sterilization (ETO, UV)
- ✓ Frequent replacement
- ✓ Gentleness on skin

- ✓ Repositionability
- ✓ Gentleness upon removal

- ✓ Atraumatic removal
- ✓ Long term wear (days)
- ✓ Body fluid management
- ✓ One-pot

- ✓ Atraumatic removal
- ✓ Long term wear (days to weeks)

Unmet Needs and Copolyester Differentiators



Desired Characteristics

- Stick firmly to skin (a very difficult substrate!)
- Easily and cleanly removed from skin when desired
- Non-toxic, non-irritating & non-sensitizing
- Atraumatic removal, even from fragile skin
- Sterilizable with gamma irradiation

Novel Copolyester Adhesive Technology

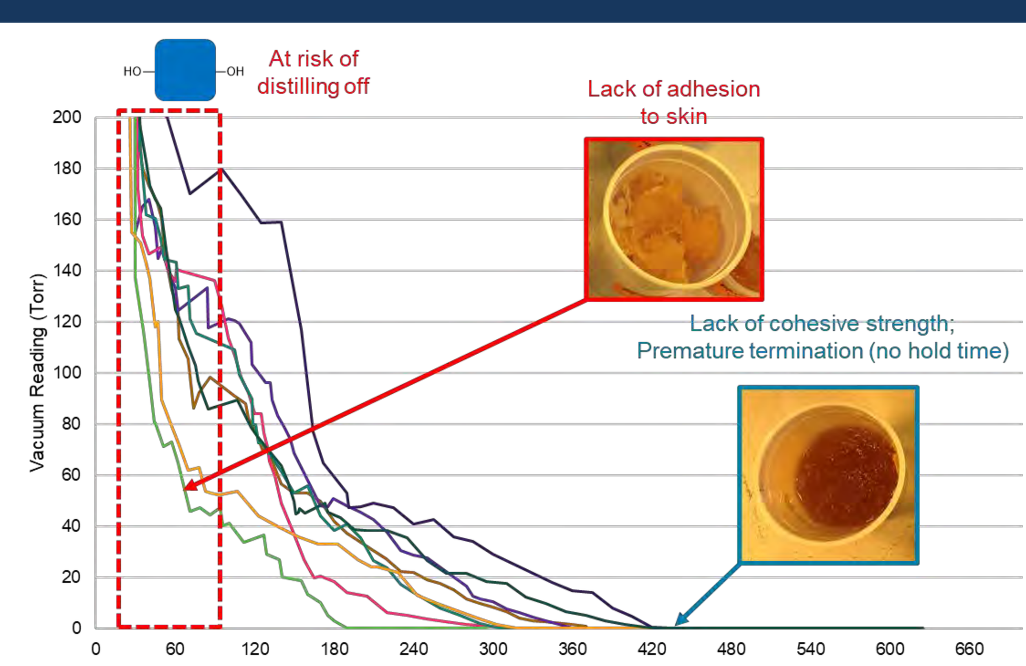
Functionality advantages:

- Higher hydrophilicity and breathability for enhanced transpiration/ body fluids management
- Gentle adhesion (tunable), with higher tack
- Low cold flow and skin irritation

Processing advantages driving cost-effectiveness, design flexibility & sustainability:

- Solvent-free 1-part adhesive
- Melt processible coatings or printing at low temps (gravure, stencil, printing)
- Transferability from releasing carrier to final substrate
- Lower coating thickness range (gr/m²) relative to skin tackiness
- Long-shelf life and no pot-life issues
- Expect to be stable to a variety of sterilization technologies (gamma, x-ray, e-beam, EO)

Process Effects

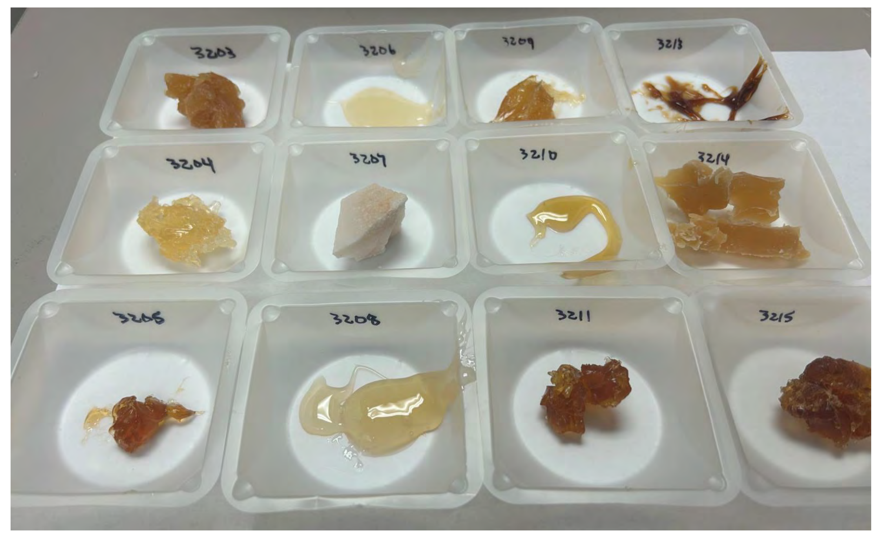


Fast distillation – strips tackifier to change product properties

Too little total vacuum – long reaction times and/or forgo in building MW

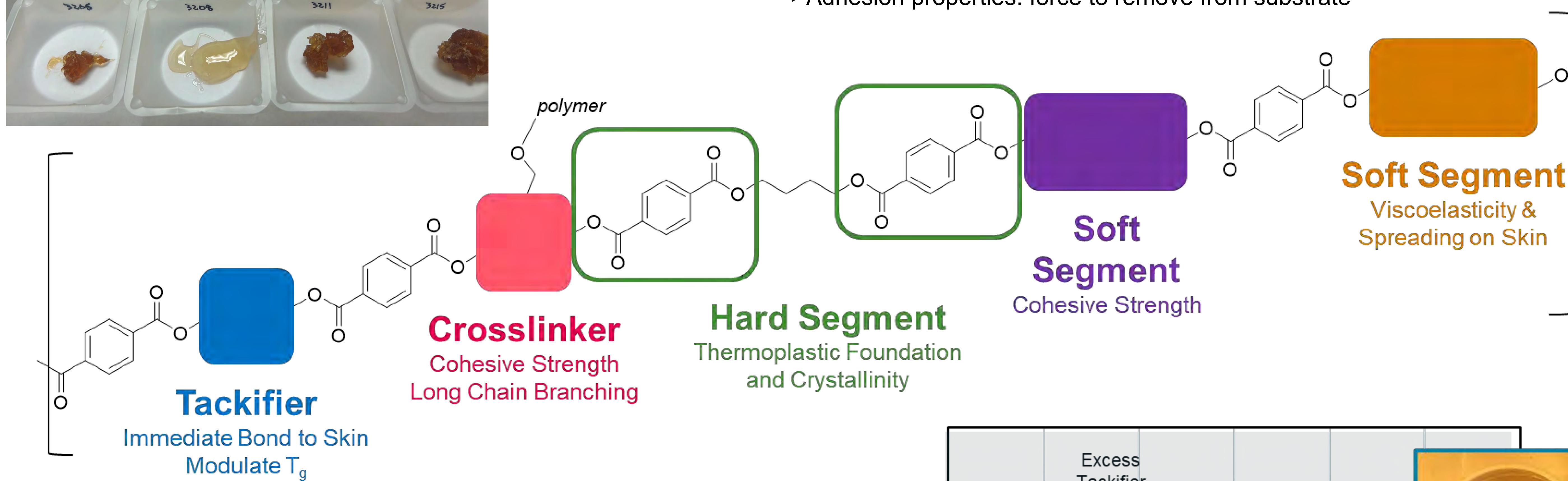
Rxn Begin → <1 Torr Vacuum → Rxn end → Total Reaction Time: ~8-10 hrs.

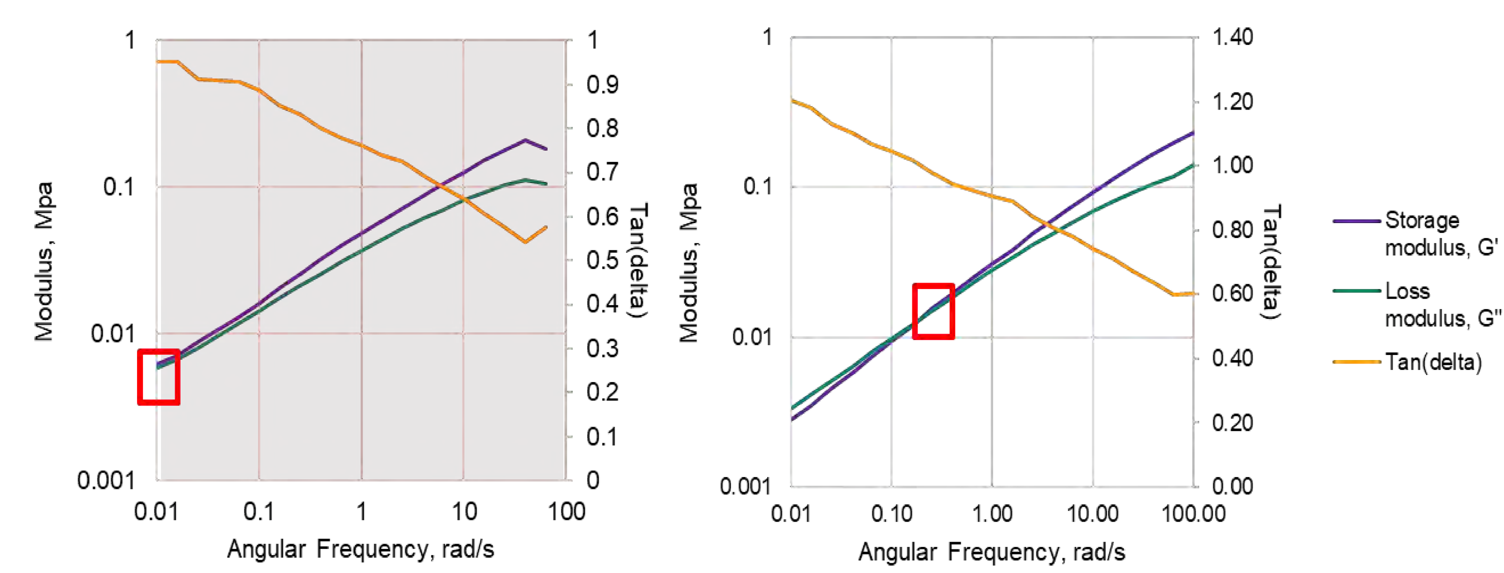
Structure-Property Relationship of Copolyesters



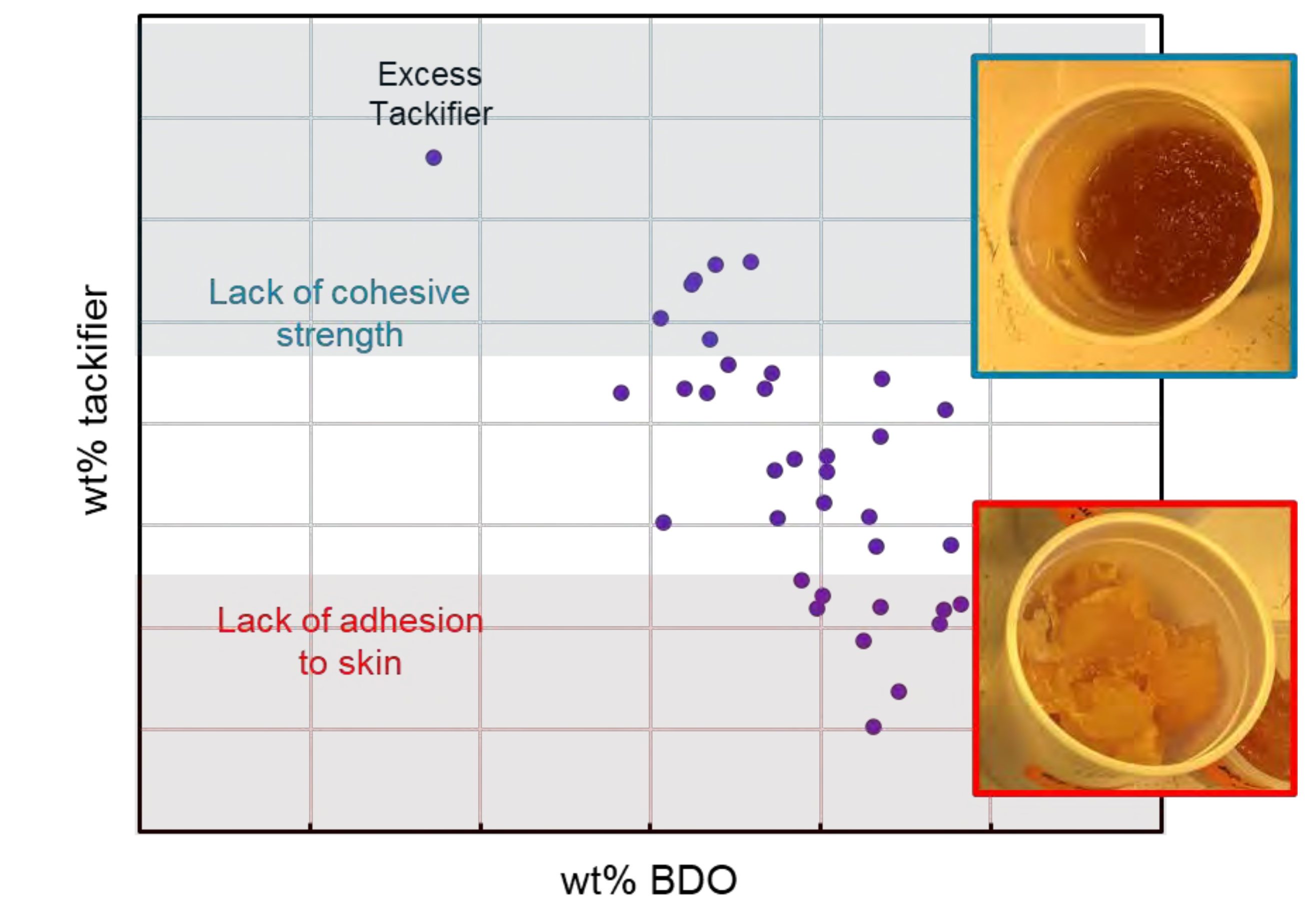
Plug and Play: Finding optimal balance of each monomer incorporation per application

✓Rheological properties (viscoelasticity)
✓Long-chain branching/polymer folding
✓Tackiness to skin
✓Cohesive strength & wettability
✓Adhesion properties: force to remove from substrate





Tackifier incorporation drastically changes rheological properties!
How do we control this?

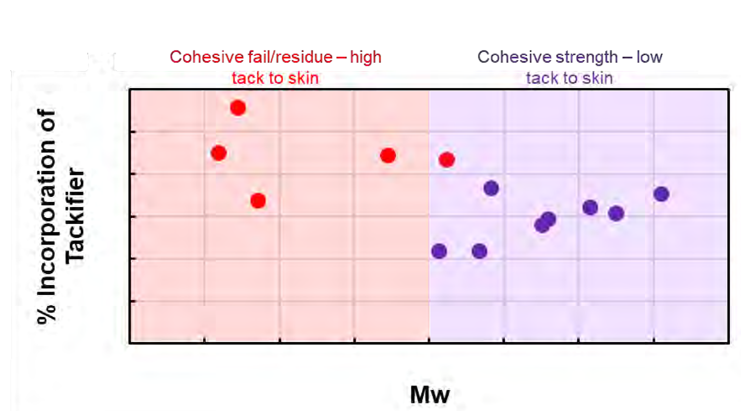


Properties and Applications

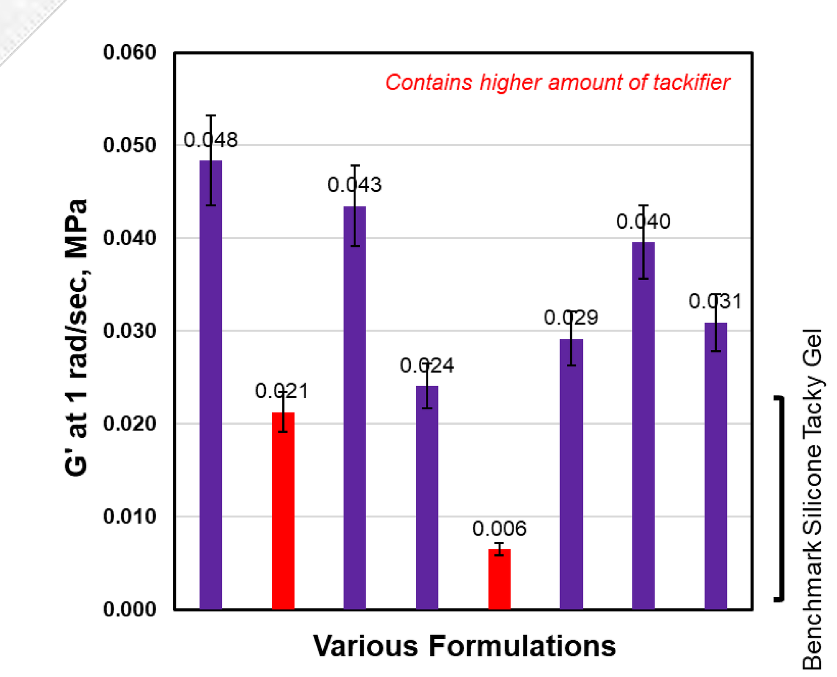
Rxn Begin → <1 Torr Vacuum → Reaction End

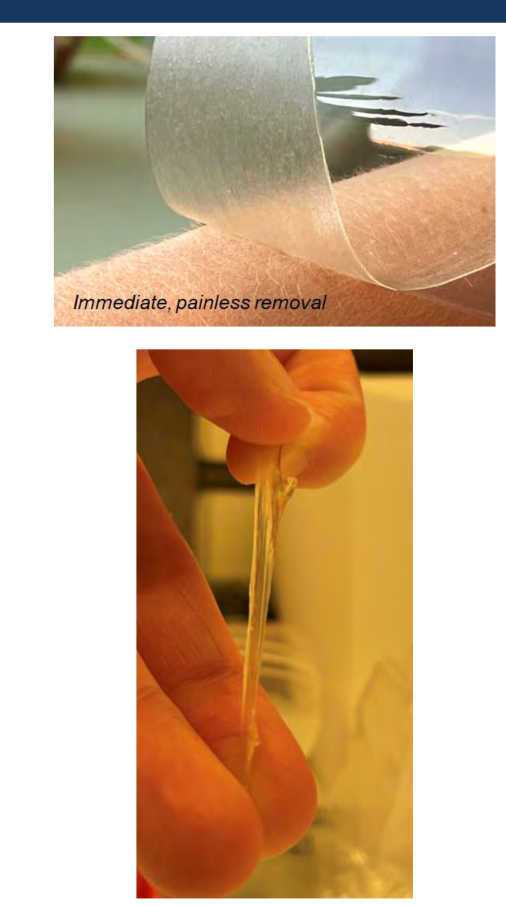
Potential distillation of tackifier & comonomers
crucial for tackiness of polymer

Distillation of BDO
crucial for cohesive strength of polymer



More tackifier = lower cohesive strength
How do we balance this?



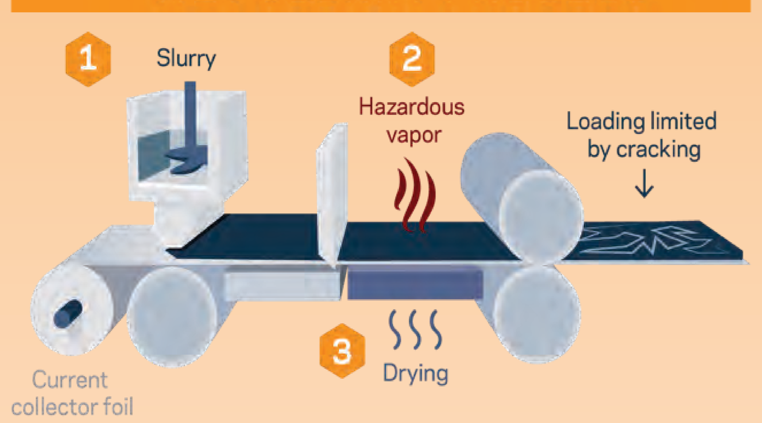


Advancements in Sustainable Manufacturing of Lithium-Ion Batteries

Connor Kulczytzky

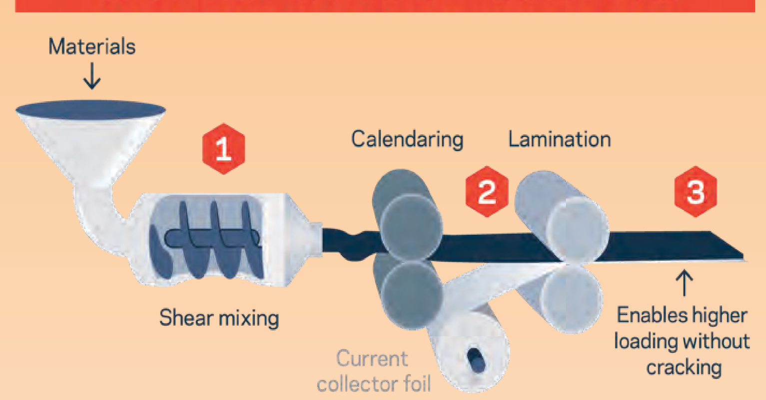
Wet Slurry vs. Dry Process Overview

WET SLURRY PROCESS



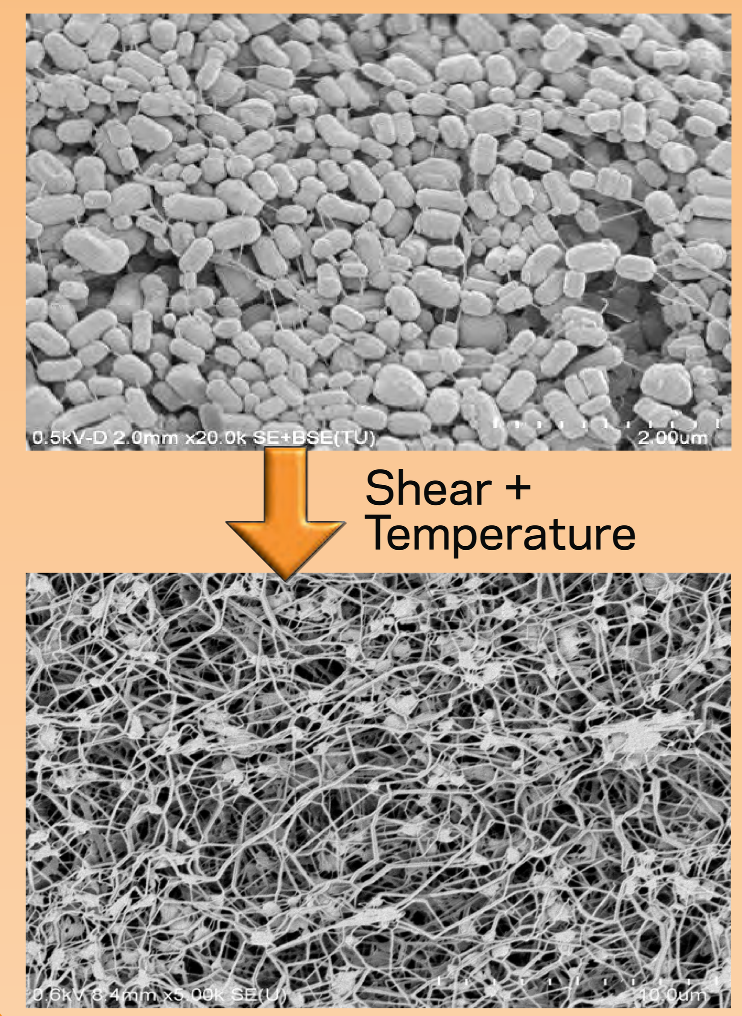
1. Binders are dissolved and mixed with active materials and conductive agents to make a viscous slurry
   - Cathode (+) requires PVDF binder dissolved in NMP, a hazardous solvent
   - Anode (-) uses other polymers in an aqueous-based slurry
2. The slurry is coated onto a current collector and dried
3. Drying is energy intensive and rate-limiting
   Necessary solvent recovery adds cost and energy consumption

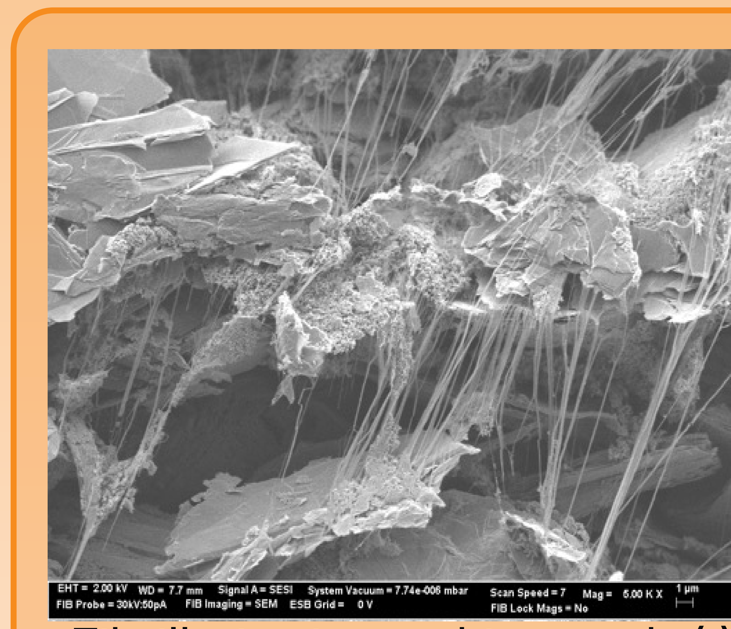
DRY ELECTRODE COATING



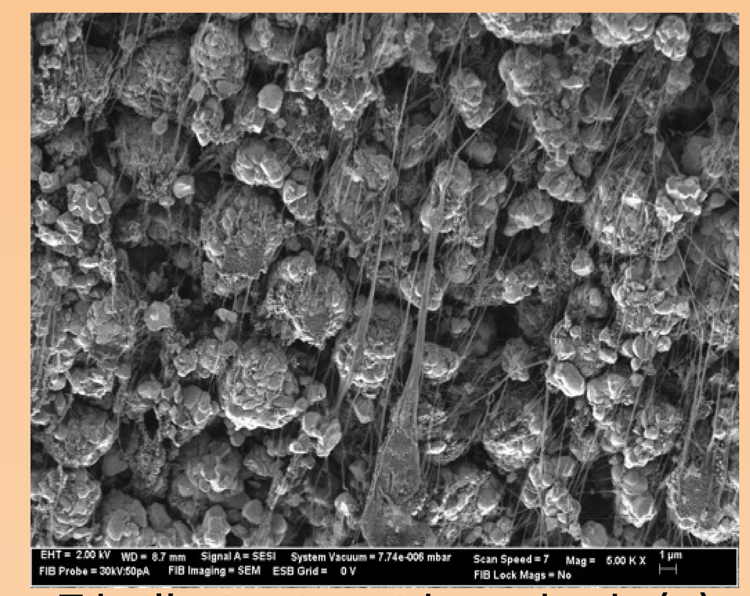
1. A fluoropolymer binder containing PTFE is shear mixed to form a fibrous network that cohesively binds electrode materials
2. Drying and solvent recovery steps are eliminated, as well as the risk of exposure to hazardous solvents (NMP)
3. Up to a ~47% reduction in energy consumption and reduced manufacturing footprint
   Enables further advancements such as higher loadings

Shear forces stretch and align PTFE chains, transforming them into long, thin fibrils. During mixing and calendering, these fibrils form and become entangled with and adhered to the electrode constituents, allowing a durable film to be formed without the need for any





Fibrillation in graphite anode (-)



Fibrillation in oxide cathode (+)

Advantages of Dry Processing

Cost Reduction

- Reduced energy consumption due to elimination of drying steps
- Elimination of solvent recovery and recycling systems

Small Footprint

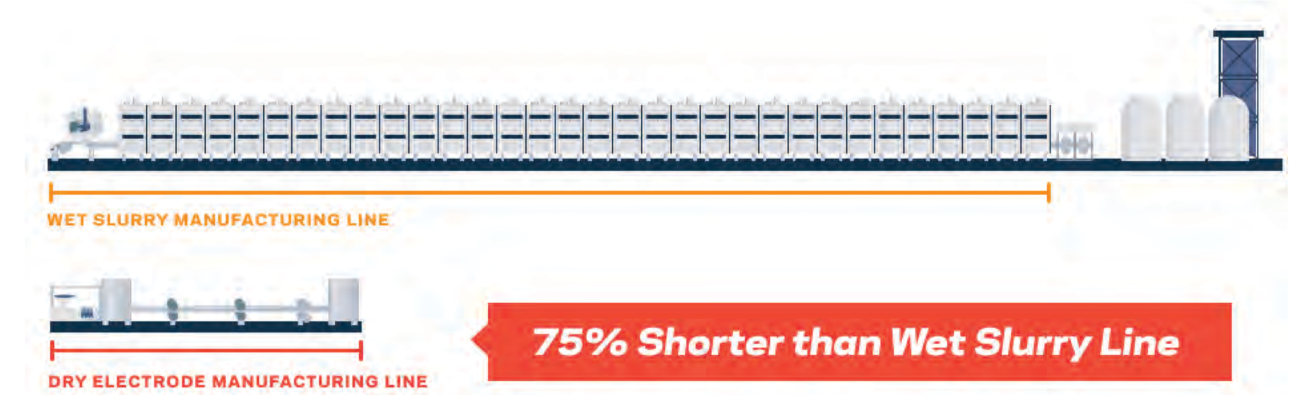
- Compact equipment design eliminates need for large drying ovens
- Reduced space requirements for solvent storage and handling

Performance

- Dry mixing allows for improved uniformity of electrodes
- Enables higher loading of active materials leading to increased energy density

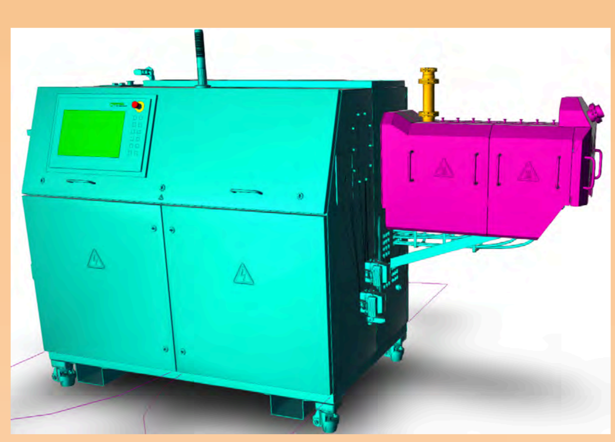
Safety

- Improved worker safety by removing VOCs
- Reduce risk of fire and explosion hazards associated with solvent use



Dry Process Equipment & Chemours' Capabilities

1 Twin-Screw Extruder (High-shear mixing)



- High shear mixing to homogenize mixture and achieve necessary fibrillation state for calendering
- Continuous process
- High feed rate

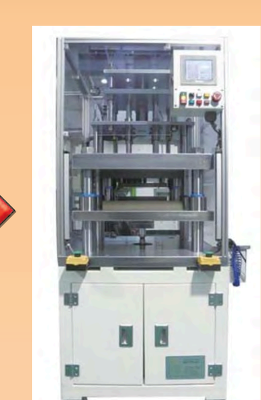
2 6-Roller Roll Mill Machine (Calendering)

- Shear forces from differential speed rolls causes alignment and elongation of PTFE, forming durable fibril network
- 6 heated differential-speed rollers providing shear and compaction
- Double sided lamination directly on

3 Pouch Cell Assembly Line

Electrodes produced from calendering need to be electrochemically tested in batteries. Pouch cells are batteries with flat pouch-shaped designs and are typically assembled in dry rooms to avoid unwanted reactions with moisture.

Electrode Punching
Punches electrodes created from calendaring using a mold



Pouch Forming
Pouch cell casting formation customized to cell

Top&Side Sealing
Hermetic sealing of pouch cells using heat and pressure

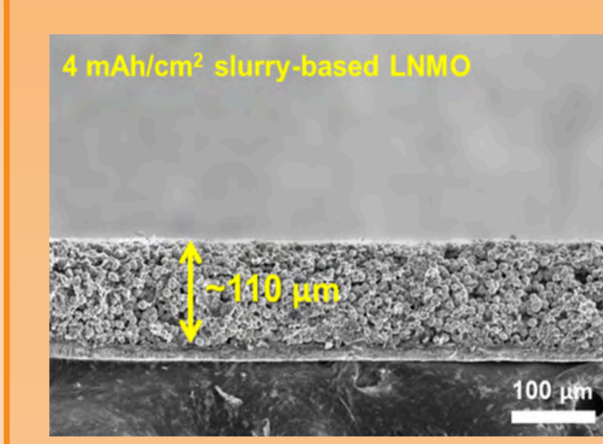
Electrolyte Filling
Precise and controlled electrolyte addition after the top and sides are sealed

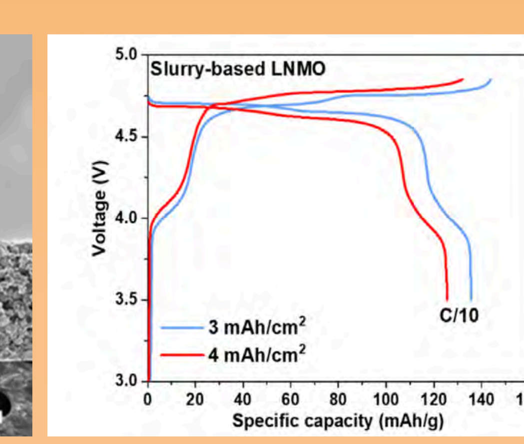
Wetting
Repeated vacuum annealing for even electrolyte diffusion

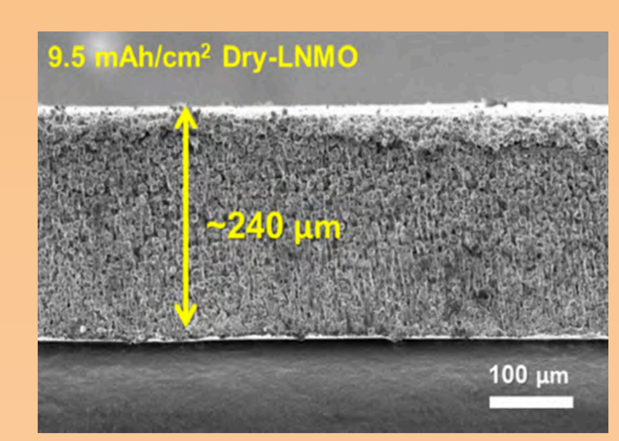
Degassing
Removes trapped air and gases from the pouch cell and performs final seal

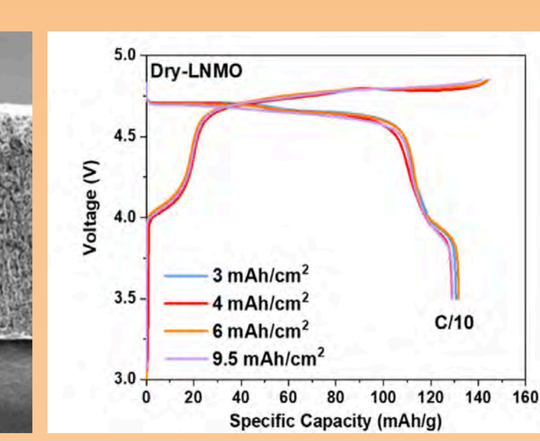
Dry Process Research

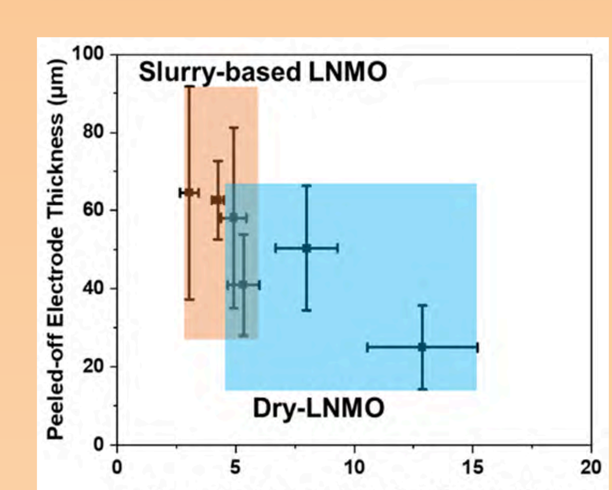
Dry Coating Process Enables Ultra-Thick LNMO Cathodes









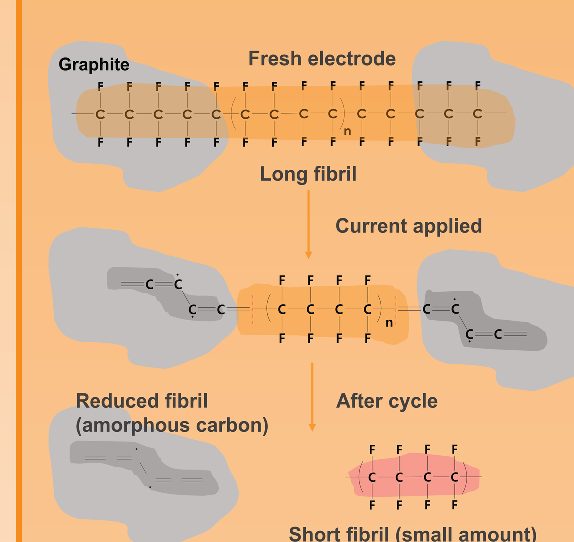


Dry-LNMO electrodes maintain similar performance even at high areal loadings of 9.5 mAh/cm². In contrast, slurry-based LNMO shows performance degradation at 4.0 mAh/cm², with increased polarization and capacity loss.

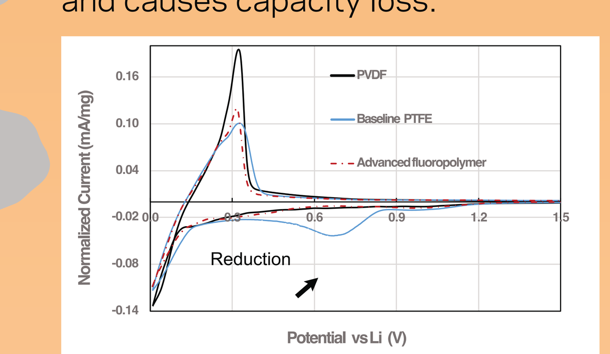
Dry-LNMO electrodes required more force (4.20 to 14.70 N/m) to delaminate while removing less material. In contrast, slurry-based LNMO electrodes peeled off more easily with less than 5.25 N/m force.

A 5V-class Cobalt-free Battery Cathode with High Loading Enabled by Dry Coating. Energy & Environmental Science. 16. 10.1039/D2EE03840D.

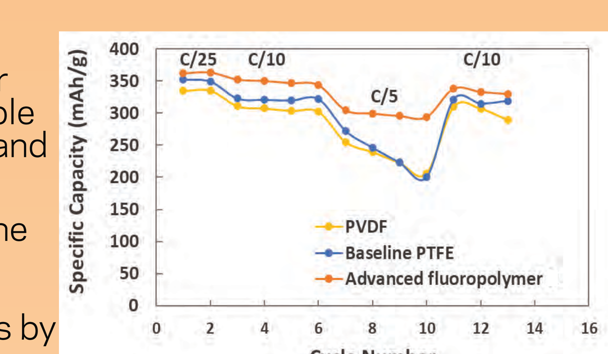
Chemours Developing Advanced Binders to Improve Electrochemical Performance and Processability



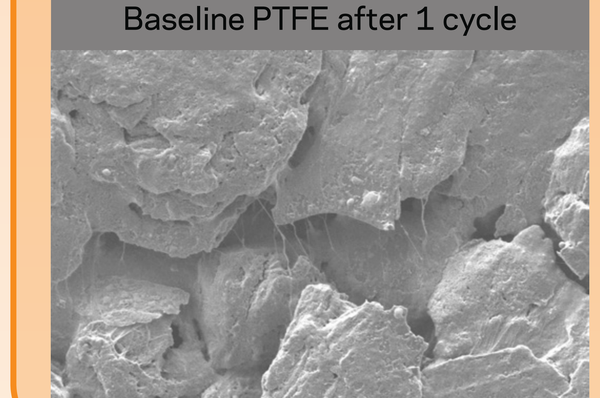
PTFE is susceptible to reduction on the anode during the initial cycles. Defluoronation of PTFE results in electrode mechanical degradation and causes capacity loss.



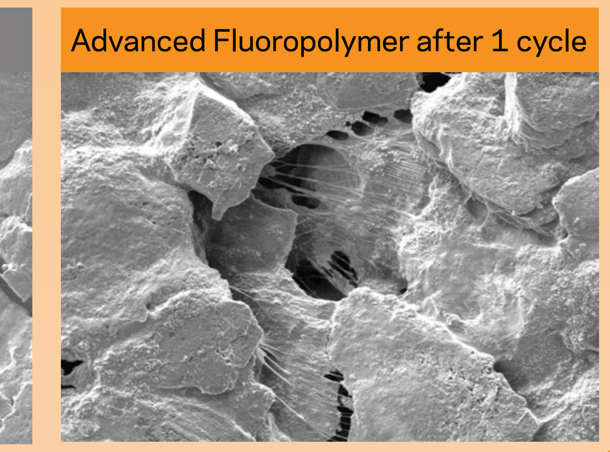
Fluoropolymer systems can be developed which maintain higher specific capacities across multiple cycles compared to both PVDF and baseline PTFE.



SEM imagery shows how baseline PTFE shows more signs of reduction than modified binder systems developed by Chemours by analyzing the fibril network.



Baseline PTFE after 1 cycle



Advanced Fluoropolymer after 1 cycle

Innovative Approaches to Road Safety: Enhancing Traffic Lane Marking through Digital Technology

DIGIT Solutions at your fingertips

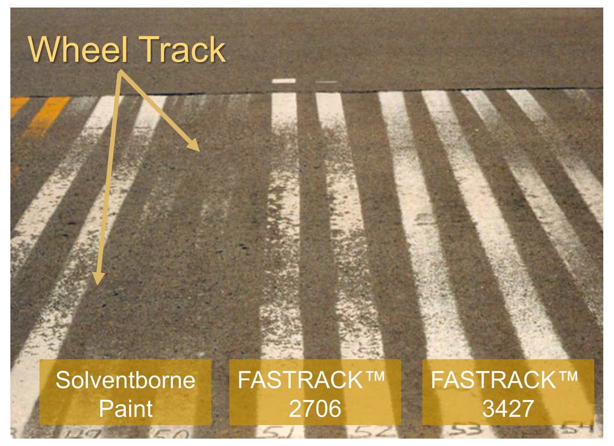
FAMS Formulation, Automation, Materials Science

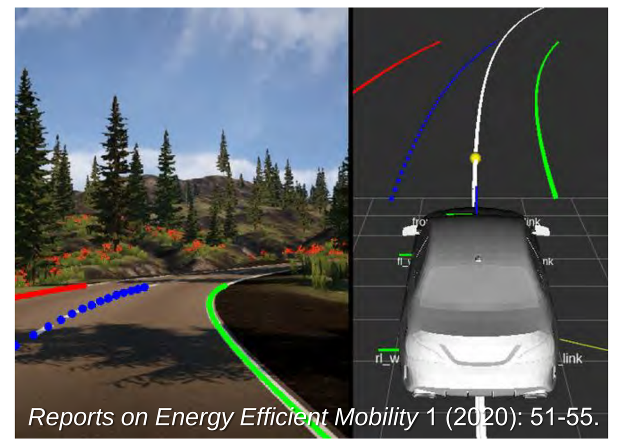
MiLOS MACHINE LEARNING + OPTIMIZATION + STATISTICS

Sam Lim, James Pagaduan, Sophie Kim, Joseph Grant, Richard Cooper, Stephanie Long, Arthur Leman, Xingyu Zhou, Zachary Wright

Dow Coating Materials Digital Innovation and Technology Team (DIGIT), Dow Coating Materials Road Markings Team, Formulation, Automation & Materials Science (FAMS), Machine Learning, Optimization & Statistics (MiLOS)

Durability and retroreflectivity govern road marking performance and facilitate autonomous mobility





Dow has been a global leader in the road markings segment, continually creating and reinforcing interactions across the value chain

Raw material supplier (Dow) → Paint formulators → Road authorities → Application contractors → Driving public

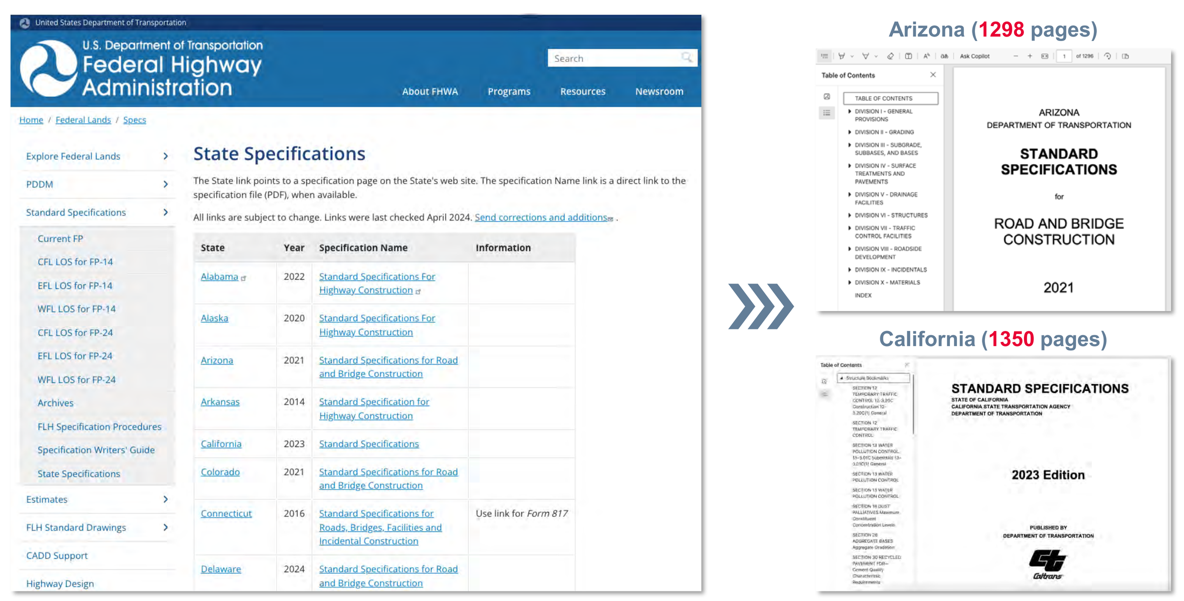
Dow is uniquely positioned to take on a variety of technical challenges

Binder synthesis · Image analysis · Digital innovation

DOW™ Specification Tracker: Digitally Empowering the Road Markings Industry

This first-of-its-kind digital service platform revolutionizes the road markings industry through an interactive, centralized database of waterborne traffic paints specifications across the United States

Challenges include lengthy specification handbooks, inconsistent terminologies, and sheer number of specs



Our novel solution involves data collection, standardization, and dashboard creation to positively influence the value chain

Data Aggregation → Data Standardization → Dashboard Development

Key Benefits

- **Paint formulators**: immediate impact on the bidding process
- **Road authorities**: elevate and simplify the level of standard requirements
- **Contractors**: easy to identify application and performance requirements

"View Specifications" feature

State	min	max
filter data...		
A	80	90
B	80	90
C	specification not stated	specification not stated
D	83	98
E	70	85
F	specification not stated	specification not stated
G	specification not stated	specification not stated
H	80	90
I	70	95

"Compare Performance Target" feature

Enter Target Specifications

Step 1: Select paint type: Standard

Step 2: Select paint specifications

Category: Performance requirements

Specification: No-pick-up time (minutes)

Data Type: Numeric

Target Value: 8

Add specification

Selected Targets

Paint Type: Standard

	Requirement	Specification	Data Type	Target Value
×	Binder Identity	FASTRACK 3427	Category	Yes
×	Compositional requirements	Binder chemistry, acrylic	Category	Yes
×	Application requirements	Glass bead type	Category	AASHTO M247
×	Performance requirements	No-pick-up time (minutes)	Numeric	8

Green: pass
Red: fail

State	FASTRACK 3427	Binder chemistry, acrylic	Glass bead type	No-pick-up time (minutes), max	# of pass (excluding not specified)
filter data...					
A	specification not stated	Yes	specification not stated	10	2
B	specification not stated	Yes	AASHTO M247	10	3
C	specification not stated	specification not stated	specification not stated	specification not stated	0
D	Yes	Yes	AASHTO M247 Type 1	10	3
E	specification not stated	specification not stated	AASHTO M247 Type 1	10	1
F	specification not stated	specification not stated	specification not stated	specification not stated	0
G	specification not stated	specification not stated	specification not stated	specification not stated	0
H	specification not stated	Yes	AASHTO M247 Type 1	15	2
I	specification not stated	Yes	AASHTO M247 Type 1	specification not stated	1

"Compute Match Score" feature

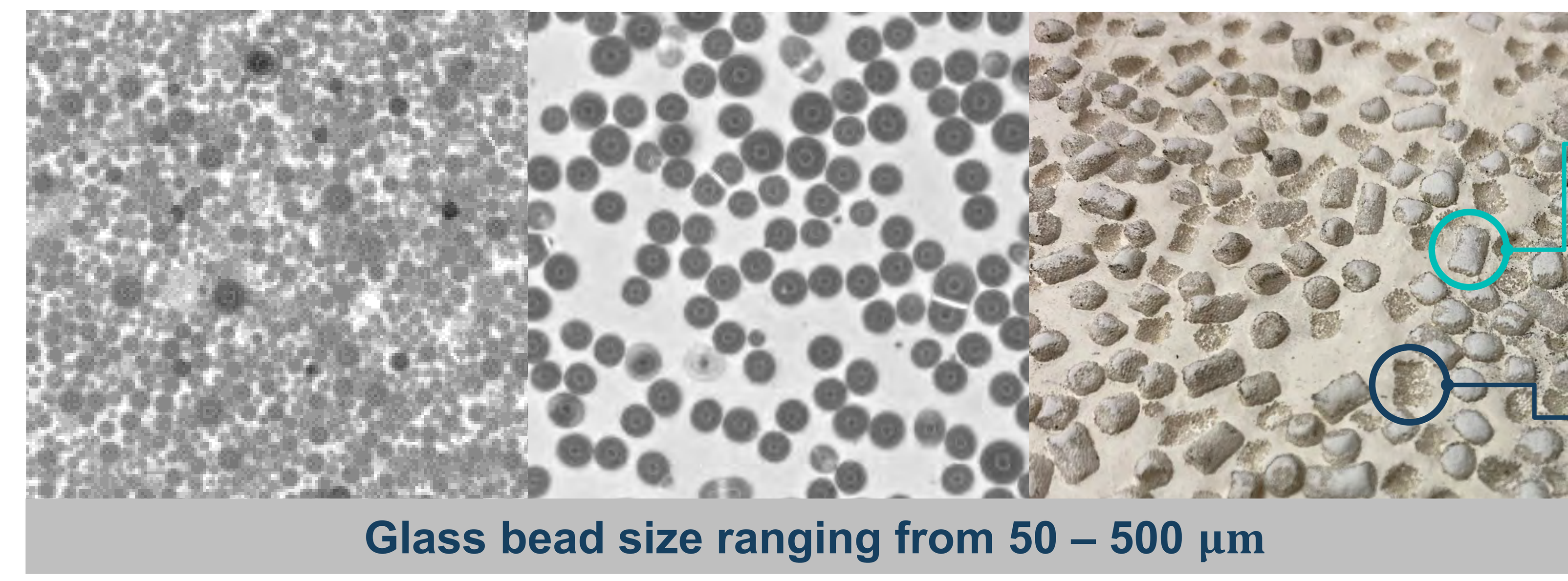
Select paint type: Standard

Select a reference state: Pennsylvania

	State	Match %	Match Count
	filter data...		
☑	J	100	123
☑	P	73	90
☑	C	72	88
☐	H	71	87
☐	L	71	87
☐	S	70	86

Developing Optical Analysis for Road Markings Performance Assessment

Features of interest



Glass bead size ranging from 50 – 500 μm

Balding – beads stripped off from elements, surface smoothed by wear / friction
Retroreflectivity ↓

Dislodgement – elements removed from a paint film, creating a surface crater
Retroreflectivity ↓
Durability ↓

Image Analysis Workflow

Paint formulation → Testing Device → Image Acquisition → Performance Assessment

Standardized Image Acquisition

Acquisition Process

- Fixed image settings
- Consistent ROI
- Various Imaging Modes
- Verify signal-to-noise ratio

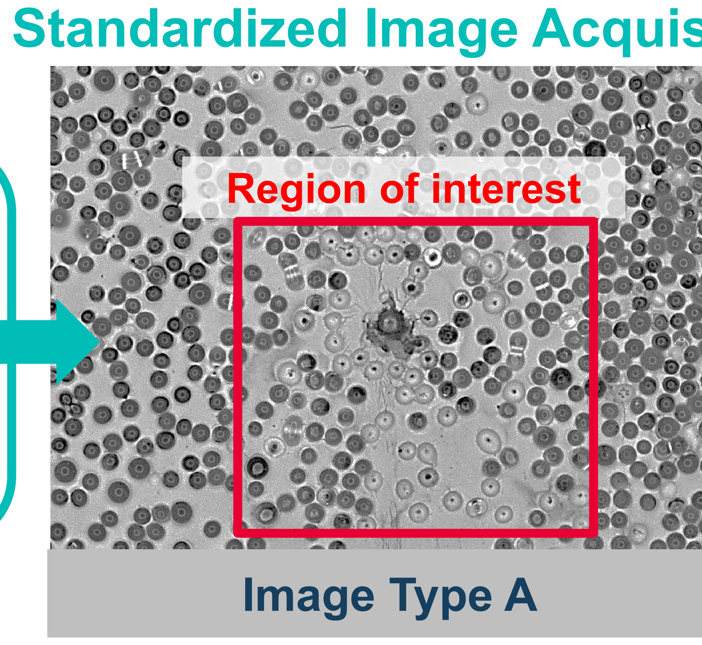


Image Type A

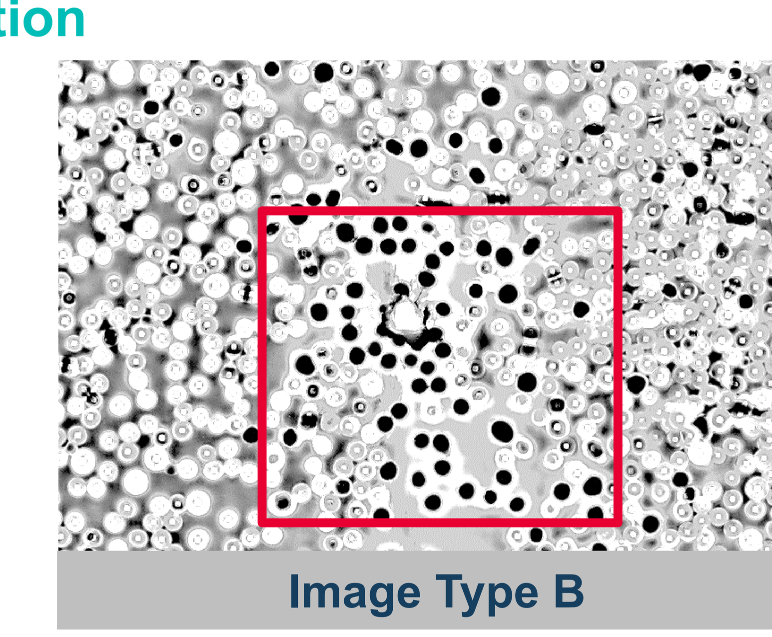
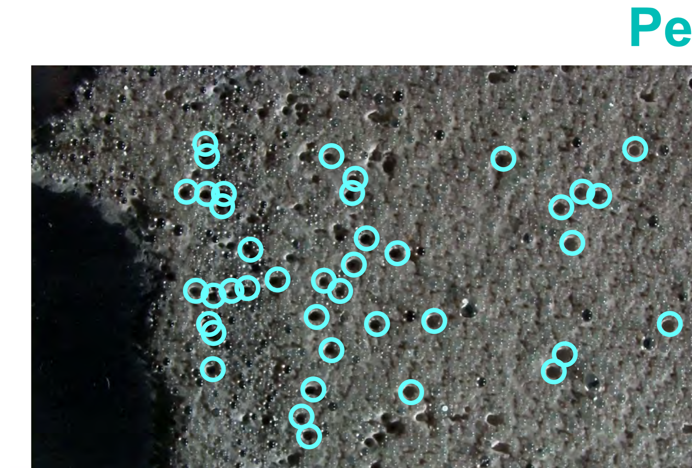
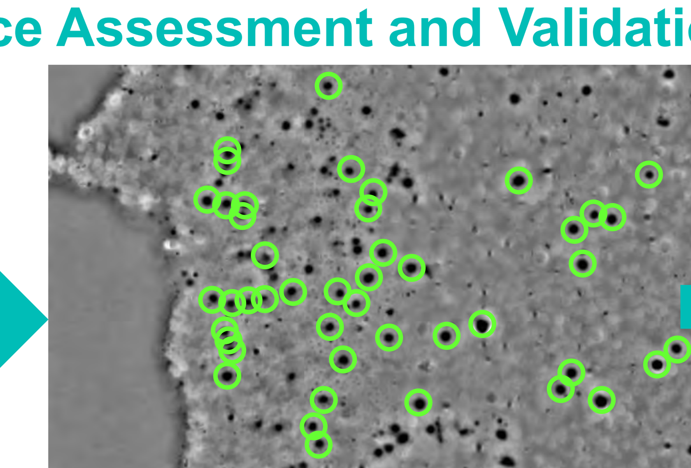


Image Type B

Performance Assessment and Validation



Validation with optical image



Final rendering of evaluation

Reported Results

- Dislodgment rate
- Balding rate
- Paint removal %
- Time-series analysis

Kim, S., Pagaduan, J. N., Leman, A., Long, S., Grant, J., Cooper, R. Waterborne Traffic Paint Specification Dashboard.
US Patent Application No. 29/927105, filed February 2, 2024. Patent pending.

DOW®

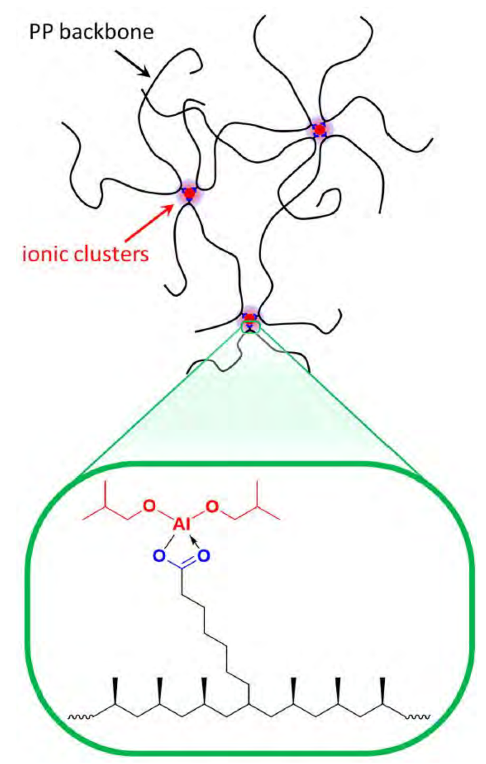
Tuning Processability of Isotactic Polypropylene (iPP) Through Blending with iPP Ionomers

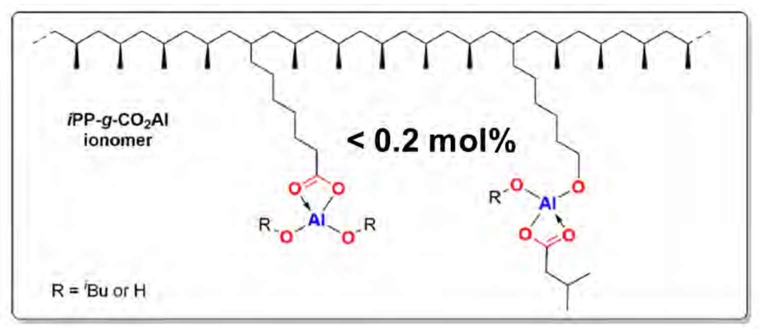
ExxonMobil

Stephanie F. Marxsen, Joseph A. Throckmorton, Tzu-Pin Lin, Carlos R. Lopez-Barron
ExxonMobil Technology & Engineering Company

Introduction to iPP Ionomers

- iPP ionomers are a new class of iPP materials with superior processability that maintain crystallinity and mechanical properties of iPP → primary target = foams
- Ion clusters act as physical crosslinks, creating an entangled polymer network





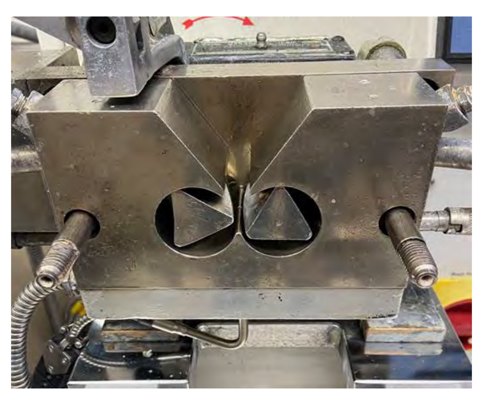
Blending Motivation

Industrial: Potential to tune material properties in a simple and cost-effective manner by adding small amount of ionomer to already commercialized iPP manufacturing process

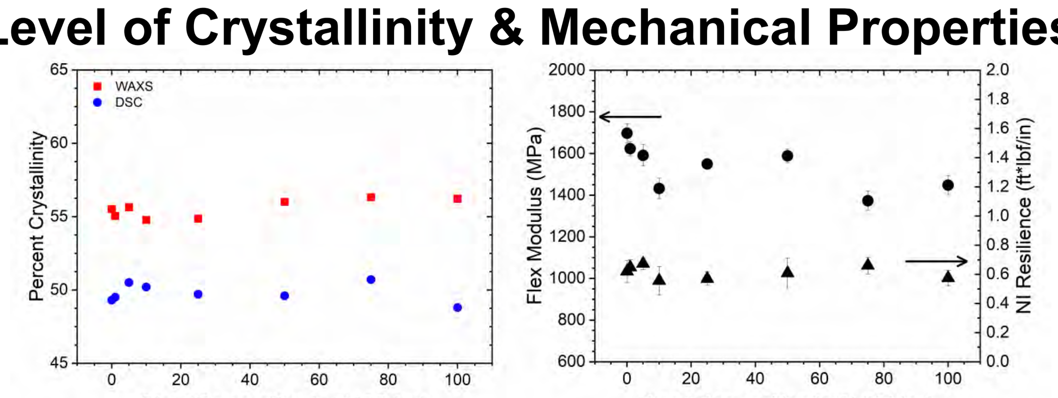
Scientific: Gain further insight into fundamental relationship between ionic crosslinking and material performance

Objective

Evaluate the impact of blending linear iPP with iPP ionomers on rheological & mechanical properties, crystallization, and microstructure

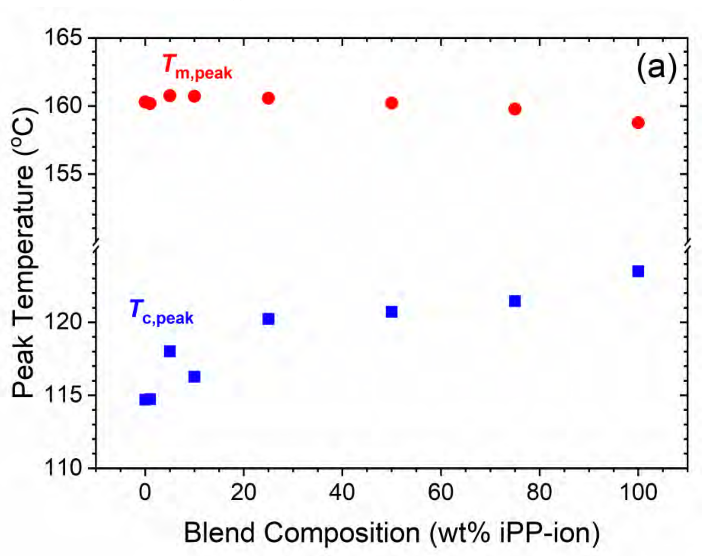


Level of Crystallinity & Mechanical Properties



No change in level of crystallinity with ion content → no change in mechanical properties

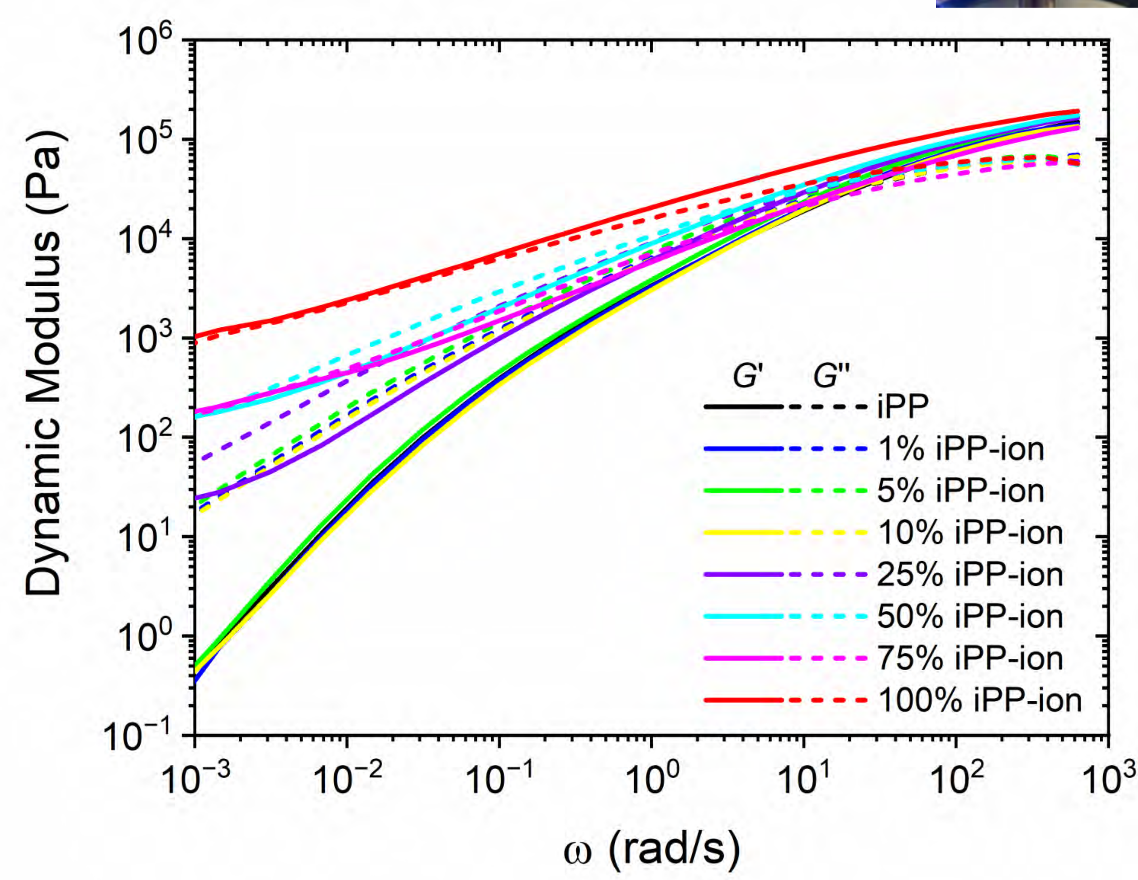
Crystallization & Melting Behavior



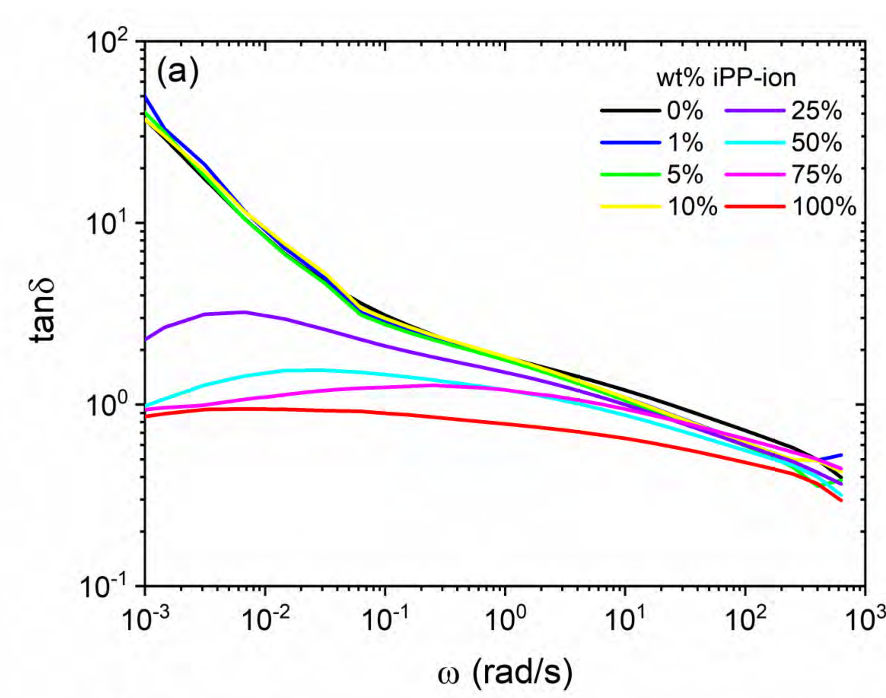
Increase in T_c (constant T_m) for increasing ion content may be beneficial for foaming applications

Shear Rheology (SAOS/DFS)

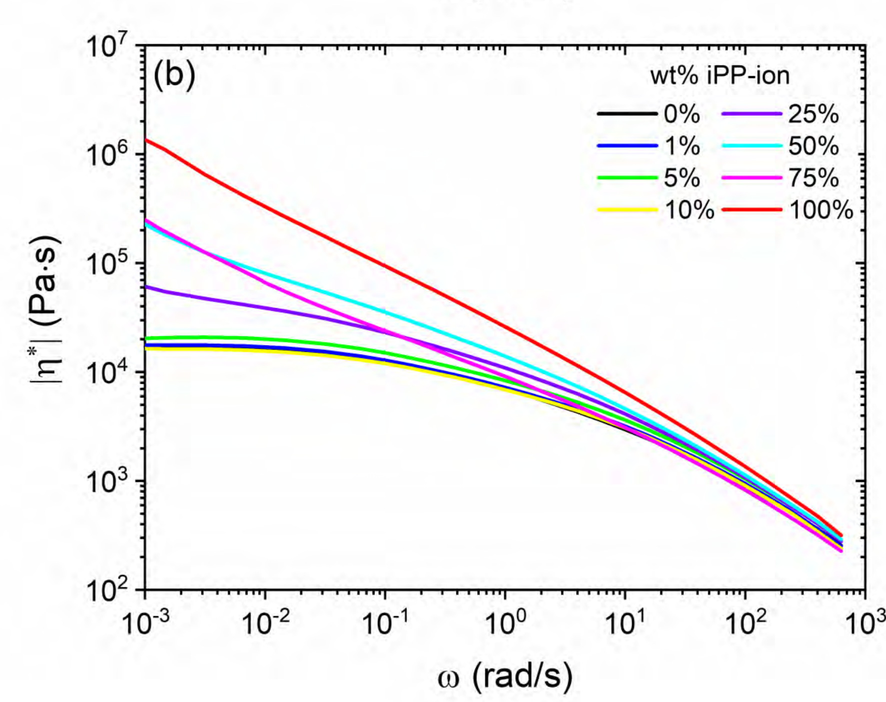
Properties of interest:
Storage modulus (G') – elastic response
Loss modulus (G'') – viscous response



- iPP shows typical response (terminal relaxation)
- **Increase in low frequency modulus in iPP-ionomer reflects slower relaxation after deformation (more elastic)**



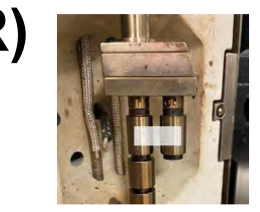
tanδ = G''/G' – damping factor (lower tanδ = larger elastic component)



|η*| = overall deformation resistance / angular frequency (ω)

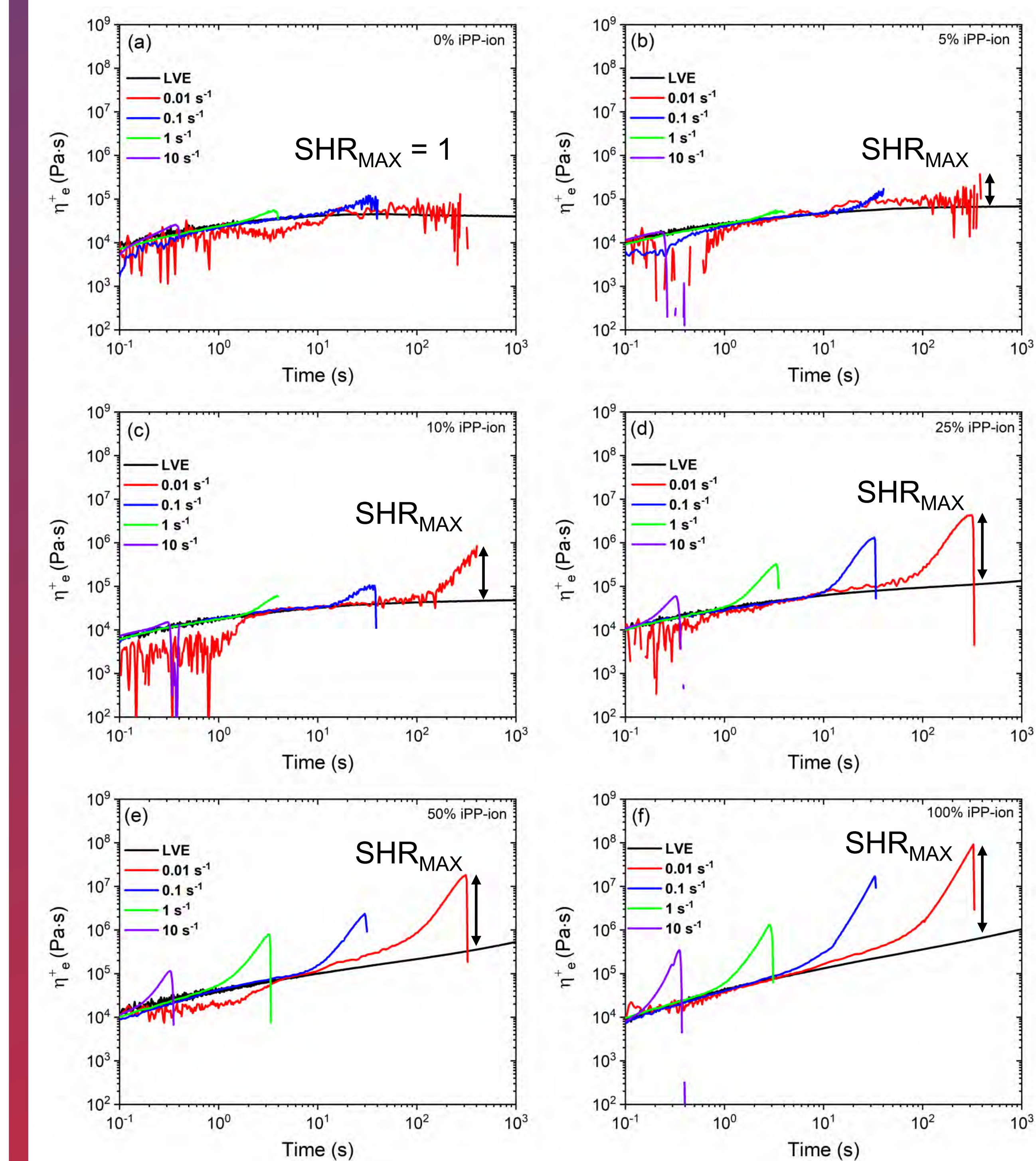
- Significant elastic component present with 25% iPP-ionomer
- All show strong shear thinning behavior → good processability

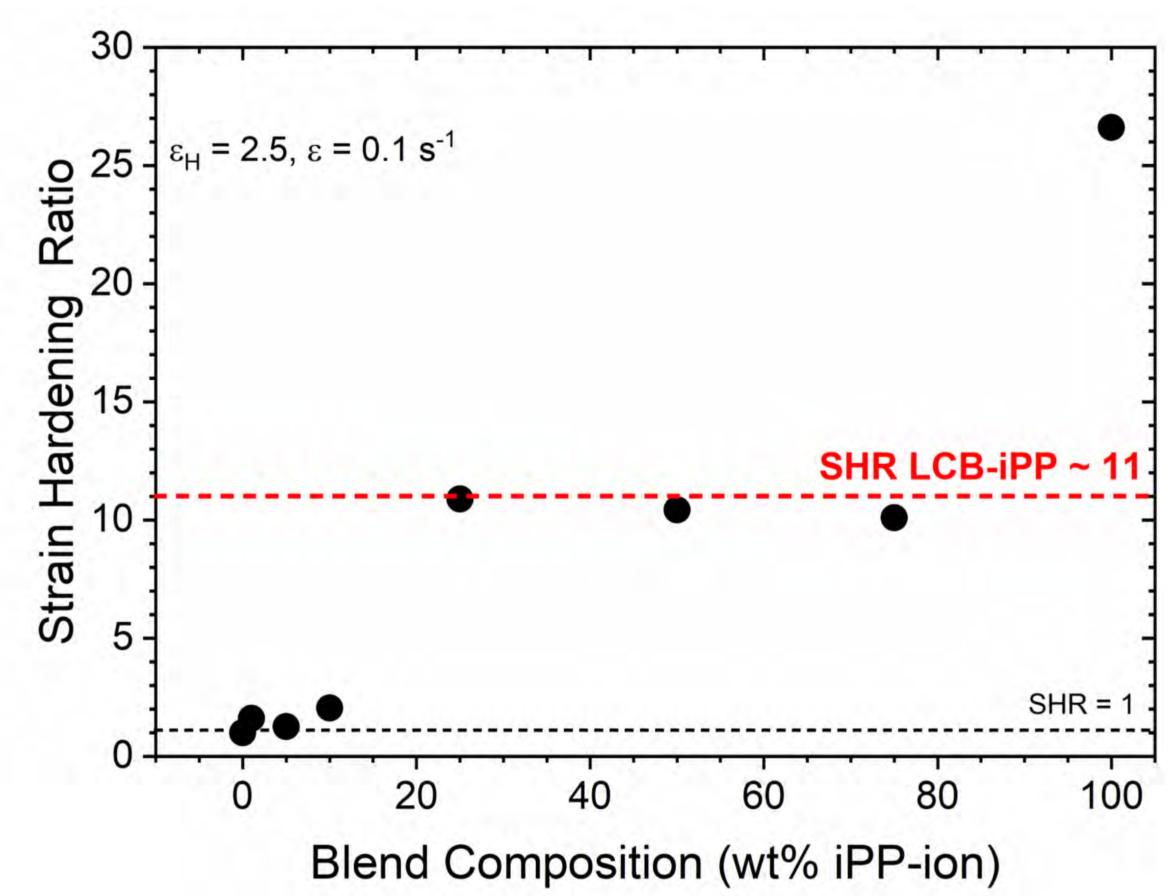
Extensional Rheology (SER)



SER properties of interest:
η_e^+ = extensional viscosity
Strain hardening behavior: observed as deviation from LVE (3η*)

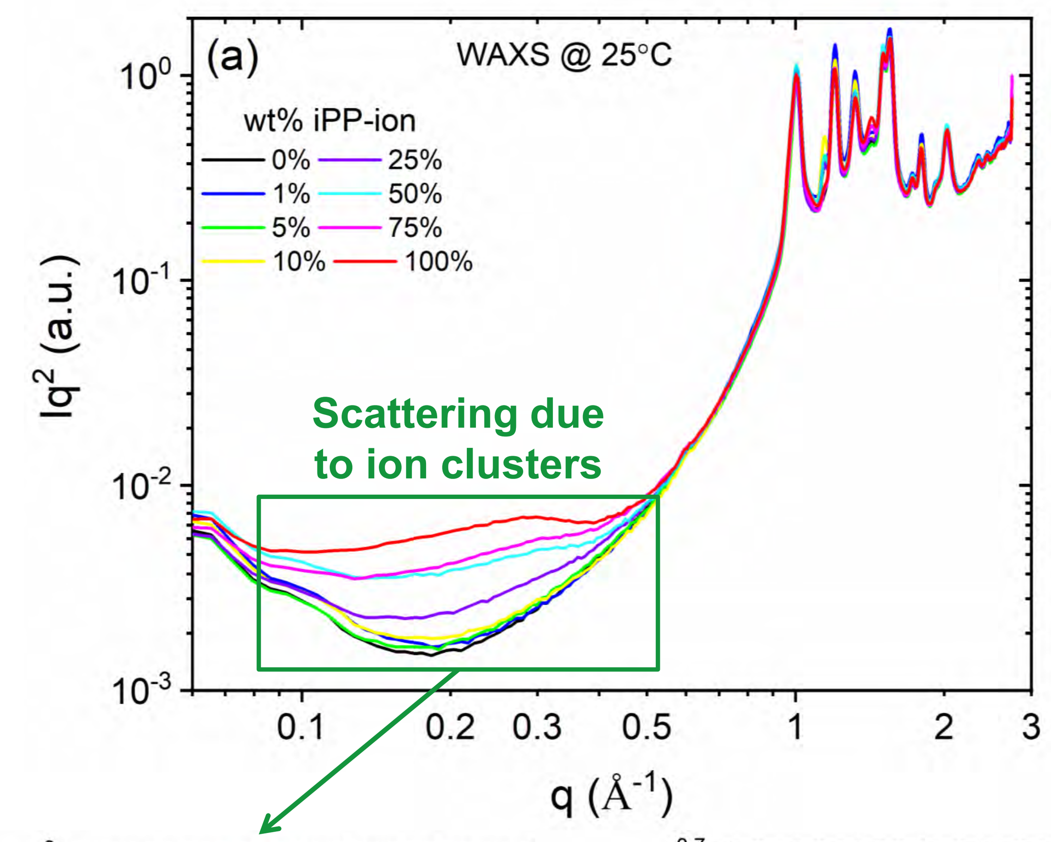
Strain rate $\dot{\varepsilon}_H$ = 0.01, 0.1, 1, 10 s^{-1}

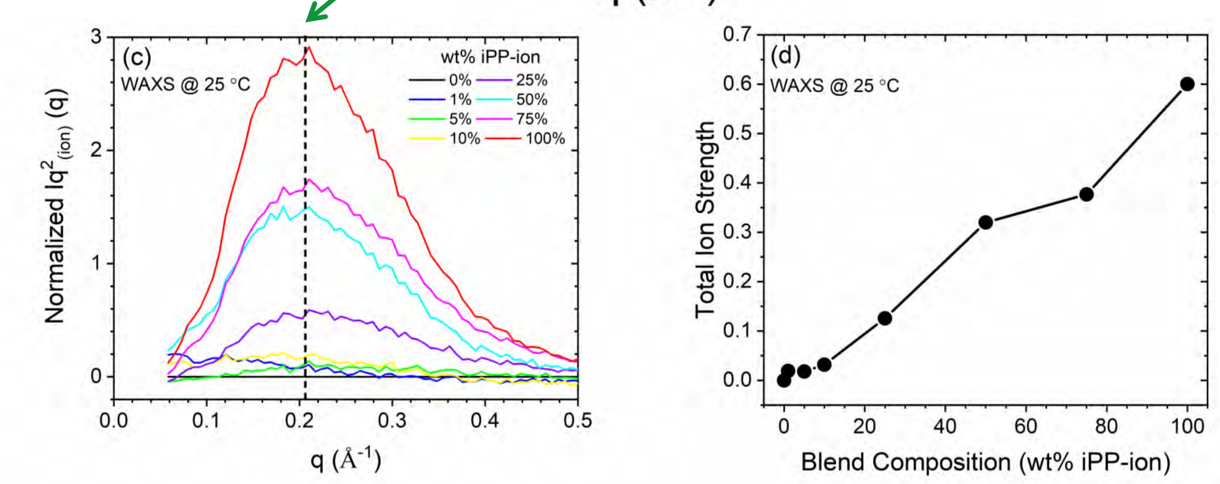




SHR of iPP-ionomer blends reaches that of LCB-iPP (g'_{vis} = 0.585) at identical strain conditions at only 25% ionomer

Structural Analysis via WAXS/SAXS





Variables correlated with composition (e.g. strain hardening, viscosity, tanδ) are also correlated with total ion strength

Conclusions

- Blending iPP with an iPP-ionomer is an effective method for tuning rheological behavior such as extensional strain hardening
- Addition of only 25 wt% ionomer produced melt strength and strain hardening levels comparable to industry benchmark
- No appreciable change in crystallinity, mechanical properties, or melting temperature with ionomer content
- ***Future direction:*** evaluate impact of blending on foaming performance → Increase in crystallization temperature with ion content may be promising

References

1) López-Barrón, C. R., Lambic, N. S., Throckmorton, J. A., Schaefer, J. J., Smith, A., Raushel, F. N., & Lin, T.-P. (2022). *Macromolecules*, *55*(1), 284–296.
2) López-Barrón, C. R., Throckmorton, J. A., & Lin, T.-P. (2022). *Journal of Rheology*, *66*(3), 657–669.
3) Embabi, M., Kweon, M. S., Wang, Y. X., Lin, T.-P., López-Barrón, C. R., & Lee, P. C. (2022). *Macromolecules*.

Acknowledgements

Research Techs - James Li, Truyen Pham, Judy Yu, Thomas Sykes, Nieves Hernandez, Artuo Leyva, Eric Canales, Mireya Luna

Metal-working Fluid Performance Metrics for Sustainability

Authors: **Shannon McGee**, Abigail Meyer, Ed Platt, Karl Zhong, Bob Evans, and Philip Zhao

ABSTRACT

In the metalworking fluid industry, accelerated sustainability adoption is being driven by stricter regulations, customer demand and the drive for innovative technologies. There are many aspects to sustainability, with many focusing on the environmental factors such as GHG emissions and carbon footprint through formulating with bio-based raw materials. However, we can also look at increasing performance of metalworking fluids as a sustainability metric. There are performance-based sustainability metrics for companies to focus on such as energy efficiency, productivity, longevity, and eliminating harmful chemicals for human health and safety. By focusing on the potential capabilities in improving sustainability for application, in addition to the potential capabilities in formulation, we can innovate sustainable solutions to support the community on their sustainability agendas. In this poster, we demonstrate comparisons between an older generation metalworking fluid and a newer generation metalworking fluid in different applications to highlight that technological improvements in performance relate to sustainability metrics.

Sustainability adoption accelerates driven by stricter regulations, customer demand and companies pushing sustainability as a differentiation

Regulations

Many important regulations enforced in last decade, e.g.:
- EU Green Deal and Paris Agreement to reduce GHG emissions
- REACH & CPL to shift away from hazardous substances
- European CBAM

Further tightened regulations expected in coming years

Customer demand

Customer demands are causing **ripple effects through value chains** affecting suppliers and sub-suppliers

For example, Auto OEMs **increasing focus on sustainability are quickly putting pressure on their suppliers**

Sustainability as differentiation

Potential to differentiate through sustainability due to increased demand from customers and public attention

Competitive advantage driver by being early in gaining experience and securing critical assets and capabilities

Customers frequently mentioned GHG emissions, water usage, circularity and hazardous components as part of sustainability

E Environment — *Living within our planetary boundaries*

S Social — *Committing to equitable outcomes*

G Governance — *Demonstrating responsible conduct*

Most mentioned by industrial fluid customers

GHG emissions	Hazardous substances	Material use, waste & circularity	Water stewardship	Air quality	Land and ocean use	Biodiversity & ecological welfare
Reducing & offsetting GHG emissions contributing to climate change	**Sensitively using** and treating **toxic products and waste**, incl. chemical and technology pollutants	**Responsible sourcing and use of resources**, incl. product, packaging, and food lifecycles - **reduce, reuse, recycle**	Sensible **water use**, water quality, and **watershed management**	**Lowering pollutants** impacting air quality and atmospheric integrity	Ensuring **long-term sustainable land and ocean use**, incl. land/ ocean change (e.g., deforestation), sound utilization practices	**Protecting and enhancing natural ecosystems** and living organisms; upholding animal welfare

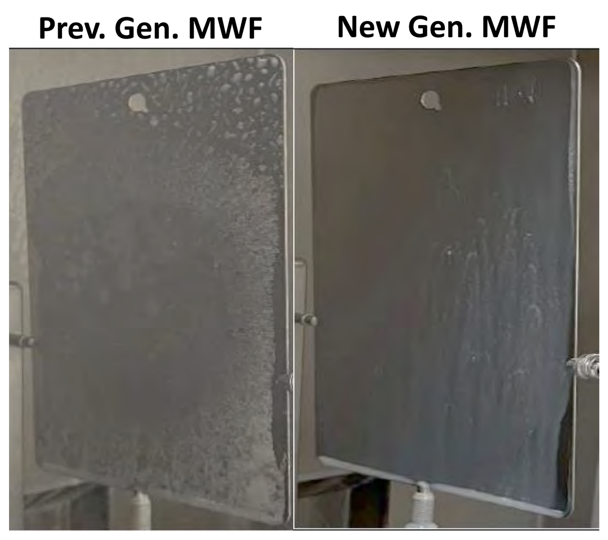
There are several potential capabilities –in formulation and application – that be used to support a sustainability agenda

Potential Capabilities in Formulation | *Potential Capabilities in Application*

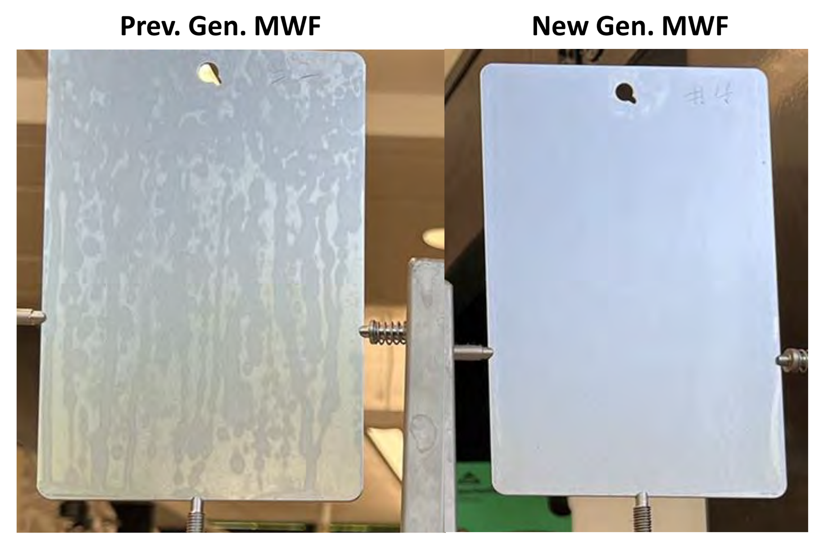
Hazardous substances	Ecological welfare	Renewable and Bio-based Raw Materials	Material use, waste & circularity	Productivity	Fluid consumption	Longevity
Using **non-CMR** and **no/low toxicity** raw materials in product formulations for **improved human health**	Products that are suitable in **sensitive environments** (e.g. forest, sea) and can **degrade rapidly to protect natural ecosystems**	**Renewable and bio-based** raw materials for sustainable formulations	**Responsible** sourcing and **reduce, reuse, recycle** use of resources for **lower waste production**	Products that can **reduce friction** and **increase energy efficiency** for enhanced productivity	More efficient industrial fluids that requires **less product** and/or **water consumption**	Ensuring **long-term efficacy** increasing sump life and tool life

The potential for sustainable innovation in industrial fluid is broad, and sustainability agendas will vary slightly across industries and geographies.

Decreasing Carry-out for less waste and water consumption



MEP Test (8% concentration; 80 ppm):
Panels after 3 hours of spraying in box



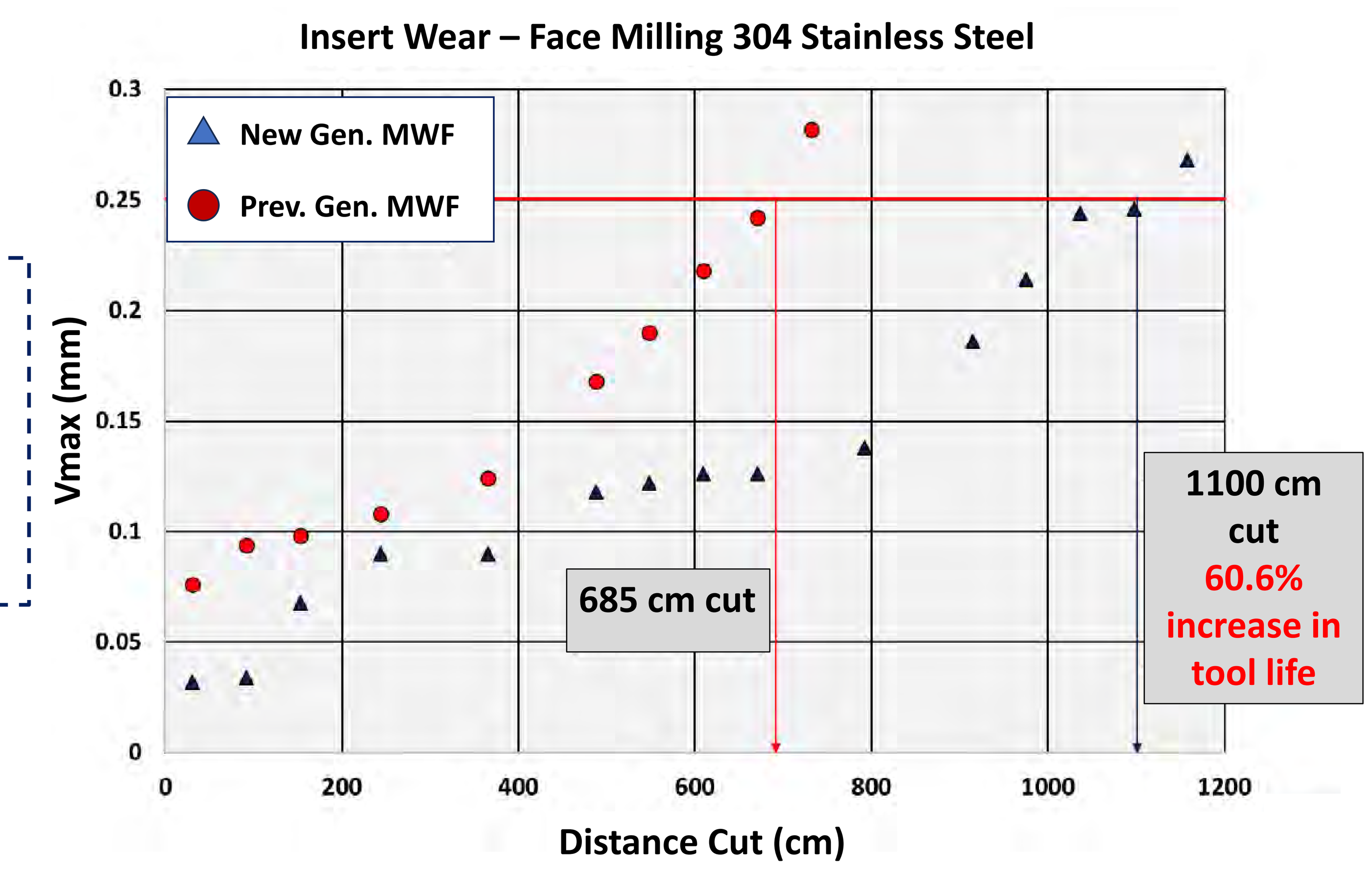
MEP Test (8% concentration; 80 ppm):
Dried overnight after spray stopped

3 hours- Spraying (boxes), 80 ppm	Prev. Gen. MWF	New Gen. MWF
Weight of Blank Panel (g)- Initial	96.492	96.540
Weight of Panel with residual Coolant (g)- 30 s	97.298	97.007
Coolant Carry-Out, g (30 s after spray stopped)	0.806	0.467
Relative Carry-out Change- 30 s (5)	Control	**-42%**

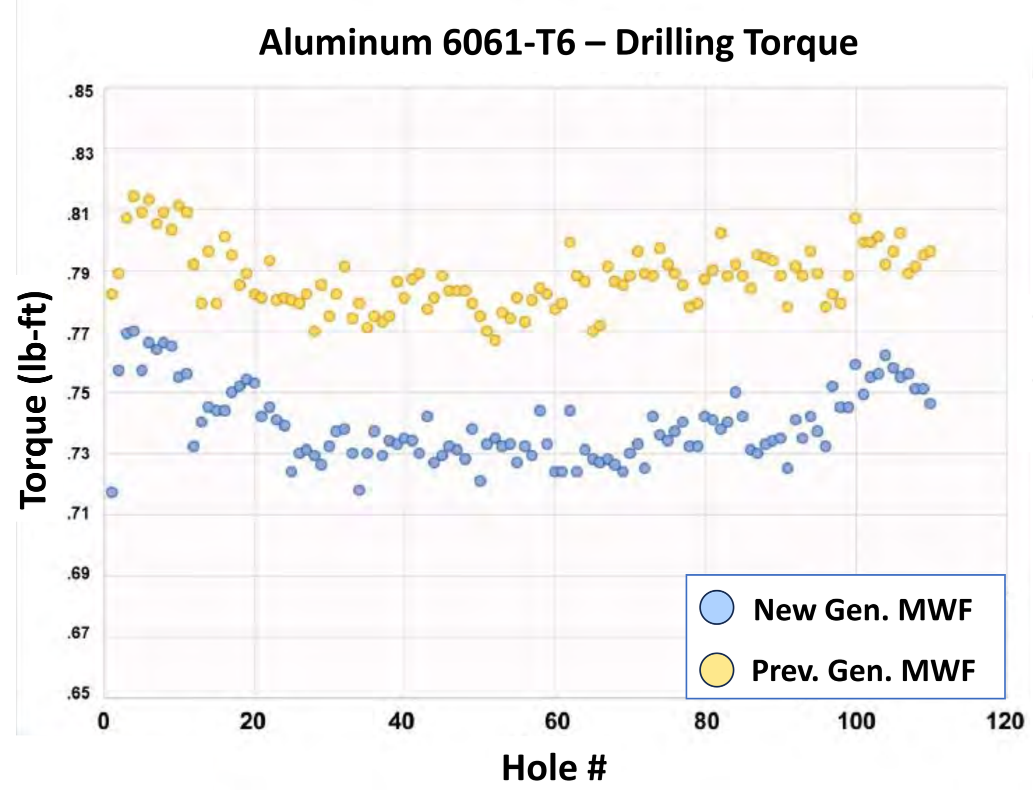
MEP tests show that the New Gen. MWF has better wetting and fluid film formation correlating to lower carry-out compared to the Prev. Gen. MWF.

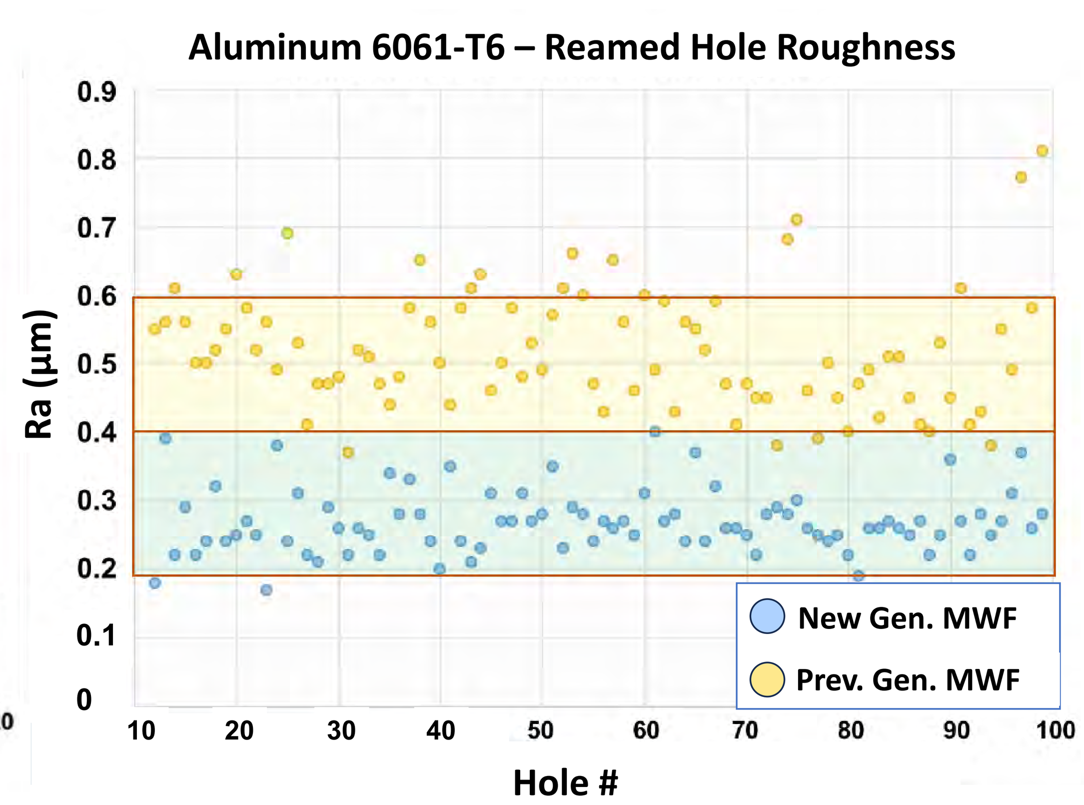
Better lubricity can help extend tool life for more efficient part consumption

Parameters
- 461 RPM
- 295 SFM (90 m/min)
- f = 0.03 ipr (0.006 ipt)
- f = 0.762 mm/rot, 0.15 mm/tooth
- **MRR = 1.11 in³/min**



Increased lubricity for lowering torque forces and part roughness can lead to better energy efficiency





Conclusion: Sustainability can come from both formulation and performance factors. Performance factors can influence sustainability in energy efficiency, consumption, and waste for a manufacturing process.

Quaker Houghton. Forward Together

Use of Keyence VHX Digital Microscope to Determine Composition and Microstructure Changes in Polymer Quenched AISI 1060

Authors: **Abigail Meyer**, Sergio Gallegos, Bob Evans, and Philip Zhao

Abstract

With increasing stringent environmental regulations, there is a focus among heat treaters to move from proven oil-based heat treat products to more sustainable but less commercially acceptable water based quenchants. A research project was completed with two aqueous polymer materials that were used to quench AISI 1060 with the goal of observing the changes in microstructure and composition of the material using our new Keyence VHX Digital Microscope. The technology of the microscope will allow us to measure elemental composition at different depths and sections of the material. In addition, the microscope will allow us to compare the changes in microstructure between quenched and unquenched samples as it can also be used as a metallographic scope. The digital microscope will allow us to quickly measure the samples and provide data that can be used to confirm water-based polymer quenchants are suitable replacements for oil-based products.

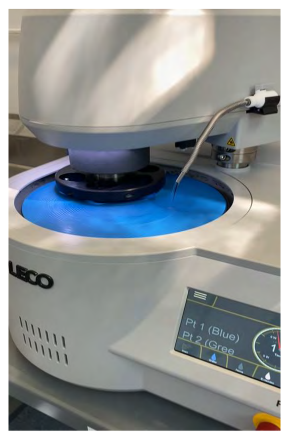
Laboratory Procedure

To evaluate the effect of concentration and temperature of quenchant A or quenchant B on hardness and microstructure of material AISI 1060 these experiments were performed.

Austenization Furnace

Polymer Quenching

Tempering Oven



Metallography Preparation

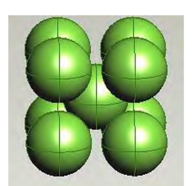
Keyence Digital Microscope

Keyence VHX Digital Microscope

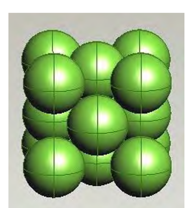
The digital microscope pictured was used as a metallographic scope to observe changes in microstructure. The digital microscope was also used to measure material composition using LIBS or "Laser Induced Breakdown Spectroscopy".

Changes in Microstructure During the Experimental Process

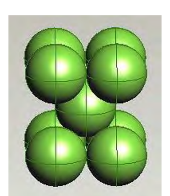
AISI 1060 Steel (Ferrite BCC Structure) → Austenization → **FCC Austenitic Phase** → Quenching → **Unstable Martensite (BCT Structure)** → Tempering → **Tempered Martensite**



AISI 1060 Steel is heated up to a temperature above the GSK line for medium carbon steel. Carbon begins to diffuse out of the lattice. This process is called austenization and changes the structure from BCC to FCC.



Austenized Steel is then quenched with an aqueous polymer material. A higher cooling rate can ensure that the steel will transform into an unstable martensite phase instead of reverting back to the original BCC ferrite structure. Faster cooling rates also ensure more uniform structure throughout the steel.

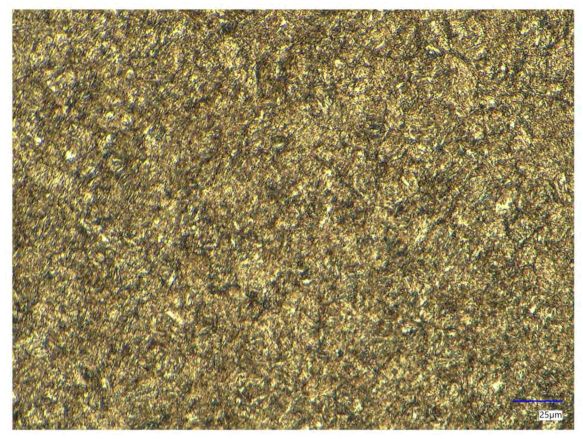


Because the steel is very hard but brittle from the austenization and quenching the steel is then tempered at what is considered a high tempering temperature which is used to increase the strength and toughness of the steel. This allows for the unstable martensite to become tempered martensite which consists of stable cementite and ferrite phases.

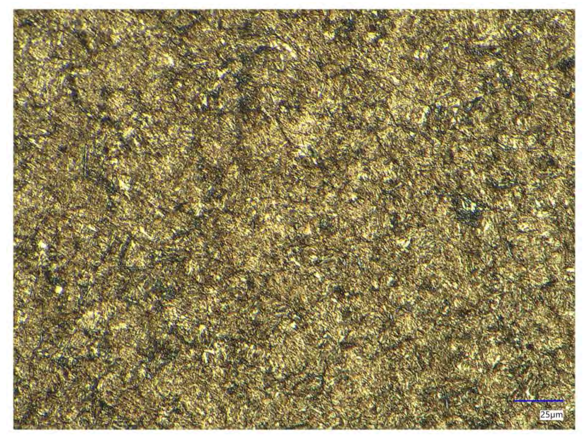
Observed Microstructure at Different Depths

Before looking at the microstructure of the samples the hardness measured on a different piece of equipment, at the surface of the sample, ¼" underneath the surface and at the center depth. With those measurements it was determined that hardness was consistent at different depths with the samples treated with quenchant A. The samples treated with quenchant B did not show consistency of hardness at different depths and thus will not be used for future research. In addition to hardness values, the microstructure of the AISI 1060 Steel after being treated with either quenchant A or quenchant B, showed inconsistent microstructure when quenchant B was used and more consistent microstructure with quenchant A. The figures below were both tempered at the same temperature.

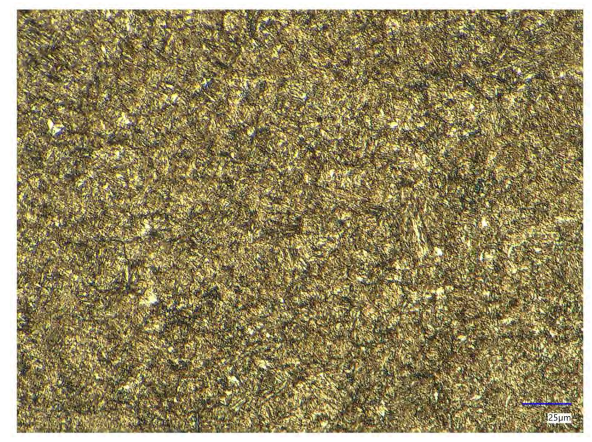
Quenchant A - 10% Concentration



a. Surface, 1000x

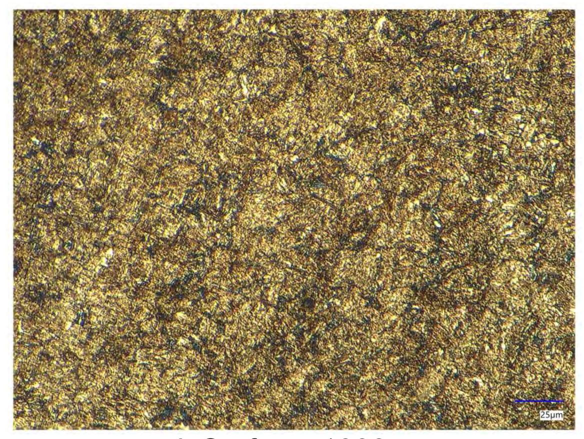


b. ¼" depth, 1000x

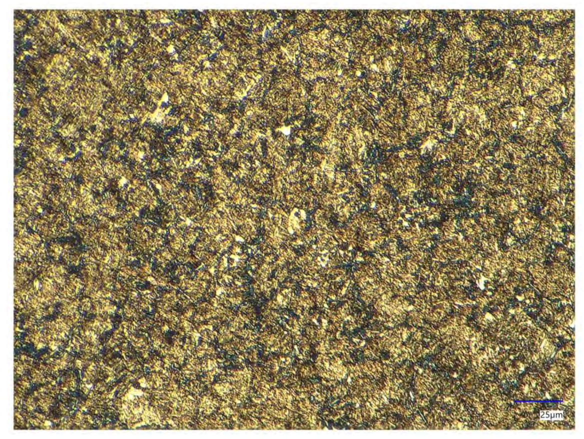


c. Center depth, 1000x

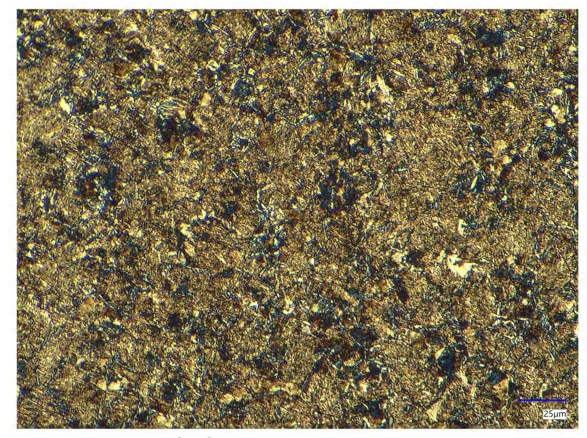
Quenchant B – 6% Concentration



d. Surface, 1000x



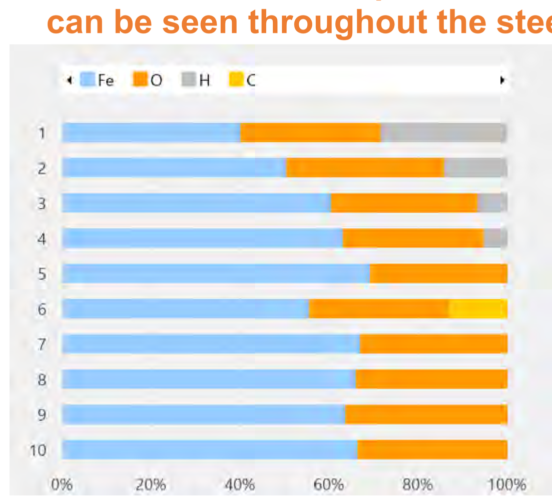
e. ¼" depth, 1000x



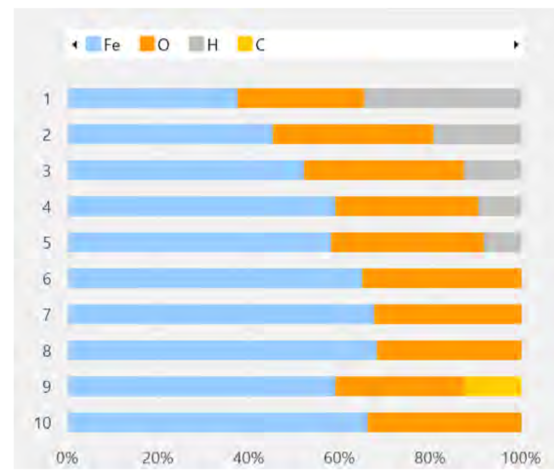
f. Center depth, 1000x

Elemental Analysis

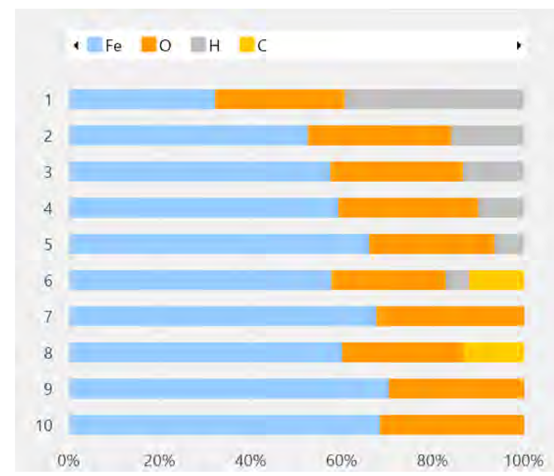
- **Samples treated with quenchant A were analyzed with the digital microscope to determine composition via two methods using LIBS. The first method is a drilling technique where a specified position on the part is hit with a strong laser 10 times where each hit is measuring a depth of 7 microns per one laser hit. This allows us to look at the variation of composition at different depths. 3 points were measured using the drilling method. Consistency can be seen throughout the steel.**



g. Composition at 10 different depths for point 1.

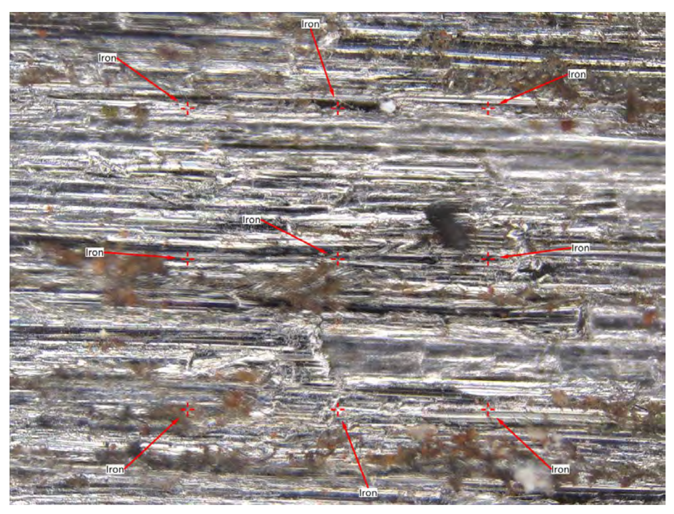


h. Composition at 10 different depths for point 2.



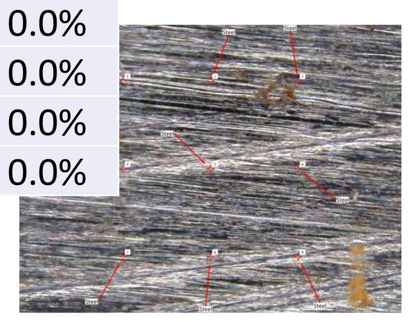
i. Composition at 10 different depths for point 3.

- **The second method is called multi-point analysis where there are 9 locations that are measured on one sample all in the same test. The AISI 1060 Steel was annealed by the supplier before delivery. For elemental analysis on the digital microscope, sample mounting is not required.**



j. As received AISI 1060 Steel (Annealed) – Results showed 100% Iron Content

No.	Presumed material	Fe	O	H	C
1	Iron hydroxide	29.5%	32.6%	37.9%	0.0%
2	Steel	40.4%	29.8%	29.8%	0.0%
3	Steel	43.6%	28.7%	27.7%	0.0%
4	Steel	37.9%	24.4%	37.7%	0.0%
5	Steel	40.1%	29.1%	20.6%	10.2%
6	Steel	38.8%	30.2%	31.0%	0.0%
7	Steel	42.6%	28.1%	29.3%	0.0%
8	Steel	43.7%	28.6%	27.7%	0.0%
9	Steel	37.0%	33.2%	29.8%	0.0%



k. Treated Steel Using Quenchant A – Composition of 9 different spots on the sample

Conclusions:

- **Different concentrations should be tested for quenchant A to determine if hardness and consistency stay the same at different depths.**
- **Test different concentrations of Quenchant B to determine if that effects consistency and magnitude of hardness and the microstructure of the steel. The assumption is that Quenchant B is not cooling the steel after it is Austenized which can cause the lattice to go from FCC to the original BCC lattice structure.**
- **Research the interactions of the quenchants with the alloying elements of the AISI 1060 Steel.**

Quaker Houghton. Forward Together

DuPont™ Vespel® for Hydrogen and Electric Vehicle Applications

Presenter: Ellen Qin, Sr. Scientist / Engineer, R&D
DuPont

Introduction

In recent years, there has been renewed interest in ways to reduce greenhouse gas emissions and achieve a more sustainable future with

1. The adoption of **hydrogen** as a clean energy source and
2. The introduction of **electric vehicles (EVs)**

These new technologies bring a set of unique challenges and technical specifications.

- For hydrogen: The design engineer must select existing materials or design new materials to solve familiar sealing, wear, and friction problems, but these materials also need to perform at both the elevated and cryogenic temperatures characteristic of hydrogen.
- For EVs, the design engineer needs to select materials that can withstand the demanding conditions of electrification including higher torque, increased rotational speed, and high temperatures, all while maintaining a compact and lightweight design.

For 60 years, **DuPont™ Vespel® polyimide parts and shapes** have excelled in extreme conditions and applications where thermal stability, electrical properties, and excellent wear and friction performance are necessary.

The Vespel® portfolio offers a range of high-performance materials that enable customers to meet the challenging problems encountered by the hydrogen and electric vehicle customers and is a material of choice in these demanding applications.


Stock Shapes

Commercially available
Different shapes and sizes
Can be machined into finished parts (Easily machinable)
Excellent material properties
Sold primarily through distributors


Custom Parts

Proprietary design
Engineering solution by DuPont
Minimize machining steps to lower costs per part
Quality assurance
Technical global support

Current Applications

Hydrogen

Valves and Pressure Reducers (Vespel® S)
Industrial and transportation applications, from production to mobility:

- Seats
- Seat Carrier Seals
- Hydrogen Receptacles
- Connectors

Pumps (Vespel® S and CR)
Pipelines, storage, refueling

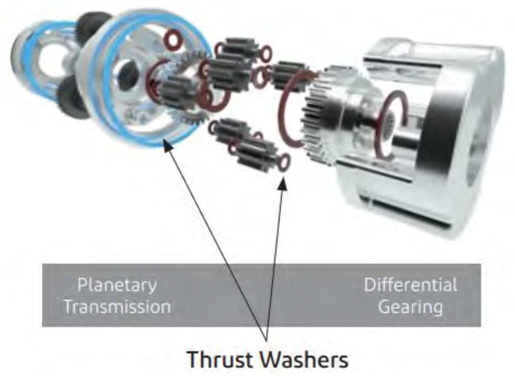
- Bearings
- Wear rings
- Piston Ring
- Bushings

Compressors (Vespel® S and CR)
Production, storage, pipeline, refueling

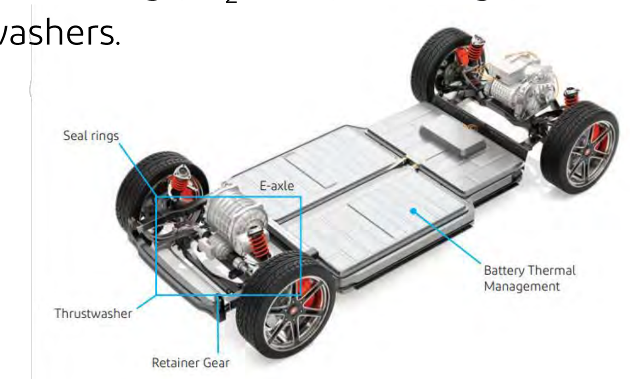
- Piston Rings
- Rider Bands
- Packing Rings
- Valve Plates

Electric Vehicles

Applications in e-Axles, differentials, torque vectoring, and disconnect systems among others.



Used in the transmission, differentials, and motors in the form of wear rings, H_2 seals, seal rings, bushings, and thrust washers.



Key Properties of DuPont™ Vespel® for Hydrogen Sealing and Storage

Challenges in hydrogen applications	Vespel® solutions
Bubble tight sealing from elevated down to cryogenic temperatures	→ A low and consistent compressive modulus and high mechanical resistance, offering exceptional sealing in a variety of typical H_2 conditions.
Potential permeability issues during storage, due to low molecular weight of hydrogen	→ Significantly lower H_2 permeability than materials like PEEK across a wide range of temperatures
Service life under high loads in wide temperature ranges, from elevated down to cryogenic	→ Excellent creep performance at high loads and elevated temperatures, "soft but strong" characteristics for sealing at low temperatures
Demanding tribological requirements, efficiency and service life	→ Low COF in air and hydrogen, helping to reduce actuation force and improve operational efficiency / reduce energy required to operate
Costly maintenance	→ Low wear rate that contributes to lowering the frequency at which components need replacement

Key Benefits for Hydrogen Applications

- Low hydrogen permeability
- Low creep
- High mechanical resistance
- Low and consistent modulus
- Low wear and friction

From DuPont™ Vespel® website: "Dupont™ Vespel® Parts for Hydrogen Propulsion Technology"; "Dupont™ Vespel® Parts for Hydrogen Energy"

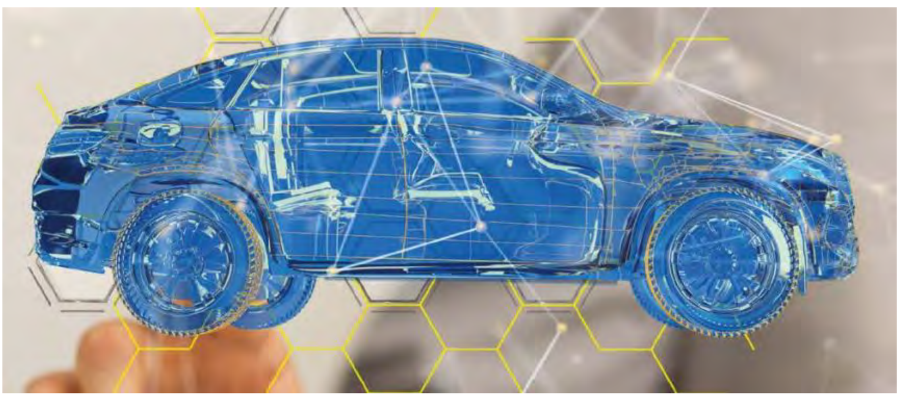
Key Properties of DuPont™ Vespel® for Electrical Vehicles

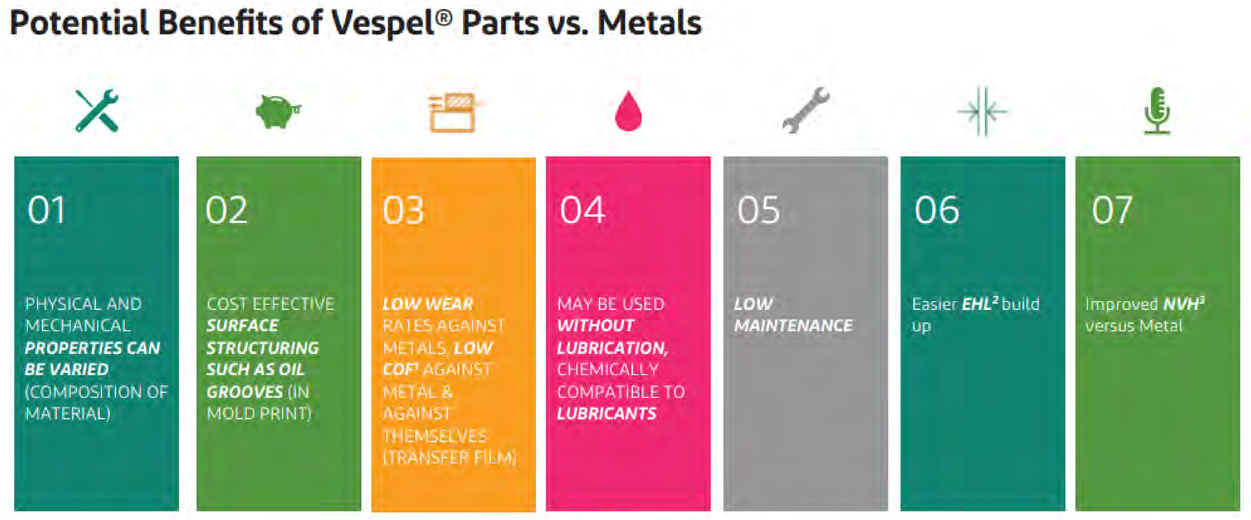
Challenges of electrification within the EV drivetrain

- Higher torque & instant Acceleration
- Higher rotational speed = high V
- The most demanding Noise Vibration Harshness requirements
- Compact design & lightweight
- Lean lubricating conditions

Vespel® meets and exceeds those challenges

- Minimizes wear and reduces friction
- Prevents seizure / fretting, low coefficient of friction (COF) at high RPMs
- High damping performance vs. metal (tan(δ))
- Lighter than metal and thinner than competitive plastics
- Self lubricating, operating under lean lubricating levels with optimized oil groove design





From DuPont™ Vespel® website: "Vespel® Parts for Internal Combustion Engine Applications;" "Vespel® Parts for E-Mobility Applications;" and "Dupont™ Vespel® High-performance Polyimides – Solutions for Battery and Hydrogen Powdered Vehicles"

Applications of Coupled Rheology – FT-IR to Polymer Analyses

Sara Reynaud, Dana Garcia, Mark Lavach, Jim Henry

[1]Analytical & Systems Research, Arkema Inc., 900 First Ave, PA 19406

[2] consultant, retired from Arkema 2021

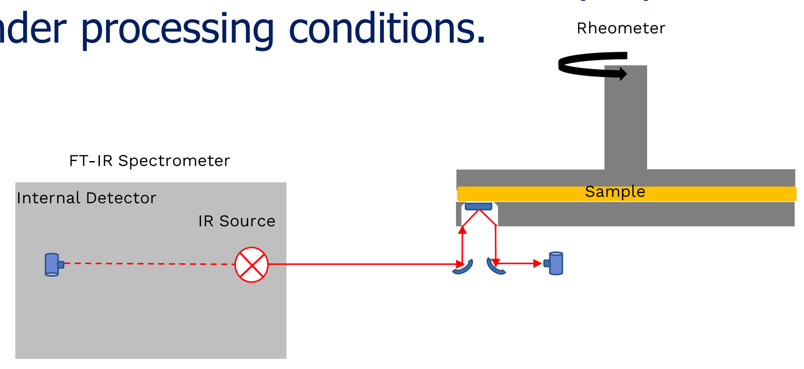
[3] Fluorinated Polymers, Arkema Inc., 900 First Ave, PA 19406

ARKEMA

MOTIVATION & OUTLINE

The advancement of coupled rheological spectroscopic techniques opens wide opportunities to study in situ structure-property-processing-performance relationships of polymers under dynamic conditions. At Arkema, we explored the use of combined Rheo-IR in the attempt to understand the mechanisms behind phenomena such as shear instability, preferential crystallization pathways, and structural changes under processing conditions.

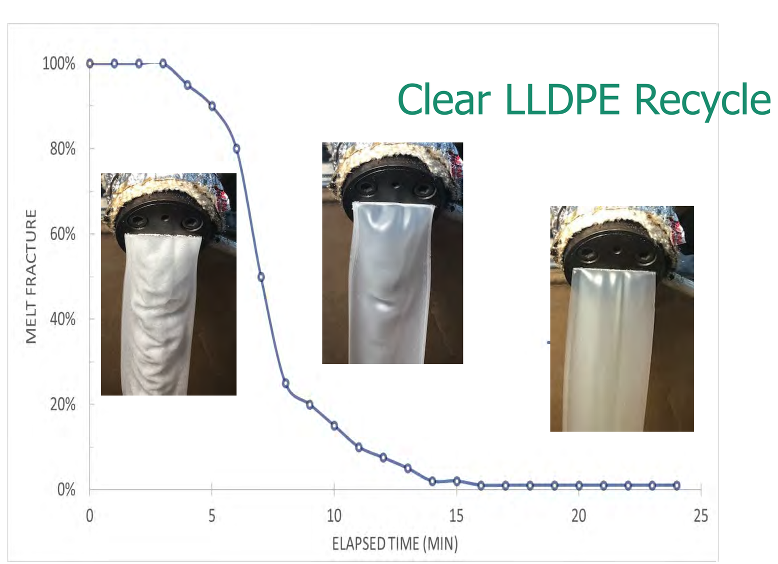
- Viscoelastic & Flow Properties
- Structural and Chemical Changes



In a more recent study, we describe the mechanisms of internal lubrication due to the addition of polymer process aids to polyethylene. In particular, we will focus on commercial polymer processing additives, PPAs, used to help melt fracture during film extrusion.

We show that addition of ppm level of PPAs into PE drastically improves the quality of extrusion. The lubrication phenomenon is due to the migration of PPAs particles to the metal surface of the die, which promotes wall slippage. Although the PPAs migration mechanism at high shear rates is well understood in the industry; very little is known about the effect of PPAs on the flow behavior of the molten polymer when processed at relatively low shear rates.

INTERNAL LUBRICATION MECHANISM OF PPA



Flat Die Study, Shear rate: 300 s^{-1}- 500 s^{-1}

Processing temperatures: 155°C–170°C

Addition of PPA offers quick benefits on processing, even in recycled polymers

- Benefit of adding PPA to other polymers
  - Elimination of melt fracture
  - Reduction of extrusion pressure
  - Enhance gloss and mechanical properties
- Mechanisms of lubrication
  - Migration of PPA to die wall- known at high shear
  - Internal lubrication (inter-particle friction)
- Materials

LDPE blended with:

I. 0 PPA
II. 550ppm PPA
III. 1100ppm PPA

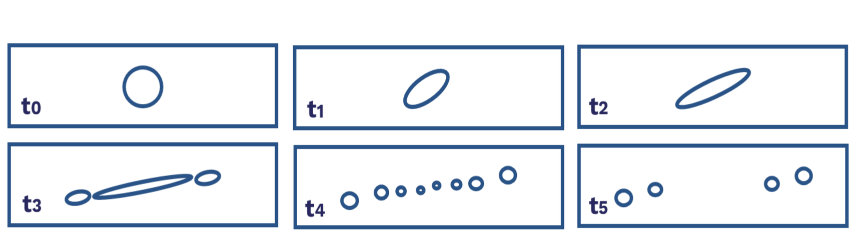
RHEOLOGY OF IMMISCIBLE BLENDS UNDER SHEAR

- Morphological changes :
  - Droplet collision
  - Alter velocity field

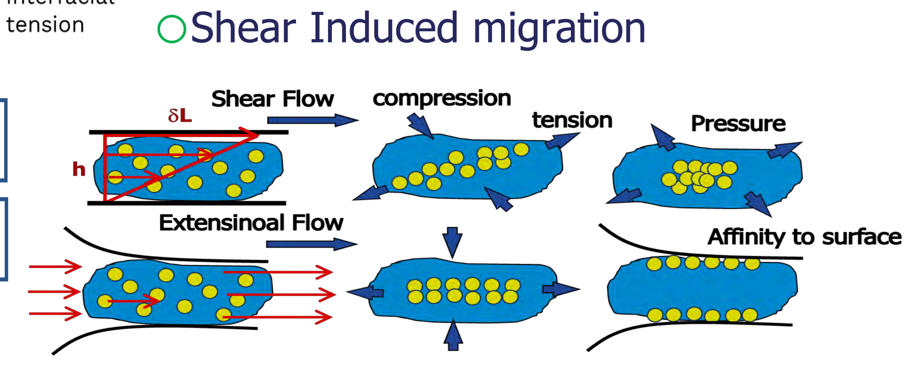
Average Stress, Volume fraction, Droplet deformation & deformation rate, Viscosity ratio, Interfacial tension

- Migration Mechanisms:
  - Diffusion migration
  - Shear Induced migration

$$Pe \equiv \frac{\dot{\gamma}}{D_{ro}} \propto \dot{\gamma}.t_D$$

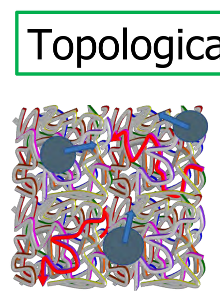


Schematics of possible morphology evolution of a single drop under shear



Topological changes alter rheology

Predicting particle migration is not trivial



- Incorporation of immiscible components affects material behavior at different microstructural lengths
  - Aggregation & Concentration
  - Polymer alignment/organization at interface
  - Interfacial structural differences
  - Various dynamics in blends affecting RHEO

EFFECT OF PPA ADDITIVES ON EXTRUSION

PPA was found to migrate to the wall of the extruder and coat the wall.
Capillary experiments were reported in the literature showing occurrence of wall slippage at the wall and reduction of shark-sink due to PPA coating of the wall.

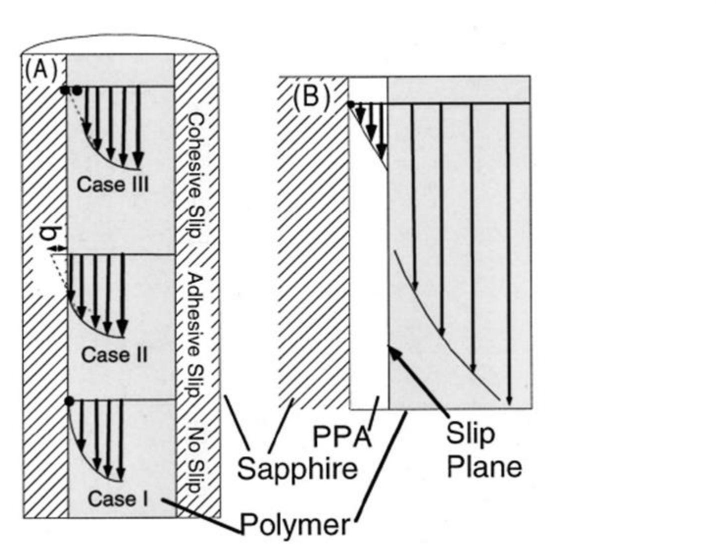


FIG. 1. (A) Possible boundary conditions at the wall–polymer interface. Case I, standard no-slip approximation; case II, slippage occurs at the wall–polymer interface; and case III, a finite layer of polymer is stuck to the wall and slippage occurs in the polymer just beyond this layer. (B) In the case of a fluoropolymer preferentially wetting the wall, slippage may occur at the polymer–polymer interface.

Migler at al.; J. Rheol. 45(2), March/April 2001

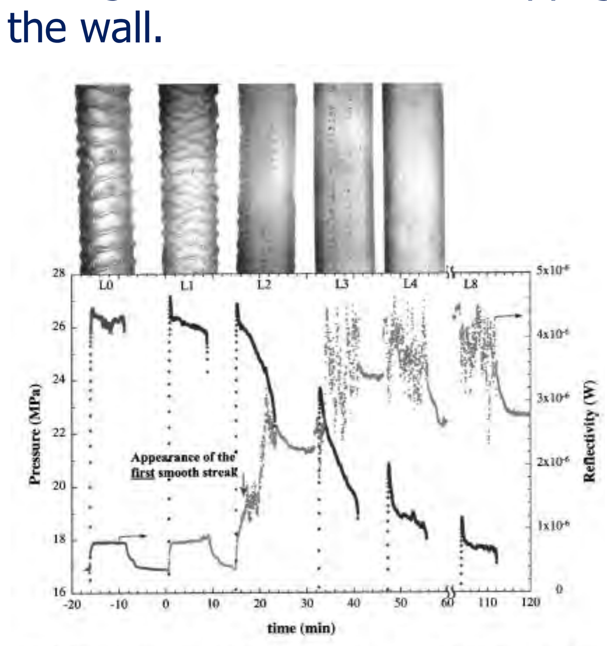
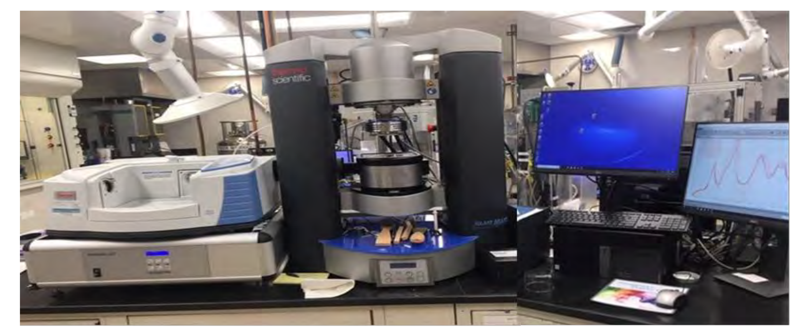


FIG. 7. Effect of the development of the PPA coating during the extrusion of 0.5% PPA/PE blend (L1–L8) shown for the four blend loads on the (a) pressure and (b) reflectivity.

Migler et al. ; J. Rheol. 47(6), 1523-1545 November/December 2003

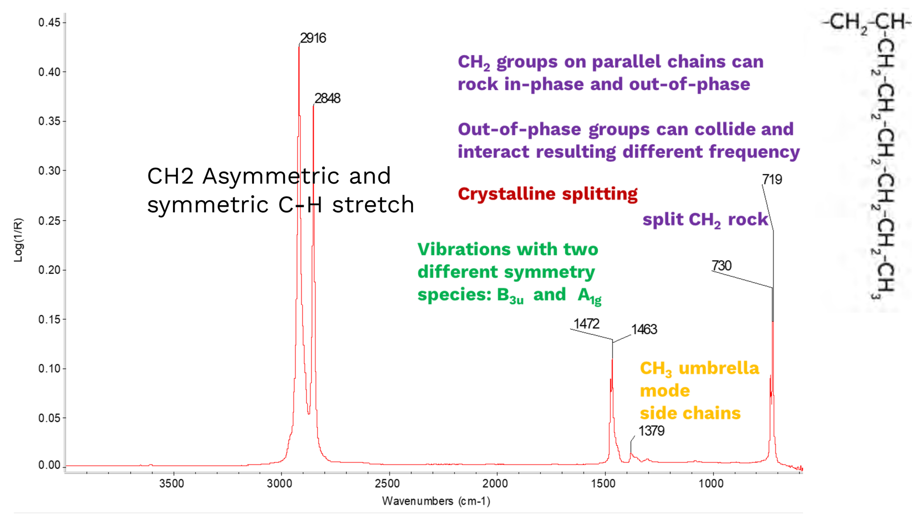
INVESTIGATING LUBRICATION MECHANISM OF PPA



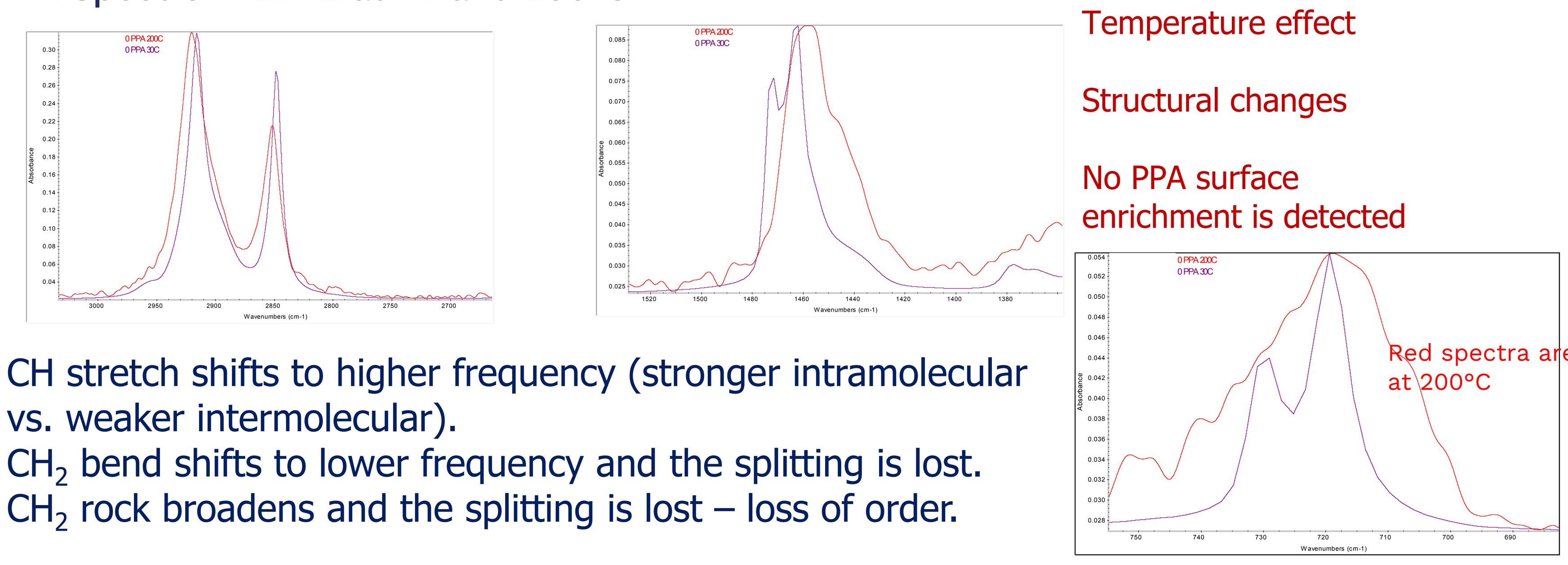
FT-IR: 200°C, 4 cm^{-1},64 scans, 2^{nd} derivative analysis

Rheology: 200°C, $\dot{\gamma}$ 50 Hz transient viscosity

FT-IR spectrum of crystalline LDPE at RT



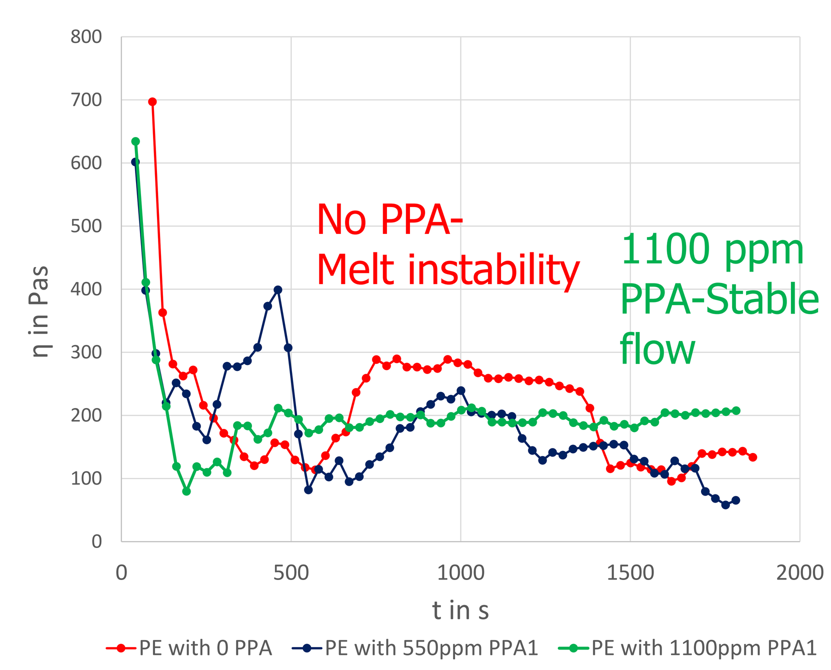
FT-IR Spectrum LDPE at RT and 200°C



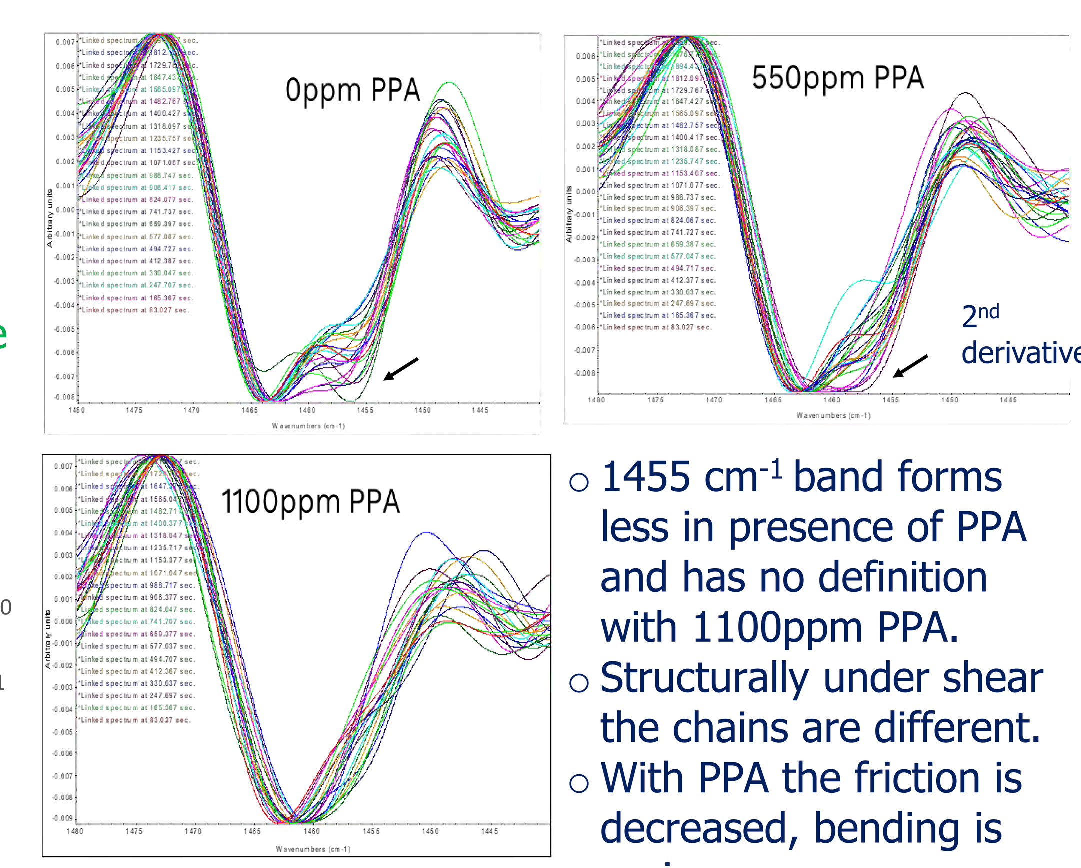
- CH stretch shifts to higher frequency (stronger intramolecular vs. weaker intermolecular).
- CH_2 bend shifts to lower frequency and the splitting is lost.
- CH_2 rock broadens and the splitting is lost – loss of order.

LDPE-PPA DYNAMIC CHANGES UNDER SHEAR- CH2 BEND MODE

Transient Viscosity at 200°C, and 50Hz



- Addition of PPA helps decrease chain-chain friction and stabilize the flow.
- 1100 ppm PPA is needed to obtain a homogeneous lubricated system.

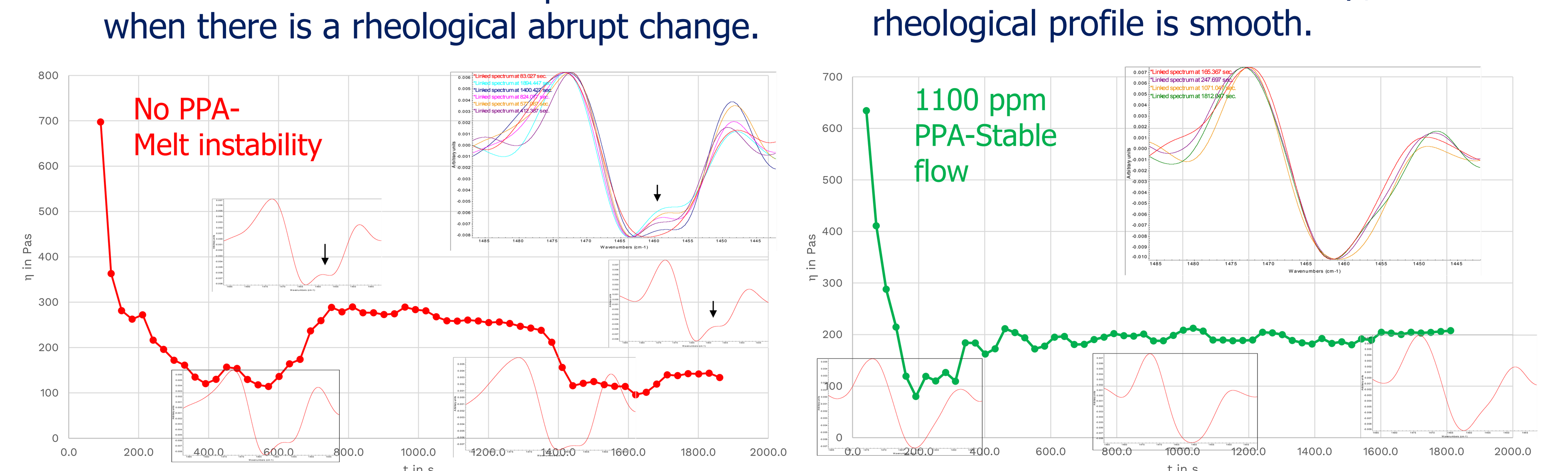


- 1455 cm^{-1} band forms less in presence of PPA and has no definition with 1100ppm PPA.
- Structurally under shear the chains are different.
- With PPA the friction is decreased, bending is easier.

IN SITU RHEO-IR ANALYSIS REVEALS INTERNAL LUBRICATION AT LOW SHEAR

The 1455 cm^{-1} band is more pronounced when there is a rheological abrupt change.

The 1455 cm^{-1} does not develop, the rheological profile is smooth.



✓ **PPA migration to the surface – not detected in the Rheo-IR**

✓ **Viscosity dynamics correlates with PE IR spectral changes:**

1100ppm to stabilize the melt (RHEO) – less hindered rotations of CH_2 bend (IR).

Re-organization of PE chains in presence of PPA affects rheology(RHEO) - Enhanced movements of chains (IR).

NEW INSIGHTS, HYPOTHESIS AND IMPLICATIONS

- Internal lubrication mechanism of PPA is a new observation
  - At low/medium shear rates PPA droplets diffuse through polymer matrix – they do not migrate to plate surface – New Insights on Internal Lubrication vs External Lubrication
  - Rheo-IR combined data helps build fundamental understanding and identify ideal PPA loads
- Implications & Learnings
  - PPA works well also in cable/wire extrusions (low shear rates)- probably due to internal lubrication mechanisms.
  - Use of PPA as polymer additive/rheological modifiers

Cable extrusion with PPA

ARKEMA

Liquid Applied Sound Damping Coatings Optimized for Next-Generation Vehicles

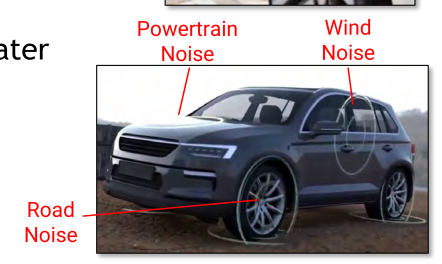
Ian D. Robertson*, Manoj Thota, Matthew Padaon

Background

Automotive Acoustics is Rapidly Evolving

Electric Vehicles Rapidly Gaining Share of Automotive Market

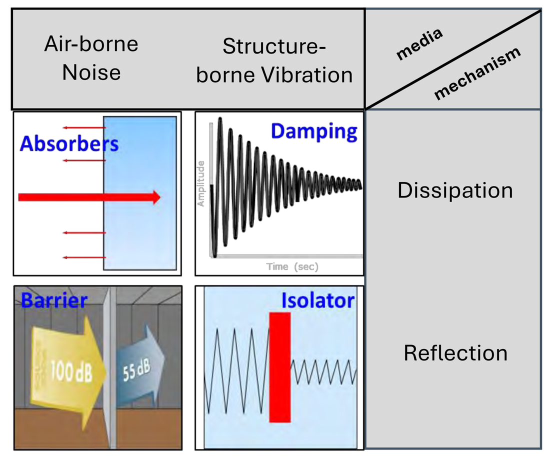
- Expected to be quiet and acoustically comfortable
- Current acoustic treatments generally designed around traditional internal combustion engine vehicles
- Damping materials typically focused on damping of steel resonance below 1000 Hz
- EVs commonly built with aluminum and have greater high-frequency vibration levels



Noise Control Mechanisms

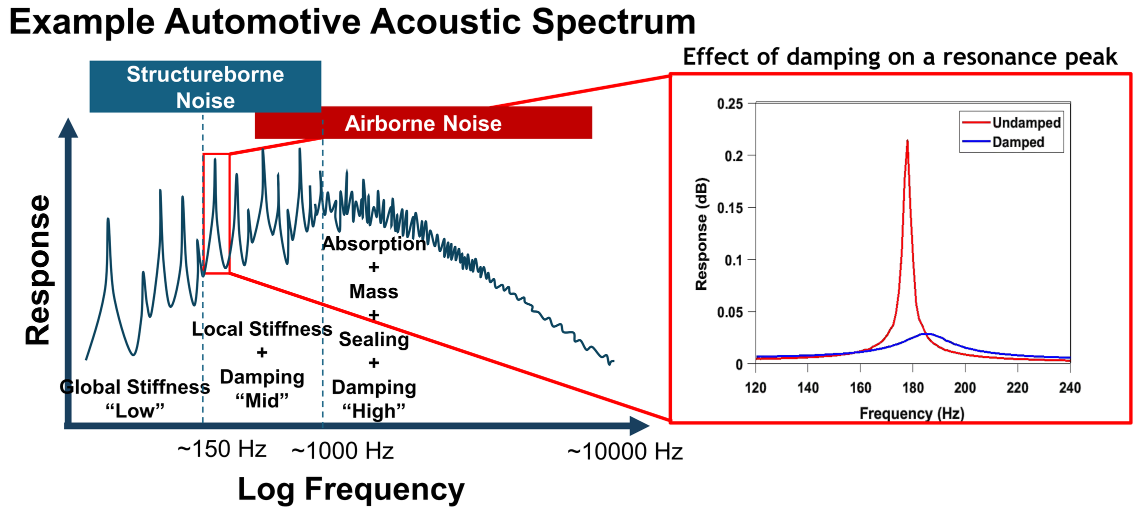
Two noise pathways
- Air-borne (noise in air)
- Structure-borne (vibration)

Noise control treatment categories
- Absorbers (foams, fibers)
  - Prevent reverberation
- Barriers (concrete, mass loaded vinyl)
  - Prevent sound transmission
- Isolators (shock absorbers)
  - Prevent vibration transfer
- Damping (LASD, damping pads)
  - Prevent resonance



Different acoustic solutions are required for different types of noise

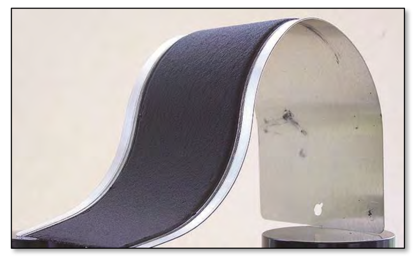
Example Automotive Acoustic Spectrum



What is Liquid Applied Sound Damping (LASD)?

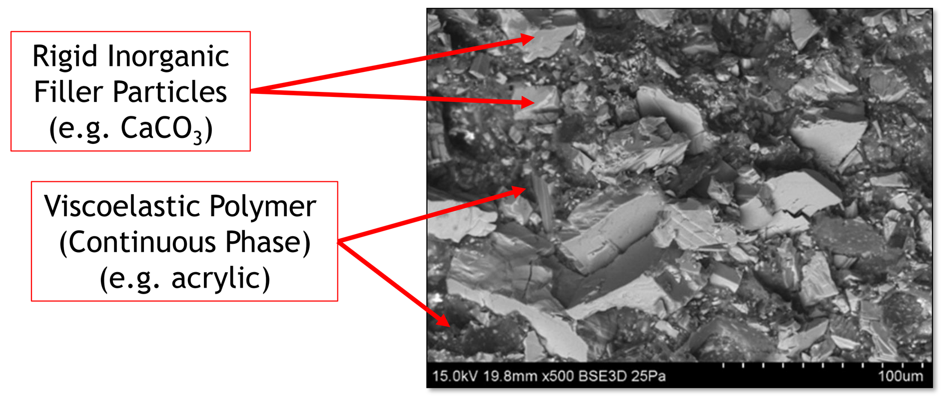
Coatings designed to reduce noise through viscoelastic damping

- Thick (1-5 mm) coatings applied to rigid structures
- Widely used in automotive industry to dampen vibrations in vehicle sheet metal
- Advantageous spray application enables robotic application processes to efficiently cover geometrically complex surfaces



LASD is a Composite

Viscoelastic polymer binds together rigid mineral particles



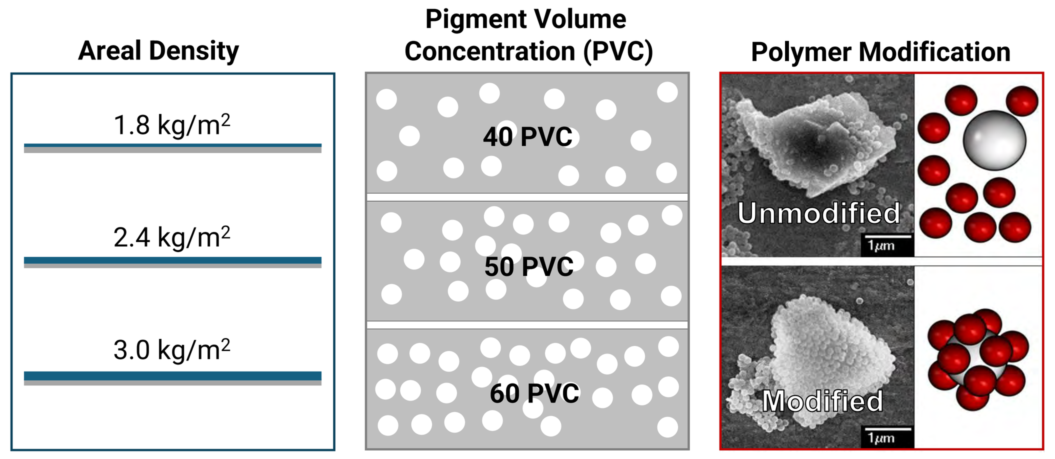
Both polymer and mineral components are essential for function as an extensional layer damping material

Objective

Design LASD to best mitigate both low and high frequency vibrations for EV applications

- LASD coatings can be modified in application level, formulation, and viscoelastic polymer design
- How do changes to these variables affect damping at high frequencies compared to low frequencies?

Variables Explored

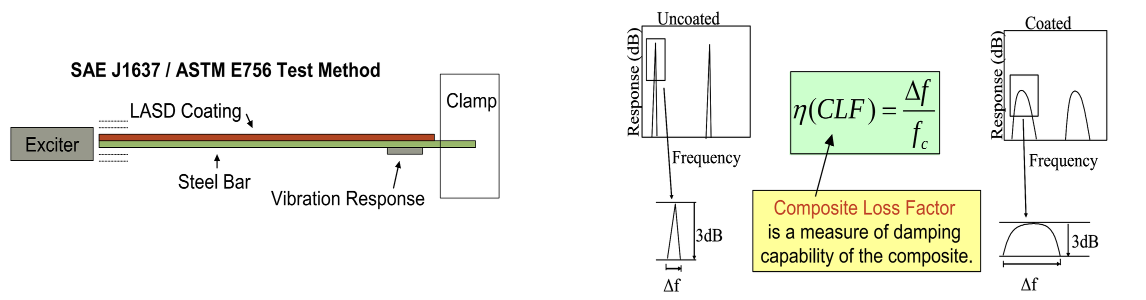


Materials & Methods

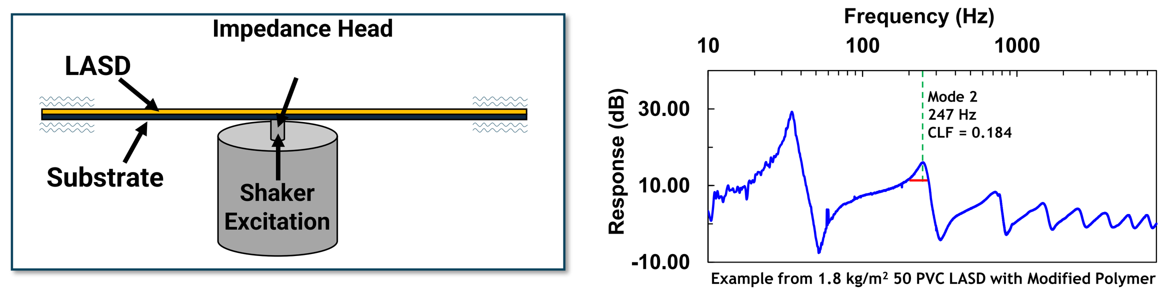
Formulations for LASD Compositions

		Weight Fraction (%)		
Material	**Function**	**40 PVC**	**50 PVC**	**60 PVC**
Polymer Emulsion (standard or modified)	Viscoelastic Binder	48.18	38.44	28.50
Water	Diluent	0.00	0.01	3.68
Polysiloxane Defoamer	Defoamer	0.17	0.17	0.17
Polyacid Dispersant	Pigment Dispersant	0.38	0.46	0.53
Surfactant (1:1 pre-dilution in water)	Stabilizing Additive	0.15	0.15	0.15
Carbon Black Dispersion	Colorant	0.50	0.50	0.50
Calcium Carbonate	Coarse Filler	39.00	48.09	54.28
Mica (325 mesh)	Coarse Filler	5.20	6.41	7.24
Starch	Baking Additive	2.89	2.31	1.71
Expandable microspheres	Baking Additive	0.30	0.30	0.30
Alkali Swellable Thickener (1:1 pre-dilution in water)	Rheology Modifier	3.24	3.17	2.94
Total		**100.00**	**100.00**	**100.00**

Damping Performance Metric - Composite Loss Factor
- Traditionally measured with steel Oberst Bar
- Measures ability of material to mitigate resonance in substrate
- Rather than capturing material properties (like E', tanDelta), CLF provides properties of the composite system (steel + LASD) for application relevance



Center Impedance Method
- Effective for highly damped samples
- Allows test on aluminum



Samples Tested
- 25.4 mm x 300 mm x 1.2 mm Al bars
- Temperature held at 23 °C

Data Captured
- Frequency response functions (FRFs) from 0-8000 Hz
- Composite Loss Factor (CLF) calculated for each mode

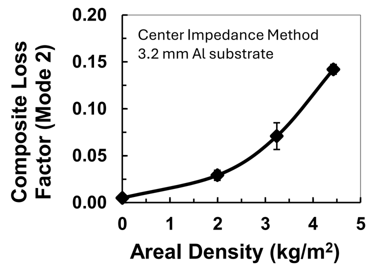
Results

Relevant past data on 200 Hz resonance in steel

Areal Density

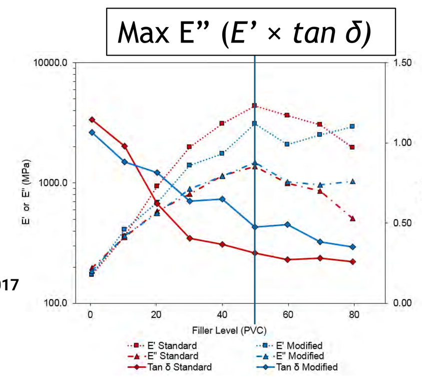
$$CLF \cong A \frac{E'_{Coating}}{E'_{Substrate}} \left(\frac{H_{Coating}}{H_{Substrate}}\right)^2 \tan \delta_{coating}$$

For equal density materials $H_{Coating} \propto Areal\ Density$

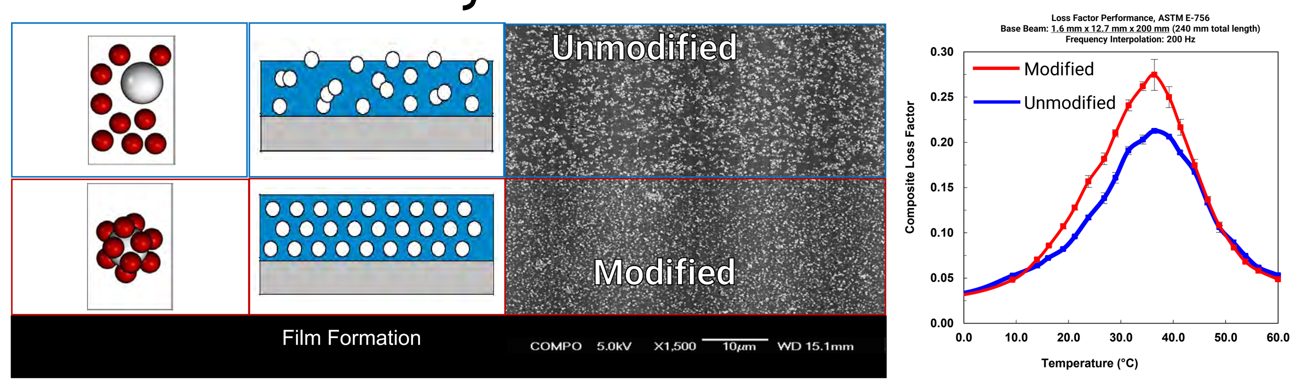


Mineral Level

Maximum damping observed at 50 PVC for low frequency testing



Polymer Modifications

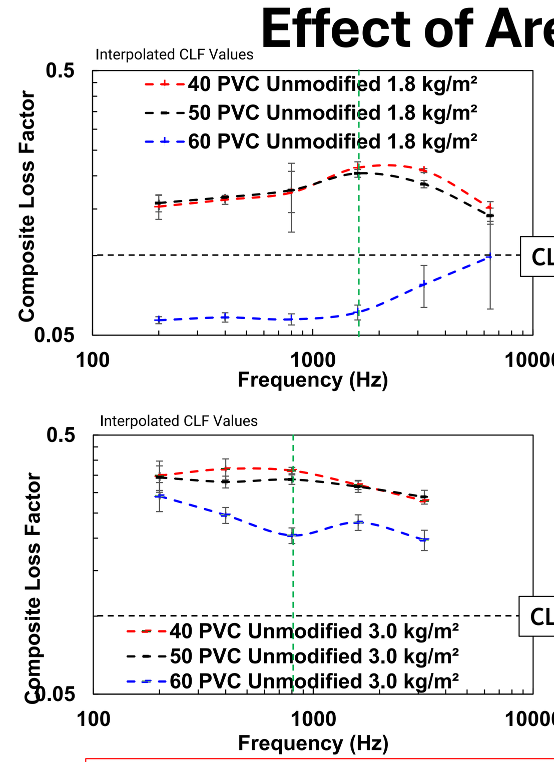


Polymers engineered to adhere well to inorganic interfaces improve dispersion of mineral filler in coatings → Improved viscoelastic properties of the composite

Better viscoelastic properties lead to improved damping at 200 Hz

Is the same observed at high frequency on aluminum?

Effect of Areal Density



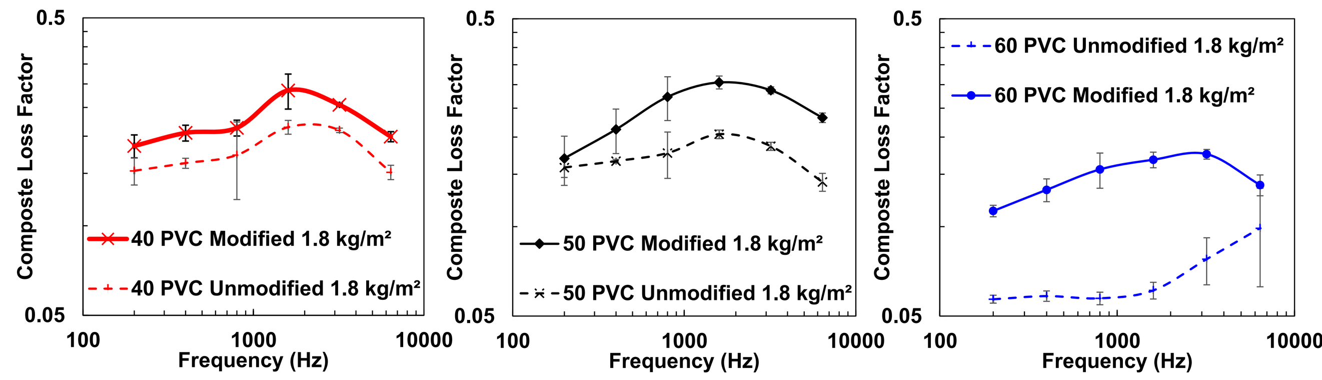
In most materials, CLF ≥0.1 from 200-3200 Hz

Peak Damping at ~1600 Hz in 1.8 kg/m² samples

Peak Damping at ~800 Hz in 3.0 kg/m² samples

Thicker coatings shift peak damping to lower frequency

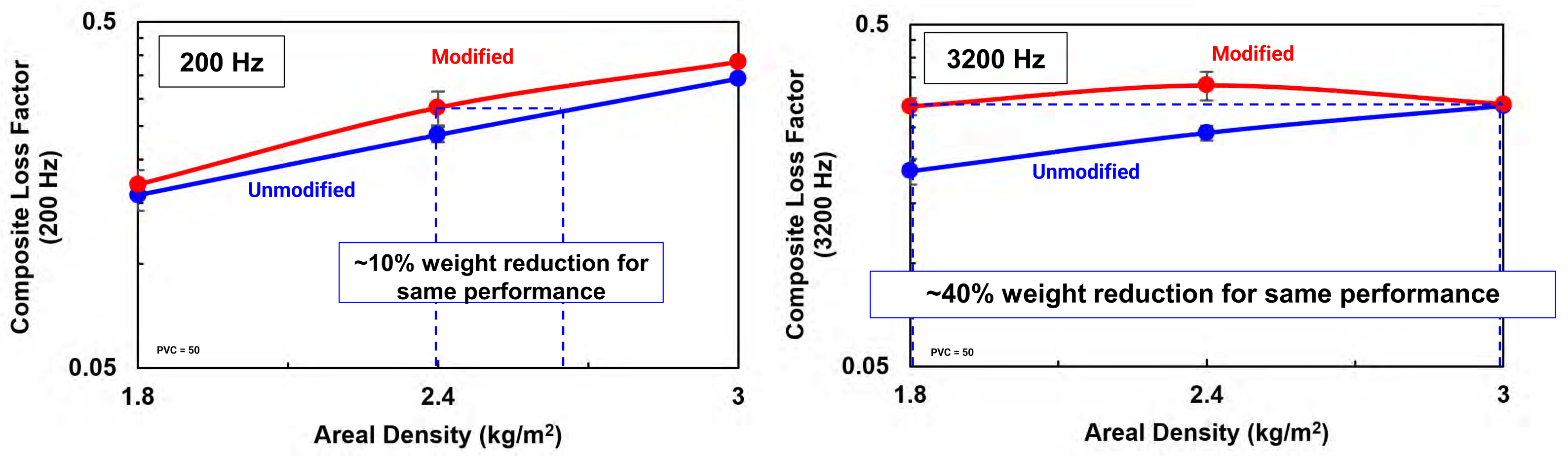
Effect of Pigment Volume Concentration (PVC)



Peak damping frequency similar for 40 & 50 PVC, but higher for 60 PVC

Polymer modification increases damping across frequency range of interest

Effect of Areal Density based on Polymer Modification



At low frequencies (200 Hz), expected increase in CLF with areal density observed

At high frequency (3200 Hz), modified polymer coating shows superior damping, but the magnitude of the advantage attenuates as areal density increases

Conclusions

- LASD is effective for damping both low and high frequency vibrations
- Coatings with polymer modified to increase interaction with mineral filler further enhance high frequency damping performance
- Optimal coating areal density depends on both polymer modification type and target frequency

Eastman Aventa™ Renew Compostable Materials

Presented by: Dr. Michael Rodig, Ph.D., Eastman Company, Kingsport TN

Global Challenges

Global Plastic Waste (2019)

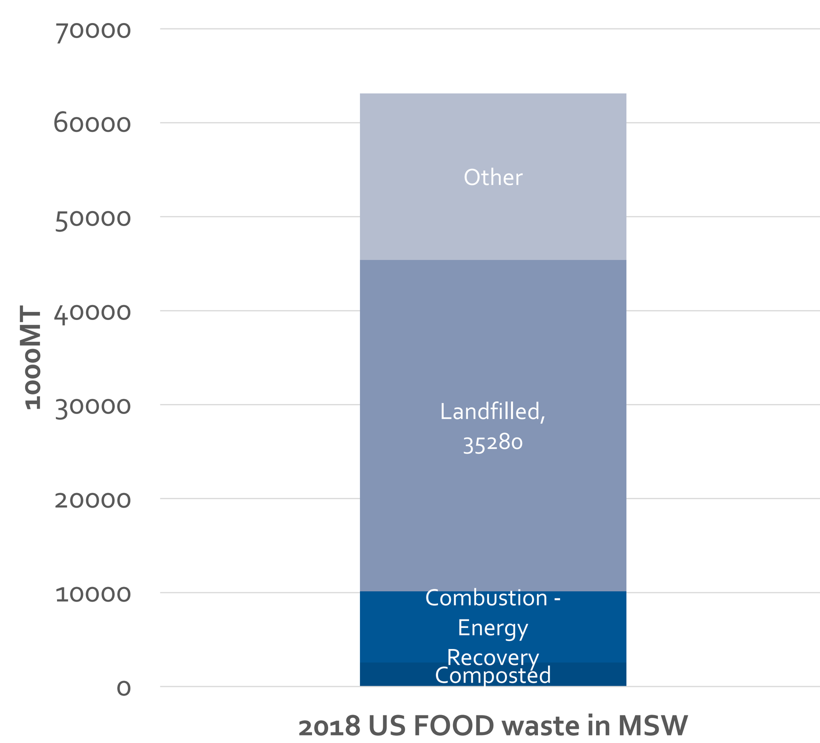
225 million tons (49%) of global waste plastic **were landfilled**

41.4 million tons (9%) of global waste plastic **were recycled**

87million tons (19%) of global waste plastic **were incinerated**

101.2 million tons (19%) of global waste plastic **were leaked**

US Food Waste (2018)

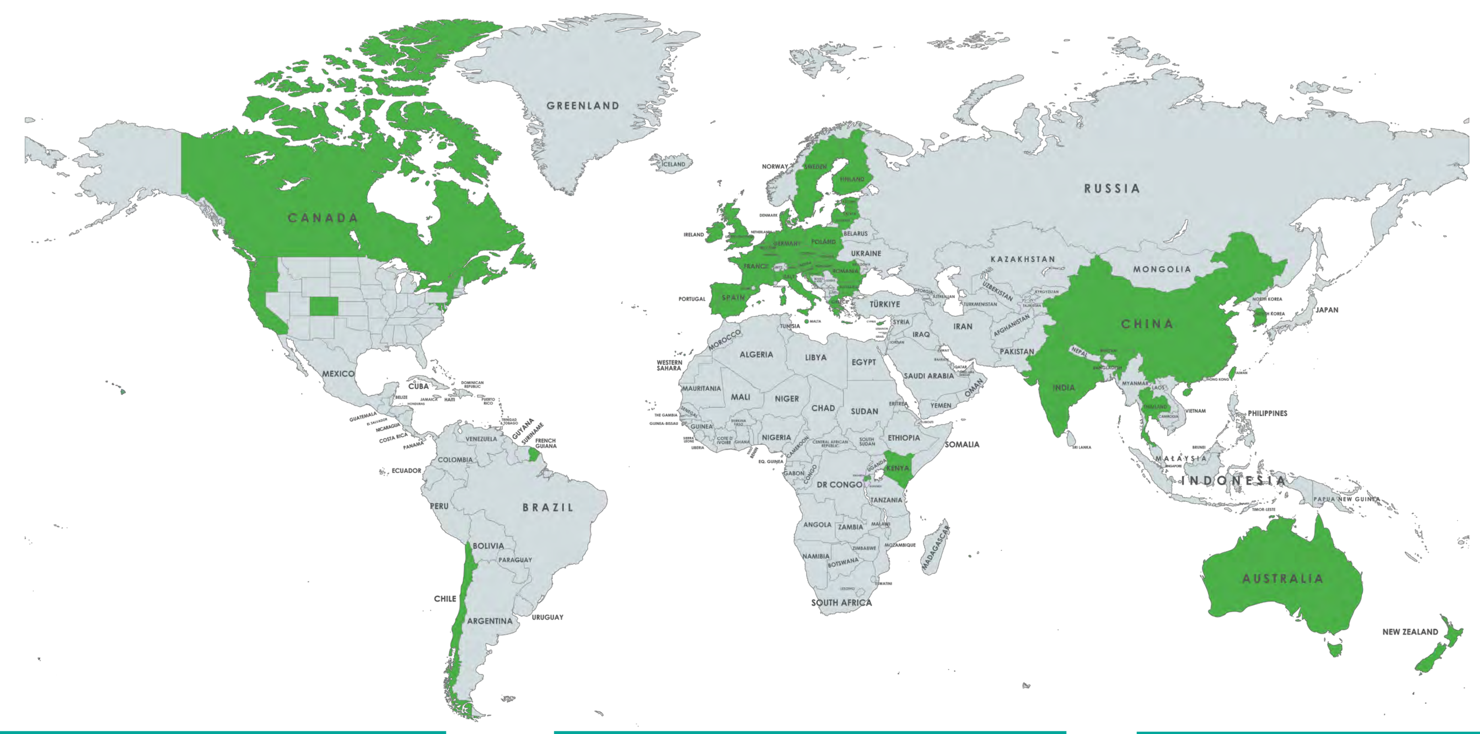


- Globally, 40% of all food produced is wasted.
- Food waste accounts for 10% of global anthropogenic GHG emissions.
- Diverting all US food waste from landfill to compost could avoid 45 million tons CO_2.
- Equivalent emissions from ~9.8million passenger cars driven in 1 year.

References:
https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry
https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/food-material-specific-data
https://www.worldwildlife.org/initiatives/food-waste/
FAO - News Article: Food wastage: Key facts and figures

Regulatory Drivers

> 40 Countries and 9 US states have some level of restriction on plastic articles



Plastic Straws

- California
- Hawaii
- Oregon
- Vermont
- New Jersey
- Washington
- Colorado
- Australia
- England
- Canada
- China
- Taiwan

Polystyrene Foam Containers

- California
- New York
- Maine
- Vermont
- Maryland

Plastic Utensils

- Hawaii
- Washington
- Australia
- France
- Canada

Eastman Technology

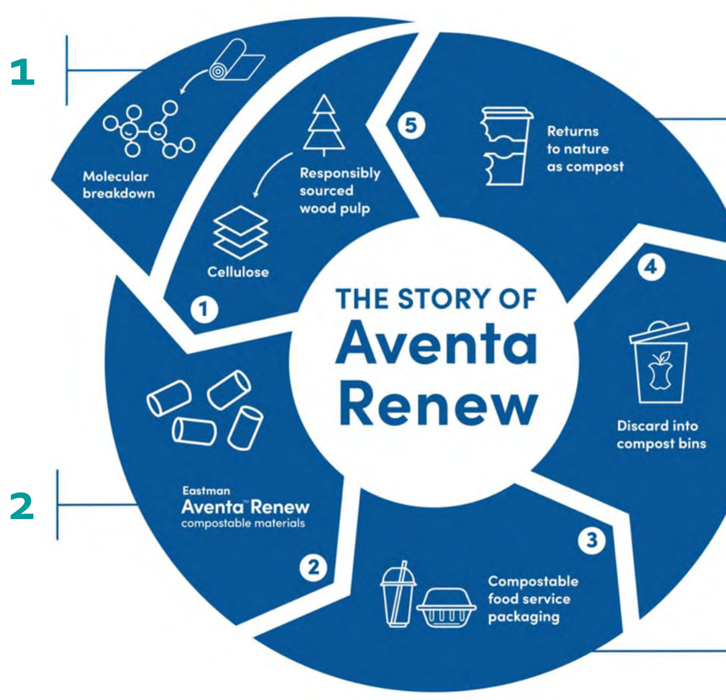
1 Mixed waste materials are diverted from landfills and **broken down into molecules to form acetic acid (vinegar)**, which is combined with cellulose to **form cellulose acetate.**

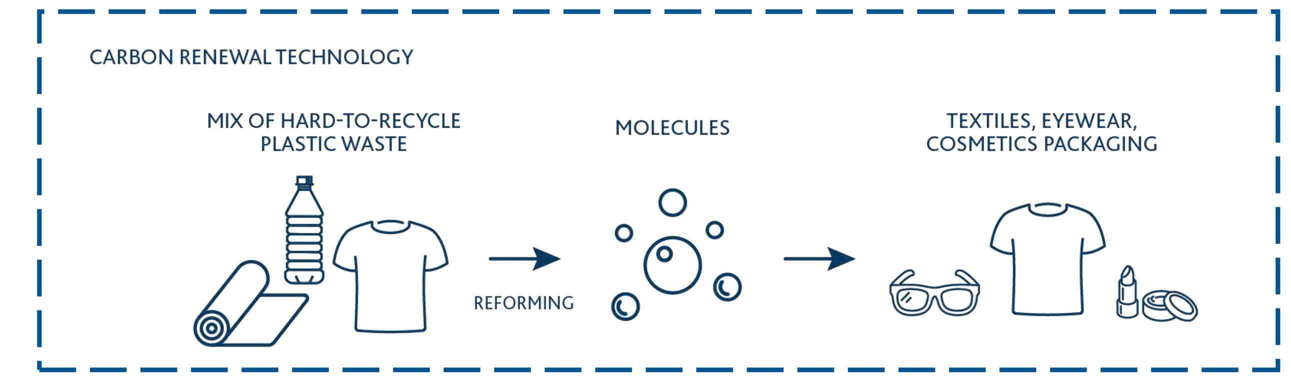
2 Cellulose acetate is **formulated to create pellets**.

3 Packaging made from Aventa Renew **performs as well** as traditional plastic.

4 Consumers discard food and packaging waste **into compost bins.** *(Home and industrial composting are possible where available).*

5 Microorganisms recognize Aventa Renew as a food source and break it down completely. Therefore, it will not remain as **microplastics.**





Impactful Markets

End Markets

Food Service

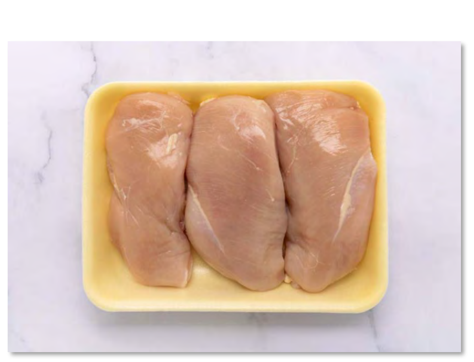
Food Packaging

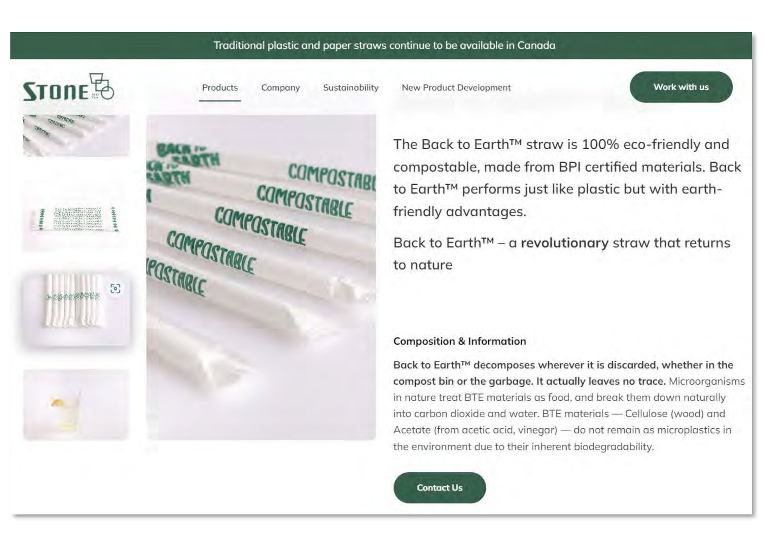
Cutlery

Straws

Clamshells

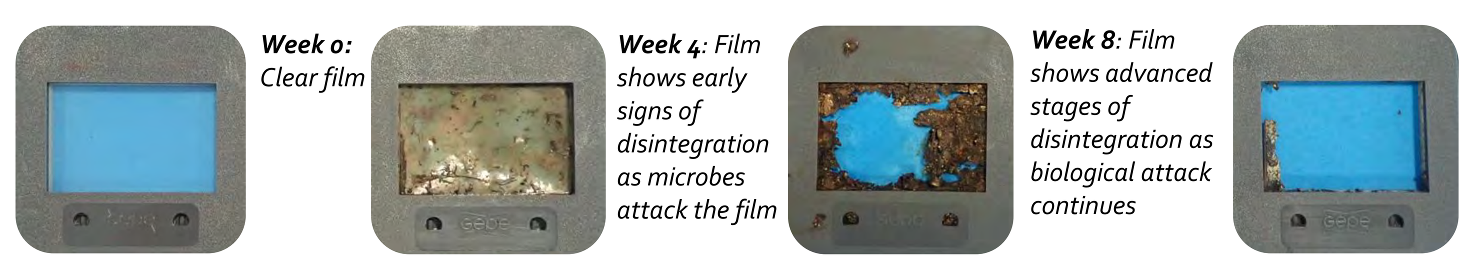
Lightweight protein trays





Proven Degradability

Standard composting disintegration test conducted by OWS per ASTM D6400 Standard. Film slides placed in compost bins with food scrap and yard waste and retrieved every month, images were captured to assess level of film breakdown.



Week 0: *Clear film*

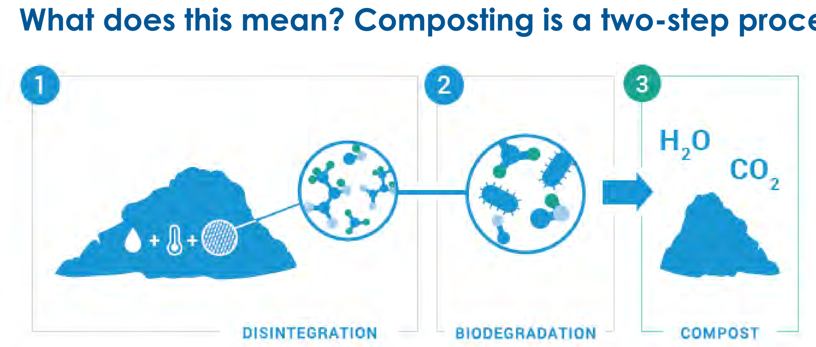
Week 4: *Film shows early signs of disintegration as microbes attack the film*

Week 8: *Film shows advanced stages of disintegration as biological attack continues*

Week 12: *Film has fully disintegrated, consumed by microbes*

Week 0 → *Week 12*

What does this mean? Composting is a two-step process.



1. Naturally occurring microbes attack Aventa Renew based articles and break them down to small fragments
2. Microorganisms in compost and soil consume and metabolize the fragments
3. End results of compost is carbon dioxide and water

Certified compostable

- Certified home and industrial compostable[3]
- Recognized by microorganisms as a food source ensuring Aventa Renew will not remain as microplastics

OK biodegradable TÜV AUSTRIA SOIL · OK compost TÜV AUSTRIA HOME · OK compost TÜV AUSTRIA INDUSTRIAL · OK biodegradable TÜV AUSTRIA WATER · BPI COMPOSTABLE COMMERCIALLY COMPOSTABLE ONLY. FACILITIES MAY NOT EXIST IN YOUR AREA.

Enabling Change

Actions being taken to grow the compostables market

Infrastructure Funding	Favorable Policies	Contamination Control	Compostability Standards
• Favorable legislations • Private and public investment • Composters financial support	• Exclusion of compostable articles from food service single use plastic bans • Simplification of compost sites permitting	• Adopt practical labeling to differentiate compostable articles • Education campaigns to help in source separation and collection	• Evaluation in multiple composting technologies • Guidelines for composters processing of compostables

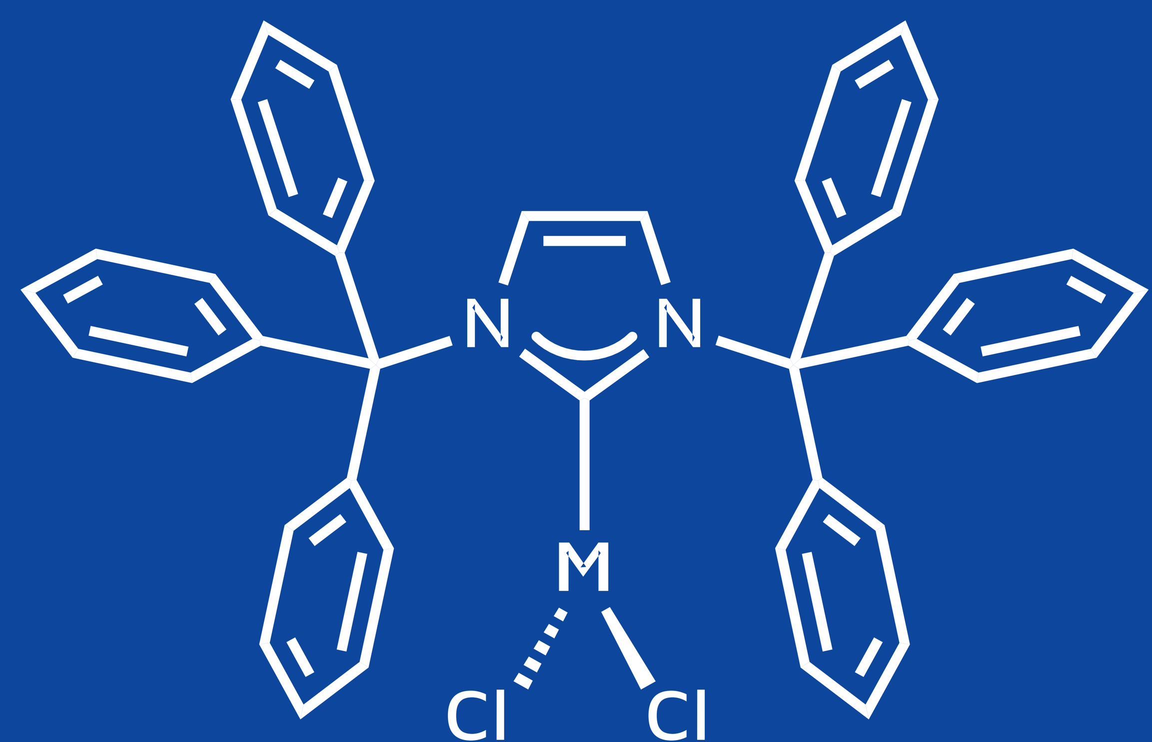
CLOSED LOOP partners · US Composting Council · TÜV AUSTRIA · ISO International Organization for Standardization · US PLASTICS PACT · COMPOSTER APPROVED · BIODEGRADABLE PRODUCTS INSTITUTE · ASTM

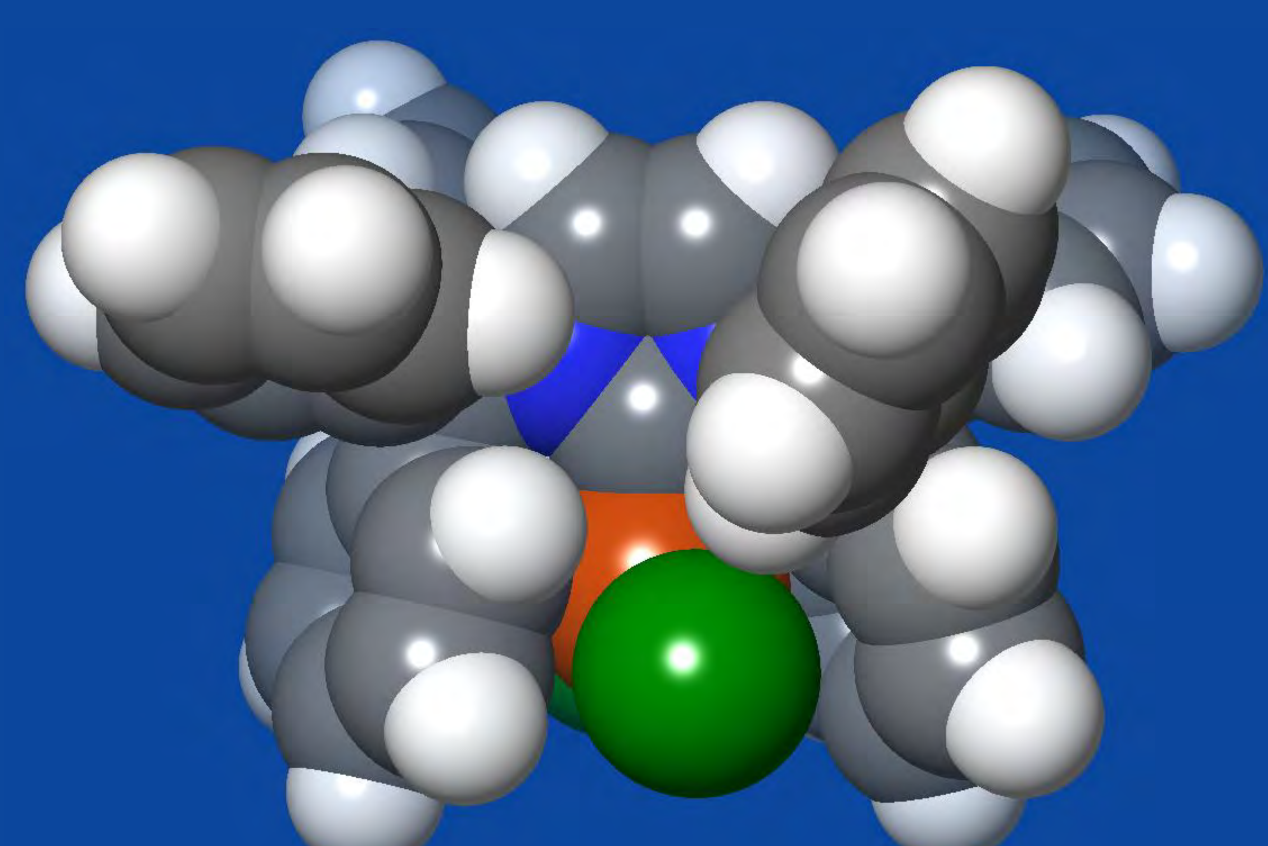
Eastman is collaborating with NGOs, trade associations, testing & standards organizations to accelerate the adoption of composting and compostable products

EASTMAN

A super bulky ligand enables the isolation of rare examples of low-coordinate iron and cobalt complexes.

These compounds can function as catalysts for carbon–carbon bond-forming processes, a fundamental reaction in organic chemistry.





ExxonMobil

Controlling metal complex speciation with ligand sterics: Synthesis of monomeric iron(II) and cobalt(II) chloride/methyl complexes using the bulky ligand ITr

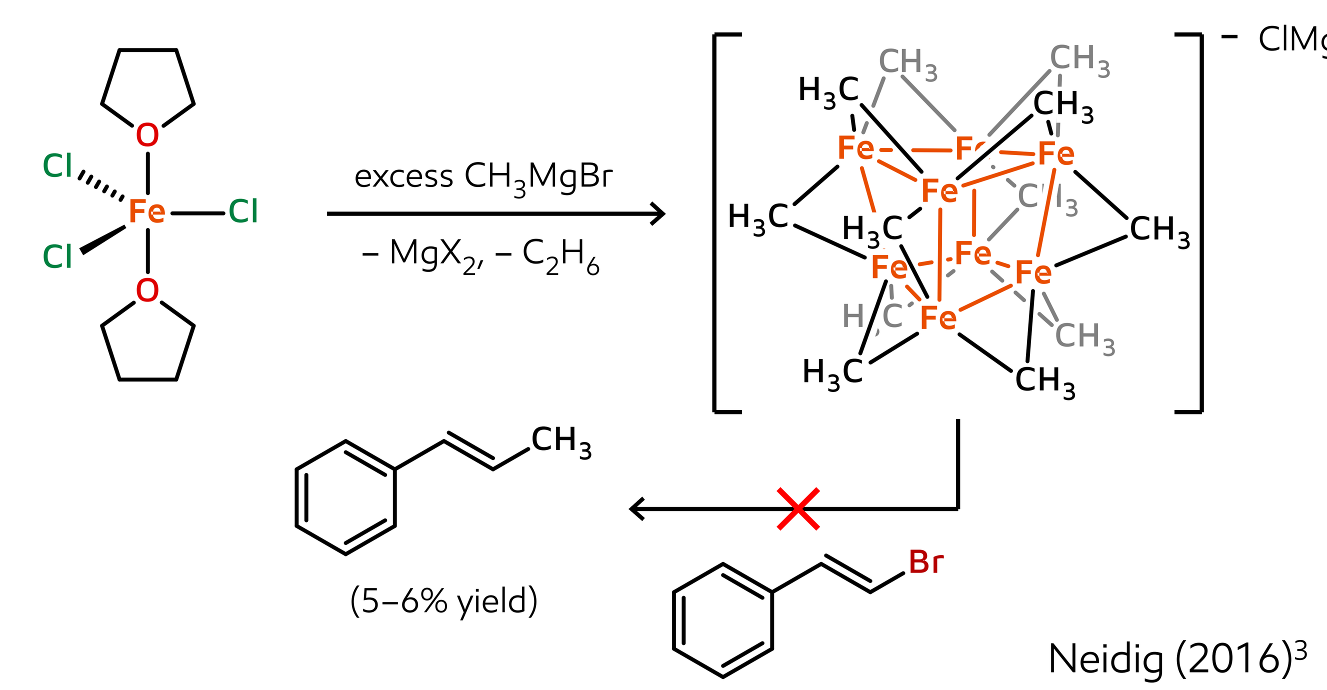
by Arun Sridharan* and Lewis Wilkins

Novel Products Research, ExxonMobil Technology and Engineering, Baytown, Texas 77520

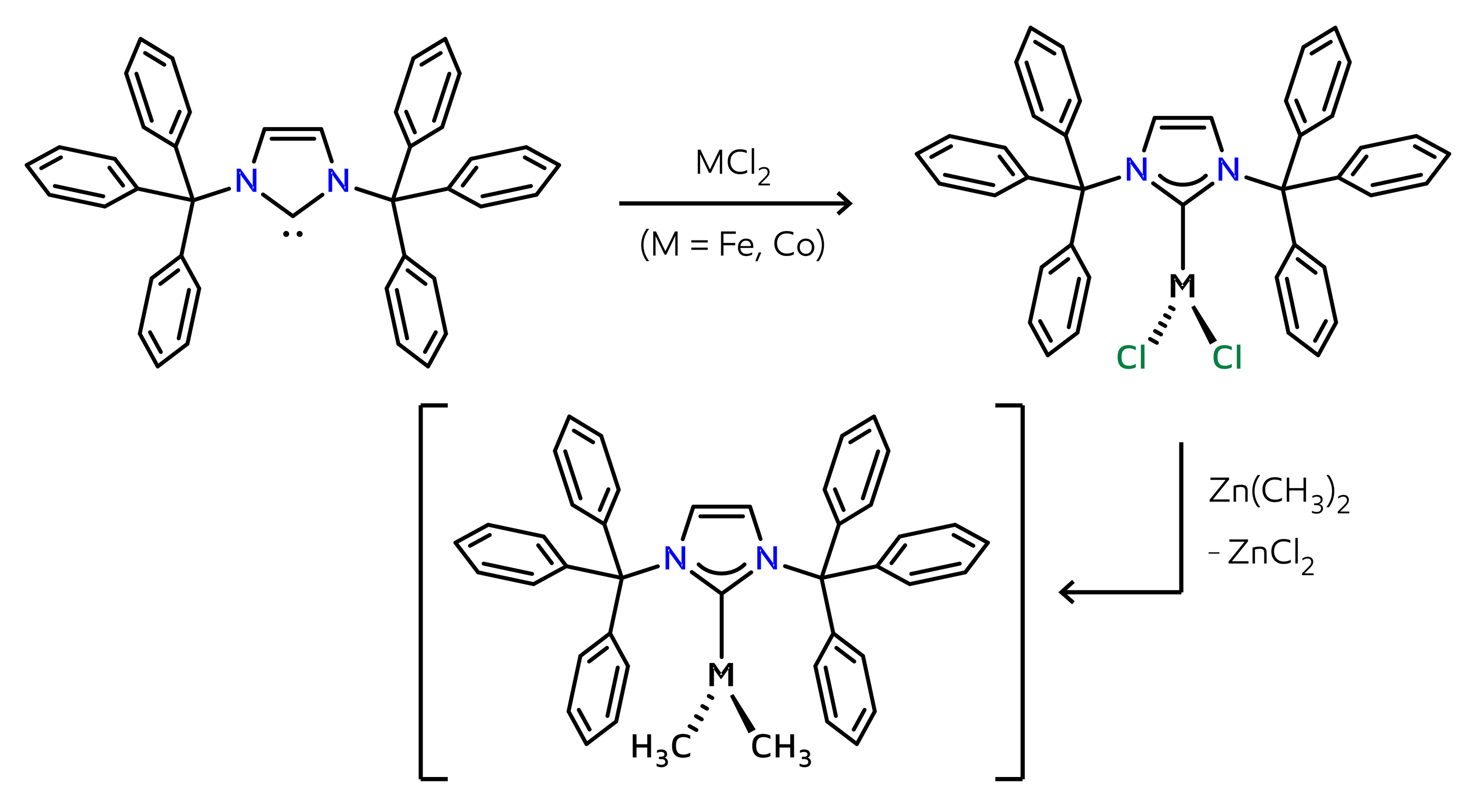
*email: arun.sridharan@exxonmobil.com

Notes and references: (1) *Chem. Rev.* **2015**, 115, 3170–3387. (2) *Chem. Rev.* **2010**, *110*, 1435–1462. (3) *J. Am. Chem. Soc.* **2016**, *138*, 7492–7495. (4) *Chem. Eur. J.* **2017**, *23*, 11249 – 11252. (5) *Dalton Trans.* **2013**, *42*, 7276–7280. (6) *Nat. Chem.* **2019**, *11*, 872–879. (7) ^{1}H NMR data obtained in CH_2Cl_2; * = residual THF and pentane; s = CH_2Cl_2 solvent. (8) Computations performed using Jaguar v12.3 (Schrodinger, Inc.) at the TPSSh-D4/def2-TZVP(-f) level of theory.

Late-transition metal–chloride (M–Cl) and –methyl (M–CH_3) complexes are common catalysts for C–C bond-forming reactions.[1,2] Without bulky supporting ligands, these species form clusters that can have reduced catalytic activity.

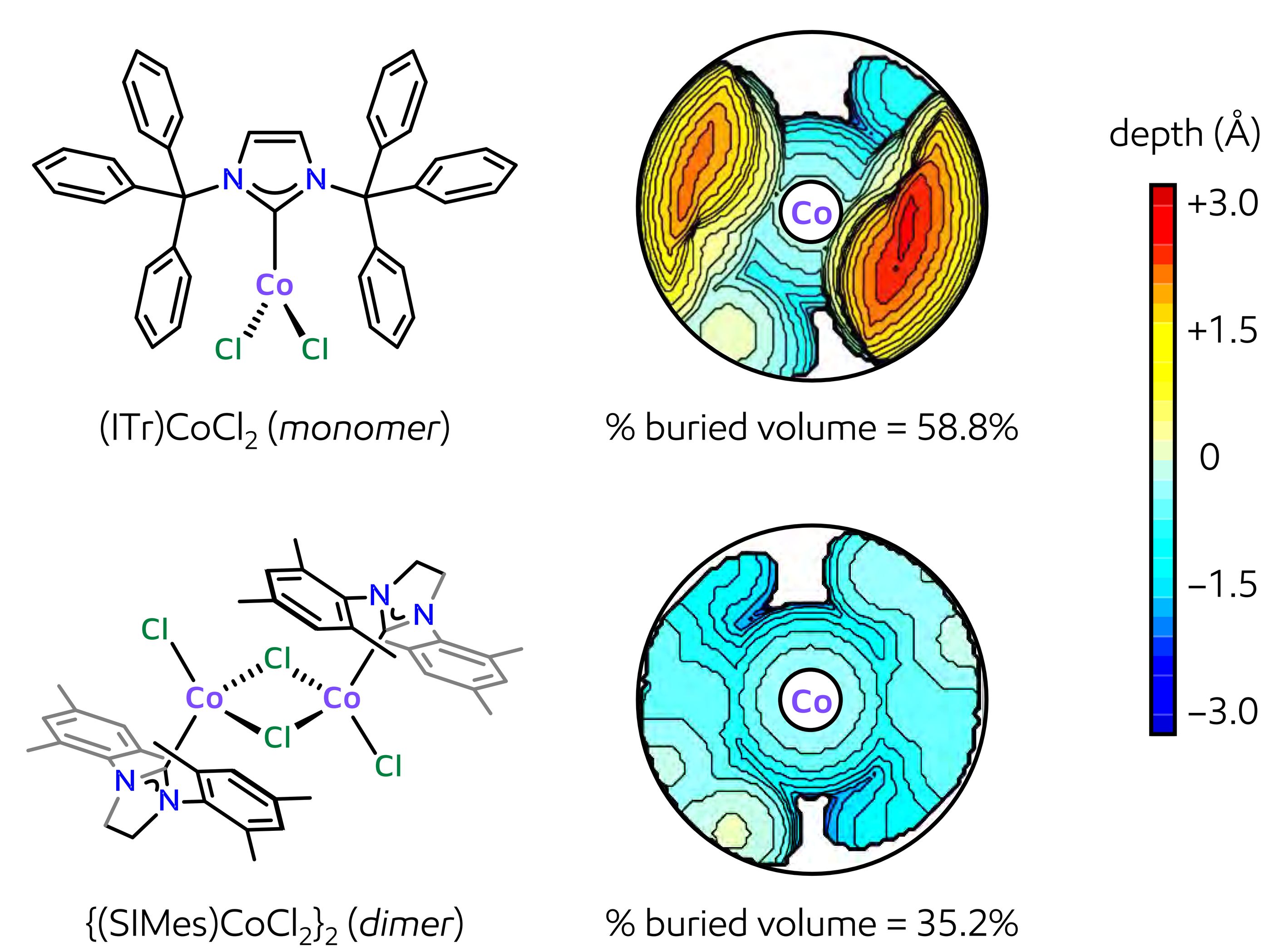


Reacting *N,N′*-bis(triphenylmethyl)imidazol-2-ylidene (ITr)[4] with $FeCl_2$ or $CoCl_2$ results in rare examples of three-coordinate M–Cl complexes that remain monomeric upon methylation.



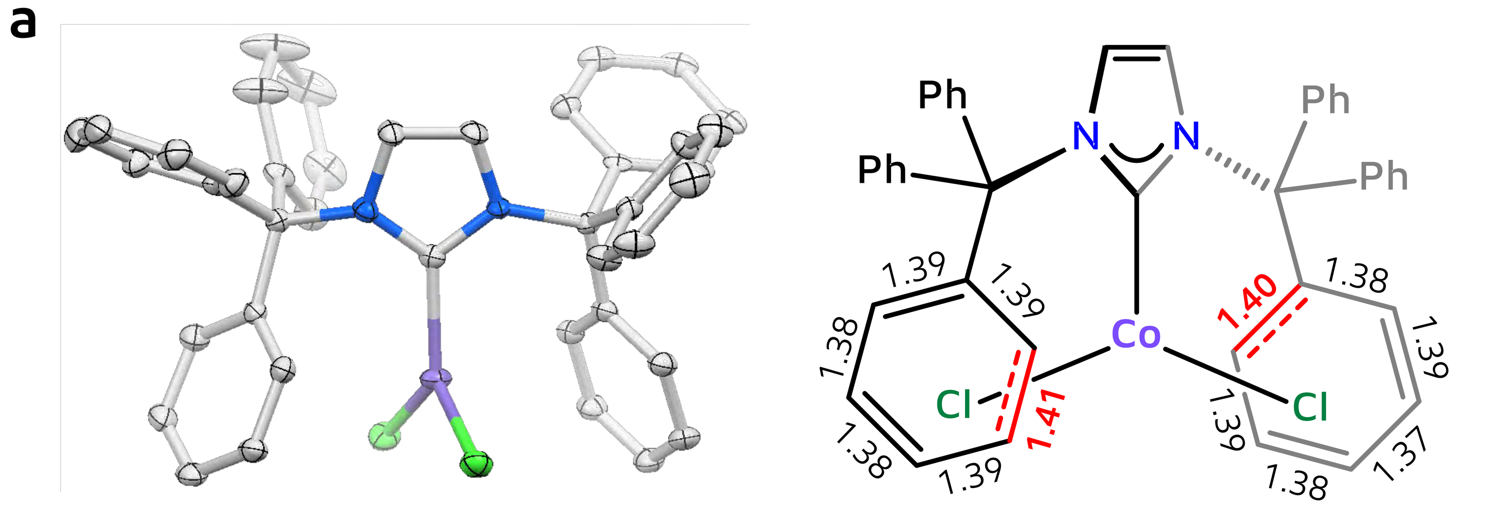
structure inferred from ^{1}H NMR spectroscopy

Topological steric maps of ITr and a related, smaller ligand (SIMes) illustrate ITr's extremely large size, which explains the differences in reactivity with MCl_2 salts (monomer *vs.* dimer).[4–6]



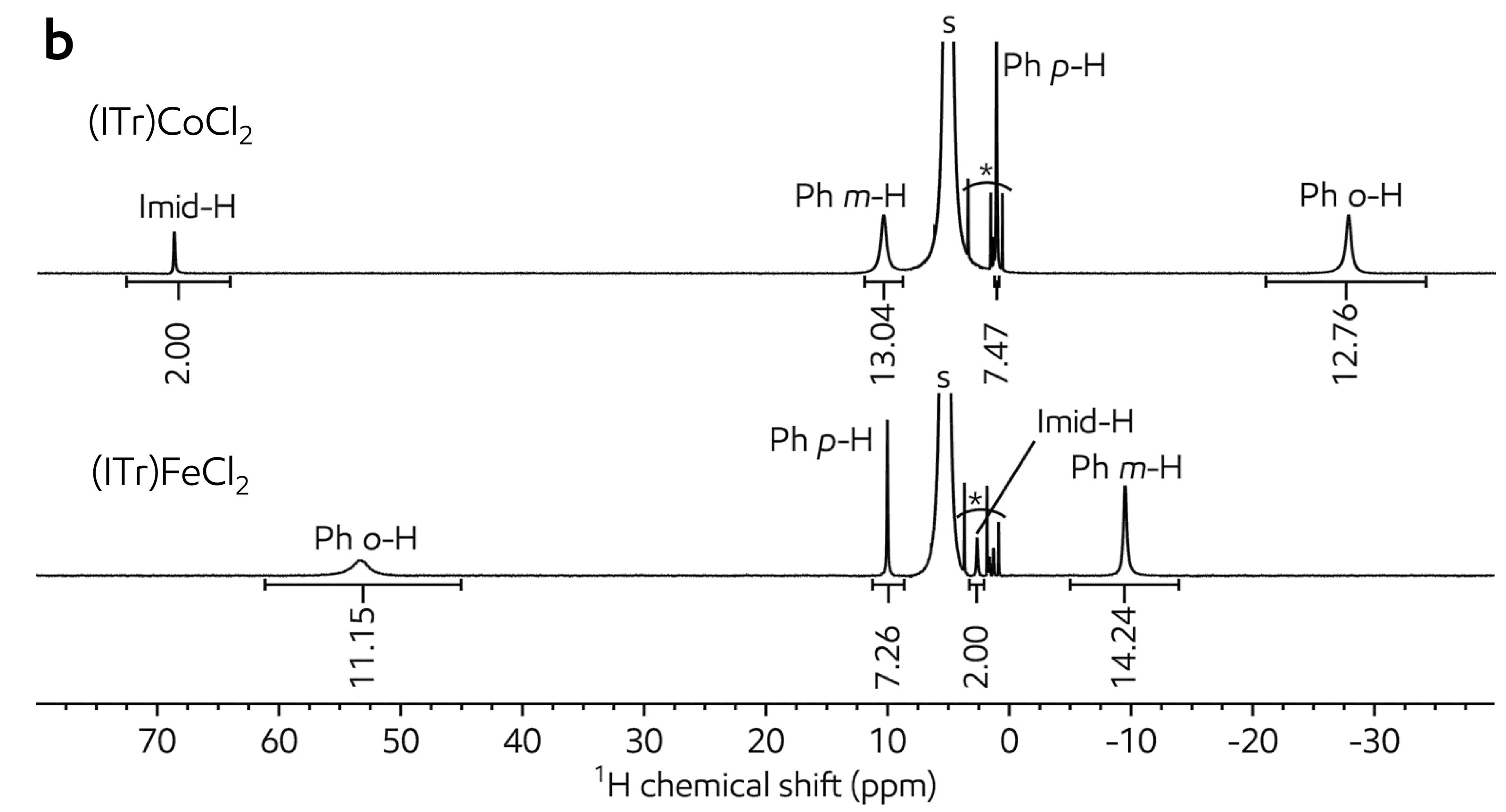
Structural, spectroscopic, and quantum chemical analysis of (ITr)$FeCl_2$ and (ITr)$CoCl_2$ indicate weak metal–phenyl interactions.

a



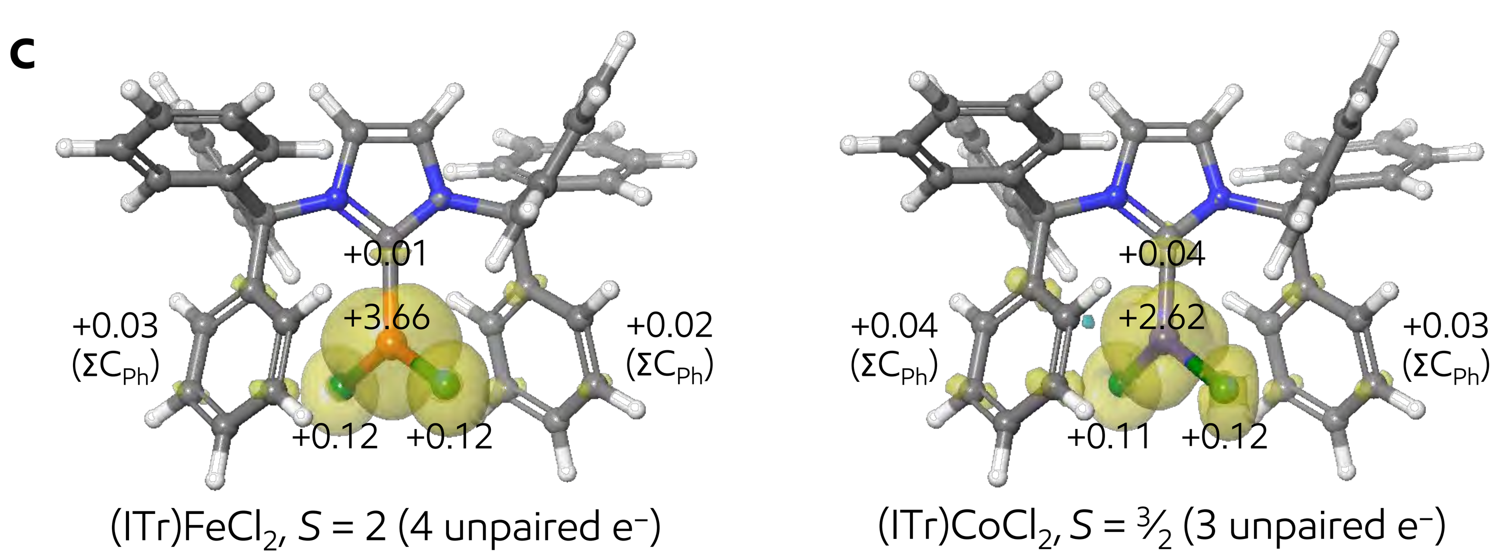
(*Left*) X-ray structure of (ITr)$CoCl_2$ with H-atoms omitted; (*Right*) C–C bond distances (in Å) of eclipsing Ph groups showing some distortion due to Co–Ph interactions

b



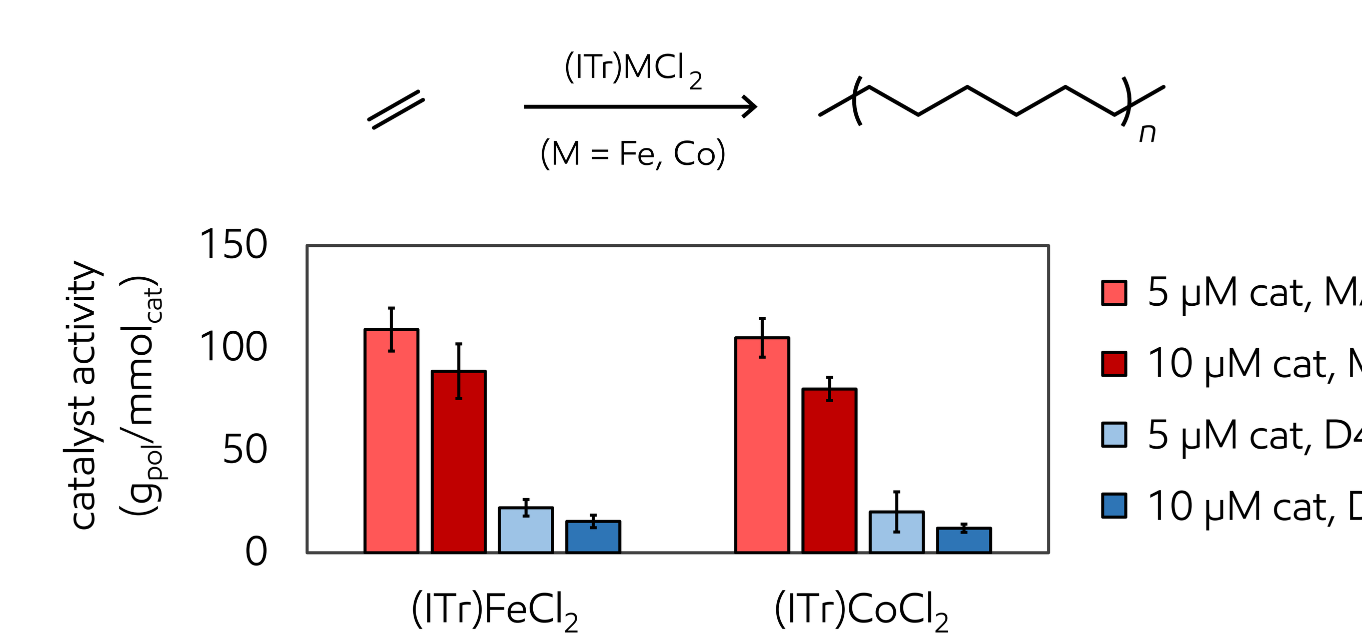
^{1}H NMR spectra of (ITr)MCl_2 complexes exhibiting full equivalence of Ph resonances (~12H:6H:12H integral ratio), indicating free N–C bond rotation in solution[7]

c



Spin density plots (0.0025 a.u.) and Mulliken spin populations of (ITr)MCl_2 complexes showing minimal spin delocalization onto eclipsing Ph groups[8]

Preliminary experiments demonstrate that (ITr)$FeCl_2$ and (ITr)$CoCl_2$ are competent catalysts for ethylene polymerization.†



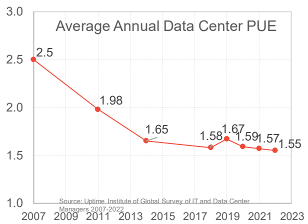
†100 psi ethylene, methylaluminoxane (MAO, 500 equiv) or D4 activator ([$PhMe_2NH$][$B(C_6F_5)_4$], 1.1 equiv) + Al^iBu_3 (5–10 equiv), 5 mL isohexane solvent, 100 °C, 30 min. Average of three replicates.

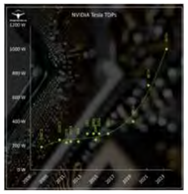
Two-Phase Immersion Cooling for Data Centers

Abigail Van Wassen,* Gustavo Pottker, Drew Brandt, Xue Sha

The Chemours Company, Thermal and Specialized Solutions
Chemours Discovery Hub – Newark, DE

Challenges of Air-Cooling in Data Centers

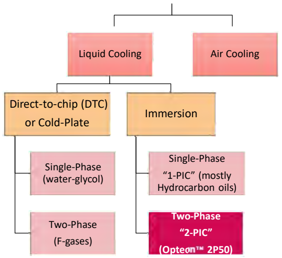




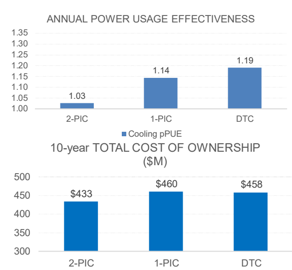
Source: R. Brink, "Igniting Change for the Future of DC Cooling." OCP Global Summit, 2023.

- Power utilization effectiveness (PUE) improvements have stalled
- Need for improved energy and water efficiency
- Next-gen chips with increased heat density for applications, such as high-performance computing or AI
- Air cooling requires oversized heat sinks, more airflow, lower supply temps and more U-space

Data Center Cooling Technologies



Virginia, US

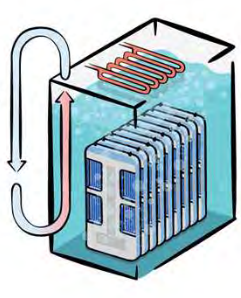


https://liquidstack.com/case-studies/unlock-the-future-of-data-center-cooling

Potential for significant energy savings with Two-Phase Immersion Cooling (2-PIC)

Benefits of Two-Phase Immersion Cooling (2-PIC)

- Relative to air cooling:
  - Significantly **improved energy/water efficiency, lower $CO_{2\text{-}eq}$ emissions** with low-GWP fluids
  - **Reduced footprint** due to higher power density
  - Longer IT hardware **lifetime**, improved reliability due to stable/lower temps
  - **No supplemental air-cooling** infrastructure
- Fluids with **no flash point** and **no flame limits**
- Capable of cooling **high power density chips**
- High potential for **heat reuse** and **fluid circularity**



Opteon™ 2P50 – New Developmental Fluid for 2-PIC

Opteon™ 2P50 Property	Units	Value
Normal Boiling Point	°C	49
Liquid Density	kg/m^3	1456
Liquid Viscosity	cP	0.62
Surface Tension	N/m	0.011
Heat of Vaporization	kJ/kg	108
Liquid Thermal Conductivity	W/mK	0.073
Liquid Specific Heat	kJ/kgK	1.09
Global Warming Potential (GWP)	N/A	10
Ozone Depletion Potential (ODP)	N/A	0
Auto-ignition temperature (IEC 62368)	°C	554
Flash Point (ASTM D93)	-	None

Fluid Stability – Short-Term and Long-Term

Short-Term

175°C for 1 week, Al, Cu, steel coupons, ASHRAE 97

Tube	Moisture (ppm)	Air Partial Pressure at filling (mmHg)	Fluoride (ppm)	Acidity (eq. ppm HCl)
1	0	0	< 0.2	12.6
2	0	481	< 0.2	12.3
3	145	0	< 0.2	10.4
4	145	481	< 0.2	4.6

- Accelerated aging
- Small amount of tarnish with high air content

Long-Term

50°C for 1 year, Al, Cu, steel coupons

- More realistic in-use conditions
- No discoloration or signs of degradation

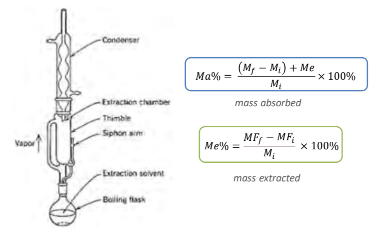
Fluid Stability Compared to Legacy Chemistry

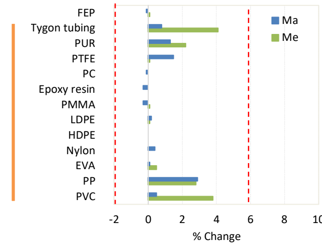
Fluid	Conditions			Results	
	Moisture (ppm)	Moisture (% of saturation limit)	Air (mmHg)	Fluoride (ppm)	Acidity (ppm eq HCl)
Opteon™ 2P50	0	0	0	< 0.2	< 0.12
	72	50%	240	< 0.2	< 0.12
	145	100%	240	< 0.2	< 0.12
	290	200%	240	< 0.2	< 0.12
Fluoroketone	0	0	0	45.8	212
	10	50%	240	42.0	342
	20	100%	240	40.2	367
	50	250%	240	113.0	1041

150°C for 1 week, Al, Cu, steel coupons with 1:1 mix of 100 ppm DOTP/TOTM

Compared to legacy technology, Opteon™ 2P50 has **better stability**

Material Compatibility

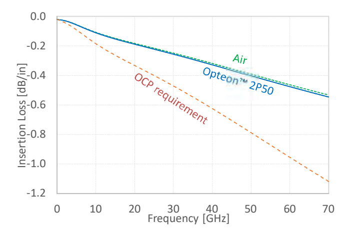




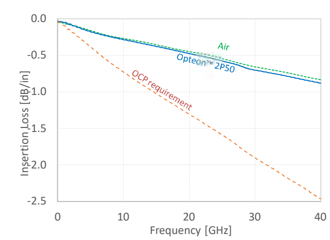
Common materials generally have **excellent compatibility** with Opteon™ 2P50

Signal Integrity Evaluations

100Ω Differential Cable



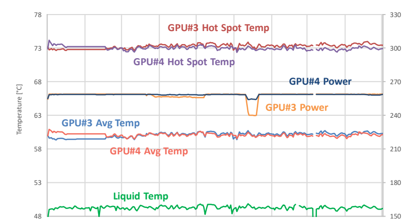
50Ω Microstrip Trace



Insertion loss analysis carried out in **CST Microwave Studio 3D** in a **1.0 meter long 100 Ω differential cable** and in a **12.7 cm / 5" long 50 Ω microstrip trace**

Nearly **no insertion loss impact** when air is replaced with Opteon™ 2P50

Ongoing Long-Term Testing with Opteon™ 2P50



- GPUs showed stable operation over ~9 months under maximum power:
  - GPU temperature variations within ~1°C
  - No IT hardware failures while filter and desiccant have not been changed.
- Several additional evaluations of Opteon™ 2P50 underway at Chemours and other third parties

Nanofiltration for Direct Lithium Extraction

Tirtha Chatterjee (R&D Project Leader), Jordi Bacardit, Denise Haukkala, Gang Wang, Jeffrey Wilbur (Presenter)

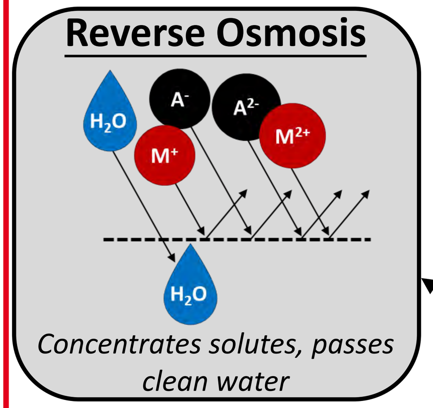
Challenge: Improve Lithium Recovery Process for Global Electrification

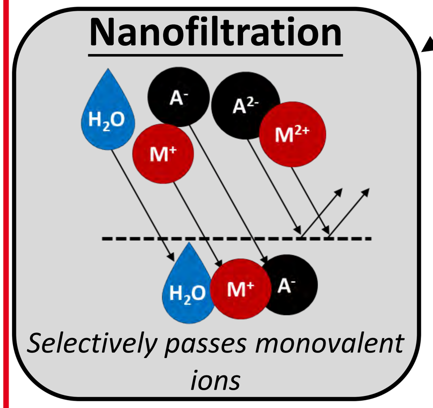
Sustainability needs and economic growth are driving global electrification and accelerating demand for purified lithium to support battery production. In the next 5 years, the Li market is expected to grow at a 10% CAGR, exceeding $9B based on production of 2.53 x 10^5 t by 2028 (BCC Research Report, 2024).

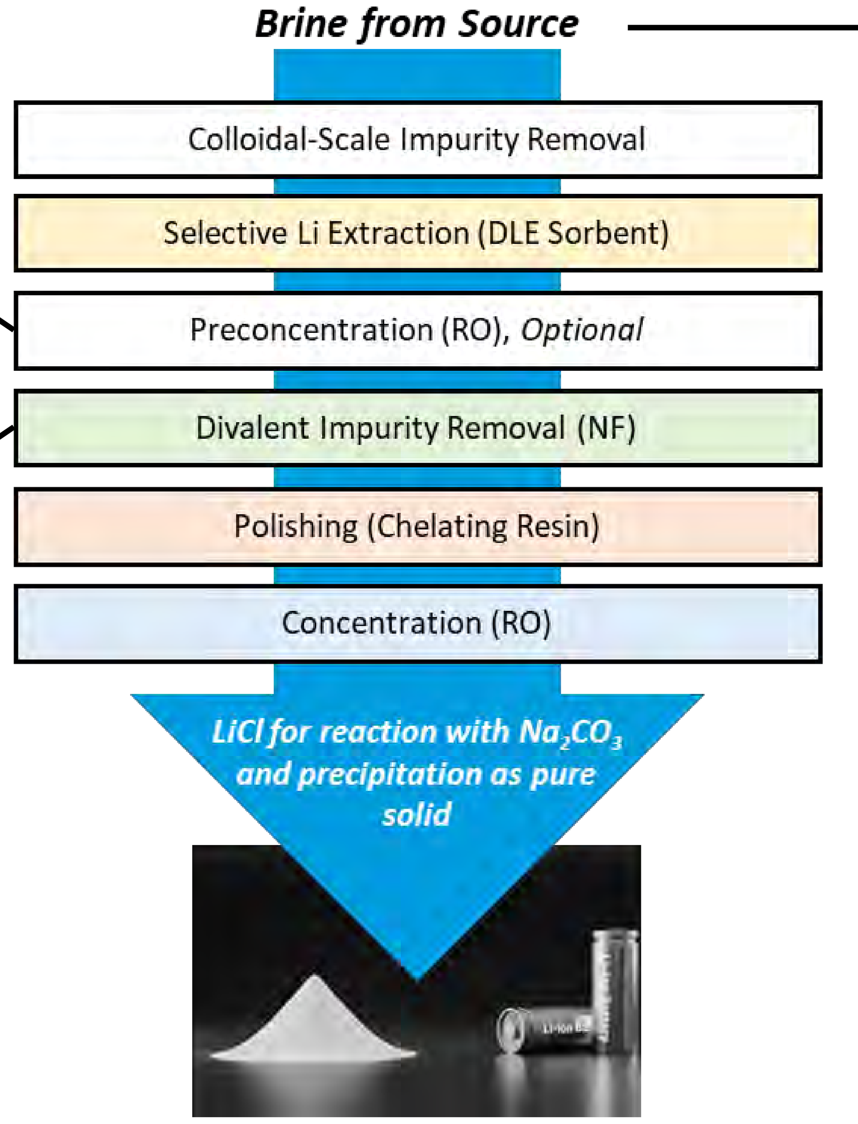
Legacy Li brine purification consists of chemical treatment followed by concentration in evaporation ponds, which is time, chemical, water, and footprint intensive, and only practical with highly concentrated sources like those found in dry salt lakes in South America. Costly, energy intensive thermal evaporation can accelerate the process and reuse water in these arid regions.

The increase in Li demand and politico-economic factors have created a need for a **faster Li purification process with minimal chemical, water, and footprint requirements to make lower purity (<300 mg/L) Li sources common in regions like North America viable**. **Direct Lithium Extraction (DLE)** is a novel approach combining selective Li extraction, typically using a sorbent, with purification, concentration, and water recovery provided by **reverse osmosis (RO)** and **nanofiltration (NF)** membranes to meet these objectives.

Approach: Sorbent, Resin, and RO/NF Membrane-Enabled DLE







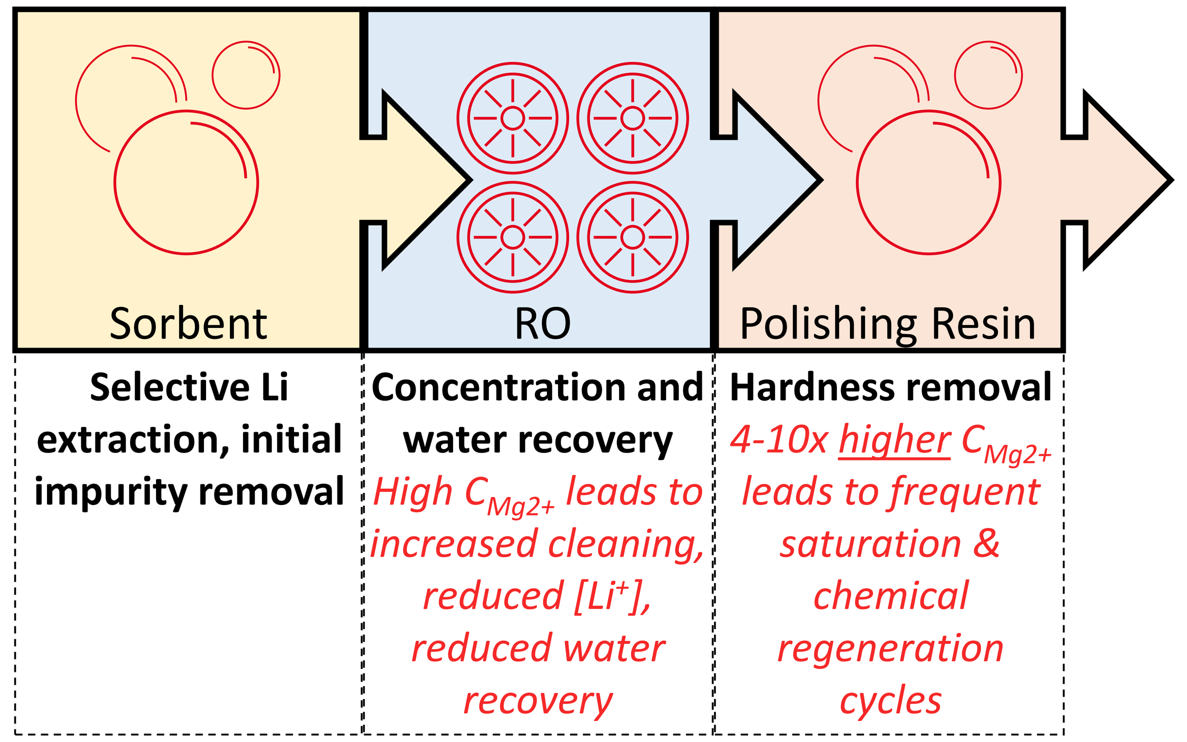
Example composition:
200 mg/L Li^+
1000 mg/L Mg^{2+}
25000 mg/L Na^+
mostly Cl^- anions

Maximize Li^+ recovery
Maximize Li^+ concentration
Maximize water recycle
Maximize throughput

Minimize impurities
Minimize operational costs

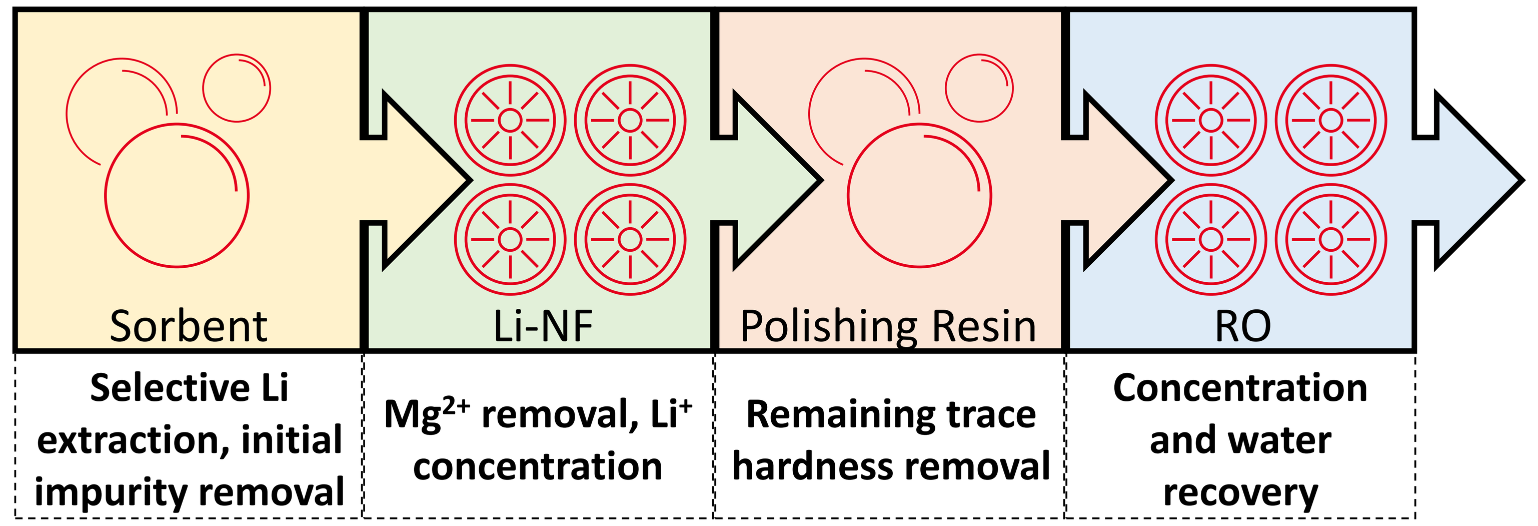
Solution: DLE with NF Maximizes Water Recycle/Throughput/Li Concentration, Minimizes Impurities & Operational Costs

Example DLE Process without Nanofiltration



↓ Water recovery
↑ Downtime
↓ Li^+ concentration
↑ Impurities
↑ Costs

Example DLE Process with Nanofiltration



↑ Water recovery
↓ Downtime
↑ Li^+ concentration
↓ Impurities
↓ Costs

Are there any downsides to NF in DLE?

Slight Li loss, almost invariably outweighed by the advantages NF provides

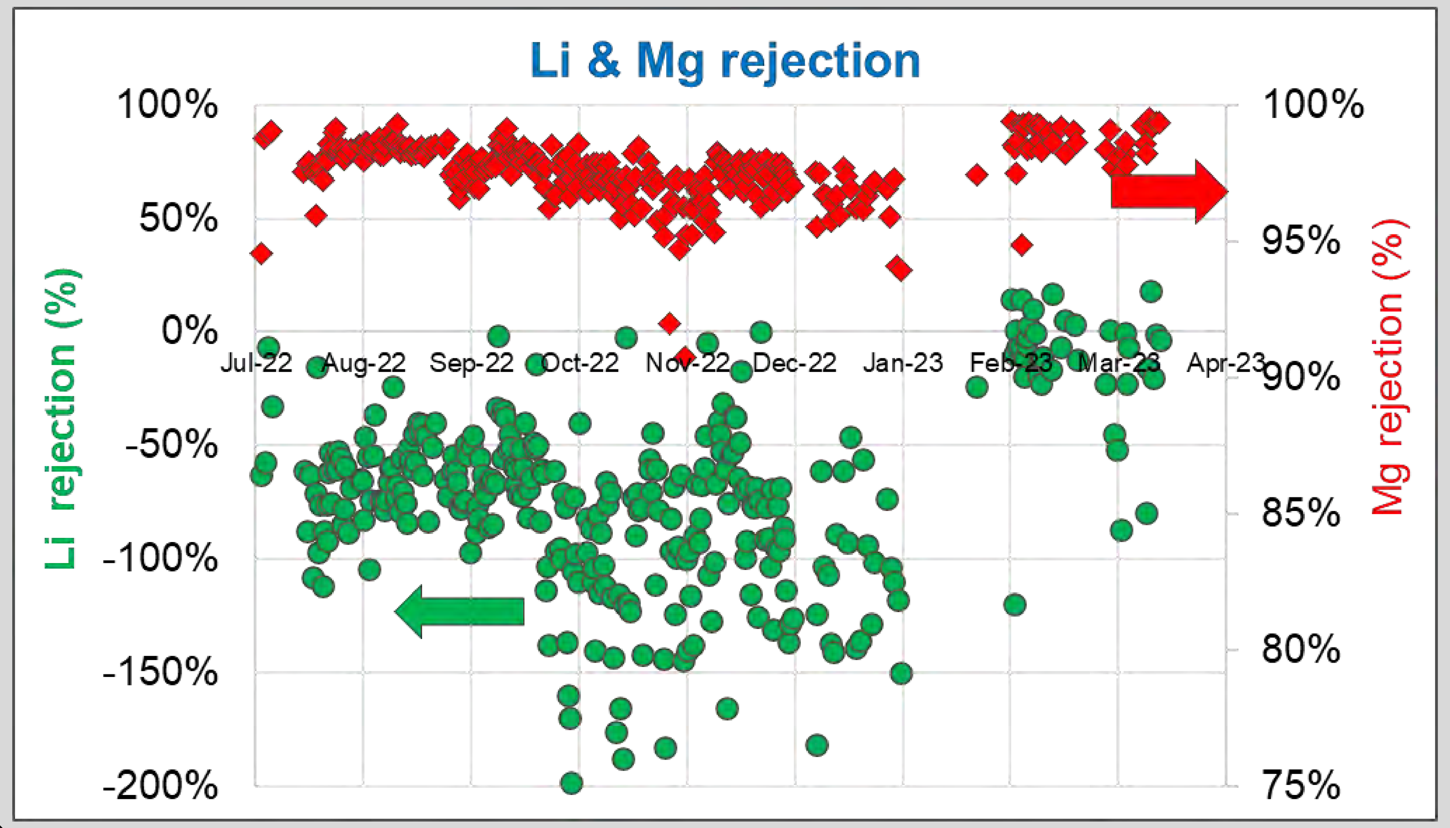
DuPont Water Solutions FilmTec™ DLE-Optimized NF

FilmTec™ LiNE-XD and LiNE-XD HP

- Lithium Nanofiltration Element – eXtra Durable (LiNE-XD)
- Class-leading Li^+ passage and H_2O permeability for Li^+ yield
- Class-leading durability for operation at pH 3-4, where selectivity is highest
- Class-leading membrane area in each element, reducing footprint
- High selectivity against multivalent cations

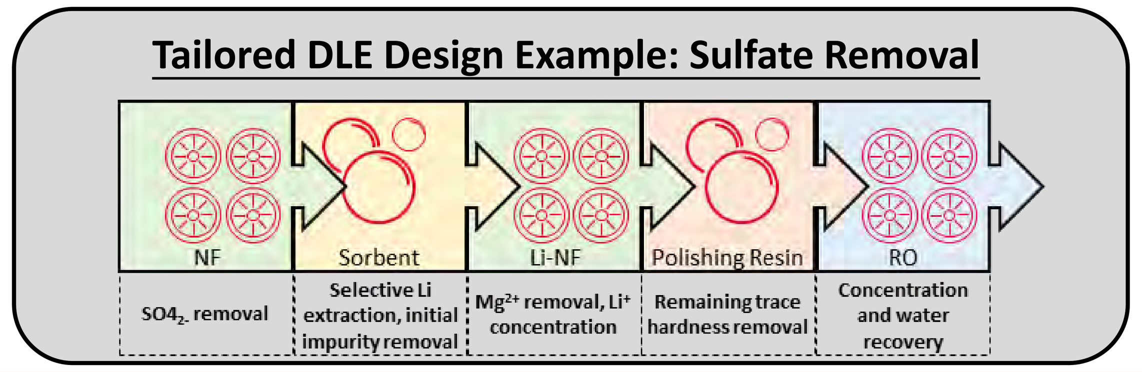
Example Pilot Data

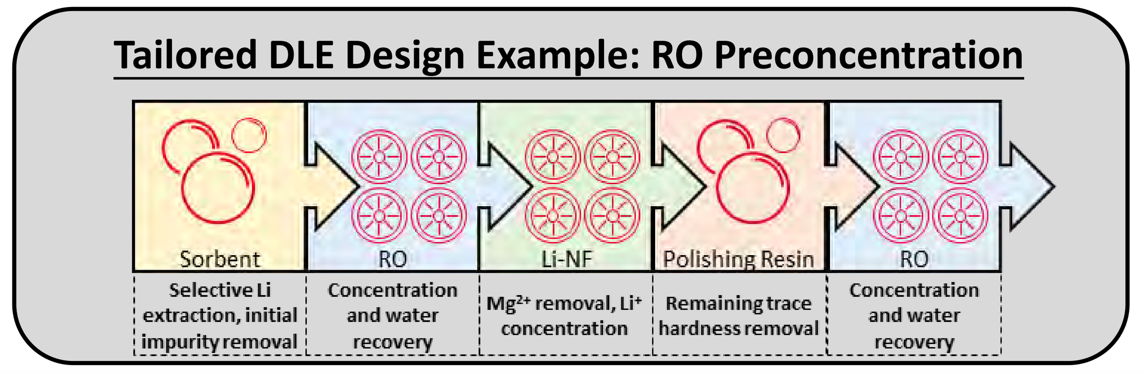
9 months of operation with 200 mg/L Li+, ~4500 mg/L Mg^{2+}, pH 3.5 feed shows >100% Li+ passage, >95% Mg++ rejection and no rejection loss over time!



Summary: NF Expands DLE Applicability to More Challenging Lithium Sources

Meeting global Li demand depends on scaling up DLE operations. Every brine source has a unique composition, requiring process and financial analysis to find the best purification scheme. NF is a powerful separation tool that improves DLE processes, but it requires both a tailored process and an NF membrane designed to provide the best separation properties for a specific DLE plant's brine source and process design. FilmTec™ LiNE-XD nanofiltration elements were designed around the needs common to most DLE processes: high Li passage, high Mg/Ca rejection, low energy requirements, and high durability at low pH.





EDISON AWARDS
FilmTec™ LiNE-XD 2024 Winner at The Edison Awards™

Enabling Sustainable Technology Deployment

Authors:
Susie Wu, Shyamal Saha, and Jesse Hellums

Affiliations:
Members of AFPM & SOCMA

Trecora:

Located in the heart of the Texas Gulf Coast industrial sector, near Houston and north of Beaumont.

Pasadena and Silsbee have the infrastructure to handle wide variety of chemicals via rail, truck, or nearby port.

We specialize in polymers and resins but have the versatility to provide many other custom manufacturing services.

Sustainability:

Growing Concerns

- Increasing reliance on fossil resources is unsustainable without mitigating environmental impact
- Transition to sustainable resources for polymer and specialty chemical production is inevitable

Sustainable Alternatives

- Polymers and specialty chemicals can be produced from renewable resources, such as:
  - **Dehydrogenation of bio-based alcohols**
  - **Recycled pyrolysis oil derived from post-consumer recycled plastic**
- These resources can be produced using conventional methods to create olefins

Trecora's Role

- Trecora is uniquely qualified to aid in the commercialization of sustainable processes
- Fundamental research is crucial in areas such as:
  - **Production**
  - **Modification**
  - **Property enhancement**
  - **New applications**
- Existing advances in exploiting renewable and sustainable resources for the production of:
  - **Specialty polymers**
  - **Specialy waxes**
  - **Specialty chemicals**

Capabilities

- Batch and continuous reactions
- Esterification
- Trans-esterification
- Dehydration
- Isomerization
- Oxidation
- Propoxylation
- Saponification
- Maleation
- Polymerization
- Hydrogenation
- Short path distillation
- Conventional distillation
- Pastilles
- Flakes
- Granules
- Filtration
- Crystalization

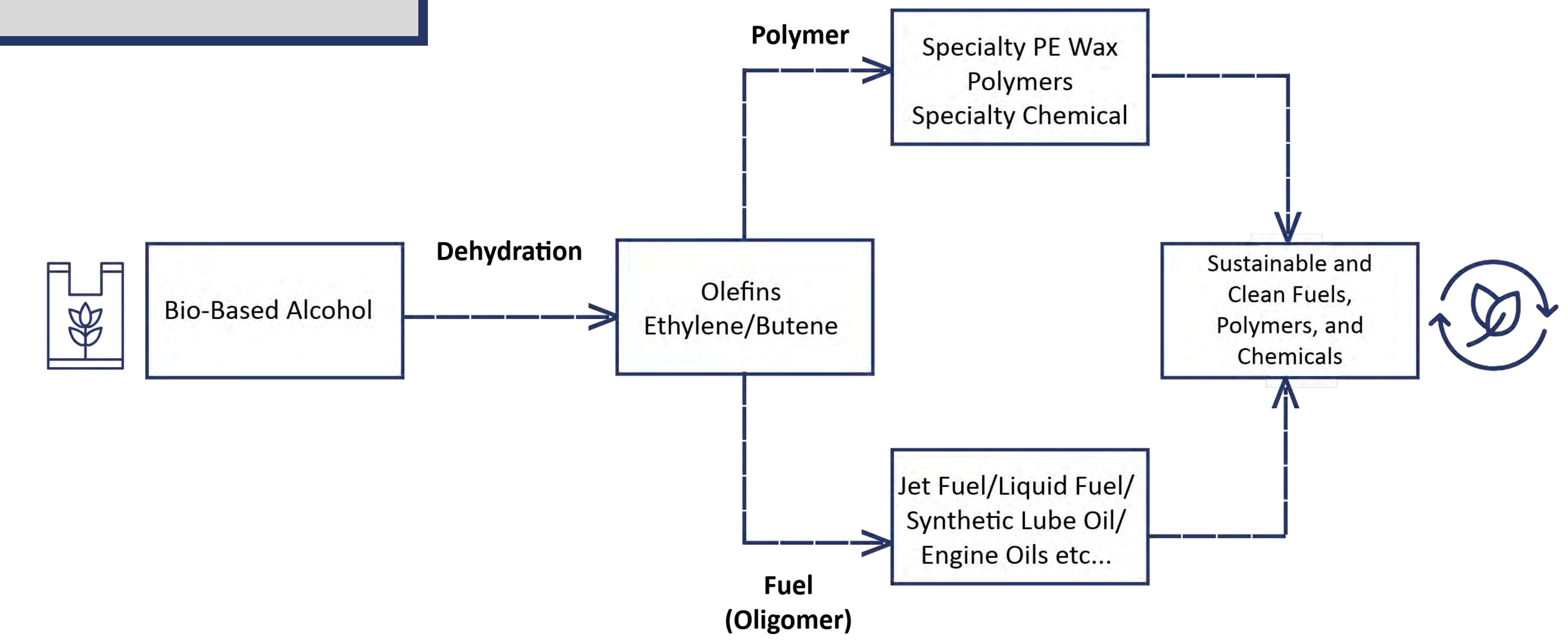
Methodology

Our project development stage gated process allows for a rapid transition between the ideation and commercial trial phases.

- Pre-ideation (conceptual)
- Ideation (capability confirmation)
- Definition (lab trial and pilot trial)
- Trial (commercial scale)
- Commercial production

Testament to our success is the fact that several customers have been with us for more than 20 years with Trecora being part of their supply chain.

TRECORA OFFERS COMPREHENSIVE SERVICES FROM LAB SCALE TO FINISHED PRODUCT TESTING, SUPPORTING A WIDE RANGE OF SUSTAINABLE TRANSITIONS THROUGH ITS UNIQUE CHEMISTRIES



TRECORA Sustainable Chemistries

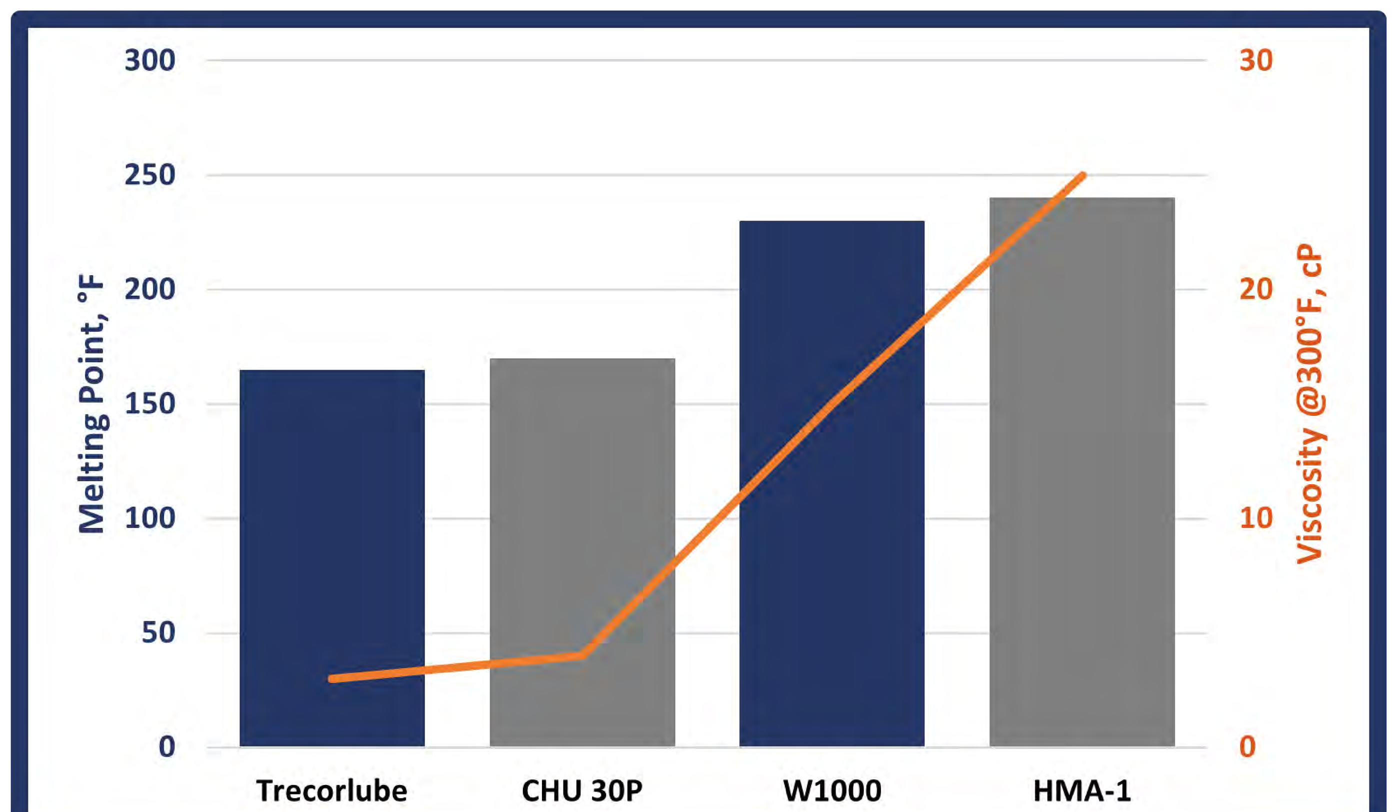
- Supported Anellotech in setting up the first demonstration plant for converting non-food biomass into renewable Benzene, Toluene, and Xylenes (Bio-TCat®)
- Supported Anellotech in its mixed plastic waste to BTX/light olefins development program (Plas-TCat®)
  - Our board of directors and plant operators played a crucial role in assisting Anellotech engineers for both programs
- Produces a commercial low carbon footprint wax for HMA and PVC applications from pre-consumer recycled material

Anellotech TCat-8 Demonstration Plant

Ratio of Products Produced with High Carbon Intensity vs. Low Carbon Intensity at Trecora's Pasadena Site

High Carbon Density

Typical Low Carbon Intensity Wax Product Properties

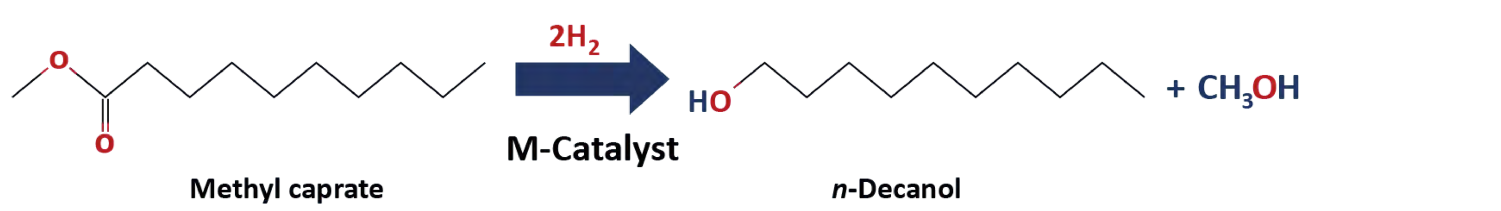


Fixed Bed Pilot Reactor

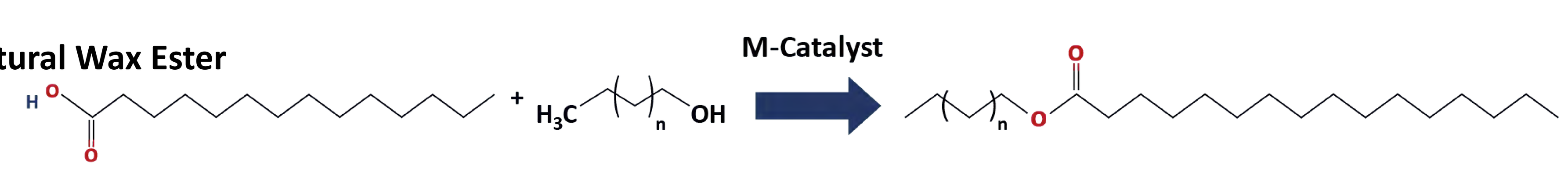
Batch Pilot

Renewable Conversion of natural feedstocks into:

- **Natural Alcohol**



- **Natural Wax Ester**



Concluding Remarks

Trecora is dedicated to providing our customers with superior quality performance and consistent value through advanced processing solutions. Our commitment to innovation and excellence is reflected in our ability to provide customized processing services for both commercialization and ongoing production.

Our expert team of engineers and chemists meticulously evaluates and executes each project, ensuring precision, speed, and success at every stage. At Trecora, we prioritize your success, delivering results that exceed expectations and set new standards for the industry.

Contact: David Altschul, Business Manager Specialty Products
Office: 847-826-8747 **Email:** david.altschul@trecora.com

TRECORA The Sustainable Wax Revolution — Made from Pre-Consumer Recycled Feedstock

This assessment evaluates the cradle-to-gate carbon footprint of waxes manufactured by Trecora. It considers factors such as raw materials, transportation, and product manufacturing, and adheres to ISO 14067:20181, ISO 140402, and ISO 140443 methodologies. The carbon footprint is quantified in kilograms of CO_2 equivalent per metric ton of product.

Goal of the Partial CFP Study: The goal of the partial CFP study is to assess the cradle-to-gate carbon footprint for polyethylene waxes, including raw material extraction and processing, upstream transportation and product manufacturing. This report is provided to aid in understanding the potential greenhouse gas impacts for the polyethylene wax product produced by Trecora using a 100-year time horizon and IPCC 2021 metrics, as specified by ISO 14067:2018.

Scope of Assessment: The scope of this product carbon footprint is "cradle-to-gate", including raw material extraction and processing, raw material transportation, and product manufacturing. Resource consumption, emissions and wastes, and their associated potential greenhouse gas emissions and removals, are calculated for the products manufactured at the Trecora facility.

Functions of Product System: Trecora polyethylene wax products are hard, high-melting point, low to medium viscosity materials derived from polyethylene resin manufacture. They can be used in various applications, including:

- **Performance Additives for Hot Melt Adhesives**: Enhancing rheological and adhesive properties
- **Modifiers for Paraffin and Microcrystalline Waxes:** Adjusting penetration and melting points
- **Lubrication and Processing Aids:** Improving processing for plastics, PVC, and rubber
- **Dry Stir-in Additives for Inks:** Enhancing ink properties

The declared unit used in the partial product carbon footprint study is one metric ton of polyethylene wax, which also serves as the reference flow for the product system.

System Boundary: The product system is a cradle-to-gate study, and includes five life cycle stages:

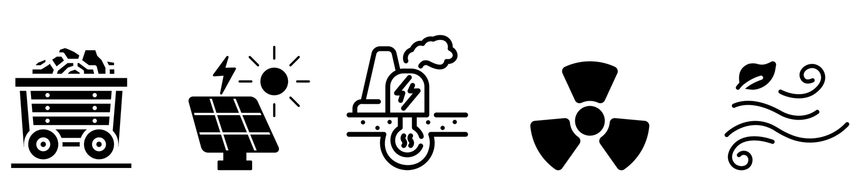
1. Raw Materials and Processing (Sourcing/Extraction) Stage
2. Packaging Materials
3. Transportation of Raw Materials to Manufacturing
4. Transportation of Packaging to Manufacturing
5. Product Manufacture Stage

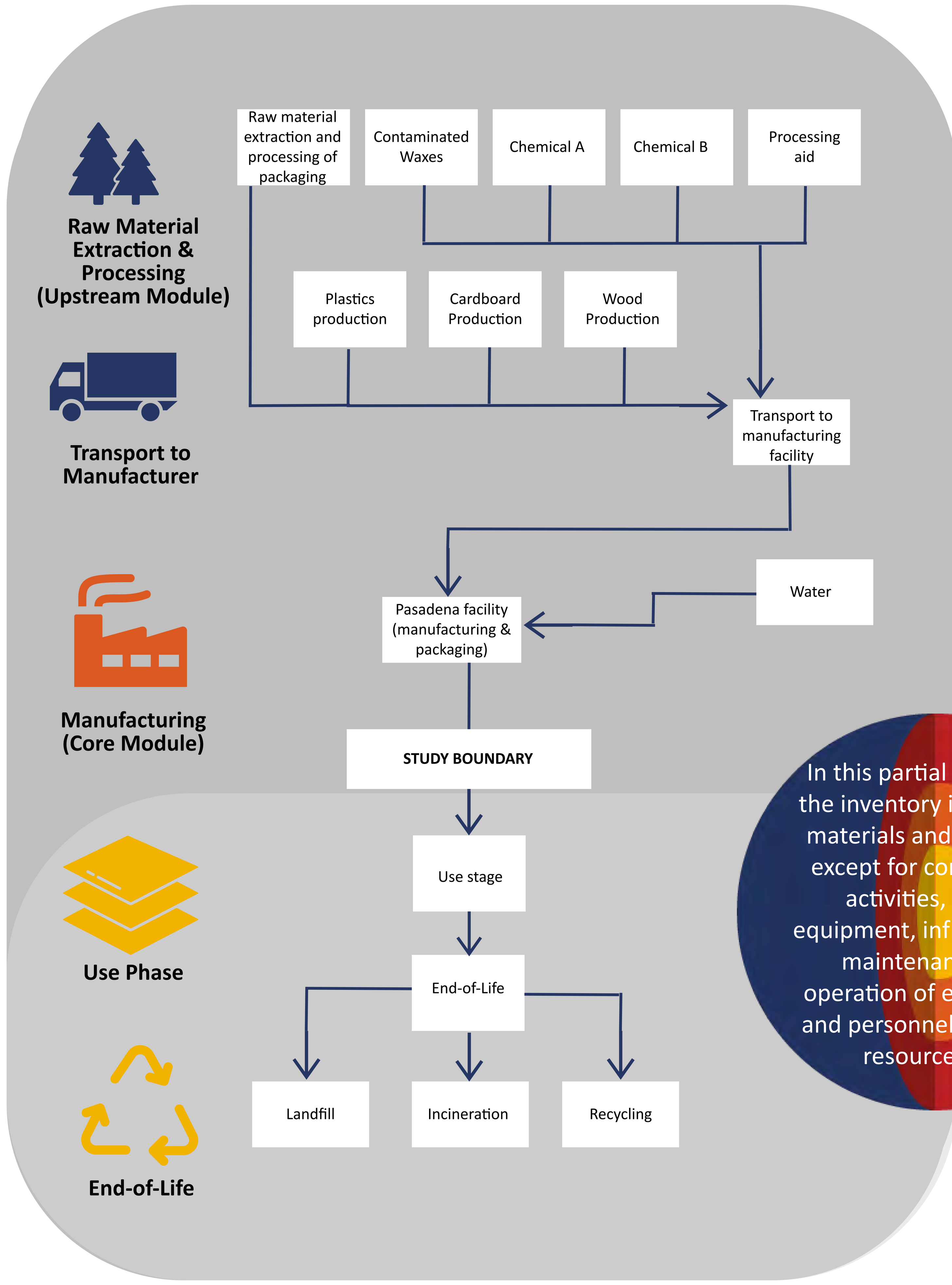
Product Composition:

Primary Materials:
- Pre-consumer recycled feedstock from various suppliers
- Chemicals
- Processing aids
- Water

Packaging Materials:
- Wooden pallets
- Plastics
- Corrugated cardboard

Feedstocks:
- Considered carbon-burden free
- Generated as byproducts of polyethylene production





In this partial CFP study, the inventory included all materials and processes except for construction activities, capital equipment, infrastructure, maintenance and operation of equipment, and personnel travel and resource use.

Trecora's Pasadena, Texas production facility is located in the ECRT eGrid EPA subregion. The Ecoinvent inventory dataset for the corresponding region TRE was modified to reflect the eGRID10 subregion energy mixes to estimate greenhouse gas emissions from electricity use at the facility. A breakdown of the ECRT electricity subregion based on fuel type is shown below.

- Coal – 17.7%
- Oil - 0.1%
- Gas - 46.5%
- Nuclear – 9.5%
- Hydropower – 0.2%
- Biomass – 0.2%
- Wind – 21.8%
- Solar – 3.5%
- Geothermal - 0.0%
- Other fossil - 0.4%
- Unknown - 0.1%

Trecora provided primary data for the production facility operations based on representative 2022 production data (EL v3.91). The source of secondary LCI data is the Ecoinvent databases11.

Much of the upstream raw materials extraction and processing could not be modeled with actual process information. Representative data from the Ecoinvent LCI databases were utilized.

Table 1. Biogenic carbon content (kg C) for the packaging containing wood or wood-based materials

Our products carbon score distinguishes between biogenic and non-biogenic carbon. Biogenic carbon comes from renewable biomass, like recent trees, while non-biogenic carbon comes from fossil sources, such as coal and oil. The impact of each type on our carbon score varies, reflecting their different sustainability profiles.

Product	Biogenic Carbon Content (kg C/ MT)
Polyethylene Wax	0
Packaging	**Biogenic Carbon Content (kg C/MT)**
Wooden Pallets	8.17
Corrugated Cardboard	0.415

Table 2. Cradle-to-gate carbon footprint results (kg CO2e) for the polyethylene waxes per metric ton of product

	Carbon Footprint Total (kg CO_2-eq)					
	Upstream Materials	Upstream Packaging	Upstream Transport- Materials	Upstream Transport - Packaging	Core	Total
Climate Change - Fossil Emissions & Removals	8.09	17.4	30.3	0.545	456	**512**
	2%	3%	6%	0%	89%	100%
Climate Change - Biogenic Emissions & Removals	$1.56x10^{-2}$	0.164	$7.98x10^{-3}$	$1.40x10^{-4}$	5.41	**5.6**
	0%	3%	0%	0%	97%	100%
Climate Change - dLUC Emissions & Removals	$2.87x10^{-2}$	$4.04x10^{-2}$	$1.58x10^{-4}$	$2.80x10^{-4}$	$4.58x10^{-4}$	0.131
	22%	31%	12%	0%	35%	100%
Climate Change - Aircraft Emissions	0	0	0	0	0	0
	-	-	-	-	-	-
Climate Change (Total)	8.13	17.6	30.4	0.546	461	**518**
	2%	3%	6%	0%	89%	100%

Future Actions:

1. **Energy Use:** Improve energy use monitoring for more accurate reporting.
2. **Core Impacts:** Focus on reducing natural gas consumption during processing.
3. **Data Gathering:** Find primary data for raw materials to improve reporting accuracy.

Limitations:

- This report only addresses climate change (ISO 14067:2018) and does not cover other environmental, health, or social issues.
- Calculations use the IPCC 2021 GWP-100 metric, which may not fully capture short-term climate impacts and excludes some short-lived climate forcers.
- The report excludes impacts such as acidification, eutrophication, and ecosystem effects. Methodology limitations include data variability and assumptions that may affect accuracy.

Contact: Gabriel Garcia, Specialty Polymers Account Manager
Office: 281-294-2025 **Email:** gabriel.garcia@trecora.com

Presenters:
Susie Wu, Shyamal Saha, and Jesse Hellums

Affiliations:
Members of AFPM and SOCMA

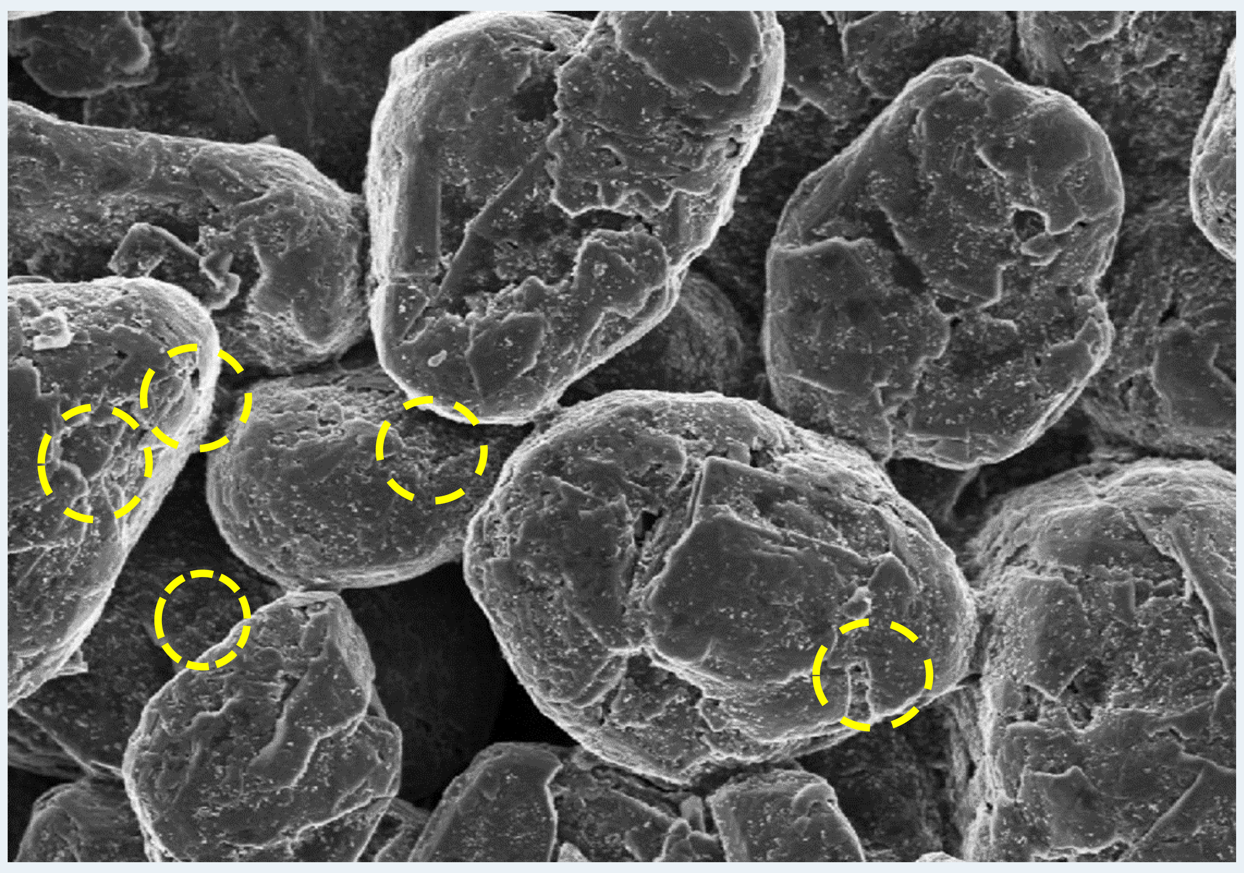
High Performance Anode Binder

Hunter Ye, Ramin Amin-Sanayei, and Wenjun Wu

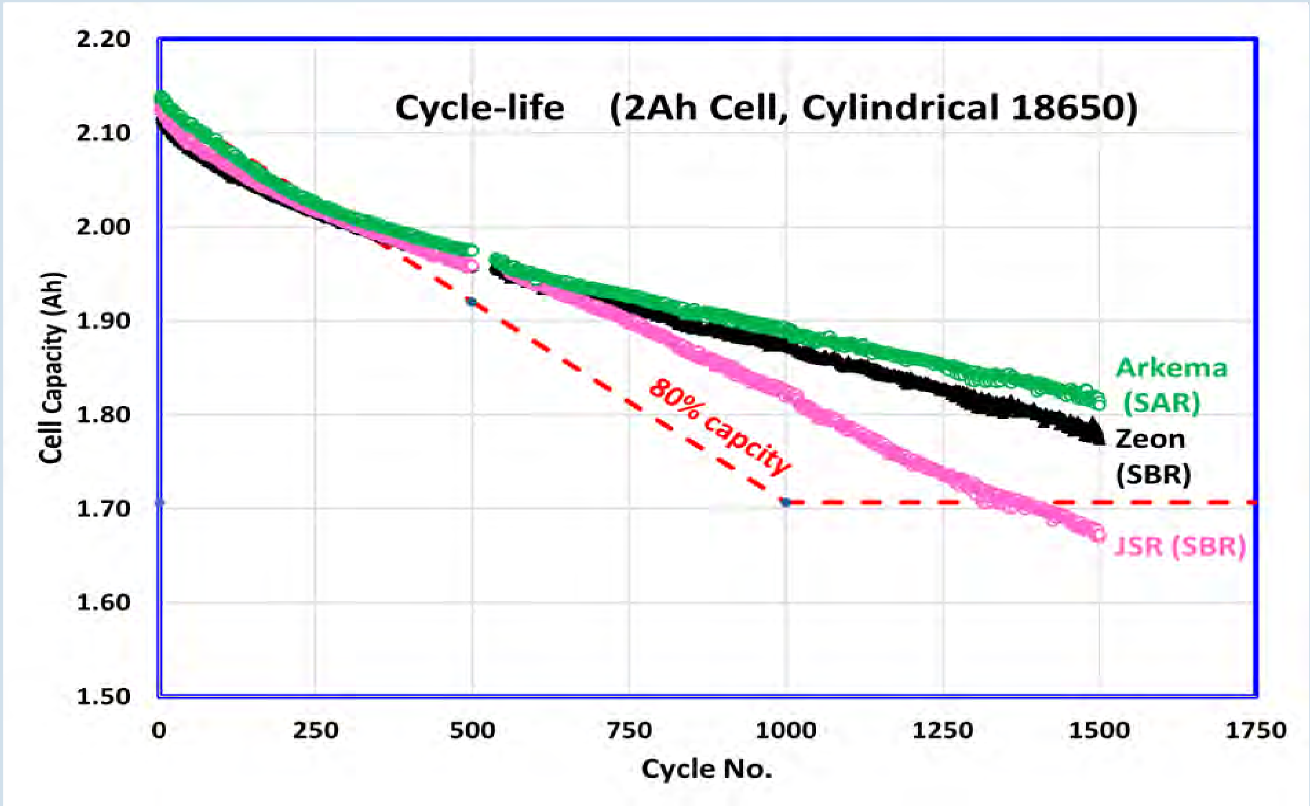
ARKEMA

New anode binder design criteria:

- High interconnectivity in anode at binder loading < 2%
- High adhesion to minimize binder usage
  - → Unique functionalities on the backbone
- Balance of swelling: high ionic conductivity
  - → Eliminating butadiene comonomer
- High C-rate capability, superb longevity
- Low impedance through z-direction
  - → Excellent binder & carbon coverage, percolated conductive matrix



High Energy 2-Ah Cylindrical Cells at 0.5 C



- Excellent cyclability in high energy density with minimal binder → High flexibility for processing and assembly

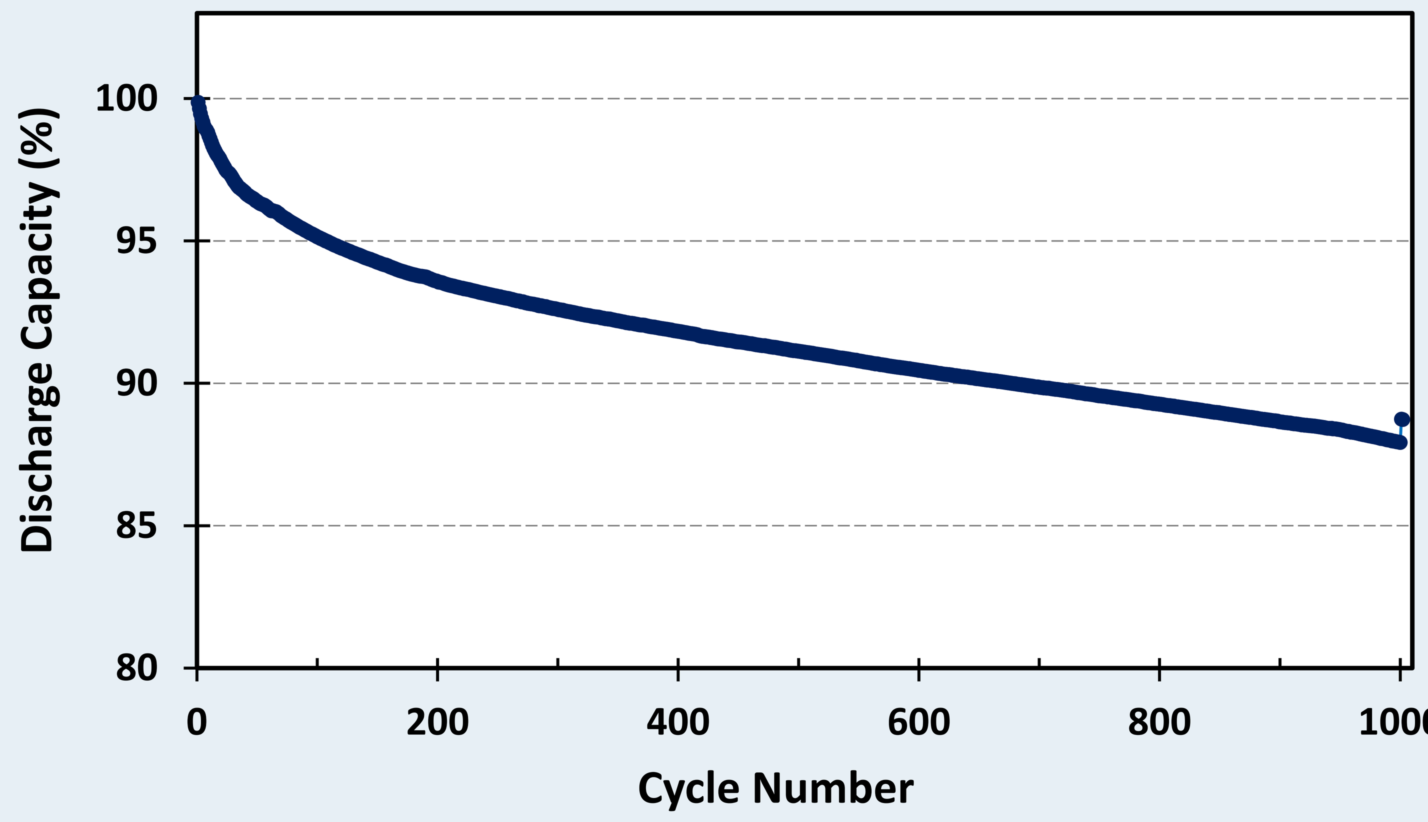
High Energy Density Anode: 97% Graphite

→ Minimal binder usage

- Outstanding results for:
  - → First Cycle Efficiency (FCE)
  - → Rate Capabilities
  - → Cycle life

Binder	Mass loading (mg/cm²)	Vol. Resistivity (Ω*cm)	1st Cycle Efficiency	2C/0.2C Ratio
Incellion El 1061	10.98	20.2	93.1 %	96.6

Longevity in 2-Ah Pouch Cells at 1 C

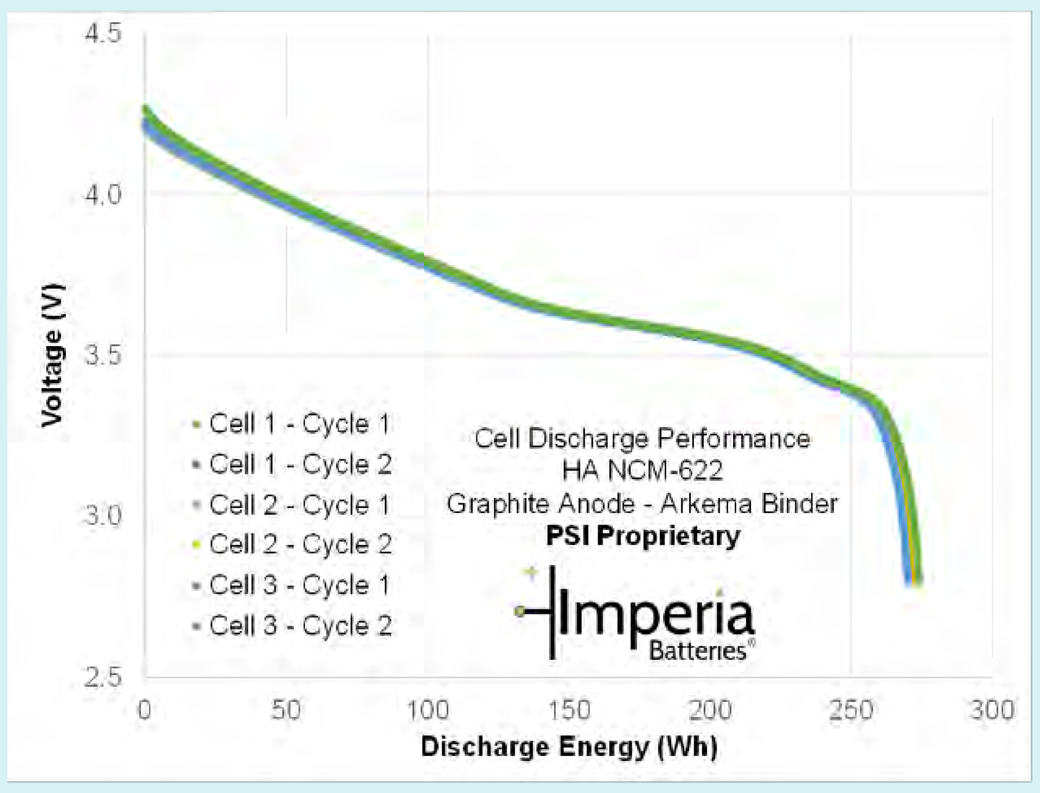


- >> 85% capacity retention over 1000 cycles
- Extended longevity in both pouch and cylindrical cells

High Loading:

- Anode: >5-8 mA/cm²
- Active material > 95%
- Low porosity ~20%
- Large cell ~ 75 Ah

275 Wh pouch cell at 0.2 C



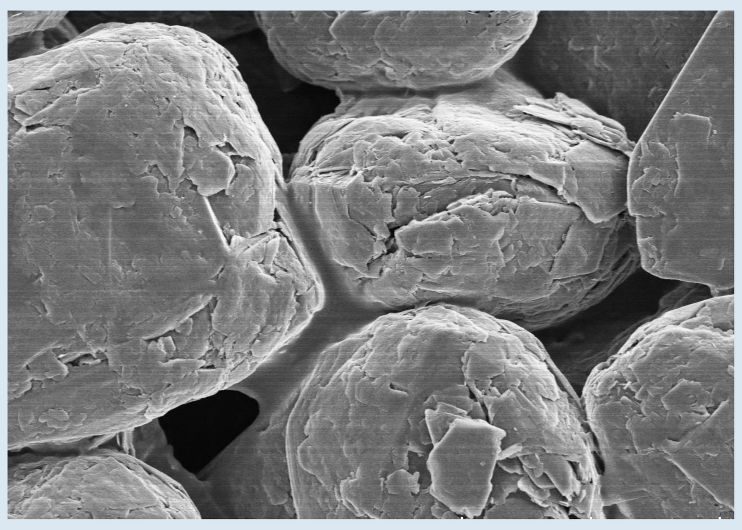
Acknowledgement to collaboration with PSI, ALE, and SCM on cell testing

Advantages of **Incellion El 1061**:

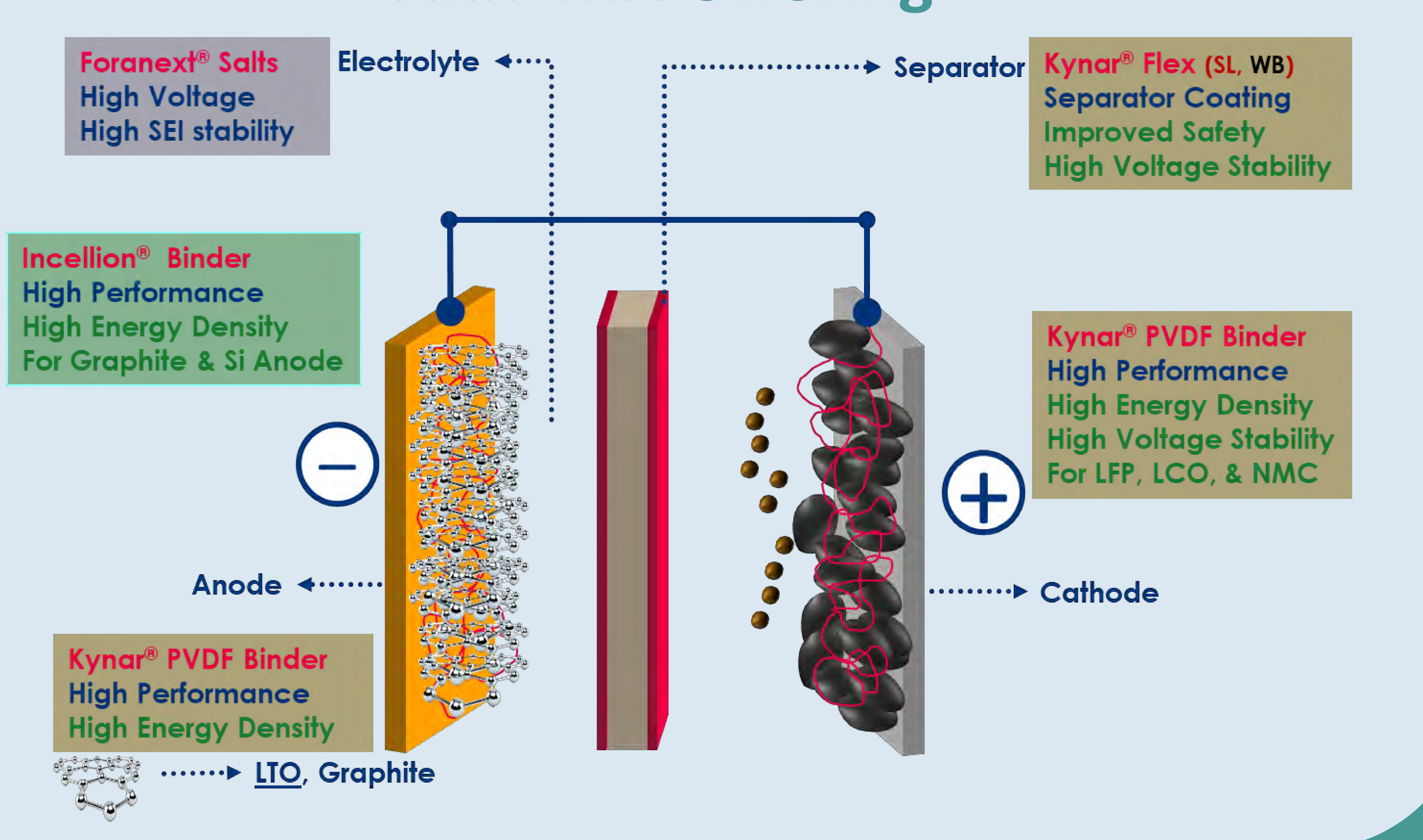
- High slurry stability
- Superb longevity in anode
- Balance of swelling and ionic conductivity
- High loading > 5 mAh/cm² at high active materials
- High energy density anode with >97% graphite loading
- Drop-in replacement for SBR

INCELLION™ El 1061

	Typical Value
Total Solids, (%)	40
pH	6.5
Viscosity, (mPa.s)	30



ARKEMA Offering

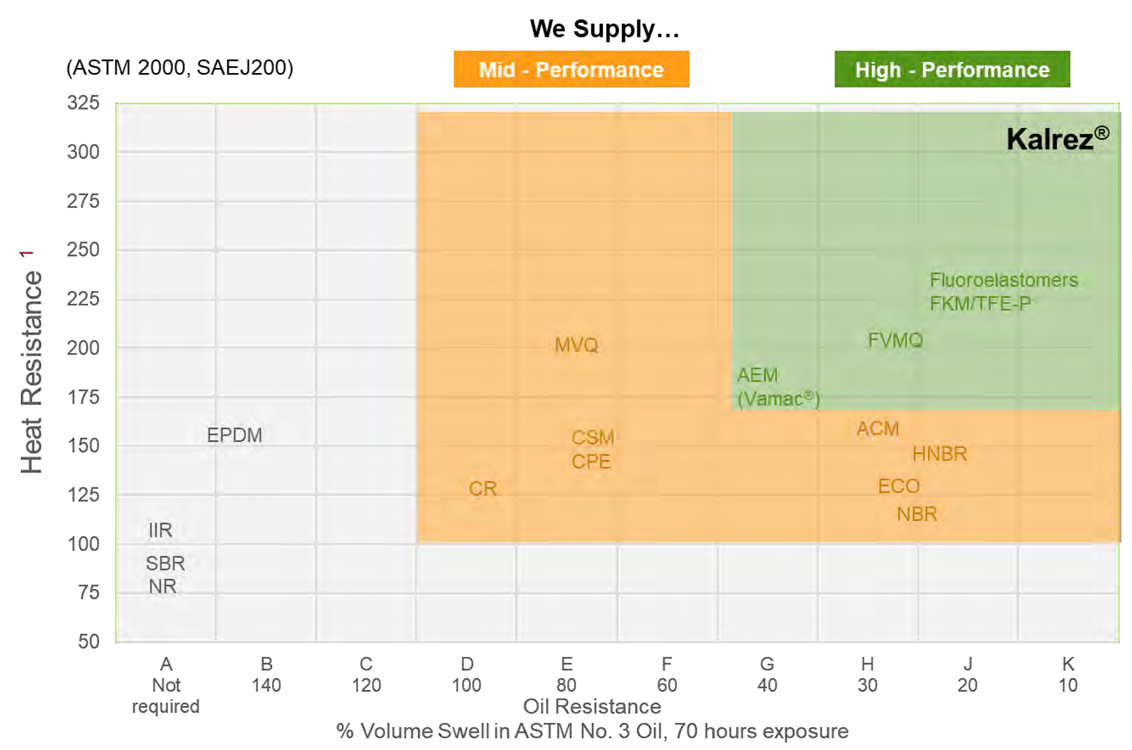


DuPont™ Kalrez® Perfluoroelastomer Parts - Improving Circularity in Specialty Sealing

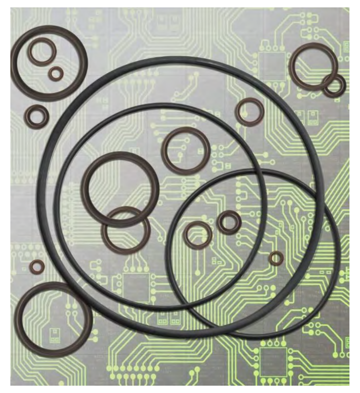
Hannah Zeitler

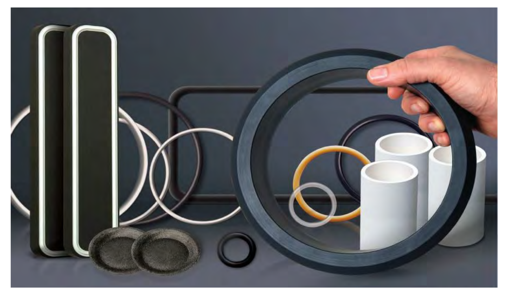
Kalrez® parts

Kalrez® perfluoroelastomer parts deliver superior sealing in extreme environments, and the portfolio is specially developed for use under harsh conditions in applications ranging from chip manufacturing and chemical processing to oil and gas, renewable energy, and aerospace.



To best serve our customers, our seals can be made in a variety of geometries and shapes ranging from traditional O-rings to valve seats to gaskets to diaphragms and many more.





Sustainability

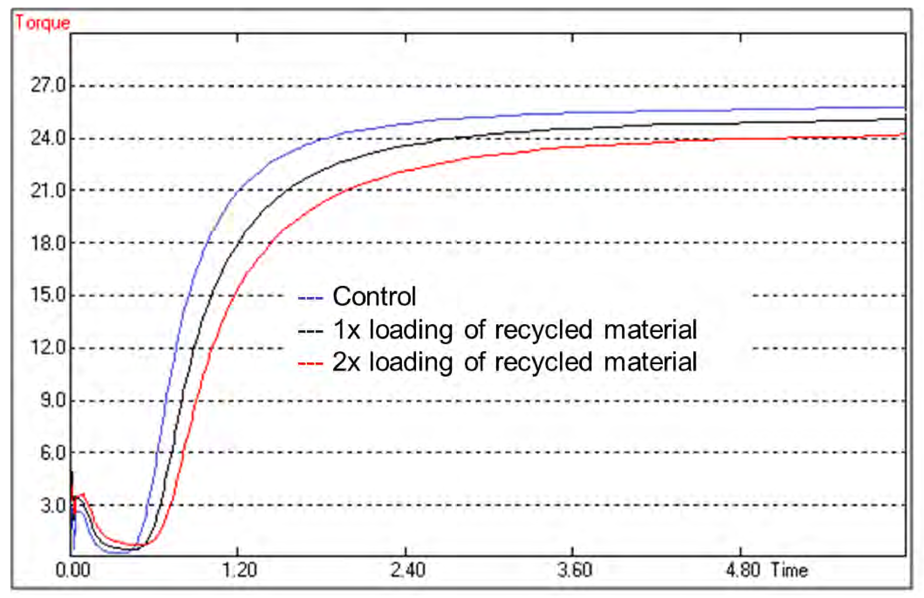
Kalrez® parts offer customers many sustainability benefits:

1. Reduced leaks and emissions – excellent sealing properties
2. Durability and long lifespan – excellent resistance to chemicals and high temperatures leading to reduced replacements
3. Reduced energy consumption – improved efficiency in applications such as pumps and valves
4. Reduced waste – extended lifetime and sealing capabilities can help reduce unnecessary scrap material

DuPont aims to improve sustainability by integrating circular economy principles into our business models and by considering life cycle impacts on the industries we serve.

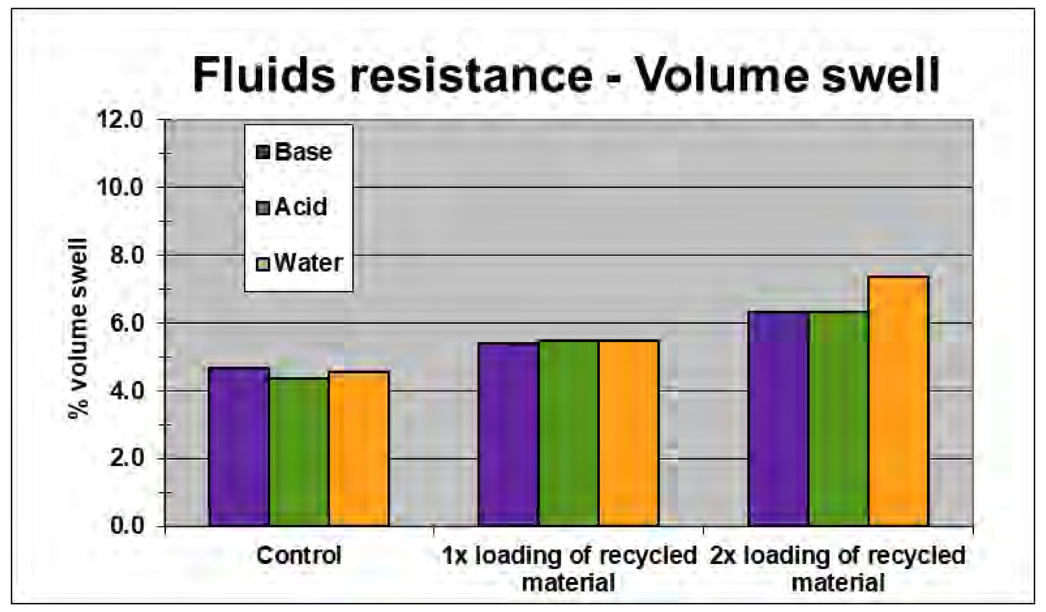
Recycling Kalrez® parts

We aim to cleanly and consistently break down the Kalrez® parts to a small particle size which will be fully characterized. The material can then be reincorporated to make new parts with the objective of minimal to no impact on the processing and physical properties. Results from an initial study are shown below.



The Moving Die Rheometer (MDR) measures an increase in torque as the polymer cures. As the curing process proceeds, the polymer becomes more crosslinked, resulting in improved rubber properties.

Volume swell is a measure of how much the parts swell after being aged in a liquid at elevated temperature. For many applications, it is important to understand the change under basic, acidic and aqueous conditions.



Additionally, compression set, elongation and tensile properties were maintained.

Data courtesy of Ron Stevens

Future Work

While initial studies have shown that potential of using recycled Kalrez® parts, there is still room for further improvements.

- Evaluate more cost-effective and sustainable techniques to prepare the scrap material
- Determine the effect of particle size and particle size distribution on compound properties
- Determine the amount of recycled material that can be incorporated into the finished parts

Acknowledgments

Andy Wheble, Doug Spahr and Marios Avgousti for their discussion and guidance.