# BOOK OF ABSTRACTS

# FIRE AND POLYMERS 2026

**MAY 17-20, 2026**
**WESTGATE HOTEL**
**SAN DIEGO, CA USA**

Organizers:

**Prof. Jaime Grunlan**
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## This Book Includes:

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# TECHNICAL PROGRAM

Fire and Polymers 2026

May 17-20, 2026

San Diego, CA

## SUNDAY, MAY 17

**Technical Program**

| | | |
|---|---|---|
| 3:00 PM | | REGISTRATION OPENS (REMAINS OPEN THROUGH MEETING) |
| | | **SESSION I**<br>Jaime Grunlan, Discussion Leader |
| 4:00 PM | | OPENING REMARKS: ALEXANDER MORGAN AND JAIME GRUNLAN |
| 4:15 PM | 1. | Alexander B. Morgan, University of Dayton Research Institute<br>*Improvements in Cone Calorimeter Best Practices: Standard Reference Materials, Maintenance Issues, and A New Potential Standard Guide with ASTM* |
| 4:45 PM | 2. | Rick Davis, National Institute of Standards & Technology<br>*Testing of Materials with ASTM E3367 – The Cube Test* |
| 5:15 PM | 3. | Jason Huczek, Southwest Research Institute<br>*Effects of Substrates and Support Systems on ASTM E84 Performance* |
| 5:45 PM | 4. | Mark McKinnon, Fire Safety Reseach Institute<br>*Best Practices for Modeling Ignition from Directly Measured Thermophysical Properties* |
| 6:05 PM | | WELCOME RECEPTION (1 HOUR) |

## MONDAY, MAY 18

| | | |
|---|---|---|
| | | **SESSION II**<br>Alexander Morgan, Discussion Leader |
| 8:00 AM | | MORNING COFFEE WITH LIGHT PASTRIES AND FRUIT |
| 8:30 AM | 5. | Sabyasachi Gaan, EMPA<br>*Recyclable Fire-Retardant Dynamic Phosphonated Networks from H-Polyphosphonates* |
| 9:00 AM | 6. | Bernhard Schartel, Federal Institute for Materials Research and Testing (BAM)<br>*Flame Retardant Polyurethane Featuring Future Challenges* |
| 9:30 AM | 7. | Marie-Odile Augé, Safran Composites<br>*Representative elementary volume Combustion Calorimeter (RevCC) : a new tool to study aircraft composites materials* |
| 9:50 AM | 8. | Abdenour Amokrane, EDF R&D<br>*Assessing the Validity of the 1D Assumption in Polymer Pyrolysis Modeling of Cylindrical Materials* |
| 10:10 AM | | BREAK |
| 10:35 AM | 9. | Jaime Grunlan, Texas A&M University<br>*Self-Extinguishing Polyester, Polyurethane, and Polyamide with Benign Polyelectrolyte-Based Coatings* |
| 11:05 AM | 10. | Federico Carosio, Politecnico di Torino – Alessandria Campus<br>*Flame retardant composites from polyelectrolyte complexes and natural fillers* |
| 11:35 AM | 11. | Douglas Fox, American University<br>*Crosslinked, carbohydrate-based, flame-resistant coatings for wood-based products* |
| 11:55 AM | 12. | Margaret J. Karim, Texas A&M University<br>*Vibratory Ball Milling of Solid State Flame Retardant Polyelectrolyte Complex for Use in Polymer Emulsions* |

## MONDAY, MAY 18, CONT'D

| | | |
|---|---|---|
| 12:10 PM | | LUNCH ON YOUR OWN |
| | | **SESSION III**<br>Bernhard Schartel, Discussion Leader |
| 2:00 PM | 13. | Serge Bourbigot, University of Central Lille<br>*Fire-retarded polymer in space-like environment* |
| 2:30 PM | 14. | Hatsuo Ishida, Case Western University<br>*Intrinsic and Extremely High Flame-Retardant, Bio-based Polybenzoxazines: Flammability Under Various Oxygen Concentrations* |
| 3:00 PM | 15. | Todd Emrick, University of Massachusetts<br>*Approaches to Polymeric Flame-Retardants: Halogen-free, Phosphorus-free, and PFAS-free* |
| 3:30 PM | | BREAK |
| 4:00 PM | 16. | Laura E. Hasburgh, Forest Products Laboratory<br>*Nanoscale X-Ray Imaging of Thermally Degraded Wood* |
| 4:30 PM | 17. | Fernando Raffan-Montoya, University of Maryland<br>*Towards Predicting ASTM D613 (Vertical Flame Test) Performance of FR Treated Fabrics Using Milligram-scale Flame Calorimetry* |
| 5:00 PM | 18. | Isaac T. Leventon, National Institute of Standards and Technology (NIST)<br>*Development of the NIST Cone Calorimeter Database* |
| 5:30 PM | 19. | Lyla (Changxin) Dong, Stanford University<br>*Polymer–Particle Hydrogels for Extended Wildfire Protection* |
| 5:45 PM | | POSTER SESSION AND RECEPTION (2 HOURS) |

## TUESDAY, MAY 19

| | | |
|---|---|---|
| 8:00 AM | | MORNING COFFEE WITH LIGHT PASTRIES AND FRUIT |
| | | **SESSION IV**<br>Serge Bourbigot, Discussion Leader |
| 8:30 AM | 20. | Gaëlle Fontaine, Centrale Lille Institute<br>*Elucidation of Fire Retardation Mechanisms: A Deep Dive into the Gas Phase* |
| 9:00 AM | 21. | Michael Großhauser, Fraunhofer LBF<br>*Future Proof Flame Retardancy: Designing Resilient Solutions for Changing Demands* |
| 9:30 AM | 22. | Margaret Baumann, Performance Polymers and Additives LLC/Pinfa NA<br>*ATO and Alternatives for Formulated FR Plastics- Pinfa NA* |
| 9:50 AM | 23. | Kelvin K. Shen, U.S. Borax<br>*Review of Testings, Applications, and Mode of Actions of Comparative Tracking Index (CTI)* |
| 10:10 AM | | BREAK |

## TUESDAY, MAY 19, CONT'D

| | | |
|---|---|---|
| 10:35 AM | 24. | Aurelio Bifulco, University of Naples Federico II<br>*Biochar in Fire protection: A sustainable alternative to other flame retardants and synergists* |
| 11:05 AM | 25. | Igor Jordanov: Saints Cyril and Methodius University, Skopje, North Macedonia<br>*Sustainable Flame-Retardant Polyelectrolyte Complexes for Efficient Treatment of Natural, Synthetic, and Blended Textiles* |
| 11:35 AM | 26. | Carl-Christoph Höhne, Fraunhofer Institute for Chemical Technology<br>*Safe-and-Sustainable-by-Design Flame Retardants for Insulation Foams* |
| 11:55 AM | 27. | Laura F. Guidugli, Florida Institute of Technology<br>*Blooming and Dust Transfer Screening of Flame-Retardant Additives in Enclosure Plastics* |
| 12:10 PM | | LUNCH ON YOUR OWN |
| | | **SESSION V**<br>Gaëlle Fontaine, Discussion Leader |
| 2:00 PM | 28. | Dido Agostinis, AIMPLAS<br>*Sustainable Phosphorus-Based Flame Retardants: Sustainable Synthesis, Structure–Property Characterisation, and Fire Performance* |
| 2:30 PM | 29. | Paul Joseph, Victoria University<br>*Ignition propensities and combustion characteristics of some ligno-cellulosic materials in the context of wildland fires* |
| 3:00 PM | 30. | Svetlana Tretsiakova-McNally, Ulster University<br>*A comparison of permeation of toxic combustion products through new and retired firefighters' jackets* |
| 3:30 PM | | BREAK |
| 4:00 PM | 31. | Carl-Eric Wilen, Åbo Akademi University<br>*A New Kid on the Block for Flame Retardancy of Expanded Polystyrene* |
| 4:30 PM | 32. | Sandra Bischof, University of Zagreb<br>*Closing the Loop: From Biomass to Innovative Flame Retardant Biocomposites & Biofuels* |
| 5:00 PM | 33. | Ramaswamy Nagarajan, University of Massachusetts Lowell<br>*Surface Functionalization Strategies for Reducing Flammability of Nylon, Cotton, and NyCo Fabric* |
| 5:30 PM | 34. | Lorenzo Tosato, University of Bologna<br>*Development and Scale-Up of Intumescent Waterborne Coatings for Wooden Structures* |
| 5:45 PM | | DINNER ON YOUR OWN |

## WEDNESDAY, MAY 20

| | | |
|---|---|---|
| 8:00 AM | | MORNING COFFEE WITH LIGHT PASTRIES AND FRUIT |
| | | **SESSION VI**<br>Federico Carosio, Discussion Leader |
| 8:30 AM | 35. | Sylvain Caillol, CNRS<br>*A Journey Around Circularity in Polymers: Bio-Based Copolymerizable Flame-Retardant Systems for Sustainable Fire-Safe Materials* |
| 9:00 AM | 36. | Krishna Suleria, University of Massachusetts Lowell<br>*Novel Durable 'No Melt Drip' Flame Retardant Coatings for Nylon 6,6 Fabrics* |
| 9:30 AM | 37. | Hajime Kishi, Univ. of Hyogo<br>*Flame retardancy of cross-linked cyanate ester/amorphous engineering polymer blends* |
| 9:50 AM | 38. | Sharon Ma, Avient Corporation<br>*Novel Fire-Resistant Composites Based on In-Situ Formation of Flame Barrier* |
| 10:10 AM | | BREAK |
| 10:25 AM | 39. | Sabine Fuchs, Hamm-Lippstadt University of Applied Sciences<br>*Synergistic bio-based flame retardant systems for polypropylene* |
| 10:50 AM | 40. | Jan Wagner, Ansbach University of Applied Sciences<br>*Can cork do more than preserve a good wine?* |
| 11:10 AM | 41. | David J. Irvin, Quantum Copper<br>*Non-Halogenated, High Molecular Weight Flame Retardant Additive to Produce Fire Resistant Fibers and Fabrics* |
| 11:30 AM | 42. | Yanfei Xu, University of Massachusetts<br>*Molecular Engineering for Enhanced Flame Retardancy and Reduced Thermal Conductivity in Polymers* |
| 11:50 AM | | CLOSING REMARKS |

# LECTURE ABSTRACTS

Fire and Polymers 2026

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San Diego, CA

1.

# Improvements in Cone Calorimeter Best Practices: Standard Reference Materials, Maintenance Issues, and A New Potential Standard Guide with ASTM

*Alexander B. Morgan*
*Group Leader and Distinguished Research Scientist*
*Center for Flame Retardant Materials Scientist*
*University of Dayton Research Institute, Dayton, OH 45469*

The Cone Calorimeter (ASTM E1354/ISO 5660) is a key instrument for quantifying the flammability of materials, and has been used to certify flame retardant products for end-use applications, as well as develop new materials. While the method has been standardized since the 1980s, and is in extensive use today, there is still room for improvement in the areas of standard reference materials, preventative maintenance to ensure reliable data, and best practices for handling difficult-to-test materials. Recent results in standard reference materials, including the proposed start of an interlaboratory study (ILS) will be discussed in this presentation. Additionally, data indicating the importance of understanding the effects of sample thickness and sample substrate will be discussed, and how this affects comparison between materials, will be presented. Finally, new work within the American Society of Testing and Materials (ASTM), Subcommittee E05 to develop a new standard guide for the cone calorimeter, will be presented.

2.

# Testing of Materials with ASTM E3367 – The Cube Test

*Mauro Zammarano**
*Engineering Laboratory, National Institute of Standards and Technology,*
*100 Bureau Drive, Gaithersburg, MD 20899-8665Gaithersburg, MD, USA*
** mauro.zammarano@nist.gov*

In 2023, ASTM introduced a new standardized cone calorimetry–based test method, ASTM E3367 [1]. Commonly known as the Cube test, it is derived from research conducted at the National Institute of Standards and Technology (NIST). The method is designed to evaluate the reaction-to-fire performance of multi-layer products, with specific provisions to suppress edge-effects.  and accurately assess the effectiveness of integrated fire-barrier layers. The test is designed to measure the ability of fire barriers in reducing the flammability of multi-layer products. Additionally, it enables the measurement of physical phenomena —such as burn-through time— that cannot be assessed using a traditional cone calorimeter test. During this presentation, the use of the Cube test in various applications, including upholstered furniture, siding materials, roofing materials, composites and lithium battery fires will be illustrated.

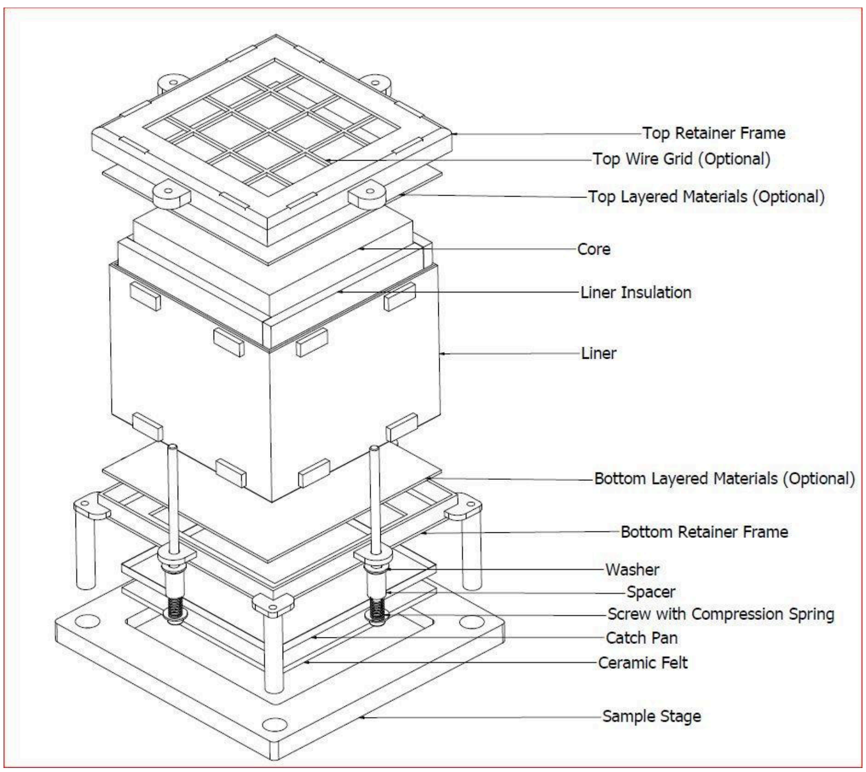


Figure 1. Schematic drawing showing the test sample holder used in the Cube test.

[1] ASTM E3367 - *Standard Test Method for Determining the Combustion Behavior of Layered Assemblies using a Cone Calorimeter*, ASTM International, West Conshohocken, PA, 2023.

3.

# EFFECT OF SUBSTRATES AND SUPPORT SYSTEMS ON ASTM E84 PERFORMANCE

*J. Huczek, M. Janssens and D. Basu, SwRI, USA*

jhuczek@swri.org

In 2019, Southwest Research Institute (SwRI) initiated an internal research program to investigate our ability to predict results in the Steiner Tunnel test, standardized in ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*. In this paper, we will focus on the experimental investigation of the effect of substrates and support systems for specimens tested in ASTM E84.

The tests focused on two different wood products. The first product is referred to as 'thin plywood,' and is a 3-mm thick decorative plywood (Brazilian Virola species). The second product is referred to as 'thick plywood,' and is a 12.7-mm thick AC grade plywood (Southern Yellow Pine species). A total of 24 tests were performed with different combinations of substrates and support systems (steel rods and/or wire mesh) and the Flame Spread Index (FSI) and Smoke Developed Index (SDI) were determined per ASTM E84.

Each plywood was tested in duplicate with the following substrates: cement board, air gap, 12.7-mm thick Type X gypsum wallboard, and 3.5-in thick paper-faced fiberglass matts (R-13). The air gap was provided by installing the plywood on a wood stud frame, which was backed by cement board. For the tests with cement board as a substrate, tests were conducted with three different types of support systems: none, only rods and rods and wire mesh combination.

Figure 1 shows an example comparison for the flame spread for thin plywood, with a cement board substrate, and with different support systems. Additional details will be provided in the presentation.

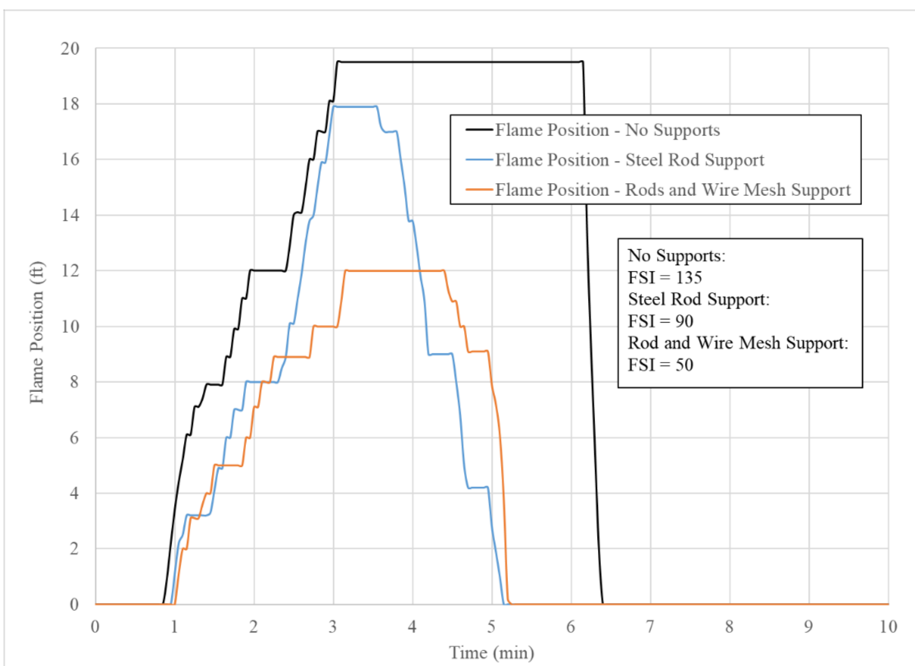


**Figure 1. Thin Plywood with Cement Board and Different Support Systems.**

4.

# Best Practices for Modeling Ignition from Directly Measured Thermophysical Properties

***Mark McKinnon, PhD, PE***
*Research Engineer*
*Fire Safety Research Institute*
*UL Research Institutes*
*6200 Old Dobbin Ln, Suite 150*
*Columbia, MD 21045*

Several practical models exist to describe the pyrolysis and ignition of condensed phase materials. These models rely on a range of measured quantities that may include response-to-fire metrics, model-dependent fitting variables, intrinsic thermophysical properties, and derived reaction parameters. The FSRI Materials and Products (MaP) Database has introduced a resource to the fire modeling community with a wealth of data on material response to thermal exposure and burning behavior. This presentation explores correlations in the measured data and strategies for the use of tabulated properties to inform ignition and burning rate models for materials.

5.

# Recyclable Fire-Retardant Dynamic Phosphonated Networks from H-Polyphosphonates

*Arvindh Sekar, Cedric Hervieu, Sabyasachi Gaan*
*Additives and Chemistry, Advanced Fibers, Empa Swiss Federal Laboratories for Materials Science and Technology, Lerchenfeldstrasse 5, 9014 St. Gallen, Switzerland. +41 58 765 7611, sabyasachi.gaan@empa.ch*

At the previous ACS Fire and Polymer conference (2024, New Orleans), we presented our work on novel phosphonated networks [1], which offered inherent recyclability and flame-retardant properties as a unified solution. Such networks were prepared by reacting a bicyclic bis-phosphite monomer with epoxy precursors. Though such resins offered excellent fire protection and thermomechanical recyclability, the bisphosphate monomer was challenging to synthesize, with low yields. To overcome these challenges, we have now designed and synthesized (Figure 1), via a facile route, a series of H-polyphosphonates that serve as building blocks for dynamic networks. The H-polyphosphonates were combined with epoxy resins [2], and polyacrylate monomers to develop phosphonated networks. These networks demonstrated a very high level of fire resistance and excellent chemical and thermomechanical recyclability. This presentation will discuss in detail the synthesis strategies for such resins, their thermal, fire, and mechanical performance, reprocessability, and applications.

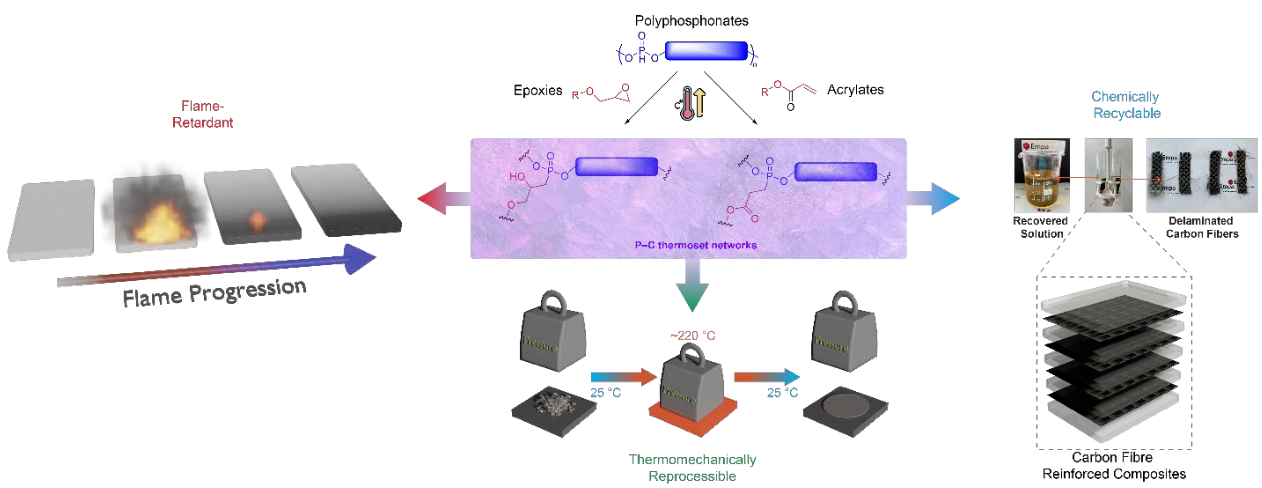


Figure 1: Synthesis and properties of phosphonated Networks

## References

1) W. Wu Klingler et al., Chemical Engineering Journal 466 (2023) 143051
2) A. Sekar et.al. Chemical Engineering Journal 520 (2025) 165779

6.

# Flame Retardant Polyurethane Featuring Future Challenges

*Bernhard Schartel*

*Bundesanstalt für Materialforschung und -prüfung (BAM),*
*Unter den Eichen 87, 12205 Berlin, Germany*

*bernhard.schartel@bam.de*

Flame retardant polyurethane (PU) foams and thermoplastic PU are proposed for insulation, seat cushioning, or cable jackets. PU consists of alternating segments that tailor the material properties while also determining the pyrolysis and fire behavior. Most PU materials are highly flammable and tend to form pool fires or burning drops; although rigid and flexible PU foams are two different stories, their low thermal inertia results in short ignition times and intensive flame spread. The important PU markets are dying for developing novel flame-retardant PU materials that outperform the existing ones. This work delivers detailed insight into the complex burning behavior of PU-materials. The comprehensive understanding of the physical and chemical processes and their complex interplay, respectively, is presented as the foundation of customized development of future PU materials.

Thanks to: AiF IGF 19078 N/2, DFG Scha 730/19, Y.Y. Chan, M Großhauser, M. Günther, Y. Hu, S.V. Levchik, A. Lorenzetti, E. Metzsch-Zilligen, R. Pfaendner, and A. Rabe (née Sut).

# Representative elementary volume Combustion Calorimeter (RevCC): a new tool to study aircraft composites materials

*Marie-Odile Augé[a], Pierre Bachelet[b], Kimkévin Ha[c], Serge Bourbigot[b]*
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*[b] Univ. Lille, CNRS, INRAE, Centrale Lille Institut, UMR 8207 – UMET – Unité Matériaux et Transformation, F-59000 Lille, France [c]Safran Seat, 60149 Saint-Crépin-Ibouvillers, France [d]Institut Universitaire de France, Paris, France*
[marie-odile.auge@safrangroup.com](mailto:marie-odile.auge@safrangroup.com)

The Representative Elementary Volume Combustion Calorimeter (RevCC)[1] provides a novel approach to assessing the fire performance of aircraft composite materials, including heterogeneous sandwich panels and structural laminates. Operating at the gram scale, RevCC enables characterization of structurally representative samples, preserving real-world layer interactions, ply orientation, and reinforcement fabric architecture—thus surpassing the limitations of microscale methods like Microscale Combustion Calorimeter (MCC). Its oxygen consumption-based design yields precise measurements of heat release rate and total heat release (Figure 1 - Left). Combined with complementary techniques, RevCC helps detect both independent and physical interlayer effects, as well as the impact of ply orientation and reinforcement type, supporting predictive modelling and efficient certification. Looking at Figure 1 - Right, RevCC confirms that with a quasi-isotropic (QI) stacking the thermal response will depend of the reinforcement nature.[2] Indeed, QI composite reinforced with a fabric show faster ignition and lower peak of heat release rate (pHHR) whereas composite reinforced with unwoven fibers exhibit a higher pHRR.

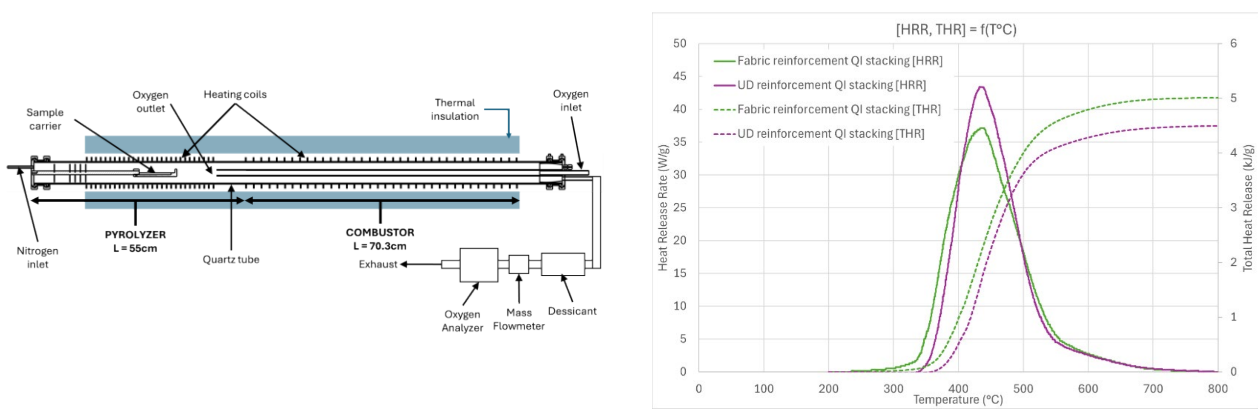


Figure 1 Left – Schematic representation of RevCC Right - Heat Release Rate and Total Heat Release as a function of the temperature for composite with QI stacking and different types of reinforcement

[1] K Ha et al 2024 J. Phys.: Conf. Ser. 2885 012030
[2] Eibl S. Influence of unwoven roving and woven fabric carbon fiber reinforcements on reaction-to-fire properties of polymer matrix composites. *Fire and Materials*. 2020; 44: 557–572

# Assessing the Validity of the 1D Assumption in Polymer Pyrolysis Modeling of Cylindrical Materials

*Abdenour Amokrane[a], Johan Sarazin[c], Serge Bourbigot[c,d]*

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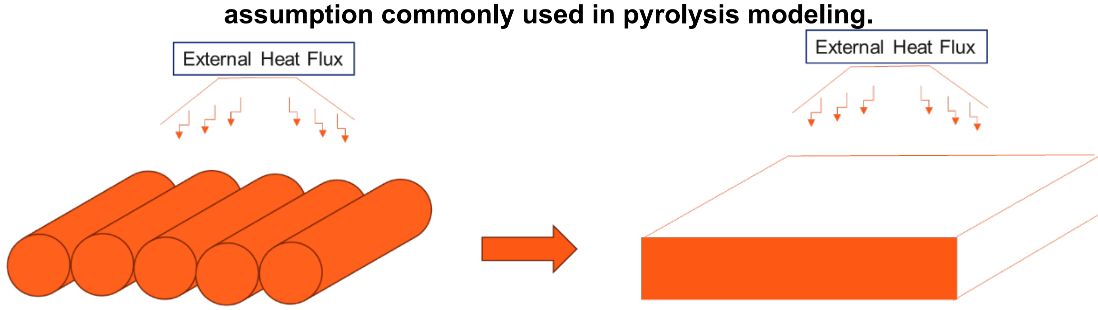
[b] *Institut de Mécanique des Fluides de Toulouse (IMFT) - Université de Toulouse, CNRS-INPT-UPS, Toulouse, France*
[c] *Univ. Lille, CNRS, INRAE, Centrale Lille, UMR 8207 - UMET - Unité Matériaux et Transformations, F-59000 Lille, France*
[d] *Institut Universitaire de France (IUF)*

This study examines the geometric effects involved in pyrolysis modeling of polymers. In the literature, the pyrolysis of cylindrical materials, such as cables and wires exposed to a cone calorimeter, is typically modeled using a 1D framework. This approach assumes a uniform heat flux on the exposed surface and symmetry in the horizontal directions, which essentially treats the cable as a flat plate (Figure 1). As a result, thermal degradation is modeled only through the material's depth. However, this major assumption has never been properly validated, and the potential errors introduced by it remain unquantified.

To address this issue, the present work combines experimental investigation and numerical modeling. Cylindrical samples of two diameters (8 mm and 16 mm) are fabricated from PMMA and compared with flat plates of identical thicknesses and material. Cone calorimeter tests are conducted on both cylinders and plates under identical conditions, using heat fluxes of 35 and 50 kW/m², to measure the Mass Loss Rate (MLR) and Heat Release Rate (HRR). The same configurations are then simulated using the Gpyro pyrolysis code.

By comparing the experimental behavior of cylinders and plates under identical conditions, along with the corresponding modeling results, the study quantifies the errors associated with applying the 1D modeling assumption to the pyrolysis of cylindrical polymers.

**Figure 1: Samples tested under the cone calorimeter: *(left)* the realistic experimental configuration; *(right)* the 1D assumption commonly used in pyrolysis modeling.**



9.

# Self-Extinguishing Polyester, Polyurethane, and Polyamide with Benign Polyelectrolyte-Based Coatings

*Jaime C. Grunlan*
*Leland T. Jordan '29 Chair Professor*
*Department of Mechanical Eng., Materials Science & Engineering and Chemistry*
*Texas A&M University, College Station, TX 77840*

Polyelectrolyte complex (PEC) coatings can render flexible polyurethane foam, polyester and nylon textiles, and engineered wood products self-extinguishing (e.g., UL-94 V-0 rating or passing ASTM D6413 vertical flame test), with only 5 – 20% added weight to a given substrate. These treatments make use of benign phosphate, nitrogen-rich, and borate chemistries. This presentation will cover the newest developments in PEC treatments, including techniques to impart wash durability. PEC coatings can be deposited using traditional roll-to-roll processing tools (e.g., flexographic printing, dip-coating, or spray-coating).

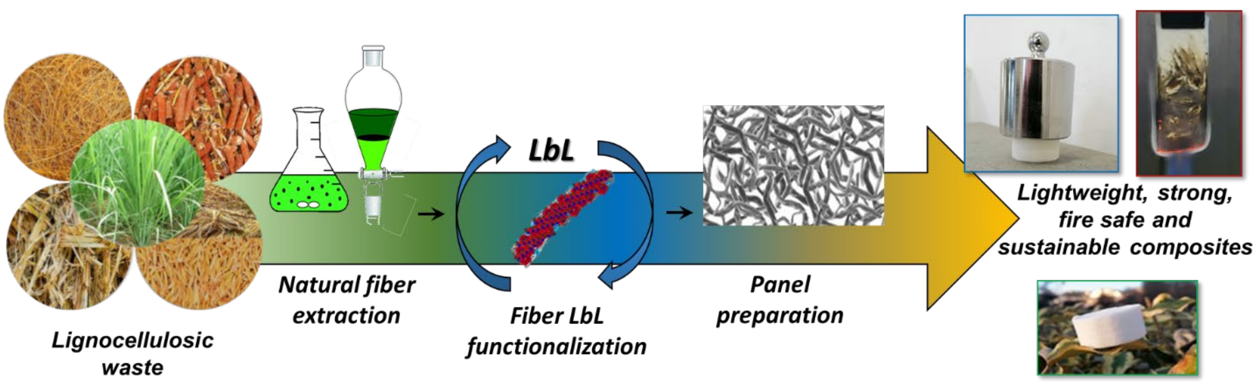
# Flame retardant composites from polyelectrolyte complexes and natural fillers

*F. Carosio*

*Department of Applied Science and Technology, Politecnico di Torino – Alessandria Campus, V.le Teresa Michel 5, 15121 Alessandria, Italy*

federico.carosio@polito.it

This contribution describes how bio-based polyelectrolyte complexes (PECs), controlled by a Layer-by-Layer (LbL) assembly, can be employed for the production of green and fire safe materials based on natural fibers or particles. The amount of natural filler typically ranges between 70-90 wt.-% highlighting the potentialities of the proposed approach in delivering lightweight porous structure with extremely high filler content. Flammability tests in horizontal configuration evidenced a non-igniting behavior where no flame persisted on the sample after the removal of the methane flame. The prepared composites also self-extinguished the flames in vertical configuration. By cone calorimetry (35 kW/m$^2$) these sustainable materials showed very low Heat Release Rate, HRR, values (pkHRR < 100 kW/m$^2$) as well as extremely limited smoke production (Total Smoke Release, TSR < 50 m$^2$/m$^2$). The achieved results clearly demonstrate the versatility of PECs in delivering functional materials where flame retardancy and sustainability are optimized.




Acknowledgement: The author also acknowledges financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union – NextGenerationEU– Project Title Green cellulose bAsed fire safe and lightweight Insulating mAterials (GAIA) – CUP project (CUP: E53D23017860001- Grant Assignment Decree No. 1389 adopted on 01/09/2023 by the Italian Ministry of Ministry of University and Research (MUR).

11.

# Crosslinked, carbohydrate-based, flame-resistant coatings for wood-based products

*Douglas Fox, Mary Ruxsarash, Lea Carrigg, and Whirang Cho*
*Professor & Chair of Chemistry*
*American University*

We have been developing highly effective flame-resistant coatings for wood-based products using chitosan as the primary component. Chitosan is the de-acetylated carbohydrate component found in anthropods, most often extracted from shrimp and crab shells. It can be dissolved in acids to produce water based coatings. In our previous work, we used hypophosphorous acid to produce films that delayed ignition of wood by nearly 4 minutes. Ionically crosslinking them with a nitrilophosphoric acid generated an intumescent coating and prevented the samples from igniting under a 50 $kW/m^2$ heat flux. However, field tests showed that the films swelled and washed away, eliminating fire protection within a month. Although the films were as effective as commercial samples tested, producing a weatherable, fire protective coating remains a desirable industrial goal. In our recent work, we have used acrylic acid and vinyl phosphoric acid to dissolve the chitosan and a number of chain extenders/crosslinking agents to produce films with significantly reduced swelling. A photoinitiator was added so that the coating could be applied as an aqueous solution, then rendered insoluble by curing in the sun. Using wooden sticks and cardboard, flame spread tests have shown that at least some of these combinations produce good flame resistant properties. Initial cone calorimetry tests on wood show promise, though developing the appropriate thickness of the coating is crucial. The balance between flame retardancy and insolubility will be discussed.

12.

# Vibratory Ball Milling of Solid State Flame Retardant Polyelectrolyte Complex for Use in Polymer Emulsions

*Dallin L. Smith[a], Kathleen Floyd[a], Margaret J. Karim[a], James Batteas[ac], and Jaime C. Grunlan[abc]*

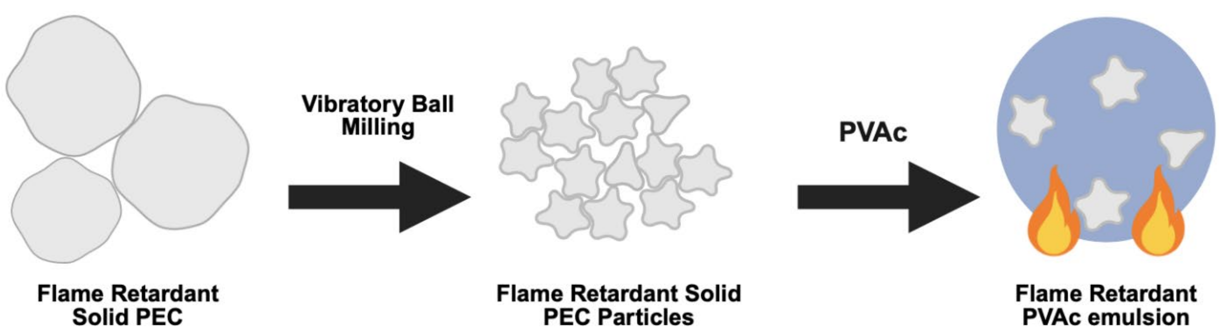
[a] *Department of Chemistry, Texas A&M University, College Station, TX 77843*

[b] *Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843*

[c] *Department of Materials Science and Engineering, Texas A&M University, College Station, TX 77843*

*Email of presenter: magskarim@tamu.edu*

Polyelectrolyte complex (PEC) coatings have been established as environmentally benign flame retardant (FR) treatments for a wide variety of substrates. However, solid-state PECs have seen limited FR applications due to the necessity of plasticizers and/or chemical functionalization to meet processibility requirements. This presentation demonstrates an alternative solid-state PEC processing approach via vibratory ball milling to reduce PEC particle size by an order of magnitude, enabling their use as FR additives in a polymer emulsion. The resulting emulsion achieves self-extinguishing behaviour and a V-0 rating with UL 94 flame resting. These results demonstrate a new approach for incorporating solid PECs as effective FR additives.



13.

# Fire-retarded polymer in space-like environment

*Serge Bourbigot[a,b] and Johan Sarazin[a]*
*[a]Univ. Lille, CNRS, INRAE, Centrale Lille, UMR 8207 - UMET - Unité Matériaux et Transformations, 59000 Lille, France*
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Fire safety in space exploration is a critical challenge due to the unique conditions of reduced gravity, low pressure, and oxygen-enriched atmospheres, which significantly increase material flammability and fire risks. This study investigates the fire behavior of fire-retarded (FR) polymers in such extreme environments, focusing on their performance under high heat fluxes and elevated oxygen concentrations (up to 35% $O_2$). Fire-retarded polyolefins will be investigated under these environments, representative of future spacecraft cabins and planetary habitats. Building on our recent work with polypropylene (PP) and low-density polyethylene (LDPE) containing ammonium polyphosphate (APP)/pentaerythritol (PER)/Synergists systems and commercial intumescent packages, the study will quantify how oxygen concentration modifies thermal degradation, peak and total heat release, and char yield using an oxygen-controlled cone calorimeter (O2CC) (Fig. 1). The Limiting Oxygen Index (LOI) and High Gas Velocity Oxygen Index (HOI) will be also examined to determine the Minimum Limiting Oxygen Concentration (MLOC), which is essential for assessing the safety of materials in spacecraft and habitats.

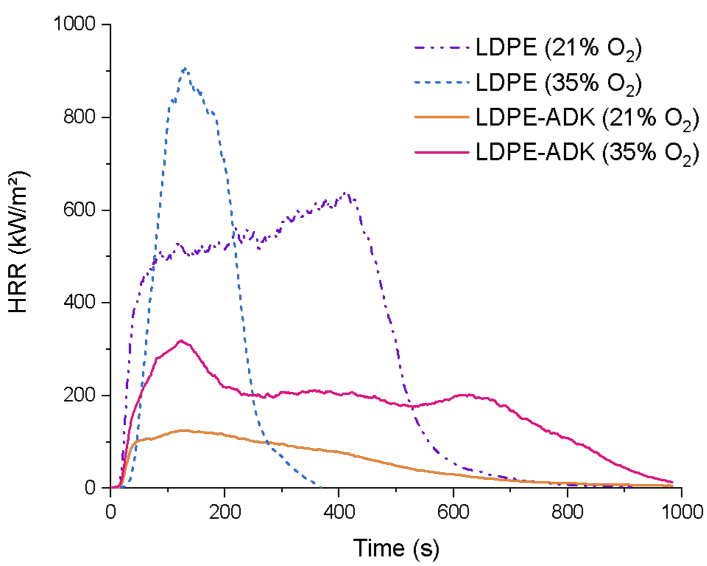


Fig. 1. HRR curves of LDPE and LDPE-ADK (ADK is Adeka FP 2500S) as a function of time at 21% (dashed line) and 35% $O_2$ (plain line) atmosphere (external heat flux = 35 kW/m²) measured with the O2CC.

***Acknowledgement:*** *This work was supported by the Centre National d'Etudes Spatiales (CNES) under APR 'Polysoot'*

14.

# Intrinsic and Extremely High Flame-Retardant, Bio-based Polybenzoxazines: Flammability Under Various Oxygen Concentrations

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Polymer products are almost always used with added flame retardants that are often toxic or lead to toxic compounds upon incineration. These are suspected to cause unknown health problems, yet it is very difficult to prove medically. We take preemptive approach by assuming these are not desirable for human health and environment. Thus, we intend to develop a class of polymers, polybenzoxazine, that offer green, sustainable and intrinsically noncombustible polymers. Benzoxazine resins are Mannich condensation products of a phenolic derivative, an aldehyde and a primary amine. Benzoxazine monomers and polybenzoxazines show unusual and advantageous properties other polymers seldom exhibit. As a result, it became one of only a few newly commercialized polymers in the past 45 years. They show near zero shrinkage upon polymerization, very high char yields up to 80%, wide Tg range from sub-zero temperature to above 400°C, low saturation water up-take less than 2% despite having hydrophilic chemical group in each chemical repeat unit, lower surface free energy than polytetrafluoroethylene (PTFE) without using fluorine atoms, and excellent chemical resistance, electrical, and mechano-physical properties [1]. Above all, the molecular design flexibility is the highest of all known polymers so that one can easily tailor desired properties. Using the above advantages, we designed benzoxazine resins using flavonoids as a phenolic source and furfurylamine as an amine source to synthesize fully bio-based benzoxazine monomers. The polymer derived from these monomers exhibited the heat release capacity around 10 kJ/g.K, one of the lowest ever reported [2, 3]. In this lecture, we will discuss the molecular design principles of such materials along with thermal and flame-retardant properties. Additionally, the flammability of polybenzoxazines are compared with other polymers under various oxygen concentration from 5 to 50%. For various polymers, we observed unexpected results and we will attempt to explain the molecular origin of such behavior.

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15.

# Approaches to Polymeric Flame-Retardants: Halogen-free, Phosphorus-free, and PFAS-free

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The restrictions and potential hazards associated with flame-retardants used today, such as (macro)molecular structures rich in halogen, phosphorus, or PFAS, help drive efforts to discover novel non-flammable materials that are devoid of these components. This presentation will describe the preparation and characterization of new types of flame-retardant organic molecules and polymers that, upon attempted burning, predominantly produce char rather than flammable gas. Aromatic hydrocarbons and nitrogen-rich heterocycles are proving especially proficient in this capacity, including for example triazoles, aromatic ketones, and combinations of the two. As will be described, cycloadduct products of these reactions studied to-date exhibit low heat release properties on their own and contribute to reductions in flammability when blended with commodity polymers. Characterization by microscale combustion calorimetry (MCC) shows that newly synthesized deoxybenzoin-containing structures prepared by cycloaddition chemistry possess low heat release capacity (HRC) values that place them in the ultra-low heat release category. In addition, inclusion of triazoles in the polymer products led to improved solubility and processibility, making this macromolecular design promising for generating useful flame-retardant materials with potential utility as coatings, fillers, and additives, and without complications associated with the use of organic halogens or other molecules of concern.

16.

# Nanoscale X-Ray Imaging of Thermally Degraded Wood

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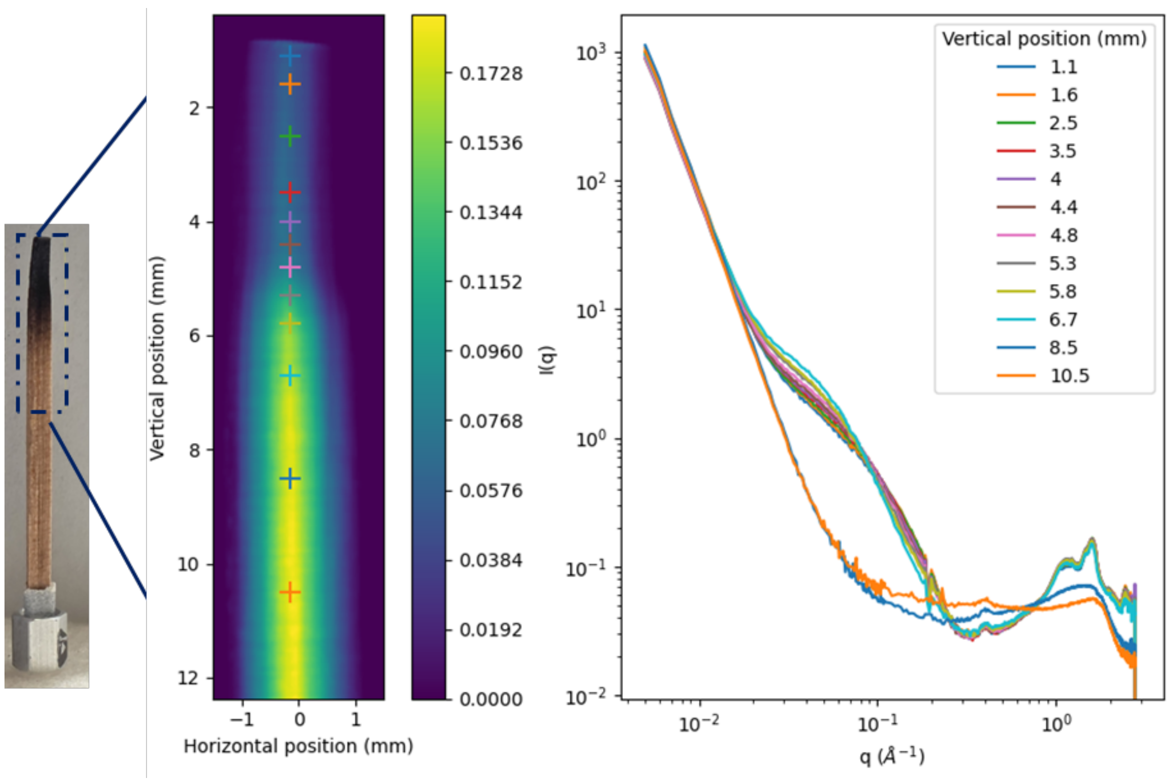
The formation of char in wood is a complex process beginning with the thermal degradation, or pyrolysis, of the wood polymers. Understanding the nanostructural changes resulting from pyrolysis will help inform the development of new fire-retardant treatments and wood adhesives that require high-temperature performance. We used thermal neutron imaging (TNI) and tomographic reconstructions based on x-ray fluorescence (XRF), and small- and wide-angle scattering (SAXS/WAXS) contrast to evaluate changes in density, microfibril size and arrangement, cellulose crystallinity, and elemental composition of inorganics across the pyrolysis zone of Douglas Fir, a common wood species utilized in construction. TNI showed increased attenuation towards the charred region, indicating a decrease in density in both early and latewood as the polymers were thermally degraded. SAXS/WAXS tomography revealed a loss of crystalline cellulose through the pyrolysis zone and changes in the SAXS signal that suggest the elementary fibril organization was modified by the fire exposure.



17.

# Towards Predicting ASTM D613 (Vertical Flame Test) Performance of FR Treated Fabrics Using Milligram-scale Flame Calorimetry

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Polymeric fibers are extensively used to produce fabrics for a wide range of applications (clothing, upholstery, vehicle interiors, among others). Most fabrics, both synthetic and natural, are highly flammable, requiring additional treatment to address this hazard. Flame retardant (FR) treatments that are effective, cheap, lightweight, environmentally friendly, comfortable, and resilient after laundering are scarce. Furthermore, adequate fire testing of novel flame retardant treatments requires relatively large samples. One widely employed method used to quantify and certify flame retardant-treated fabrics is the Vertical Flame Test (VFT) (ASTM D6413). ASTM D6413 characterizes fabric flammability by measuring the char length and burn duration of a 300 mm x 76 mm fabric sample exposed to a Tirrill burner flame for 12 seconds. ASTM D6413 testing can be prohibitively expensive during early R&D phases since producing treated samples in the laboratory with the right dimensions for testing and in the right amounts for multiple tests can be difficult. Based on these challenges, it is desirable to identify methods that can screen the flammability performance of fabrics using a fraction of the sample size required for certification testing.

Milligram-Scale Flame Calorimeter (MFC) has emerged as an ideal method for screening fabric flammability. The MFC is a bench-scale apparatus that pyrolyzes 30-50 mg solid fuel samples in a controlled anaerobic environment and subsequently burns the gaseous products in an axisymmetric laminar diffusion flame. The MFC uses Oxygen Consumption Calorimetry to determine Heat Release Rate and Heat of Combustion of the sample while a calibrated embedded thermocouple monitors the process temperature and can be used to determine ignition temperature. The MFC provides flammability data akin to that obtained from cone calorimetry and has been successfully benchmarked using data from pure polymers as well as polymers treated with bromine and phosphorus-based FRs. Preliminary testing has shown that the MFC is as effective at measuring flammability behavior of fabric samples as it was at measuring that of plastic disks and powders.

In this work, we present a methodology by which data from MFC testing (heat release rate, ignition temperature, heat of combustion), of 12 fabric samples (with/without FR treatments) is augmented with thermogravimetric-differential scanning calorimetry (TGA-DSC) data (heat capacity and heat of melting) to generate a suite of dimensionless parameters that allow for the prediction of ASTM D613 performance. In particular, one dimensionless parameter discriminates fabrics that burn through from those that don’t, while a second parameter ranks and predicts the char length for those fabrics that do not exhibit burn through. By implementing this methodology, the ASTM D613 performance of a fabric can be predicted using 2 orders of magnitude smaller samples (including repeat tests) than a single ASTM D613 sample. A brief discussion on MFC automation will also be presented, enabling further acceleration of R&D testing in addition to the significant improvement in sample size and preparation time requirements vs. existing methods.

18.

# Development of the NIST Cone Calorimeter Database

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Since its development at NIST in 1982 (then the National Bureau of Standards, NBS), the cone calorimeter has enabled the study of material flammability behavior in response to well-characterized heating conditions. Data collected in these tests – e.g., sample heat release rate (HRR; based on oxygen consumption calorimetry) and mass loss rate (MLR) as well as smoke and toxic gas production – has been crucial in the selection and development of materials to meet regulations, standards, and codes for the fire performance of products. Unfortunately, the measurements from more than 40 years of NIST cone calorimeter testing are currently presented across dozens of separate publications, making it difficult to effectively access, analyze, and use.

This project aims to create a digital repository of cone calorimeter data that allows easy access to experimental measurements and derived properties (e.g., heat of combustion, ignition and fire growth parameters, and average MLR or HRR in response to known heating conditions). This continually growing database is publicly accessible, version-controlled, and designed for use by fire safety scientists and engineers outside of NIST. Ongoing systematic review of existing files has identified thousands of experiments on a wide range of materials including commodity plastics, woods, cables, vegetative fuels, and flooring and other building materials. Preliminary reports, plots of measurement data, and tabulated property values are viewed using a custom, web-based user interface. Material property information can be directly used for engineering calculations. Processing tools are in development to export key values with standard formatting needed for use as model inputs in the Fire Dynamics Simulator, FDS.

Through a systematic review of existing files, all measurement data is identified, linked to an original NIST publication, and then processed to ensure standardized formatting of test data and metadata as well as consistent post-processing and property derivation across all tests. For each experiment, critical data is organized into two separate files: a .CSV file for measurement data (e.g., time-resolved sample mass, HRR, and gaseous species production) and .JSON files for metadata (e.g., test conditions, sample preparation, key test events, and material source/descriptive information). These data file formats, naming conventions, and analysis/archiving workflows have been designed based on years of experience gained from internal development of the NIST Fire Calorimetry Database (www.nist.gov/el/fcd) and FDS (www.github.com/firemodels/fds) and a global collaborative effort led by the Measurement and Computation of Fire Phenomena (MaCFP) Working group (www.github.com/MaCFP). Parsing tools have also been written to automatically analyze and standardize data files produced by commercial cone calorimeters in use around the world, allowing data from multiple labs to be incorporated into the repository.

***Keywords: Fire Modeling, Heat Release Rate, Material Properties, Oxygen Consumption Calorimetry***

19.

# Polymer–Particle Hydrogels for Extended Wildfire Protection

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Recent catastrophic fires highlight the need for fire-retardant materials that protect properties at the wildland–urban interface. Polymer–particle (PP) hydrogels have emerged as promising carrier materials for prophylactic wildfire retardants due to low cost, scalability, and ease of manufacturing. Polymer selection, gelation mechanisms, aging behavior, and practical design considerations govern the development of sprayable hydrogels with controlled rheological behavior and thermal response. Under direct flame exposure, the hydrated gel undergoes a heat-activated transformation into a lightweight, porous, and mechanically adherent aerogel barrier, extending protection beyond water or conventional sprayable gels. Dynamic crosslinking enables the PP hydrogel platform as a versatile framework for gel-based retardant formulation development. New field-relevant testing approaches, including three-dimensional site-scale configurations, are also introduced to inform future scaled deployment.


# LUCIDATION OF FIRE RETARDANCY MECHANISMS: A DEEP DIVE INTO THE GAS PHASE

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Nowadays, organic polymers are widely used in many applications; however, their flammability poses a major safety issue. To address this problem, the incorporation of flame retardants into polymer materials has been extensively developed over the past few decades. It is now well established that their mode of action can occur in the condensed phase and/or in the gas phase. However, to design new efficient formulations, it is required to fully understand the physicochemical mechanisms involved. However, the identification of these mechanisms in the gas phase remains a major challenge due to the complexity of the reaction processes and the limitations of the tools currently available. In this context, we have developed and implemented a set of experimental approaches to elucidate the modes of action of flame retardants in the gas phase. These methodologies will be presented and illustrated through a representative case study.

21.

# Future Proof Flame Retardancy: Designing Resilient Solutions for Changing Demands

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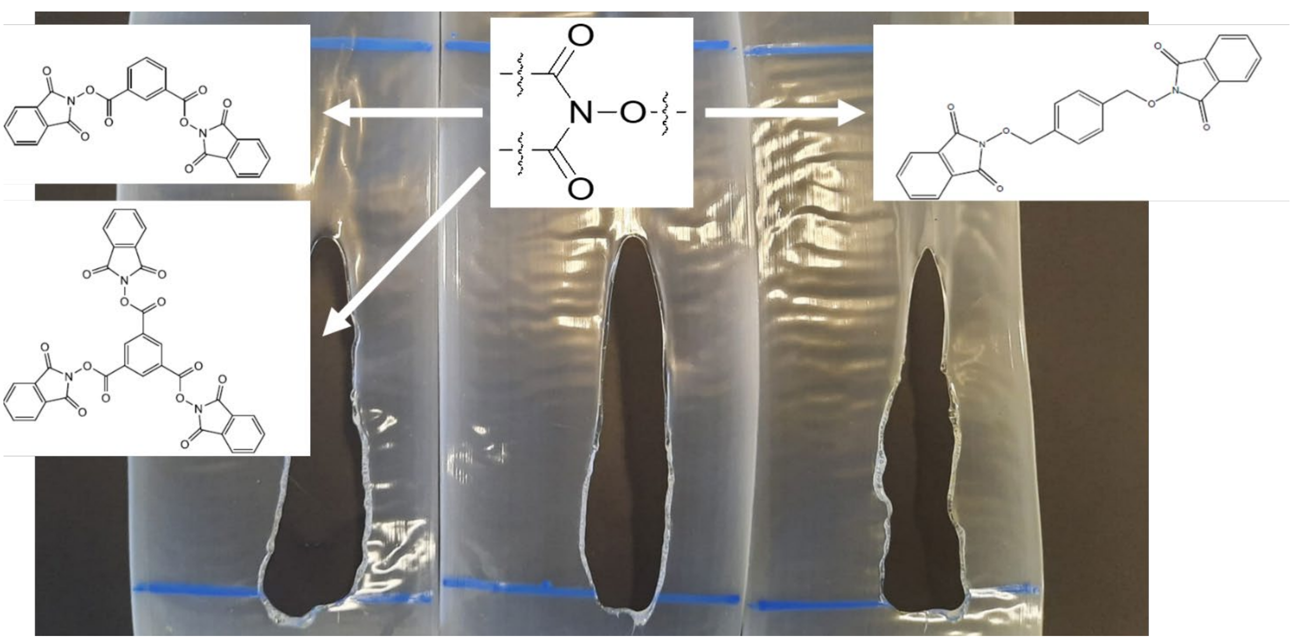
As global demands on material performance and sustainability intensify, flame retardant technologies must consider stringent safety, regulatory, and resource constraints. The presentation focusses on the oxyimide class of flame retardants and highlights recent advances that extend the applicability to future-oriented flame-retarded polymer formulations. Oxyimides represent halogen and peroxide-free, nitrogen-based radical generators that promote efficient radical quenching and char formation during incineration, avoiding critical or environmentally problematic elements.Building on established mechanistic concepts, newly optimized oxyimide structures demonstrate enhanced thermal stability, improved polymer compatibility, and greater formulation flexibility. These attributes are particularly relevant in the context of constrained global resources and the growing need for resilient material solutions. Comparative performance data for different commodity and engineering polymers are discussed to illustrate how oxyimide-based systems can meet evolving fire safety requirements. The presented results highlight the potential of refined oxyimide flame retardants as a robust pathway toward sustainable fire-retarded products and applications.



22.

# ATO and Alternatives for Formulated FR Plastics- Pinfa NA

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*Performance Polymers and Additives LLC/Pinfa NA*

Due to recent supply constraints on antimony trioxide (ATO) and related antimony compounds, as well as mounting environmental, health and safety concerns, the marketplace has been looking for ATO replacements in halogenated flame retarded formulations. This presentation explores the current ATO situation and summarizes literature, patent, and PINFA supplier information for complete ATO replacement while achieving a UL 94 V0 rating in major thermoplastic halogenated systems.

# Review of Testings, Applications, and Mode of Actions of Comparative Tracking Index (CTI)

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CTI is a measure of how well an insulating polymer can resist the formation of conductive paths (tracking) on sample surface when exposed to electrical stress and contaminants. The test methods, applications, and mode of actions will be reviewed in this presentation. In addition, the new EV requirements of high voltage testing (up to 1500 volts) will be discussed. The use of multifuctional zinc borate as an additive to enhace polymer CTI will also be presented.

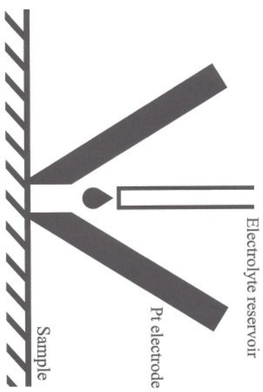


Figure 1. CTI testing apparatus

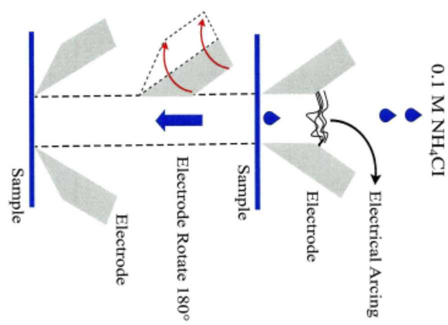


Figure 2. Modified CTI apparatus for high voltages

Consumer electronics, automotive industry, industrial machineries, telecommunication, solar power/wind energy, and aerospace/aviation, where electronic components are exposed to moisture, dust and high voltages. Materials with higher CTI is a vital parameter in material selection for electrical engineering, impacting safety, reliability, and the overall design of electrical and electronic systems.

In E/E application, the CTI value will continue pushing to higher value due to high speed charging and miniaturization of small electrical parts. Zinc borate is a multifunctional flame retardants and function as CTI enhancer. Borate can inhibit oxidation of char. A new generation of insulation material is needed for miniaturization and performance improvement. Parameters such as temperature and air pressure are yet to be evaluated.

24.

# Biochar in Fire protection: A sustainable alternative to other flame retardants and synergists

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Biochar (BC), derived from the thermo-chemical conversion of waste organic materials like coffee grounds and sewage sludge, offers a sustainable alternative to conventional flame retardants [1-3]. Biochar's unique properties, such as high thermal stability and charring behavior, make it an effective component in fire-safe polymeric systems like coatings, composites, and textiles. In particular, by incorporating biochar into epoxy resins, significant improvements in fire protection, such as a UL 94 V0 rating, were achieved in vertical flame spread tests (Figure 1). Coffee-derived biochar, when combined with ammonium polyphosphate (APP) and a sol-gel Si-Ti-Mg mixed oxide, reduced peak heat release rate and total smoke production by 65 and 11 %, respectively [2]. Similarly, biochar from hydrothermal liquefaction of civil sewage sludges, when combined with other additives (e.g., APP and urea), produced self-extinguishing composites with V0 rating [3]. These materials demonstrated strong flame retardancy, primarily due to the formation of a stable char and reduced smoke emission. Future research efforts will focus on optimizing biochar properties and integrating it into bioplastics or recycled polymers for a wider application toward the design of sustainable, fire-safe materials.

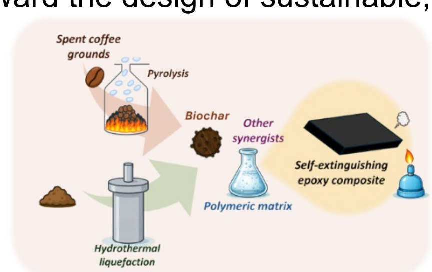


**Figure 1.** Preparation of self-extinguishing epoxy composites containing different biochars.

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25.

# Sustainable Flame-Retardant Polyelectrolyte Complexes for Efficient Treatment of Natural, Synthetic, and Blended Textiles

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Textile fabrics, as polymer-based materials, are inherently flammable and can readily propagate fire while releasing toxic gases during combustion. Depending on their composition, textiles may consist of natural fibers, synthetic fibers, or their blends. Natural fiber–based fabrics typically burn rapidly with sustained flaming, whereas synthetic fabrics tend to burn without intense flames, producing molten, burning droplets that can spread fire even after the visible flame has been extinguished. To mitigate these fire hazards, a wide range of flame-retardant chemistries has been developed. Nevertheless, many commercially used systems are still based on brominated compounds, which are environmentally harmful and associated with toxic and carcinogenic effects. Consequently, extensive research efforts have focused on developing sustainable, environmentally friendly, and bio-sourced flame retardants. Here, we report the fabrication of sustainable flame-retardant textile materials using intumescent systems composed of positively charged polyelectrolytes (chitosan or egg white proteins) and negatively charged polyelectrolytes (lignin or pectin), combined with nitrogen- and phosphorus-containing low-molecular-weight additives and tailored to the specific fiber composition. Fiber-specific flame-retardant strategies were demonstrated for cotton, polyester, and nylon/cotton (NYCO) textiles using water-based, bio-derived polyelectrolyte coatings. Effective flame retardancy was achieved at weight gains of approximately 6–10% for cotton, 40–45% for polyester fabrics, and 15–20% for blended nylon/cotton fabrics. For cotton fabrics, multilayer nanocoatings impart self-extinguishing behavior with only five bilayers applied, yielding char residues exceeding 30% at 600 °C and reductions of up to 60.1% in peak heat-release rate, 59.3% in total heat release, and 81.5% in fire growth capacity, while preserving mechanical properties and air permeability. For polyester, enzymatic–corona pretreatment enables efficient layer-by-layer deposition, achieving flame retardancy with only four bilayers, resulting in 43% lower peak heat-release rate, 23% lower total heat release, and 40% lower fire growth capacity. In NYCO fabrics, conformal polyelectrolyte complexes formed via a one-step complexation process generate an intumescent char layer leading to significant reductions in total heat release (32.6%) and fire growth capacity (37.9%) without compromising fabric flexibility. Overall, these results highlight scalable, environmentally benign flame-retardant chemistries tailored to the distinct physicochemical characteristics of different textile fibers, offering viable alternatives to conventional halogenated systems.

26.

# Safe-and-Sustainable-by-Design Flame Retardants for Insulation Foams

*Carl-Christoph Höhne[1], Benedikt Bitzer[1], Thomas Hennequin[2], Joséphine Steck[3], Marie Carriere[3], Nienke Ruijter[3], Susan Dekkers[2], Neeraj Shandilya[2], Chen Li[2], Valeria Berner[1], Paul Barthel[1], Jennifer Limburger[1], Jan Geerds[1], Anja Dennard[1], Martin Himly[4], Norbert Hofstaetter[4], Sabine Hofer[4], Sabrina Zambotti[5], Ayse Ay[6], Maximilian Bernard[7], Herbert Scharnagl[7], Leonhard Ritter[7], Tobias Moss[8], Roberto Chinchilla[8], Anita Sosnowska[9,10], Tomasz Puzyn[9,10], Szymon Zdybel[9,10], Poornima Nagesh[11], Laura Magnasco[12], Martina Riccio[12], Vanessa Alvear[13], Beatriz Alfaro[14], Sabine Fuchs[15], Jean Louis Beckmann[15]*

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The European Green Deal underscores the need for a Safe and Sustainable-by-Design (SSbD) strategy for chemicals and innovative materials. To support this goal, guidelines that define SSbD criteria and provide data-driven recommendations have been developed. Despite these efforts, successful implementation of SSbD in R&D projects remains limited. The PLANETS project [1] addresses this gap by promoting practical, cost-efficient SSbD strategies across the entire lifecycle - from molecular design and formulation to recycling and end-of-life management - using a tiered assessment approach as a case study during the development of SSbD flame retardants for thermoset and thermoplastic insulation foams. The presentation includes current results of the development of several classes of SSbD flame retardants from academic and industry partners for thermoplastic (expandable polystyrene EPS foam, extruded polyethylene XPE foam) and thermoset (polyurethane and polyisocyanurate foams) foams.

[1] https://www.project-planets.eu/

# Blooming and Dust Transfer Screening of Flame-Retardant Additives in Enclosure Plastics

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Flame-retardant (FR) additives are essential for meeting electronic housing fire-safety standards, but long-term additive migration can create surface "blooming" and potential transfer into indoor dust. We evaluated ABS, PP, and PC/ABS coupons representative of consumer electronics and formulated them with common FR packages (TBBPA, decaethane, and the phosphate RDP) designed to achieve UL-94 V-0 performance. We evaluated (1) flammability (UL-94), (2) thermal stability (TGA), (3) blooming using ASTM D8280-20 paper-flag collection with IC/ICP-MS endpoints, and (4) direct contact transfer into standard test dust using a small-chamber approach (ASTM D5116-25) at two dust loadings (30 and 60 $g/m^2$) over 5-35 days. All FR formulations self-extinguished and achieved V-0, while controls showed prolonged after-flame and dripping. Blooming and chemical transfer of FR into dust were detected only for PP+decaethane; other formulations remained below detection through 35 days at 70°C.

28.

# Sustainable Phosphorus-Based Flame Retardants: Sustainable Synthesis, Structure–Property Characterisation, and Fire Performance

*Dido Agostinis – AIMPLAS*

Phosphorus-based flame retardants (P-FRs) are among the most effective halogen-free solutions for reducing fire risk in polymeric materials, yet their next generation must balance high performance with improved sustainability. In this work, we report the synthesis of novel P-containing flame retardant structures using greener strategies, including solvent minimization, milder reaction conditions, and the use of renewable or low-toxicity building blocks where feasible. The obtained materials are comprehensively characterized by spectroscopic and thermal methods (e.g., NMR/FTIR, elemental analysis, TGA/DSC), and their morphology and dispersion in representative polymer matrices are assessed to establish structure–property relationships. Flame-retardant efficiency is evaluated through standardized fire testing (e.g., LOI, UL-94, cone calorimetry), supported by analysis of condensed-phase char formation and gas-phase inhibition pathways. Overall, the study demonstrates how rational phosphorus chemistry, coupled with sustainability-oriented design, can deliver effective flame retardants with reduced environmental footprint and robust fire performance.

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# Ignition propensities and combustion characteristics of some ligno-cellulosic materials in the context of wildland fires

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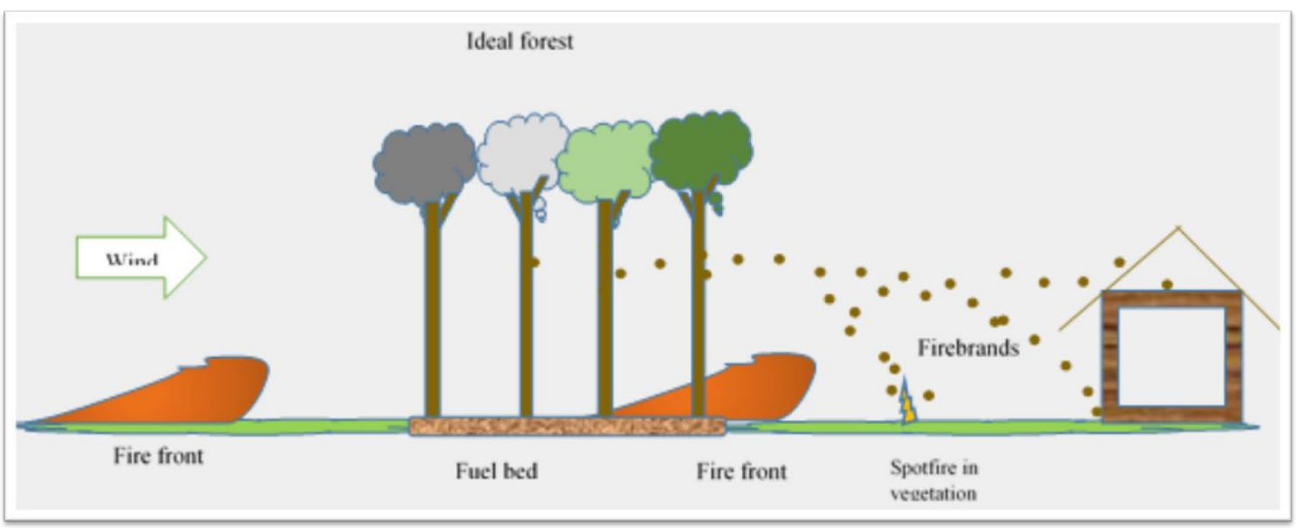
Combustion characteristics of ligno-cellulosic materials are of great interest in the context wildland fires, as they form the primary fuel load. Given the heterogeneous nature and wider compositional variations amongst the ligno-cellulosic components that are involved in these types of fires, the combustion attributes of such materials are often complex. In order to devise effective means of passively protecting residential buildings at the wildland urban interfaces (WUI), especially in the event of 'spot' fires brought about by firebrands, we have investigated the overall pyrolytic profiles and flammability characteristics of these materials. In this context, we have also conducted some studies pertaining to common vegetative fuels that are found in pine and eucalyptus forests situated in the Victorian-region of Australia. With a view to deciphering the decomposition pathways and combustion features of these materials, we have also employed a host of analytical techniques that encompassed thermal, calorimetric and flammability assessment tests.



30.

# A comparison of permeation of toxic combustion products through new and retired firefighters' jackets

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This paper presents an experimental study of the permeation of toxic combustion products through layers of firefighters' protective jackets using a customized small-scale setup. The swatches of three new (unused) and one retired (used) ensembles were exposed to fire effluent generated by burning a mixture of solid fuels. The transfer of toxic compounds such as polycyclic aromatic hydrocarbons (PAHs), volatile and semi-volatile organic compounds (VOCs), carboxylic acids with long hydrocarbon chains and other compounds was monitored using Gas Chromatography-Mass Spectrometry (GC-MS) technique. The results revealed that all ensembles were effective in preventing the movement of larger PAHs such as pyrene, bezo(α)pyrene, and phenanthrene across the layers to the interior of a jacket. However, it was found that toluene, naphthalene and its derivatives, some fatty acids and/or their esters could diffuse through the layers of a retired suit and two of the new (unused) ensembles. In addition, an endocrine disruptor, bis(2-ethylhexyl)phthalate, was detected on both sides of all ensembles. For the new ensemble, with a polyfluorinated finish in its membrane layer, one fluorinated compound was detected in the exposure chamber, but not on the cooler side of the swatch. Furthermore, it was found that the retired suit could not prevent the diffusion of acidic vapors as the pH levels on both the exterior and interior of this ensemble had similar and strongly acidic values.

# A New Kid on the Block for Flame Retardancy of Expanded Polystyrene

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The Anthropocene has placed unprecedented strain on the planet's ecological boundaries—thresholds that define the safe operating space within which humanity can continue to develop sustainably. By 2023, six of the nine planetary boundaries had already been exceeded.[i] This highlights the urgent need for alternatives to conventional, resource-intensive uses of raw materials and energy, which are incompatible with maintaining Earth's long-term stability and resilience.

At the same time, global building-related energy consumption continues to rise, accounting for roughly 30% of total energy use worldwide.[ii] Substantial reductions in both energy demand and material consumption can be achieved through the use of foamed insulation materials. Expanded polystyrene (EPS), for instance, offers several advantages—its lightweight structure (up to 95% air), low thermal conductivity, impact resistance, ease of processing, and low cost.

However, EPS suffers from a critical drawback: it is highly flammable and, when ignited, produces dense smoke, toxic gases, and high heat release. Improving its fire resistance is therefore essential. After the ban of hexabromocyclododecane (HBCD)—formerly the dominant flame retardant for both EPS and XPS—polymeric brominated flame retardants, used in combination with dicumene as a synergist, have become the standard within the European Union.

Looking ahead, halogen-free flame retardant technologies are expected to gain prominence, as regulatory bodies increasingly scrutinize and potentially restrict the use of brominated flame retardants due to their environmental and health impacts.

In this presentation, I will introduce a novel halogen-free flame retardant suitable for incorporation during styrene suspension polymerization or during the extrusion of general-purpose polystyrene, enabling the subsequent production of flame-retarded EPS.

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[i] Katherine Richardson, et al, Earth beyond six of the nine planetary boundaries, Science Advances 9(27) (13 Sep 2023).

[ii] https://www.iea.org/energy-system/buildings

32.

# Closing the Loop: From Biomass to Innovative Flame Retardant Biocomposites & Biofuels

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The concept of closed loop in the context of biomass involves eco-design of sustainable system where organic materials are continuously reused and recycled, minimizing waste and environmental impact. Green multifunctional composites made from biomass-derived fibers and sustainable polylactic acid (PLA) are gaining significant attention due to their environmental benefits and versatile applications. PLA is a biodegradable polymer derived from renewable resources, therefore its reinforcement with natural fibers is resulting in fully biodegradable composites. In the first step fibers were extracted from *Spartium Junceum* L. and *Sida Hermaphrodita* energy crops. Further important outcome of this research is the cascade usage of solid residues remaining after the fiber isolation for biofuel production, supporting the zero-waste principle. In the second step fibers were functionalized with mixture of vegetable drying oil, montmorillonite nanoclay (MMT), zinc oxide and milled cork and positioned between two PLA sheets to form sandwiched structure. Our results confirmed very good mechanical, thermal and protective properties of composites reinforced with biomass-derived fibers, such as excellent flame retardance and antibacterial effectiveness. Developed green composites offer innovative solutions to environmental challenges posed by traditional materials while their wide range of applications make them an essential component in the transition towards a more sustainable future.

**Keywords:** closed loop, biomass-derived fibers, green biocomposites, flame retardancy, zero-waste

# Surface Functionalization Strategies for Reducing Flammability of Nylon, Cotton, and NyCo Fabric

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Cotton, Nylon and a 50/50 blend of Nylon and Cotton (Nyco) are widely used by the department of defense for a variety of applications due to the excellent combination of mechanical properties, comfort, and availability at a reasonable cost. However all these fabrics are flammable and to address the flammability of these fabrics, several approaches have been developed over the years. Cellulosic fabrics typically require phosphorus-based flame-retardant compounds to impart self-extinguishing characteristics. Various chemistries and processes were developed to covalently functionalize phosphorus based compounds on to cotton fabric. These compounds help in catalyzing the carbonization of cellulose, increasing the char formation, and giving rise to self-extinguishing fabrics with a char length of less than 4 inches in standard vertical flame tests. Nylon is also extremely flammable but exhibits excellent mechanical properties and therefore used in numerous applications including tents. Nylon being a flammable thermoplastic material it exhibits flaming melt dripping behavior upon exposure to flame. Polyphenols such as tannic acid can be coated onto the surface of the fabrics via acid dyeing techniques to yield nylon fabric with self-extinguishing characteristics. However, melt dripping and flaming drips cannot be controlled using this approach. To address this a novel phosphorus–nitrogen flame retardant based on DOPO (9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide)-imine has been synthesized and characterized. The flame retardant was thermally grafted onto Nylon fabric, to ensure durability of the coating while preserving mechanical strength, flexibility, softness of the fabric while providing self-extinguishing characteristics without any melt dripping. Nyco is also inherently flammable, despite its excellent mechanical properties. The burning behavior is also unique due to the combination of a natural fiber (cotton) and a thermoplastic polymer (nylon) in the fiber blend which gives rise to the scaffolding effect. To address the flammability of Nyco fabric, several approaches have been developed. The combination of polyphenols along with a phosphorous containing compounds can impart FR characteristics. However, the launder durability of FR behavior was limited. More recently modified forms of DOPO have been synthesized and coated on Nyco fabric and durable FR behavior has been observed. A systematic approach to functionalizing Nylon, Cotton and Nyco fabric along with structure-activity relationship will be presented. Detailed spectroscopic and thermal characterization of all treated fabric will also be presented. Preliminary mechanistic understanding of FR action in each of these cases will also be presented.

# DEVELOPMENT AND SCALE-UP OF INTUMESCENT WATERBONE COATINGS FOR WOODEN STRUCTURES

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The present work reports the development of a free-melamine water-based intumescent coating for the fire protection of wooden structures. The core components of the intumescent coating, an acid source, a blowing agent, and a carbon source, were combined with a urea-formaldehyde (UF) binder. The latter was characterized by $^{13}$C-NMR and MALDI-TOF spectroscopy to determine respectively the polymer structures and molecular weight with particular attention to the determination of volatile substrates (formaldehyde). Thermal and fire-retardant properties of the formulation was characterized by thermogravimetric analysis (TGA) and cone calorimeter, yielding $THR_{600s}$= 19 MJ/m$^2$ and $HRR_{600s}$= 68 KW/m$^2$, demonstrating robust fire-protective properties. The process is now progressing toward large-scale implementation, with the next development phase involving pilot-plant production.

# A Journey Around Circularity in Polymers: Bio-Based Copolymerizable Flame-Retardant Systems for Sustainable Fire-Safe Materials

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*Research Director, CNRS*
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*https://www.icgm.fr [icgm.fr]*

The growing demand for fire-safe polymeric materials is increasingly constrained by environmental, health, and regulatory requirements, particularly regarding halogenated flame retardants and fossil-derived additives. In this context, developing sustainable, non-toxic, and circular flame-retardant solutions represents a major challenge for polymer science. In recent years, our group has developed platforms of bio-based aromatic building blocks derived from natural phenols such as tannins, lignin-based vanillin, eugenol, and cardanol, enabling the design of intrinsically flame-retardant and copolymerizable systems. These renewable monomers can be functionalized with epoxy, amine, cyclic carbonate (for non-isocyanate polyurethanes), (meth)acrylate, or isocyanate groups, allowing their covalent incorporation into thermosets and copolymers rather than physical blending.

Special attention has been devoted to the development of biosourced flame-retardant additives and comonomers, exploiting aromaticity, phenolic structures, and phosphorus-containing motifs to enhance char formation, thermal stability, and fire performance. These approaches have been applied to epoxy resins, polyurethanes (including fully bio-based systems), demonstrating efficient fire retardancy while preserving mechanical properties and long-term stability. Beyond material design, we address end-of-life considerations, showing that the use of copolymerizable, biobased flame-retardant building blocks is compatible with chemical recycling strategies. We report the recycling of thermosetting biobased polyurethane foams and the closed-loop recovery of bio-based monomers and fibers from epoxy composites, paving the way toward circular, fire-safe polymer systems.

Overall, this work illustrates how biosourced, copolymerizable flame-retardant additives can reconcile fire performance, sustainability, and circularity, offering new perspectives for the next generation of sustainable fire-resistant polymers.

# Novel Durable 'No Melt Drip' Flame Retardant Coatings for Nylon 6,6 Fabrics

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Nylon 6,6 is widely used in high-performance textiles, including military uniforms and protective gear; however, its inherent flammability and 'melt dripping' during burning pose serious safety concerns. To address this limitation, a novel phosphorus–nitrogen flame retardant based on DOPO (9,10-dihydro-9-oxa-10-phosphaphenanthrene-10-oxide)-imine was synthesized and structurally confirmed using FTIR and NMR spectroscopy. The flame retardant was thermally grafted onto Nylon 6,6 fabric to impart durability while maintaining mechanical strength, flexibility, softness, and fabric hand. Thermogravimetric analysis demonstrated enhanced thermal stability and increased char yield for treated fabrics compared to neat Nylon. Vertical flame tests showed self-extinguishing behavior with reduced burn length. It is hypothesized that the synergistic action of gas-phase radical quenching and condensed-phase char formation are responsible for the effectiveness of DOPO-based chemistry in enhancing the fire safety of Nylon-based materials. This work provides a feasible pathway for developing high-performance Nylon 6,6 fabric with flame retardancy without melt dripping upon ignition, opening the possibility for utilization in numerous applications.

**Keywords**: Nylon 6,6, thermal grafting, DOPO, flame-retardant

**References:**

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37.

# Flame retardancy of cross-linked cyanate ester / amorphous engineering polymer blends

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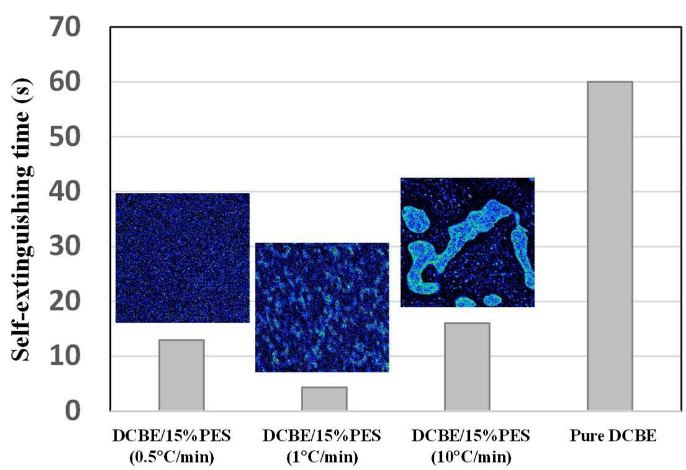
Cross-linked cyanate ester polymers are characterized by their high heat resistance, low water absorption, and low dielectric constant. These polymers are cross-linked by the trimerization of cyanate groups, which makes them less flammable than cross-linked epoxy polymers. This presentation examines the effects of blending amorphous engineering polymers with cyanate ester polymers on phase structure and flame retardancy. Dicyanate ester of bisphenol E (DCBE) was used as the liquid cyanate ester monomer. Polyether sulfone (PES) and functionalized polyphenylene ether were selected as the amorphous engineering polymers for making cross-linked polymer blends. After curing, DCBE/15 wt% PES blends formed co-continuous phase structures ranging from submicrometer to micrometer scales due to polymerization-induced phase separation. The phase sizes and glass-transition temperatures of the two phases varied with ramp rates for curing. The self-extinguishing times of the blends were shorter than that of the pure cross-linked cyanate ester and depended on the curing ramp rates (see figure).



38.

# Novel Fire-Resistant Composites Based on In-Situ Formation of Flame Barrier

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*sharon.ma@avient.com*

Thermoplastic composites offer compelling advantages—including lightweight, recyclability, and high impact resistance—but their inherent flammability poses a significant challenge, particularly in uni-directional (UD) continuous glass fiber reinforced systems. This study introduces a novel flame-retardant composite that forms a cohesive, self-supporting ceramic-like barrier in situ at relatively low temperatures. The new material demonstrates exceptional thermal stability, maintaining dimensional integrity and resisting deformation under exposure to temperatures up to 1000 °C. Cone calorimetry tests showed a 22% reduction in peak heat release rate and a 31% decrease in total smoke production compared to control samples. Additionally, the composite exhibits significantly lower linear shrinkage and bending deformation, as well as good thermal shock resistance. This integrated flame-retardant approach has been effectively applied to sandwich panel constructions, achieving ASTM E84 (Steiner Tunnel test) Class A ratings with limited flame spread and low smoke development. Furthermore, the panels successfully passed NFPA 286 (Corner Room Fire test), confirming their performance at the system level.

# Synergistic bio-based flame retardant systems for polypropylene

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A halogen-free, bio-based flame retardant derived from cellulose esters and phosphorylated sugar alcohols (CeAcBu-PAHE) and its synergistic combination with synergistic disulfide co-flame retardants like poly-*tert*-butylphenol disulfide (PBDS) in polypropylne is presented. A modified diacrylate derivative (CeDiAcBu-PAHE) was synthesized to improve compatibility with nonpolar polyolefin matrices (Figure 1).
Thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), limiting oxygen index (LOI), UL 94 vertical testing, and pyrolysis GC–MS were used to evaluate their flame-retardant efficiency and mechanisms.

The combination of CeAcBu-PAHE with PBDS combination showed strong synergistic effects, achieving a UL 94 vertical classification with total afterburning times below 11 s, increasing the LOI to ~22 % at only 5 wt. % loading. Pyrolysis GC–MS detected phosphorus- and sulfur-containing volatiles, confirming a gas-phase radical-inhibition mechanism. Although no significant char formation was observed at low loadings, the bio-based flame retardant system achieved flame-retardant performances comparable to commercial phosphorus references at substantially lower phosphorus content.

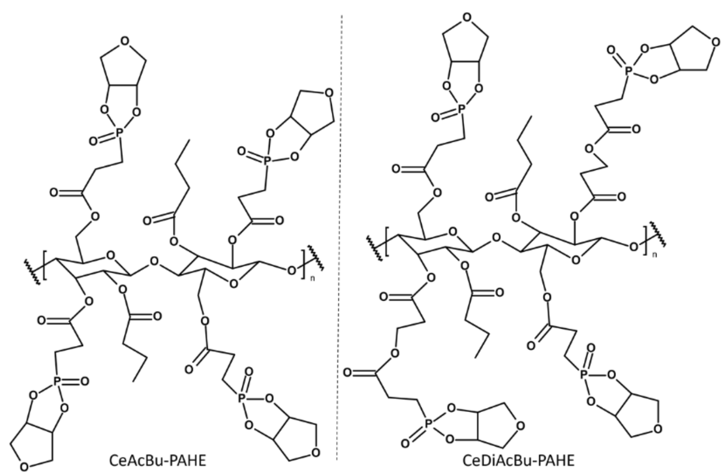


**Figure 1**: Chemical structure of the bio-based flame retardants

40.

# Can cork do more than preserve a good wine?

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Flame retarded bioplastics: The flame retardancy of three cork particle sizes was investigated in polylactide acid (PLA) and combined with barrier forming ammonium polyphosphate (APP), flame-poisoning 9,10-dihydro-9-oxa-10-phosphaphenanthren-10-oxid (DOPO) and the newly synthesized bio-flame retardant melem phytate.
V0 was achieved with only 10wt.% APP, DOPO, and melem phytate, respectively. With increasing particle size, cork composites reduced peak heat release rate (pHRR) from 703kW/m² (PLA) to 280kW/m² in PLA with 20wt.% cork. Combining flame retardants and cork resulted in a crucial reduction in fire load up to 43% and pHRR up to 64%. Maximum tensile strength remained constant across the cork particle sizes. Injection molding and 3D printing were successful.

41.

# Non-Halogenated, High Molecular Weight Flame Retardant Additive to Produce Fire Resistant Fibers and Fabrics

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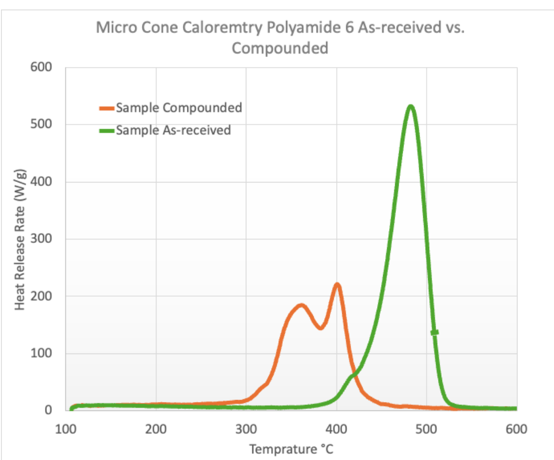
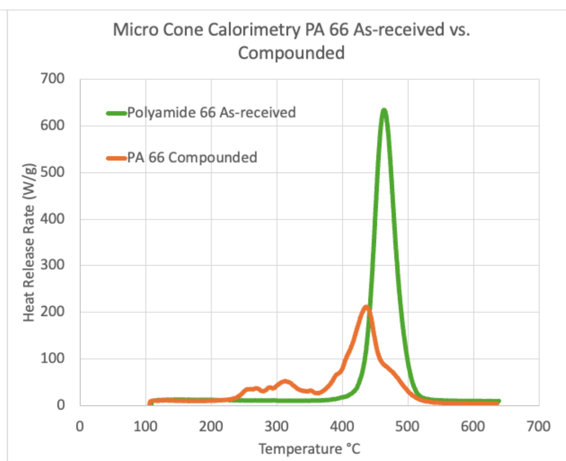
Increasing regulatory restrictions on halogenated flame retardants have necessitated the development of alternative solutions. Quantum Copper has formulated a non-halogenated, high-molecular-weight additive that is exempt under EPA guidelines. While certain polymers exhibit intrinsic flame resistance, most engineering thermoplastics remain combustible and require additive incorporation to achieve acceptable fire performance. Conventional aromatic polyamides (meta- and para-phenylene amides) provide superior flame resistance but are cost-prohibitive and exhibit limited processability.

We report a novel class of non-halogenated flame-retardant additives designed for melt blending with aliphatic polyamides. Incorporation into polyamide 6 reduced peak heat release rate (pHRR) from 525 W/g to 210 W/g, while polyamide 66 exhibited a reduction from 650 W/g to 205 W/g, as measured by cone calorimetry. Beyond thermal performance, these formulations maintained sufficient rheological properties to enable successful monofilament extrusion. Current work focuses on optimizing additive dispersion, evaluating mechanical property retention, and refining processing methodologies.




42.

# Molecular Engineering for Enhanced Flame Retardancy and Reduced Thermal Conductivity in Polymers

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Enhancing flame retardancy and reducing heat conduction in polymers is critical for preventing fire-related injuries and property damage, especially in construction and heating systems.[1] Challenges persist due to unclear thermal transport mechanisms, which have not been extensively explored compared to crystals.[2,3] Existing theories cannot accurately predict thermal transport properties, necessitating further experimental validation.[4] While common polymers have low thermal conductivities, efforts are needed to lower these limits further. This talk focuses on designing polymers with enhanced flame retardancy and reduced thermal conductivity at the molecular level. Introducing small molecules into polyurethane as scattering sites for heat transfer effectively reduces thermal conductivity.[5] Our results demonstrate a notable 30% decrease in thermal conductivities of polyurethane-blends compared to pure polyurethane, with a significant 50% decrease in heat release value. Leveraging the structure of widely used polyurethane enables us to enhance thermal resistance, potentially benefiting various thermal applications.

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# POSTER PROGRAM

Polymers for Fuel Cells, Energy Storage, and Conversion 2025

November 2-5, 2025

Safety Harbor, FL

# MONDAY, MAY 18, 2026

| | **POSTER PROGRAM** |
|---|---|
| 1. | Youssouf Abdelhafiz, **Abdenour Amokrane**, Gérald Debenest, and Serge Bourbigot<br>EDF R&D<br>*Assessing Key Assumptions in Polymer Pyrolysis Models and Reducing Experimental Effort Using GA-Based Inverse Modeling* |
| 2. | **Karen Cortes-Guzman**, Demchuk Zoriana, Tang Mengjia, Sumathipala Kuma, Hun Diana E., and Saito Tomonori<br>Oak Ridge National Laboratory<br>*Molecular Architecture Effects in Phosphorous Flame Retardants: Quantifying the Influence of Phosphate Loading vs Aromatic Content in Fire Performance* |
| 3. | **Zoriana Demchuk**, Karen Cortes Guzman, Mengjia Tang, Kuma Sumanthipala, and Diana Hun<br>Oak Ridge National Laboratory<br>*Non-toxic, Affordable Phosphorous-Based Flame Retardants for Multi-substrate Applications* |
| 4. | **Ryan Greene**, Alec Tripi, Isaac Leventon, and Kevin McGrattan<br>Fire Research Division, National Institute of Standards and Technology<br>*Measurement of the Average Molecular Formula of Gaseous Pyrolyzates Produced by Combustible Solids* |
| 5. | **Grace Inman**, Kathryn Wnuk-Fink, Aaron Bruckbauer, Cailtin Hudecek, Matthew Halloran, Aanchal Jaisingh, and Michael D. Burkart<br>University of California San Diego<br>*Recent Advances of 100% Bio-Based Thermoplastic Polyester Polyurethanes and Future Directions for Renewable Flame-Retardant Materials* |
| 6. | **Margaret J. Karim**, Dallin L. Smith, Zachary Buck, Kristin L. Smith, Sarah G. Fisher, and Jaime C. Grunlan<br>Texas A&M University<br>*Chemical Anchoring and Crosslinking of Polyelectrolyte Complex for Durable Flame Retardant Cotton* |
| 7. | **Athena Kolli**, Changxin (Lyla) Dong, Matthew Szedlock, and Eric A. Appel<br>Stanford University<br>*Advancing Sustainable Wildfire Management with Struvite-Based Hydrogel Retardants* |
| 8. | **Jessica Passaro**, Immacolata Mazzuoccolo, Immacolata Climaco, Giulio Malucelli, Antonio Aronne, Pietro Russo, Sabyasachi Gaan, and Aurelio Bifulco<br>Institute of Polymers, Composites and Biomaterials (IPCB)<br>*HTL Biochar and Functionalized PVP–Silica Fiber Reinforced Flame-Retardant Epoxy Composites* |
| 9. | **Madigan Petri**, Dallin L. Smith, Maya D. Montemayor, Federico Carosio, and Jaime C. Grunlan<br>Texas A&M University<br>*Universal intumescent polyelectrolyte complex treatment for cotton, polyester, and blends thereof* |

| | POSTER PROGRAM |
|---|---|
| 10. | **Koteswar Rayachur**, Krishnamurthy Munusamy, Jainam Shah, Ravi Mosurkal, Jayant Kumar, and Ramaswamy Nagarajan<br>University of Massachusetts, Lowell<br>*High-Performance Flame-Retardant Fabrics via Scalable Thermal Grafting of Novel DOPO Derivatives* |
| 11. | **Luyi Sun**<br>University of Connecticut<br>*Scalable and Environmentally Friendly Flame-Retardant Nanocoatings via One-Step Self-Assembly* |
| 12. | **Kun-Ling Teng**, Yuan-Hsiang Yu, Hsinjin Edwin Yang, and Yao-ting Huang<br>Fu Jen Catholic University<br>*Nitrogen-Containing Ni-MOF/Polyurethane Composites: Influence of Dispersion Strategy on Thermal Stability and Flame-Retardant Performance* |
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# POSTER ABSTRACTS

Polymers for Fuel Cells, Energy Storage, and Conversion 2025

November 2-5, 2025

Safety Harbor, FL

1.

# Assessing Key Assumptions in Polymer Pyrolysis Models and Reducing Experimental Effort Using GA-Based Inverse Modeling

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This study investigates the pyrolysis of calcium carbonate-filled PVC (FPVC) using the Gpyro software, supported by experimental data from cone calorimeter tests, TGA (Thermogravimetric Analysis), DSC (Differential Scanning Calorimetry), and TPS (Transient Plane Source) measurements. Cone calorimeter experiments measured MLR (Mass Loss Rate) and HRR (Heat Release Rate) under heat fluxes of 35 and 50 kW/m² for two sample thicknesses (3 mm and 6 mm), while TGA and DSC characterized chemical kinetics and reaction enthalpies, and TPS assessed thermal conductivity.

The objective is to evaluate common assumptions in polymer pyrolysis modeling. To this end, inverse simulations were performed using a Genetic Algorithm (GA) coupled with Gpyro, optimizing the model on one or two cone calorimeter tests and validating it on others. Two key assumptions were examined: (1) extending virgin material properties to degraded states, and (2) considering thermal radiation within pores.

Results show that allowing property variation significantly improves accuracy, while radiation has only a minor effect. An addition, the study confirms that GA-based inverse modeling is a powerful tool for completing missing input parameters and that optimizing only the most influential parameters is sufficient for reliable predictions.

Although this study focuses on FPVC, the proposed methodology is broadly applicable to other polymers. It can significantly reduce the number of experiments required to determine thermophysical properties and assess the physical assumptions, making pyrolysis modeling more efficient and cost-effective.

2.

# Molecular Architecture Effects in Phosphorous Flame Retardants: Quantifying the Influence of Phosphate Loading vs Aromatic Content in fire performance

***Cortes-Guzman Karen P.*[1]*;*** *Demchuk Zoriana[1]; Tang Mengjia[2]; Sumathipala Kuma[2]; Hun Diana E.[2]; Saito Tomonori[1].*

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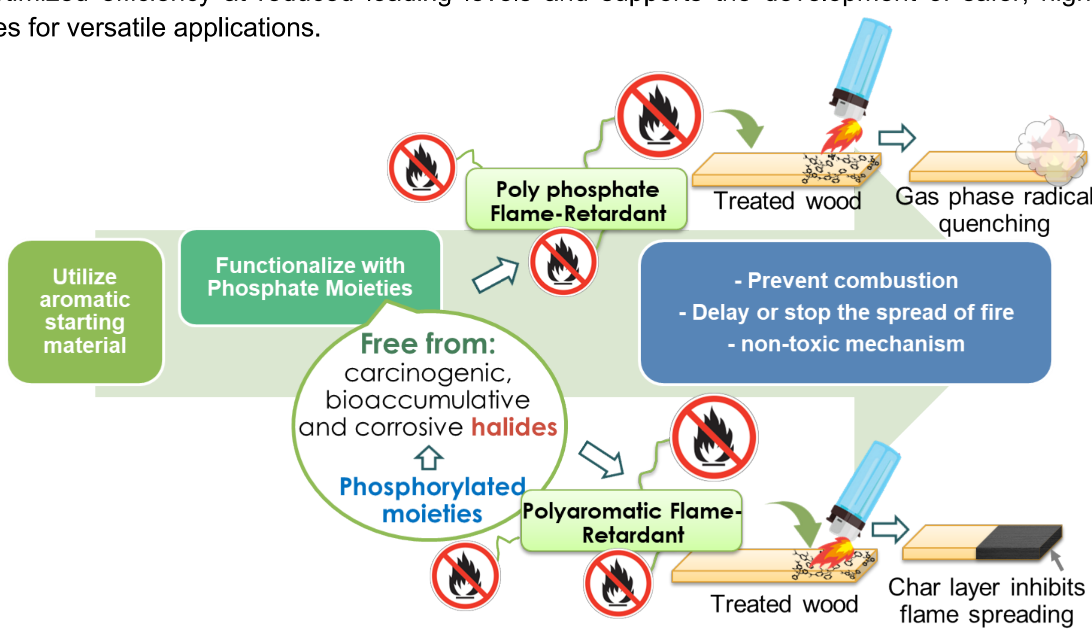
Phosphorus-containing flame retardants are widely recognized for their ability to act through both gas-phase radical quenching and condensed-phase char-forming mechanisms; however, the relative contribution of molecular structure parameters that govern these pathways remains insufficiently understood. In particular, the effect of phosphate functionality density and aromatic content presents a critical design variable for halogen-free non-toxic flame-retardants.

In this work, we systematically investigate the structure-property relationships governing flame-retardant performance by analyzing the influence of phosphate moiety concentration from aromatic ring content within a controlled series of synthesized flame retardants. By varying phosphorus loading independently from aromaticity, we quantify how these structural parameters influence thermal degradation pathways, char formation, and combustion behavior. Thermal analysis (TGA) is performed to analyze the influence on the char yield with the varying structures. The burning of multiple substrates loaded with these flame retardants following UL-94 methodology, allows comparison of the effectiveness of the flame retardants in stopping the flame spread, as well as the reduction of mass loss after burning. Our results demonstrate that phosphate density and aromatic content contribute synergistically but through distinct mechanistic pathways: increased phosphate functionality primarily enhances gas-phase action and inhibition of the flame spread, whereas aromatic content modulates structural integrity and barrier properties of the residue, influencing heat and mass transport during combustion. The findings provide quantitative insight into the transition between gas-phase-dominated and condensed-phase-dominated flame-retardant behavior as a function of molecular architecture.

This mechanistic understanding establishes molecular design guidelines for phosphorus-based flame retardants with optimized efficiency at reduced loading levels and supports the development of safer, high-performance additives for versatile applications.

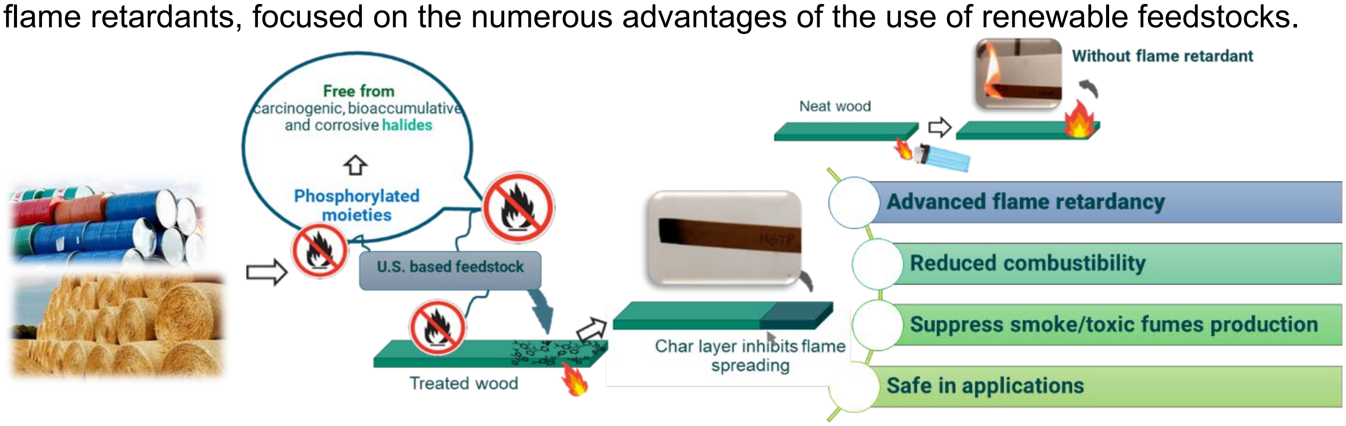


3.

# Non-toxic, Affordable Phosphorous-Based Flame Retardants for Multi-substrate Applications

*Zoriana Demchuk, Karen Cortes Guzman, Mengjia Tang, Kuma Sumanthipala, Diana Hun*
*demchukz@ornl.gov*

Incorporation of fire retardants in different types of products is one of the essential steps in the material production process to minimize fire risk and meet fire safety requirements. There are a variety of commonly used flame retardants based on halogen, mineral, and other compounds that gained popularity due to their efficient flame-retardant behaviors. However, especially in the case of halides, there are numerous toxicity related issues and negative environmental effects that have urged the building sector to deviate from their use and focus on the development of non-toxic alternatives. Therefore, to enhance the affordability and safety of flame retardants, the synthesis of flame retardants from domestic feedstocks with a dual flame-retardant mechanism has been established. The range of domestic/waste including glycerol, vanillin, and gallic acids has been converted into series of flame retardants using one-step approach by incorporation of phosphoric moieties into their structures. The established pathways allow to develop high-performance flame-retardant materials using energy-efficient approach. The introduction of abundant aromatic structures from domestic feedstocks allows to reach high charring capabilities in materials where these efficient flame retardants have been incorporated, increasing the char yields from 1-2% to 39%, which significantly enhances the flame suppressing properties of the designed materials. Studies show that inclusion of phosphoric moieties into structures allows the displacement of flame enhancing radicals, by releasing non-flammable and non-toxic gasses, therefore inhibiting the spread of fire in the gas phase. The resulting non-toxic, affordable flame retardants have been incorporated in wood substrates, insulation foams, polymer films, fabrics, and natural fibers where the results show that only 1-5% of loading of flame retardant allows to suppress the flame completely. This study represents a novel approach for the development of flame retardants, focused on the numerous advantages of the use of renewable feedstocks.



4.

# Measurement of the Average Molecular Formula of Gaseous Pyrolyzates Produced by Combustible Solids

Ryan Greene[1], Alec Tripi[1], Isaac Leventon[1], Kevin McGrattan[1]
[1]*Fire Research Division, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, United States of America*

Fire phenomena including ignition, burning rate, and flame spread are dependent on coupled interactions be-tween the solid- and gas-phases. Physics-based fire models such as the Fire Dynamics Simulator (FDS) require a comprehensive set of input parameters to capture this behavior. Specifically, an accurate description of the gaseous pyrolyzates which serve as the fuel for combustion is needed. While tools such as the cone calorimeter or microscale combustion calorimeter (MCC) can measure the fuel's energy content (i.e., heat of combustion, $\Delta H_C$), they are unable to define its thermophysical properties (e.g., diffusivity, D, heat capacity, c, and conduc-tivity, k) or the stoichiometry of the overall reaction.

The difficulty in identifying these species lies in the fact that the majority of materials pyrolyze into numerous volatile compounds. While methods exist to identify specific molecules, they often miss several compounds resulting in an incomplete mass balance. Furthermore, these techniques are time and resource intensive, limiting their applicability. Current modeling convention is therefore to use a surrogate fuel to represent the gaseous mixture. In FDS, predefined surrogates such as propane are available. Users can also define a molecular formula for the surrogate fuel which is used to calculate its thermophysical properties. Several studies have used this later approach, generating a molecular formula based on the elemental composition of their materials. While these user-defined surrogates may achieve more accurate stoichiometry, they may fail to sufficiently represent the molecular weights of the volatile species.

In this work, an experimental method was developed to generate a more accurate representation of the average pyrolyzate produced by a combustible solid. An organic elemental analyzer was used to determine elemen-tal composition (weight% CHNS-O), while a heated, non-stirred pressure vessel was used to determine the molecular weight of the average gaseous pyrolyzate. In the elemental analyzer, mg-scale samples of powdered material are either combusted to determine CHNS content or flash pyrolyzed to determine O content. Analyte gases produced by these reactions are separated and quantified through gas chromatography thermal conduc-tivity detection. For charring materials, elemental analysis was also performed on the char to determine the composition of the pyrolyzates themselves. Verification testing using a set of analytical standards accurately has demonstrated that atomic composition can be measured within 2% of its expected value. The pressure vessel consists of a stainless-steel chamber held within an insulated heating jacket. Gram-scale samples are pyrolyzed within the sealed, inert environment until pressure and temperature within the vessel stabilize. Pyrolyzate molecular weight, $W_{pyro}$, is determined through the application of the ideal gas law prior to heating and once stability has been achieved. Calibration runs performed without a sample demonstrated ideality held within 1.5%, while validation testing using materials with known decomposition products demonstrated an average accuracy of 4.6%. Results from tests performed on Poly(methyl methacrylate) (PMMA), polyoxymethylene (POM), high density polyethylene (HDPE), acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), Eastern White Pine, and Western Red Cedar (WRC) will be presented. Results from WRC testing were used in numerical simulations of upward flame spread, demonstrating significant improvement in predicted heat release rate and flame structure compared to cases where propane is the assumed fuel vapor.

5.

# Recent Advances of 100% Bio-Based Thermoplastic Polyester Polyurethanes and Future Directions for Renewable Flame-Retardant Materials

*Grace Inman, Kathryn Wnuk-Fink, Aaron Bruckbauer, Cailtin Hudecek, Matthew Halloran, Aanchal Jaisingh, Michael D. Burkart**

*UC San Diego Department of Chemistry and Biochemistry*

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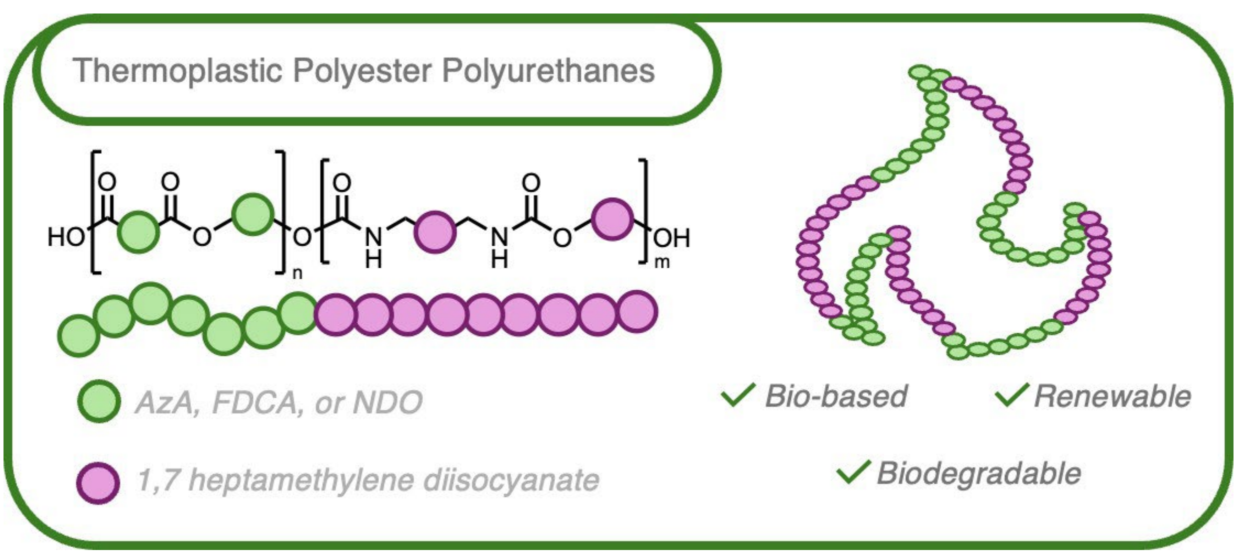
By leveraging flow chemistry advances in bio-based isocyanate synthesis and aromatic polyols, we have designed tunable TPU polymer structures that combine elasticity, durability, and controlled degradation. With our recently developed 100% biobased monomers such as 2,5 furandicarboxylic acid (FDCA), azelaic acid (AzA), and 1,9 nonanediol (NDO), our materials span all polyurethane classes such as TPUs, WPUDs, and foams. Preliminary work has shown that the integration of biobased aromatic moieties in our TPU materials enhances char formation and thermal stability when flame tested. Additionally, by integrating biodegradability with high-performance flame resistance, this work establishes a pathway toward polymer systems that addresses both fire safety and sustainability challenges. Future directions will focus on embedding phosphorus, nitrogen, and sulfur functionalities into isocyanate and polyol monomers to create covalently bonded flame-retardant systems.



6.

# Chemical Anchoring and Crosslinking of Polyelectrolyte Complex for Durable Flame Retardant Cotton

*Margaret J. Karim*[a] , *Dallin L. Smith*[a], *Zachary Buck*[b], *Kristin L. Smith*[c], *Sarah G. Fisher*[a], *and Jaime C. Grunlan*[abd*]

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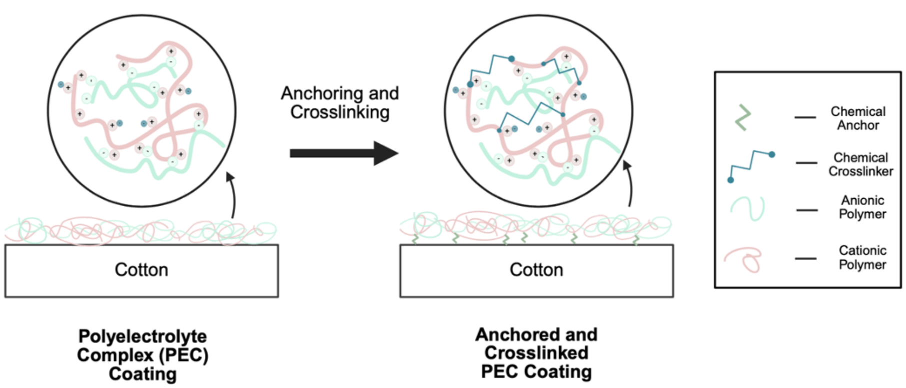
Halogen-free, environmentally benign flame-retardant (FR) polyelectrolyte complexes (PECs) formed from amine-containing polycations and phosphate-containing polyanions can render cotton textiles self-extinguishing. However, the practical use of PEC-based coatings is limited by poor wash durability, as their non-covalent interactions are easily disrupted in the wash cycle. In this presentation, we demonstrate a dual strategy to improve PEC durability on cotton textiles through covalent anchoring and PEC crosslinking. This approach produces robust polymer networks that maintain intumescent and self-extinguishing behavior even after 15 laundering cycles. The combined anchoring–crosslinking strategy significantly enhances the practicality of PEC-based FR coatings, advancing their potential for sustainable textile applications.



7.

# Advancing Sustainable Wildfire Management with Struvite-Based Hydrogel Retardants

*Athena Kolli, Changxin (Lyla) Dong, Matthew Szedlock, Eric A. Appel**
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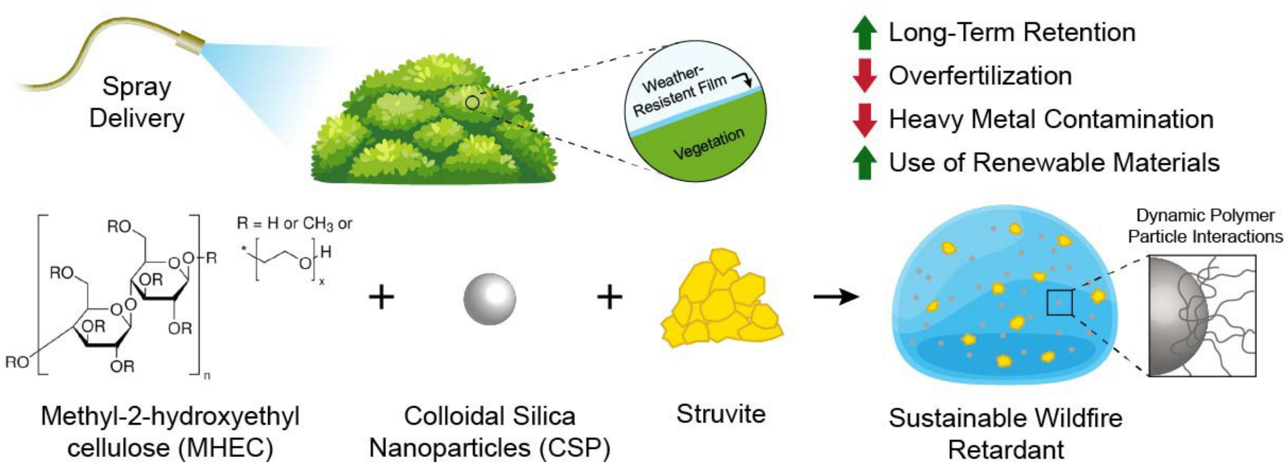
Wildfires pose a large and growing burden, with more than 10 million acres burned annually and associated costs and damages exceeding $500B in the United States alone. Current aerial fire retardants rely on ammonium polyphosphate (APP) formulations, which weather rapidly from treated surfaces, contribute to eutrophication, introduce heavy metal contaminants, and depend on non-renewable mined phosphates. Struvite, a nutrient-rich mineral recovered from wastewater, has been identified and investigated as a promising sustainable alternative to APP. By incorporating struvite within a polymer-particle hydrogel, a sprayable long-term retardant has been developed. Struvite possesses a similar fire-retarding chemistry to APP and thermal analyses demonstrate that the struvite hydrogel recapitulates key thermal decomposition behavior of APP. Mass spectrometry shows orders-of-magnitude lower heavy metal content relative to commercial formulations. Initial field-scale and environmental studies demonstrate that this struvite-based retardant has the potential to replace conventional retardants with a more sustainable approach to wildfire management.



8.

# HTL Biochar and Functionalized PVP–Silica Fiber Reinforced Flame-Retardant Epoxy Composites

Jessica Passaro[1,*], Immacolata Mazzuoccolo[2], Immacolata Climaco[2], Giulio Malucelli[3], Antonio Aronne[2], Pietro Russo[1], Sabyasachi Gaan[4], Aurelio Bifulco[2]

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This study investigates the valorization of biochar obtained from the hydrothermal liquefaction (HTL) of municipal sewage sludge to improve the sustainability of the overall process. The biochar was used as a functional additive in epoxy resins to enhance flame retardancy. After characterization, it was incorporated into an epoxy matrix (Figure 1) cured with a cycloaliphatic amine, together with tailored whisker-like silica particles coated with electrospun poly(vinylpyrrolidone) [1] to improve compatibility. Combined with ammonium polyphosphate and urea, these fillers enabled the development of no-drip, self-extinguishing composites achieving a V0 rating in UL-94 tests. Cone calorimetry showed a ~36% reduction in peak heat release rate and a 10% decrease in total smoke release. Flame retardancy mainly occurred in the condensed phase through the formation of a continuous ceramic char. Viscoelastic properties were largely maintained, with moderate changes in flexural behaviour. The composites also showed hydrophobic behavior, with water contact angles around 120° [2].

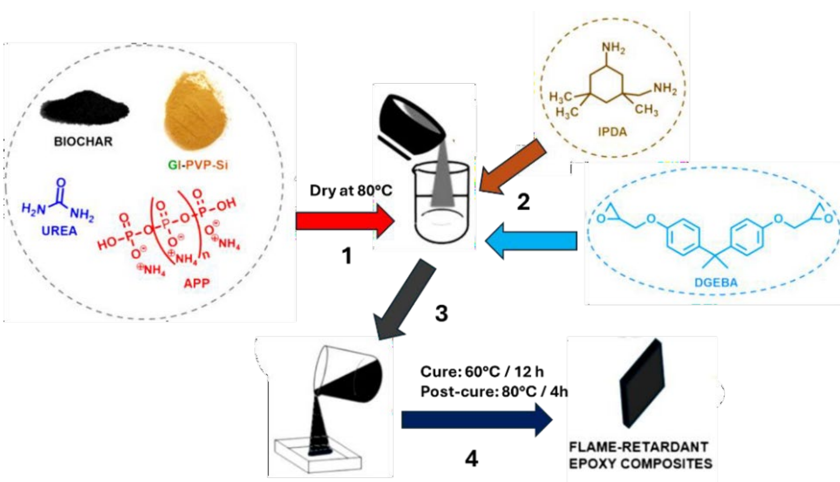


*Figure 1. Synthesis procedure of epoxy composites.*

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# Universal intumescent polyelectrolyte complex treatment for cotton, polyester, and blends thereof

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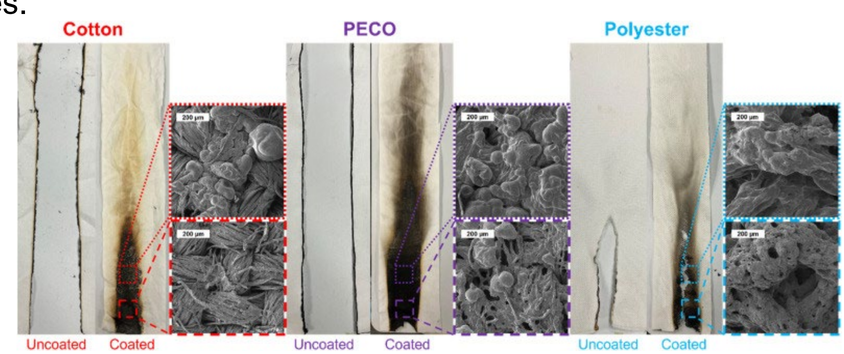
Given that the substrate is an active component in many flame retardant systems, it is difficult to apply the same approach to different materials and still achieve sufficient flame inhibition. However, polyelectrolyte complex (PEC) coatings have a broad substrate tolerance and are a potential universal treatment. PECs that contain nitrogen and phosphorus provide the blowing agent and acid source respectively while the carbon-rich substrate provides the char source. In the present study, a water-based PEC composed of poly(allylamine HCl) and sodium hexametaphosphate was applied to cotton, polyester, and blended cotton/polyester textiles via a coating and deposition process. The PEC reduced the flammability of all three substrates, including improved char yield, heat release, and volatile emission. Further strategies to enhance the wash-durability of this coating will be discussed. These results showcase intumescent PECs as effective and adaptable flame retardant coatings with the potential to replace potentially harmful alternatives.



10.

# High-Performance Flame-Retardant Fabrics via Scalable Thermal Grafting of Novel DOPO Derivatives

Koteswar Rayachur[1], Krishnamurthy Munusamy[1,2], Jainam Shah[1], Ravi Mosurkal[3,4], Jayant Kumar[2,4] and Ramaswamy Nagarajan[1,4*]

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[4]*The HEROES Initiative, Center for Advanced Material, University of Massachusetts, Lowell, MA, USA 01854*

The demand for PFAS-free, halogen-free, and environmentally responsible flame-retardant (FR) solutions is increasing, particularly for textile applications that require both durability and breathability. NyCO (nylon–cotton) fabrics are widely used in military, outdoor, and industrial garments due to their strength and comfort. However, their inherent flammability limits performance in fire-risk environments. Consequently, developing durable and scalable FR treatments for NyCO fabrics is a highly desirable objective.

We have developed a durable, breathable, scalable, halogen-free FR treatment based on a 9,10-Dihydro-9-oxa-10-phosphaphenanthrene-1-oxide (DOPO)-derived FR compound that can be directly grafted onto NyCO fabrics. The coating is applied through a rapid, chemistry-driven process compatible with industrial textile finishing, offering strong potential for efficient and scalable manufacturing. The treated fabrics exhibit excellent FR performance, characterized by rapid self-extinguishing behavior and fabric damage lengths below 5 inches in vertical burn testing. The treatment also demonstrates wash durability, maintaining high performance after ~10 laundry wash cycles. Air-permeability measurements confirm that fabric breathability is largely preserved after FR treatment. This work presents a practical and environmentally safer FR technology with significant potential for next-generation protective textiles.

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11.

# Scalable and Environmentally Friendly Flame-Retardant Nanocoatings via One-Step Self-Assembly

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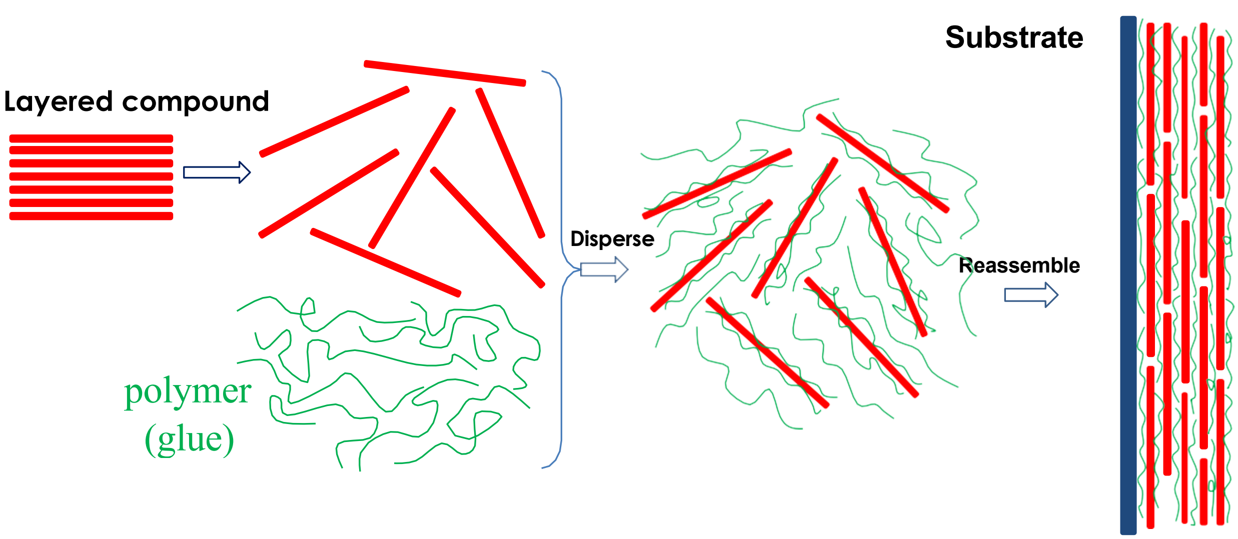
Flame-retardant additives are the most common approach for improving the flame resistance of materials. Among them, organohalogen and organophosphorus compounds are the two most widely used classes. Although these additives are effective in slowing flame propagation, they may also pose potential health and environmental concerns. Herein, we present an alternative strategy for achieving effective flame retardancy through the formation of a thin, waterborne nanocoating on the substrate surface. The nanocoating is produced by a one-step self-assembly process, during which hundreds of layers of inorganic nanosheets become highly aligned parallel to the substrate surface. This well-organized, nacre-like structure creates an effective physical barrier against both heat and oxygen, thereby delivering outstanding flame-retardant performance. The coating can be applied to a wide range of substrates, including films, sheets, foams, and fabrics. It is also compatible with various industrial coating methods and has been successfully scaled up in an industrial coating setup.



12.

# Nitrogen-Containing Ni-MOF/Polyurethane Composites: Influence of Dispersion Strategy on Thermal Stability and Flame-Retardant Performance

*Kun-Ling Teng, Yuan-Hsiang Yu*, Hsinjin Edwin Yang, Yao-ting Huang Department of Chemistry, Fu Jen Catholic University, New Taipei City, Taiwan 242062, ken880418@gmail.com*

In this study, thermoplastic polyurethane (PU)[1] was synthesized from polyethylene glycol and hexamethylene diisocyanate, and a nitrogen-containing nickel-based metal–organic framework (Ni-MOF) was incorporated as a halogen-free flame-retardant filler to mitigate the intrinsic flammability of PU[2]. The PUNi-MOF composites were fabricated via solution mixing, in situ polymerization, and pre-modification routes, and the effects of Ni-MOF loading and dispersion strategy on morphology, thermal properties, mechanical behavior, and microscale combustion performance were systematically investigated. Results from thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), and microscale combustion calorimetry (MCC) demonstrate that, under suitable preparation routes and at low Ni-MOF contents, the initial decomposition temperature and storage modulus of PU are enhanced, while the peak heat release rate and heat of combustion are effectively reduced, confirming that well-designed interfacial interactions and uniform MOF dispersion facilitate the formation of a protective char layer and significantly improve flame-retardant efficiency.

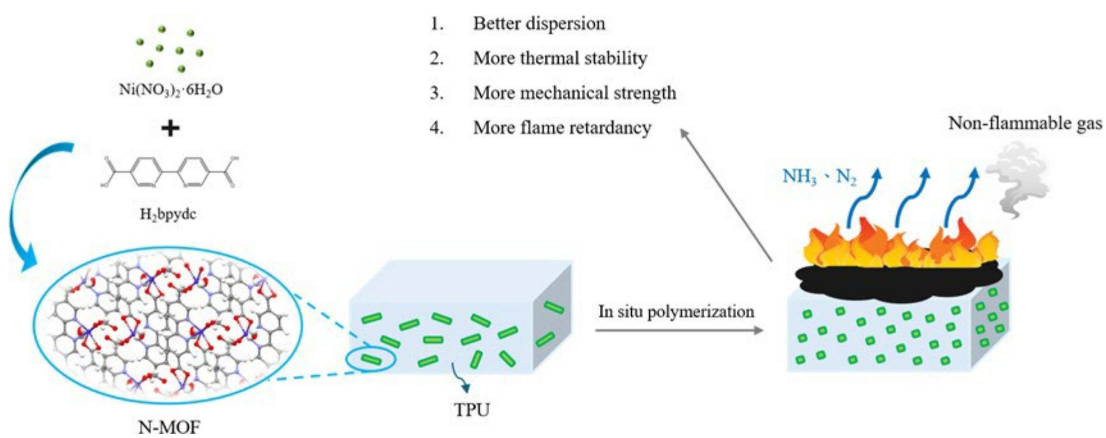



Figure Schematic illustration of PU/Ni-MOF composites

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# Eu MOF/Polyimide Nanocomposite Films with $Eu_2O_3$/Carbon Char Barriers for Enhanced Halogen-Free Flame Retardancy

*Kun Ling Teng, Yuan-Hsiang Yu, Hsinjin Edwin Yang*

*Department of Chemistry, Fu Jen Catholic University, Taiwan; Society of Plastics Engineers (SPE), etc.*

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This work developed Eu metal organic framework (Eu MOF)/polyimide (PI) nanocomposite films with covalent Eu MOF–ODA linkages, achieving nanoscale dispersion while retaining thermal and mechanical properties of PI. Adding 1–5 wt% Eu MOF maintained Td, onset at 511–521 ℃, raised char yield to 53–56 wt%, and reduced peak heat release rate from 159.6 to 111.1 W $g^{-1}$ and total heat of combustion by ~18%, lowering the flammability index from 0.209 to 0.118. Lewis-acidic $Eu^{3+}$, MOF porosity, and $Eu_2O_3$/graphitized-carbon residues synergistically enhanced condensed-phase, halogen-free flame retardancy.

14.

# Stress-Induced Changes in PFAS in Structural and Wildland Firefighter Textiles

*Andre L. Thompson,[1] Andrew Maizel,[1] Audrey Tombaugh,[1] Halen Solomon,[1] Bruce Benner,[2] Alix Rodowa,[2] Michelle Donnelly,[1] Rick Davis[1]*

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*[2]Chemical Sciences Division, Material Measurement Lab, NIST Speaker*

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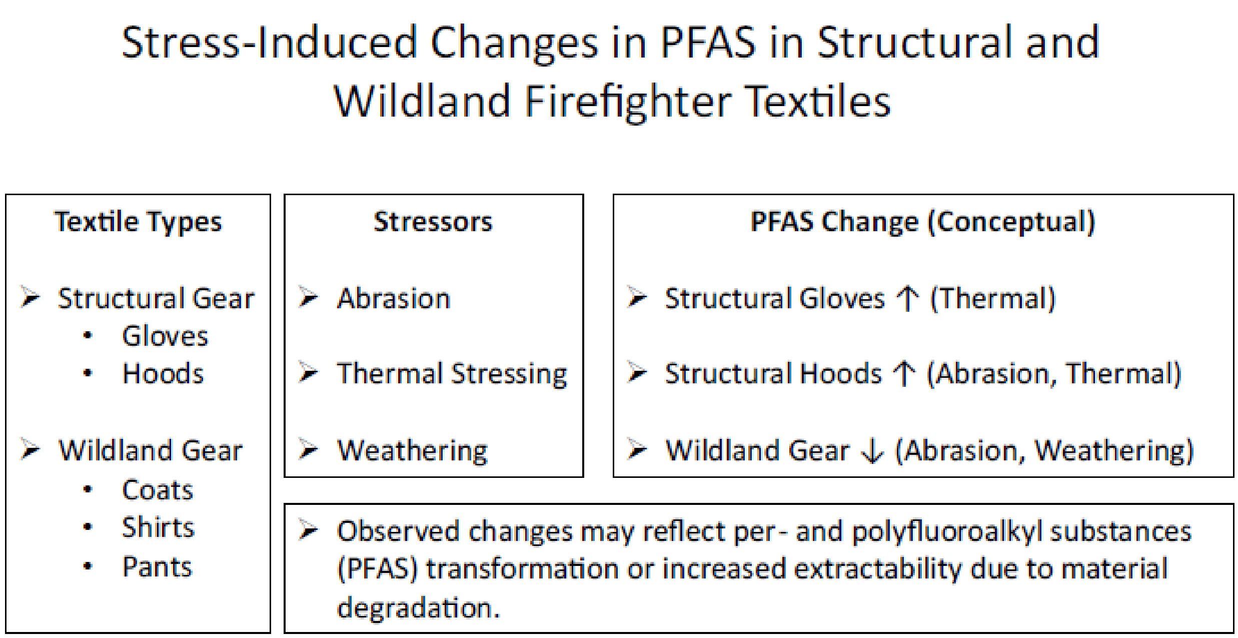
Structural and wildland firefighter textiles have been identified as potential sources of exposure to per- and polyfluoroalkyl substances (PFAS). This study evaluated PFAS concentrations in structural gloves and hoods, and wildland coats, shirts, and pants following abrasion, thermal stressing, and weathering. Measurements of 56 PFAS across 22 samples showed that stressors altered PFAS levels. Relative to unstressed textiles, glove layers exhibited higher total PFAS after thermal stressing, and hood textiles showed increases after abrasion and thermal stressing. Wildland textiles exhibited lower total PFAS following abrasion and weathering. These trends were driven by shifts in dominant PFAS within each textile type. While stressors influenced PFAS concentrations, the methods used could not distinguish between chemical transformation and increased extractability due to material degradation.



15.

# Protecting Critical Infrastructure: Advanced Intumescent Coatings for Commercial and Industrial Applications

*Haley Young, PPG Industries*

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Passive fire protection (PFP) coatings are critical safety systems that provide structural fire resistance. Intumescent coatings function through sophisticated chemical mechanisms, generating gases that expand the coating into a thick char layer. This expansion process is crucial for PFP effectiveness, significantly reducing heat transfer to the underlying steel substrate. Fire scenarios are categorized into two primary types. Cellulosic fires (building fires involving wood and textiles) develop gradually, while hydrocarbon fires (involving flammable liquids) are more severe in their temperature escalation. Each fire type demands specifically formulated intumescent systems to ensure adequate protection. PPG's intumescent coating portfolio leverages advanced polymer chemistry to deliver comprehensive fire protection. The PPG STEELGUARD® coatings range includes both sustainable waterborne and solvent-based options, engineered for specific cellulosic application requirements and conditions. For hydrocarbon applications, PITT-CHAR® NX epoxy intumescent coating is designed to resist severe pool fires, jet fires and explosions in both onshore and offshore environments.

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June 6-9, 2027
Rohnert Park, CA
ORGANIZERS: KLOSIN, REGISTER, RAGAERT, SOARES, AND WAGENER

## NGRPC 2027

Theme: Novel Polymers: Innovations in synthesis, design, material properties, and application
May 3-5, 2027
University of Florida