The 4th Triennial International Aircraft Fire and Cabin Safety Research Conference
Lisbon, PORTUGAL, November 15-18, 2004

RECENT DEVELOPMENTS IN ULTRA LOW HEAT RELEASE PLASTICS FOR AIRCRAFT INTERIORS

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FIRE SAFETY RESEARCH AT THE FAA

FIRE SAFETY

REGULATORY & CERTIFICATION SUPORT FOR AIRCRAFT CABIN FIRE SAFETY

SYSTEMS & CABIN FIRE SAFETY

MATERIALS FIRE SAFETY

IN FLIGHT FIRE PROTECTION

- Misc. & Hidden Materials
- Cargo Liners

POST CRASH FIRE PROTECTION

- Cabin Materials
- Fuselage Burn-Through
- Evacuation Slides

FIRE RESEARCH

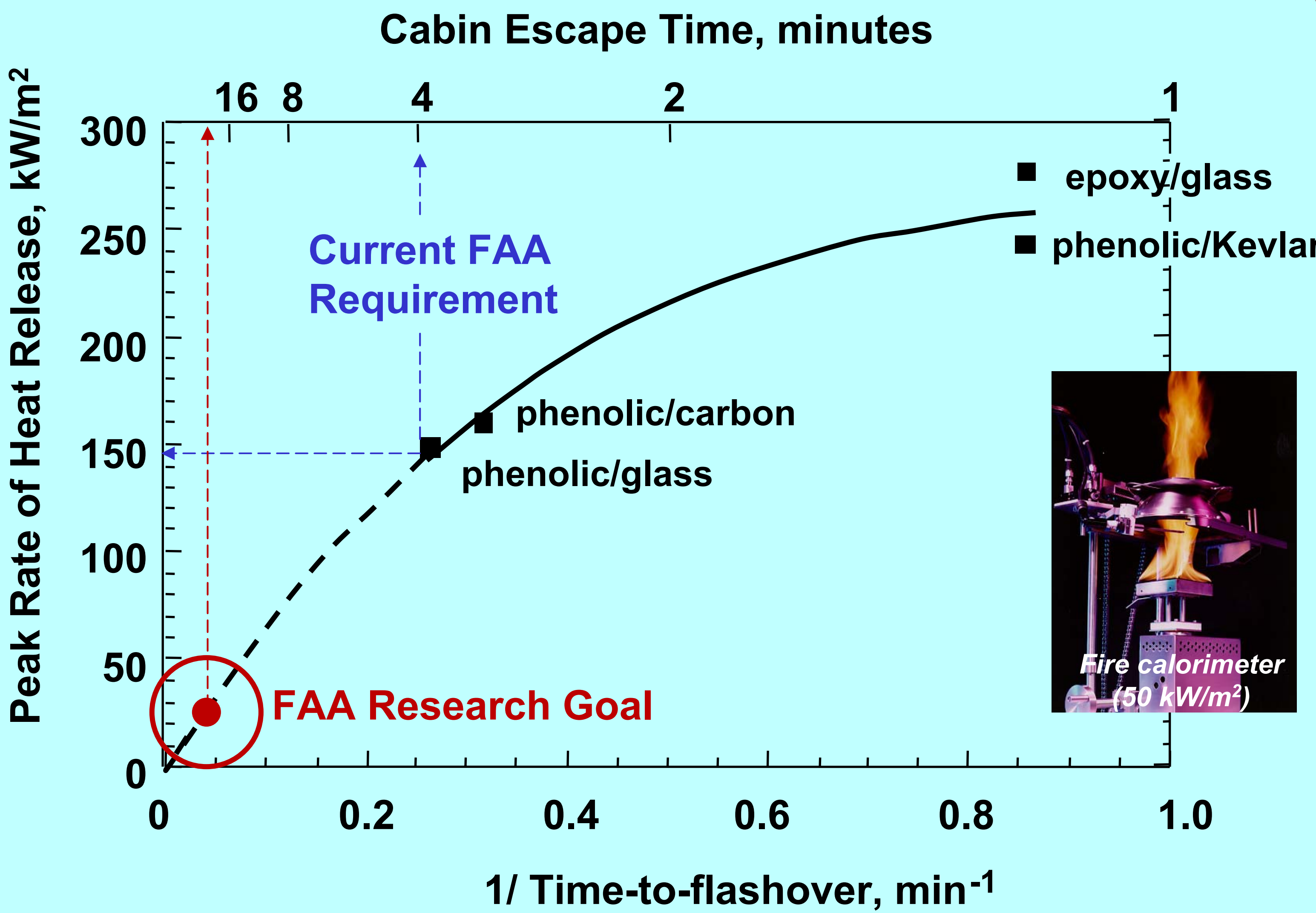
ENABLING TECHNOLOGY FOR A FIREPROOF AIRCRAFT CABIN BY 2010

ULTRA FIRE RESISTANT MATERIALS

- Elastomers/Rubber
- Thermoset Resins
- Thermoplastics
- Fibers

SUPPORTING SCIENCE & TECHNOLOGY

FULL SCALE TESTING IN AIRCRAFT AT FAA



FIRE RESEARCH: 1995-Present

OBJECTIVE

Eliminate Burning Cabin Materials as a Cause of Death in Aircraft Accidents

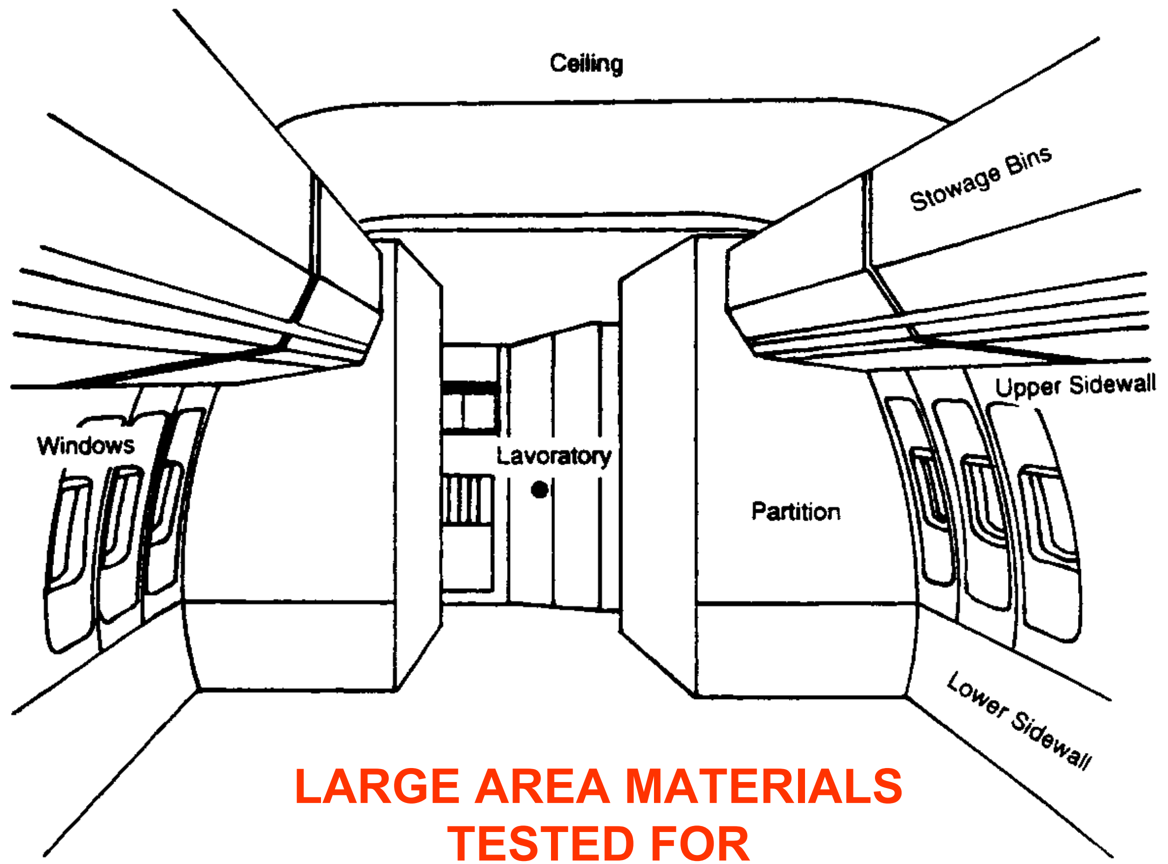
STRATEGY

Reduce Heat Release Rate of Cabin Materials by 10X

APPROACH

- Understand Why & How Plastics Burn
- Synthesize New Ultra Fire Resistant Polymers

HEAT RELEASE RATE BY 14 CFR 25.853 (a-1)



LARGE AREA MATERIALS
TESTED FOR
HEAT RELEASE AND SMOKE

Rate of Heat Release
Apparatus (OSU)

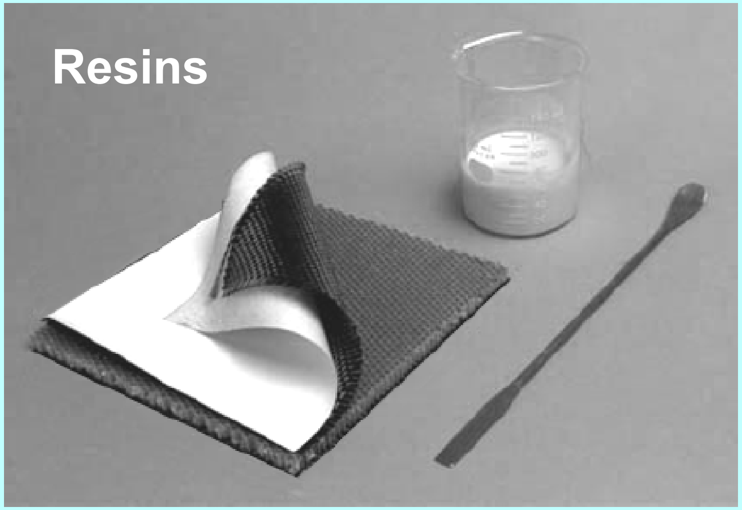
Next Generation Cabin Interiors

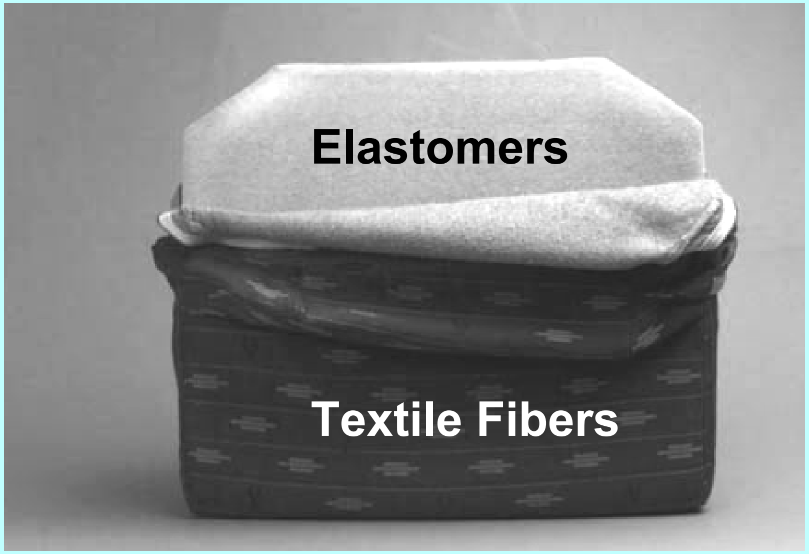
Next Generation Cabin Interiors

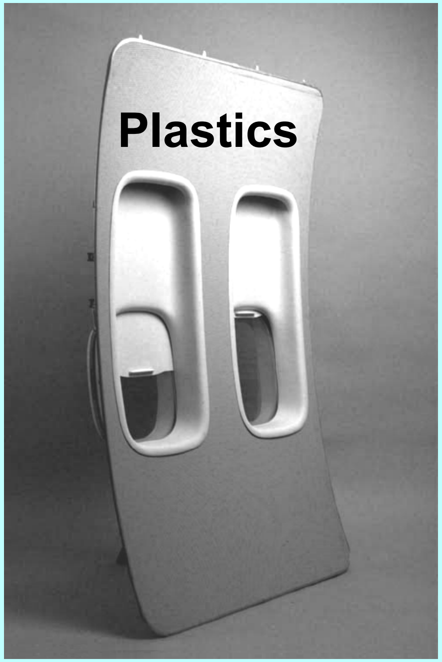
Next Generation Cabin Interiors

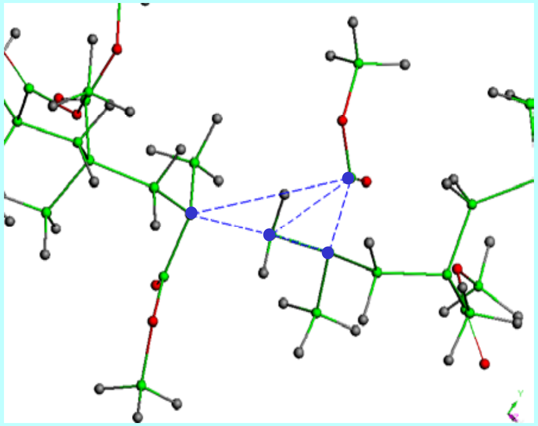
Next Generation Cabin Interiors

FIRE RESISTANT MATERIALS: Deliverables









Supporting Science & Technology

SUPPORTING SCIENCE & TECHNOLOGY

***GOAL*: Develop a lab (micro) scale heat release rate (HRR) test for research samples (milligrams)**

SCALE

Atomic
Molecular
Materials
Coupons
Components
Structures

METHOD

Spectroscopy

μHRR?

Flame Tests

Fire Tests

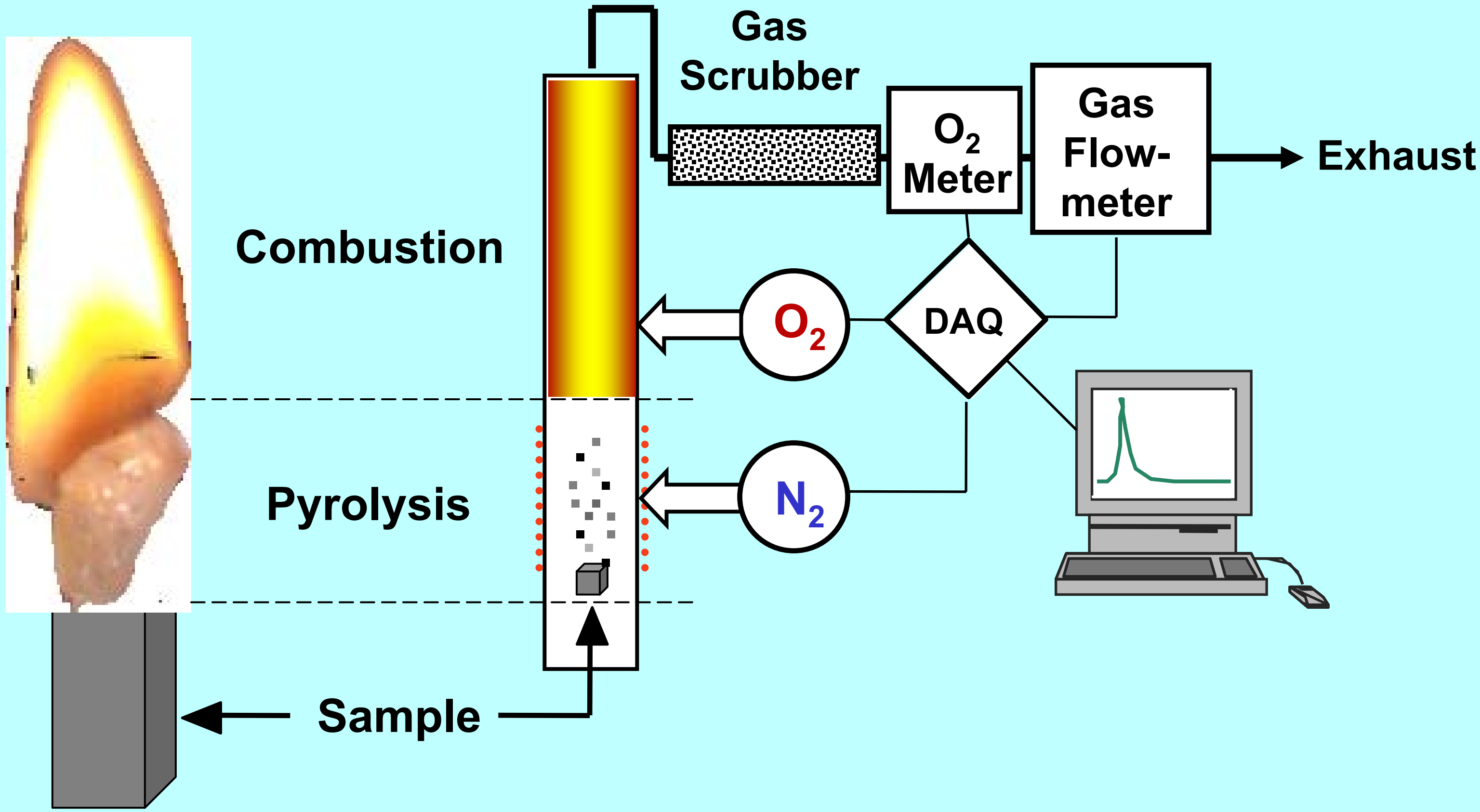
Bench-scale

Full-scale

10^{-22} 10^{-6} 10^{-4} 0.01 1 100 10^{4} 10^{6} 10^{8}

SAMPLE MASS, grams

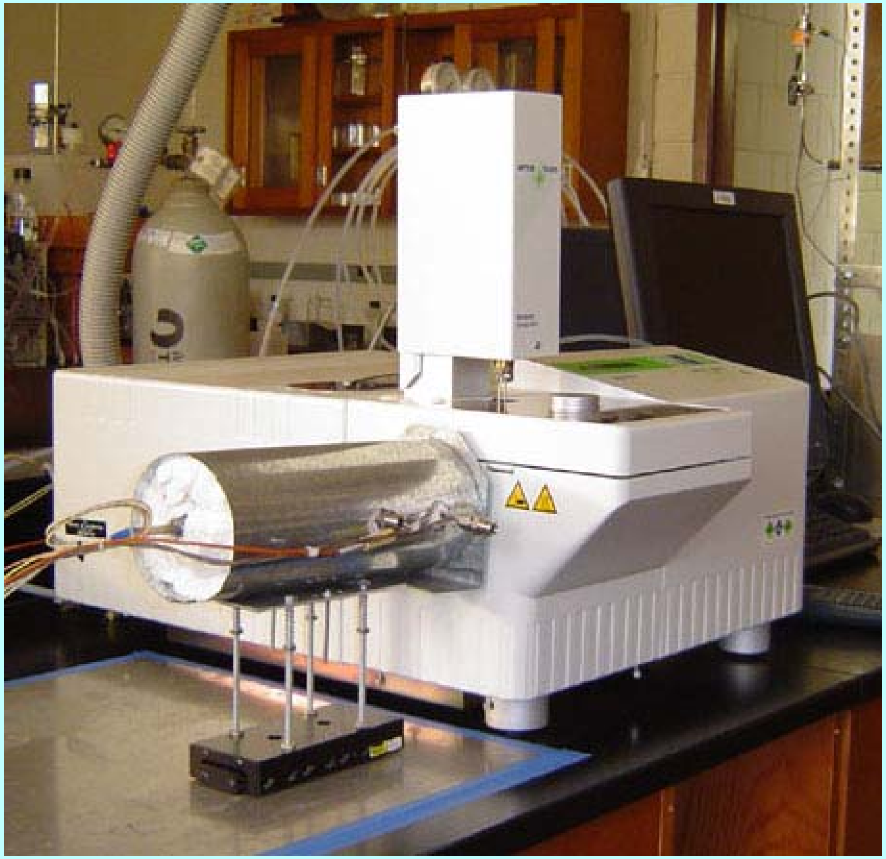
μHRR APPROACH: Controlled (Non-flaming) Combustion



Flaming Combustion

Pyrolysis-Combustion Flow Calorimetry (PCFC)

LAB SCALE HEAT RELEASE RATE (μHRR)



TGA Combustion Accessory

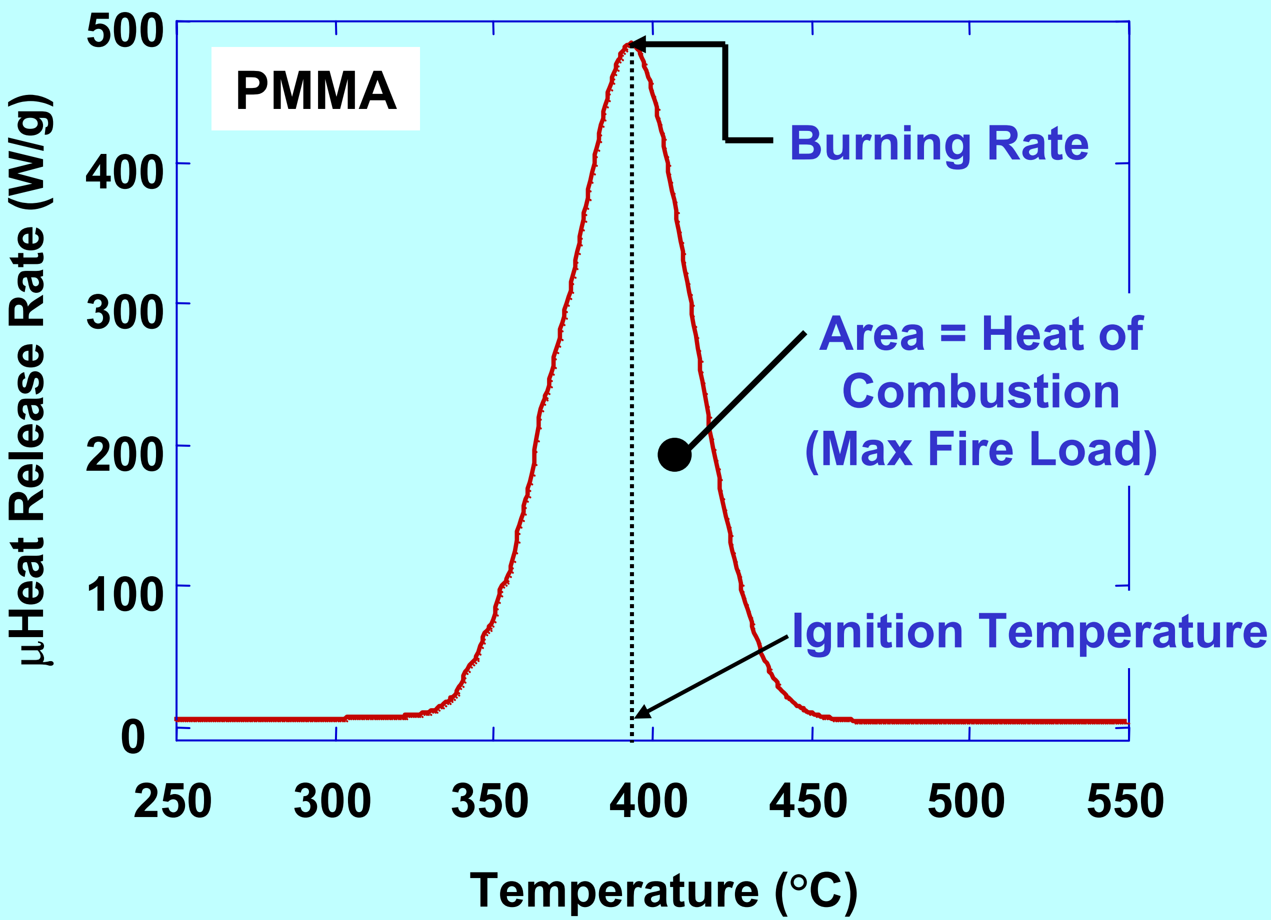
PYROLYSIS-COMBUSTION FLOW CALORIMETRY (PCFC)

Stand-Alone Device

(Commercial License Pending)

RELATIONSHIP OF μHRR TO FIRE HAZARD

Micro Scale HRR Test



Bench Scale Test

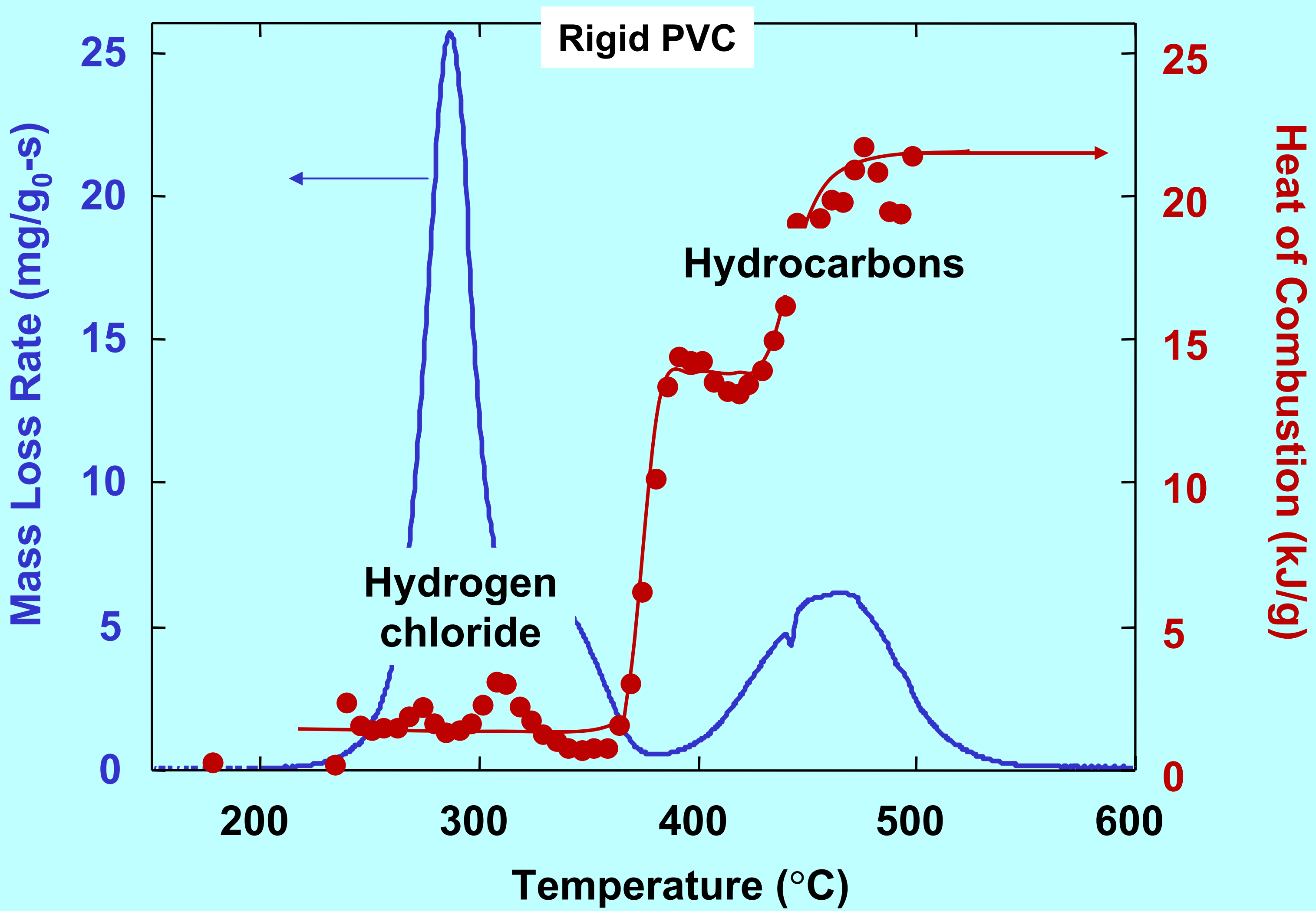
- Cone Calorimeter
- OSU Calorimeter
- UL-94
- LOI

- Oxygen Bomb Calorimeter

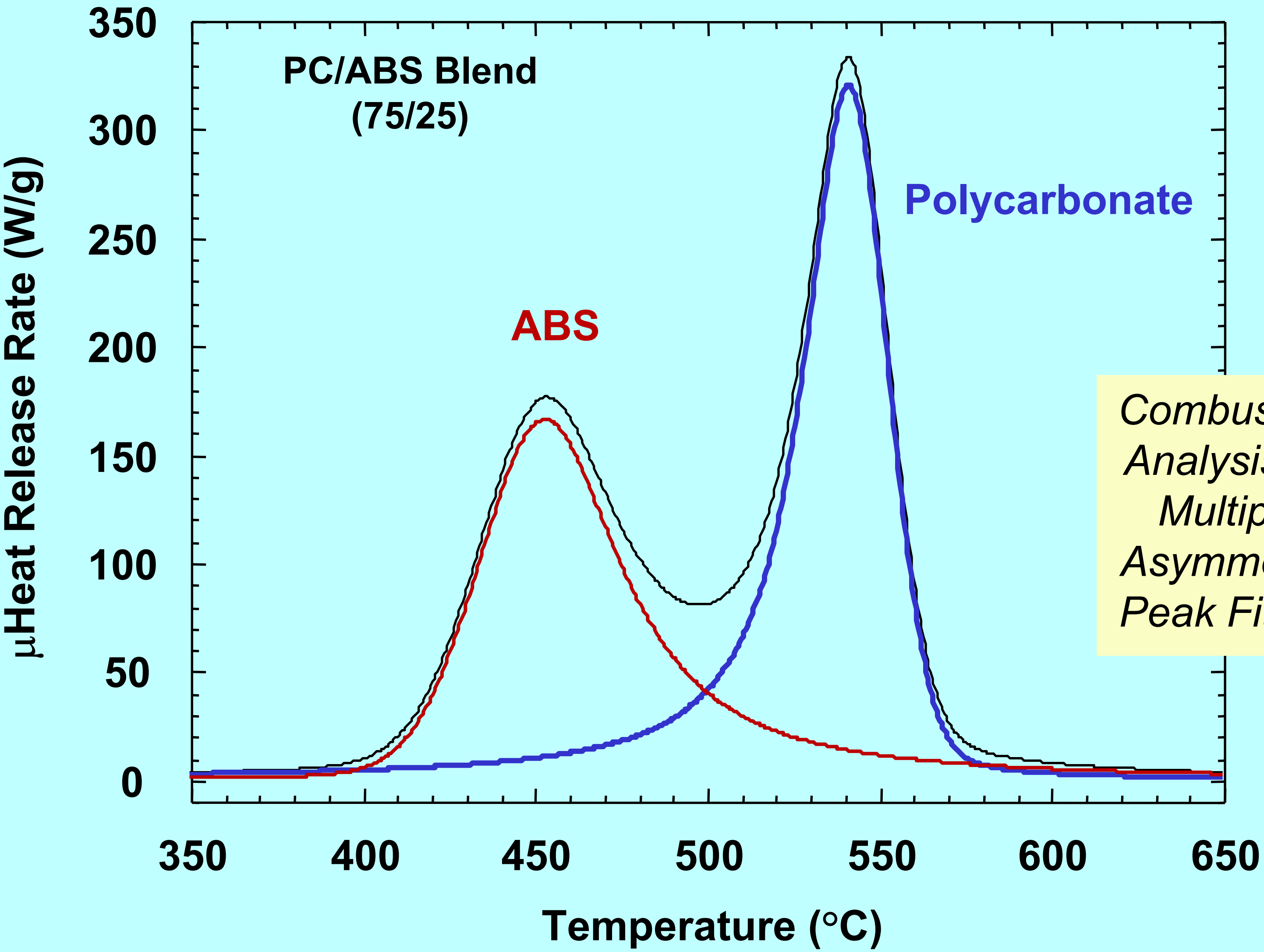
- Setchkins Furnace
- Glow Wire Ignition

μHRR WITH THERMOGRAVIMETRIC ANALYSIS (TGA)

… Gives Heat of Combustion of Decomposition Products

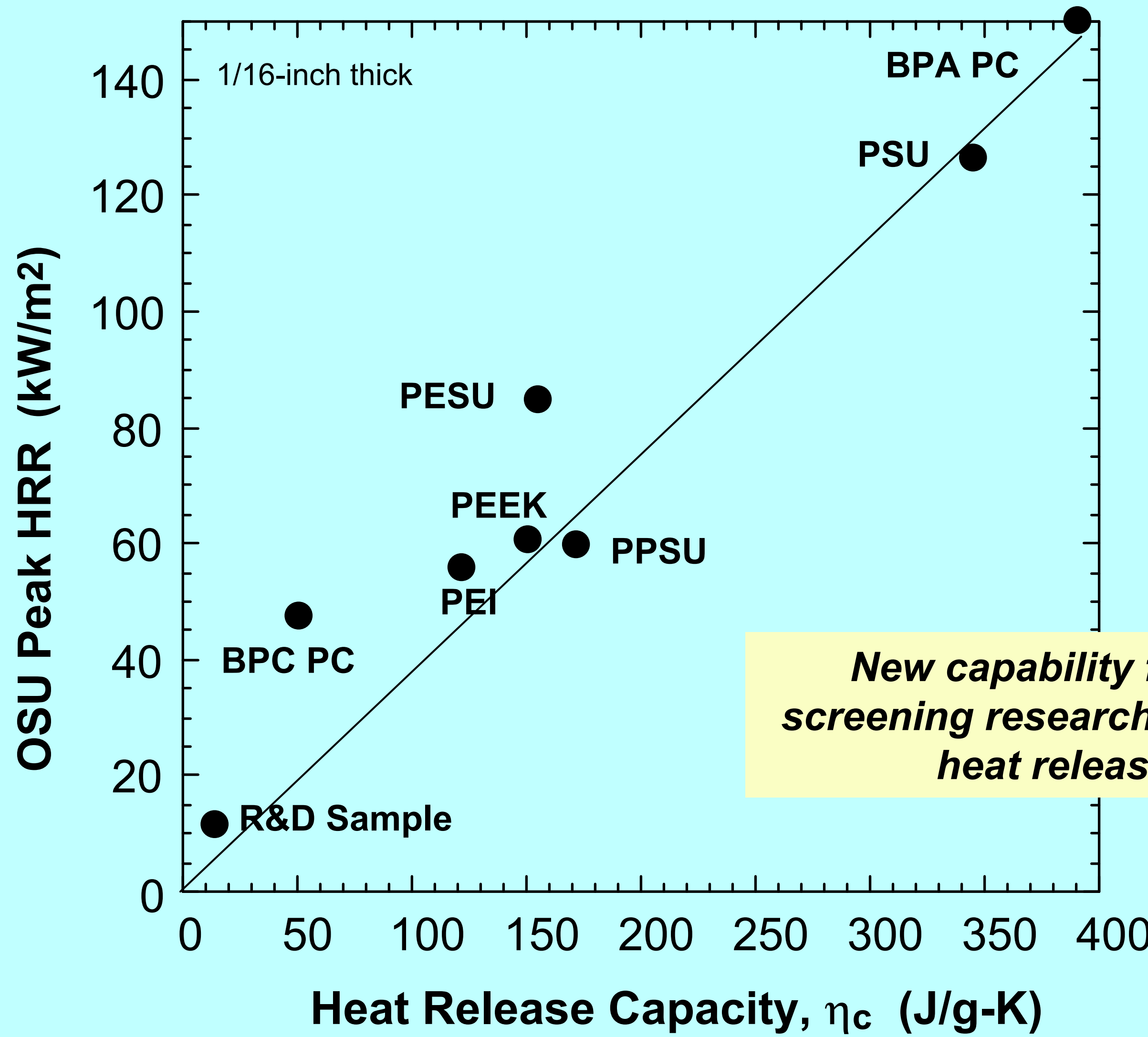


μHRR OF BLENDS AND FLAME RETARDANT ADDITIVES



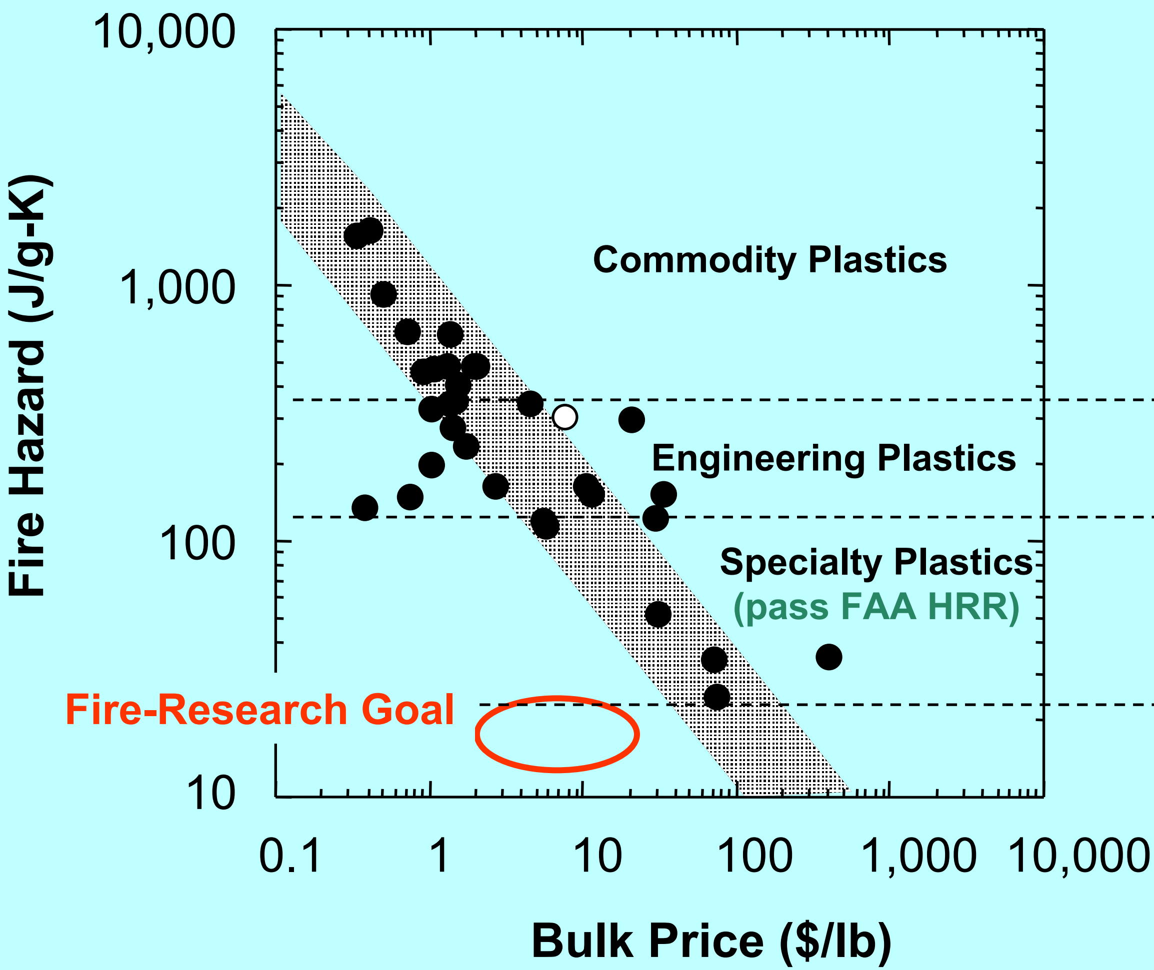
Combustion Analysis by Multiple Asymmetric Peak Fitting

MICRO SCALE HEAT RELEASE PREDICTS OSU TEST RESULTS



New capability for rapidly screening research polymers for heat release rate

FIRE HAZARD CLASSIFICATION BY MICRO HRR



FLAMMABILITY

Self Sustained Burning

Self Extinguishing

No Ignition

Noncombustible

FIRE RESISTANT MATERIALS: Requirements

- Tough / Flexible
- Soluble In Common Solvents
- Low Temperature Processing

Comparable to Current Materials

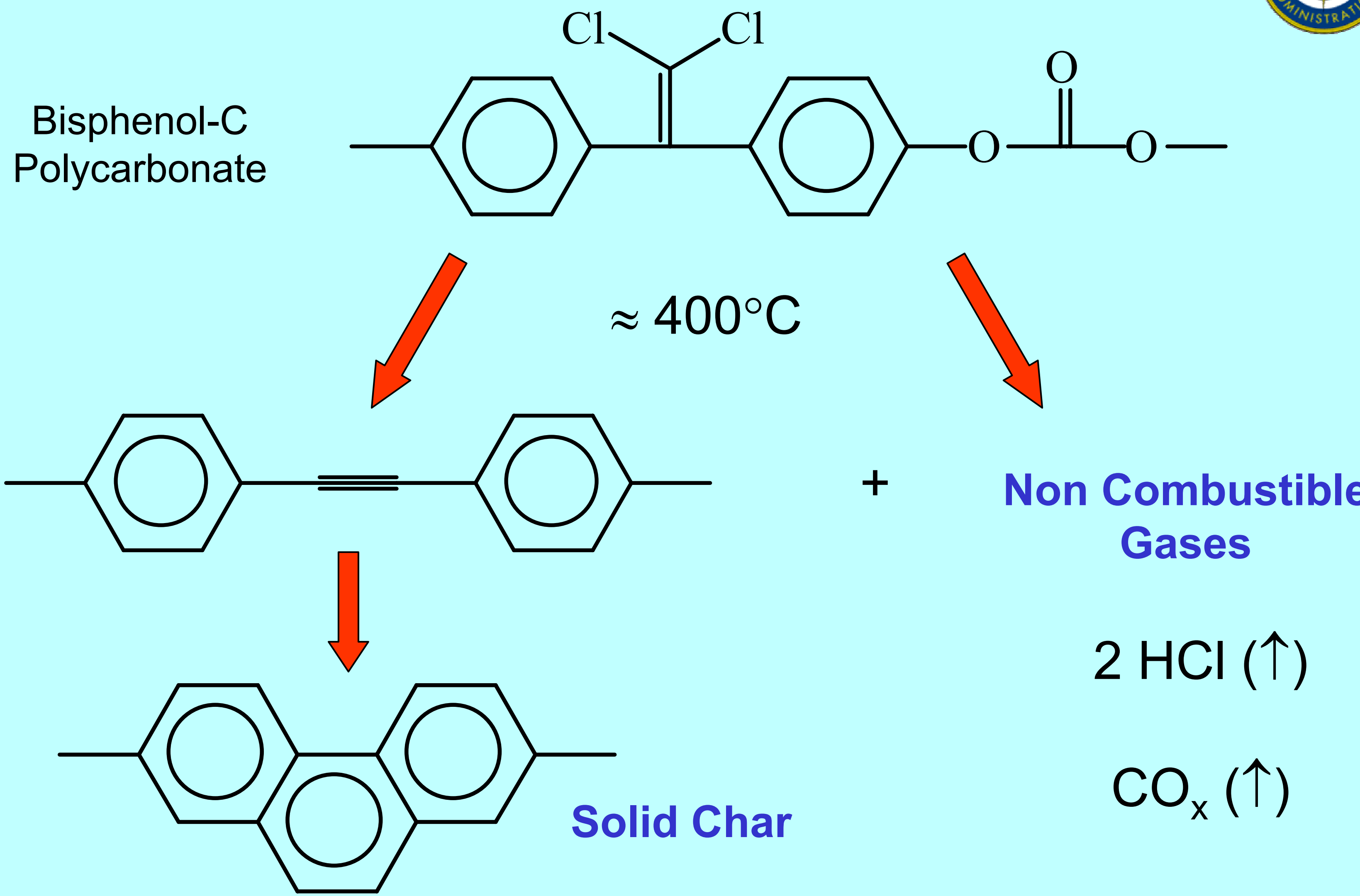
- Ultra Fire Resistant …

"Fire Smart" Polymer → **Noncombustible Gases (↑)**

Inert Residue / Char

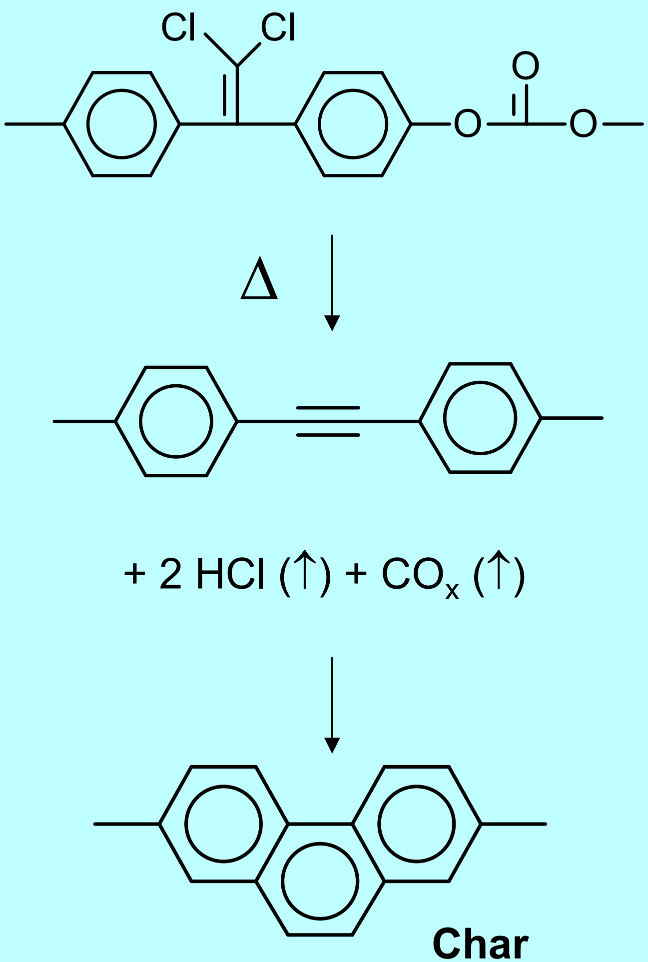
fire

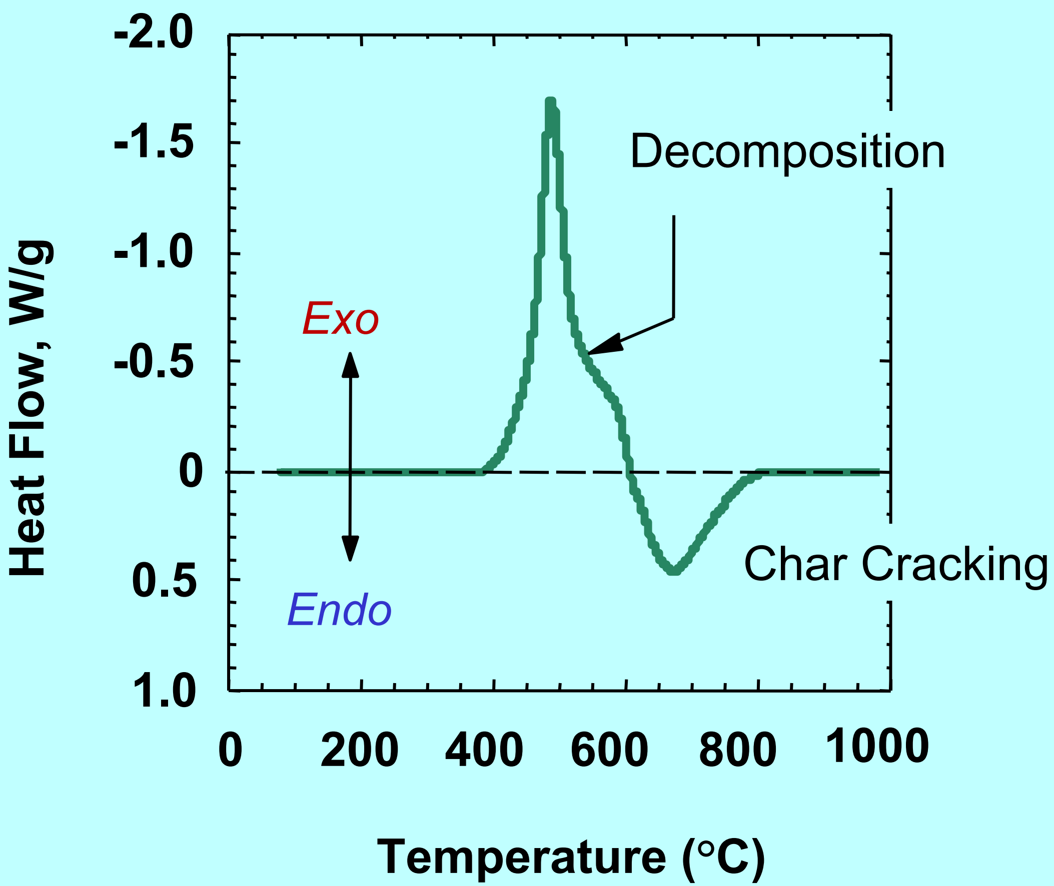
FIRE SMART MECHANISM IDENTIFIED



M. Ramirez, DOT/FAA/AR-00/42, and A. Factor, GE Plastics (2000)

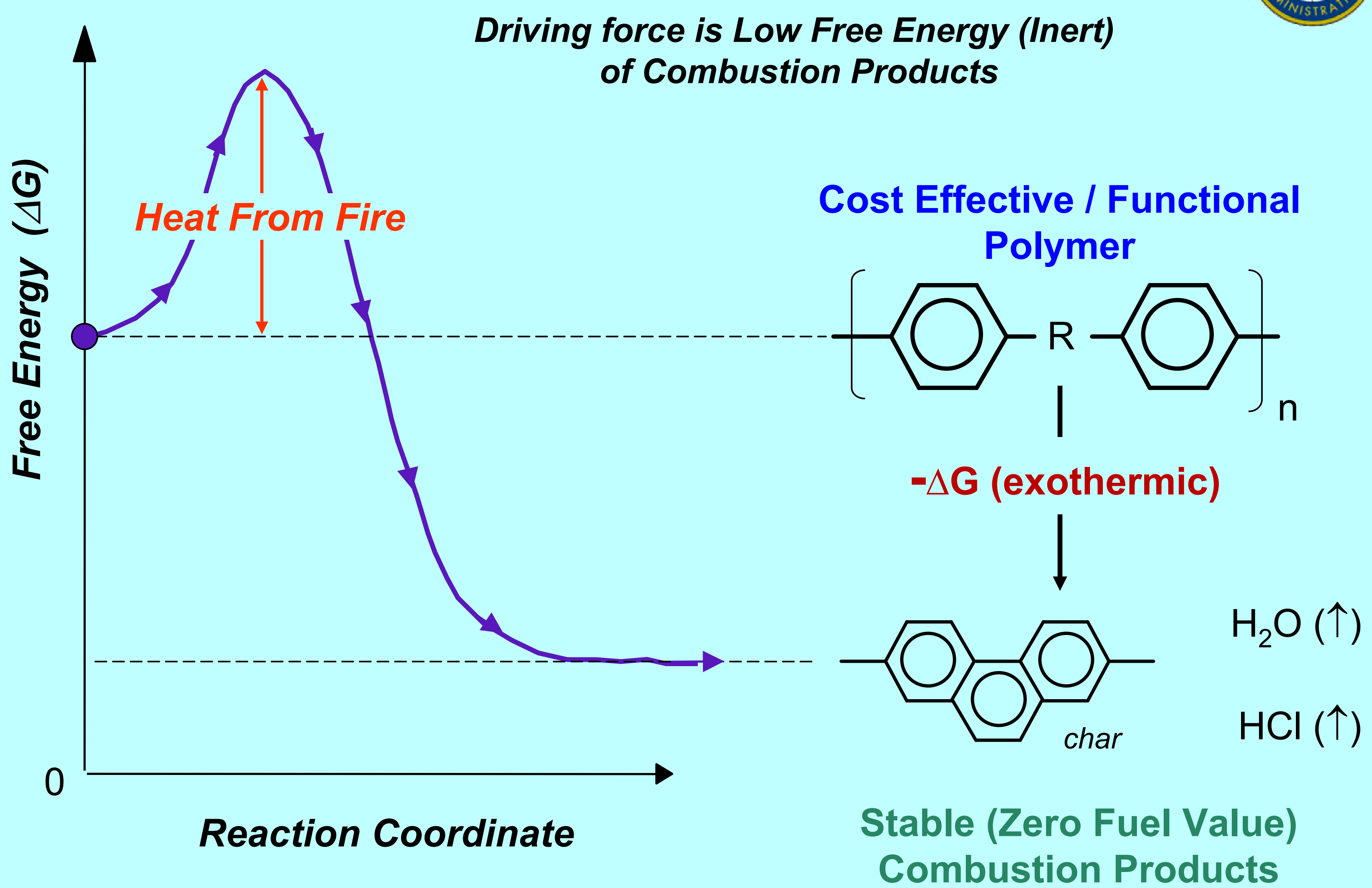
FIRE SMART MECHANISM IS EXOTHERMIC



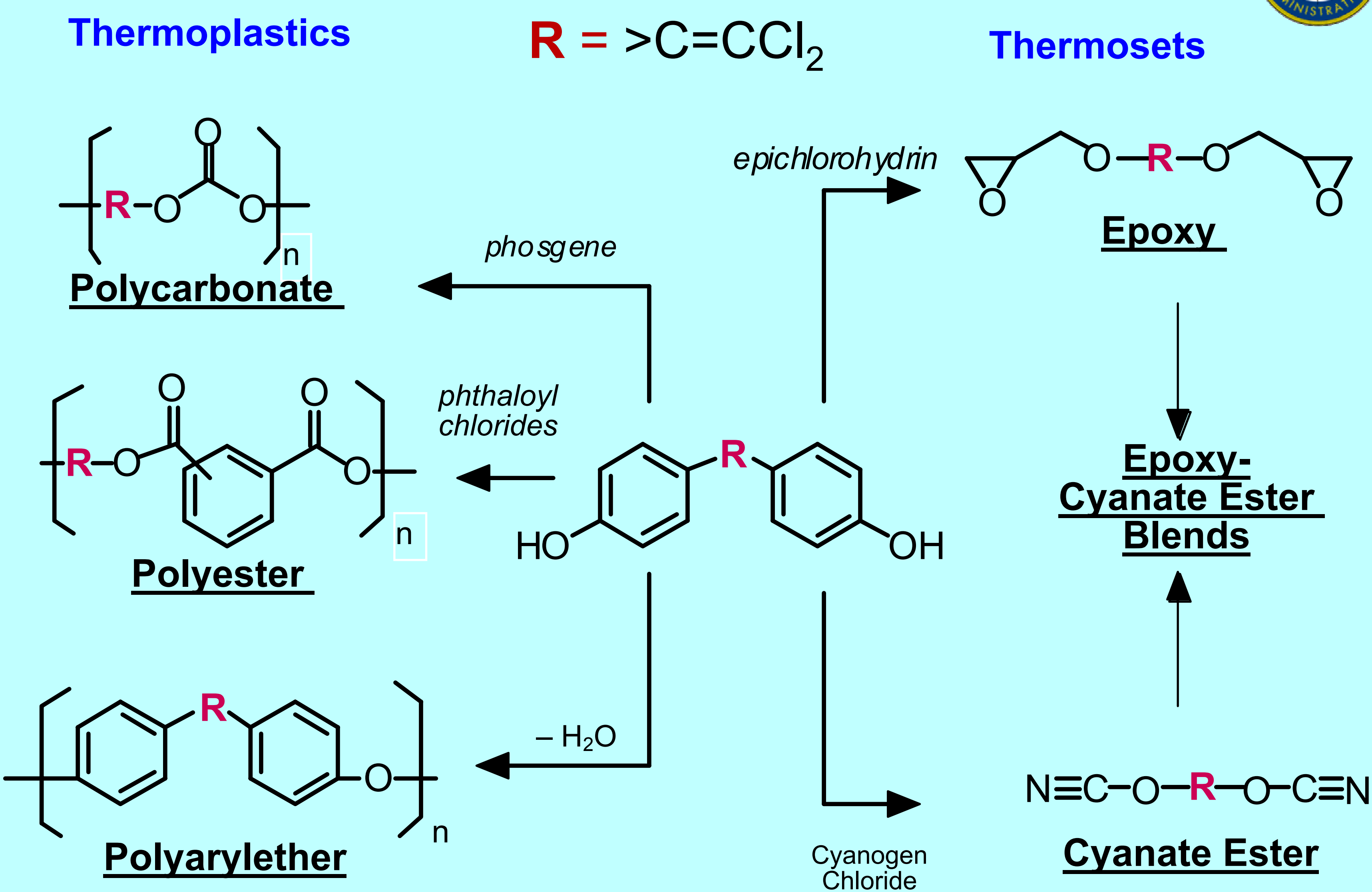


Differential Scanning Calorimetry

FIRE SMART POLYMERS: Why They Work



FIRE SMART POLYMERS BASED ON BISPHENOL-C



FIRE RESISTANT PLASTICS

BPC Polyarylates (U. of Mass/Amherst)

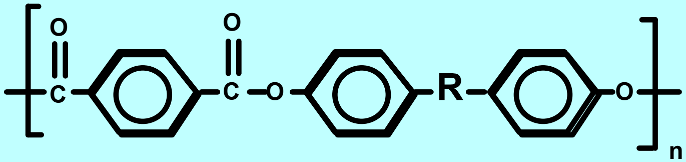
BPC Polycarbonate (Dow Chemical)

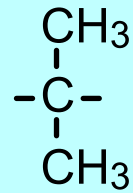
BPC Polyether (Rice University)

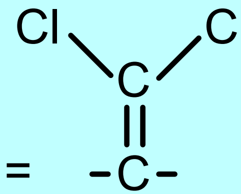
BPC Polysulfone (SMRC, SBIR I)

Polyphosphine Oxides (VPI)

POLYARYLATES: BPA versus BPC

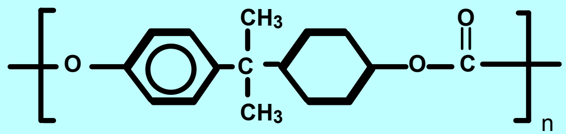
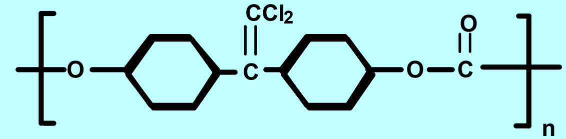


R = 

R = 

Morphology	Amorphous	Amorphous
HDT (°C)	160-174	160
Flex Modulus (ksi)	325	391
Flex Strength (psi)	11,000	11,700
Tensile Failure Strain (%)	50	50
NBS Smoke (D_m)	109	N/A
Oxygen Index (%)	36	47
Heat Release Capacity (J/g-K)	460	18

POLYCARBONATE: BPA versus BPC

	LEXAN™	Chloral Polycarbonate
		
Morphology	**Amorphous**	**Amorphous**
T_g (°C)	**152**	**168**
Flex Modulus (ksi)	**336**	**376**
Flex Strength (psi)	**16,300**	**16,200**
Tensile Yield Strain (%)	**10**	**11**
NBS Smoke (D_m)	**165**	**75**
Oxygen Index (%)	**26**	**56**
Heat Release Capacity (J/g-K)	**390**	**29**
FAR 25.853(a-1) Heat Release Peak/Total* (kW/m²) / (kW-min/m²)	**153 / 58**	

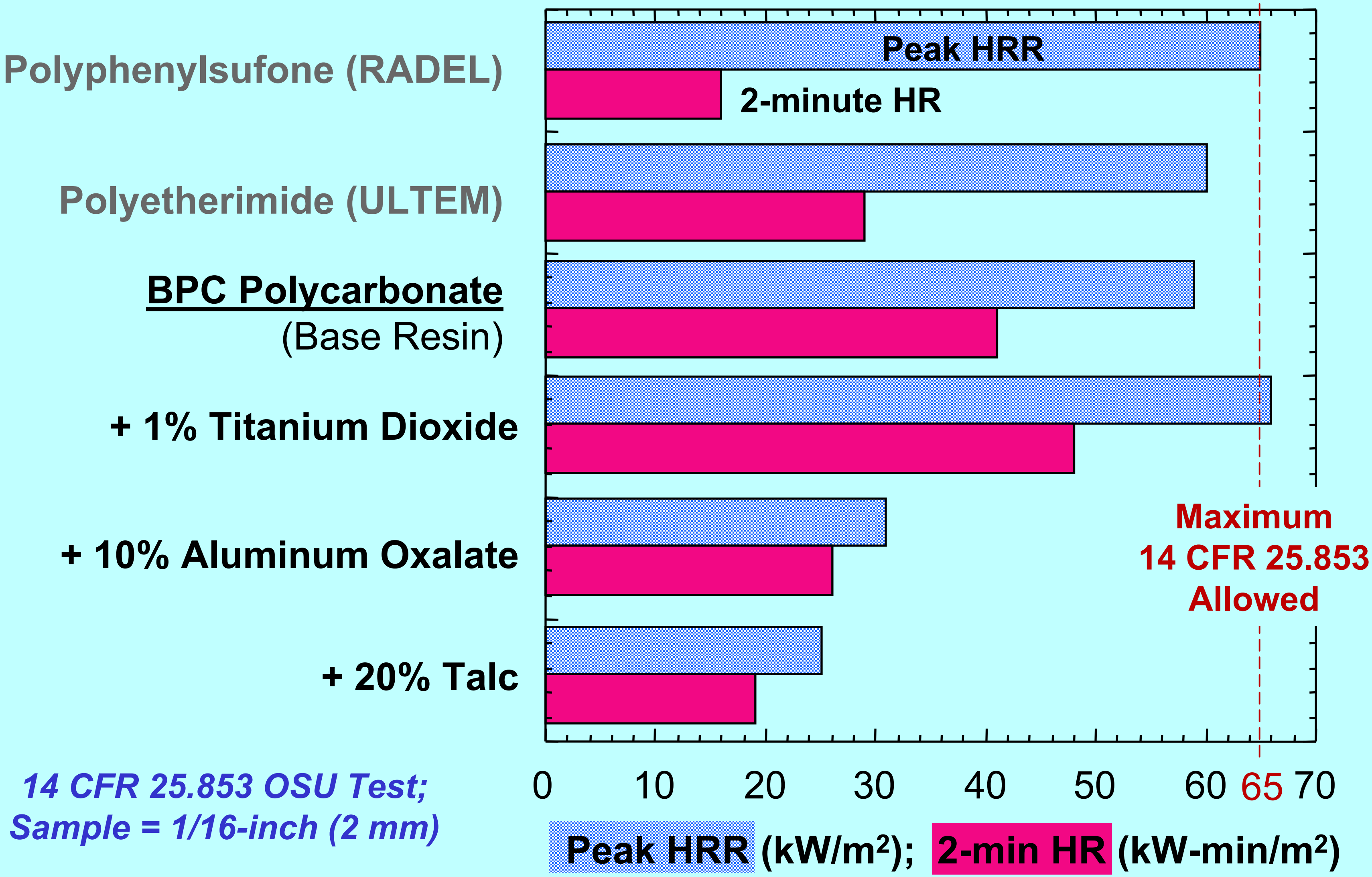
*0.063 in

See Next Slide

BPC POLYCARBONATE: FAA HEAT AND SMOKE

	Peak HRR (kW/m^2)	Total HR @ 2-min ($kW\text{-}min/m^2$)	Smoke Density, D_m
Lab 1	48	34	N/A
Lab 2	59	41	N/A
Lab 3	38	27	4
	61	45	
	47	37	
1/16-inch (2 mm)	51	40	
	56	44	
	43	33	
	50 ± 8	38 ± 6	4
14 CFR 25.853	**65**	**65**	**200**
Result:	**PASS**	**PASS**	**PASS**

BPC POLYCARBONATE: Effect of Additives on HRR



14 CFR 25.853 OSU Test;
Sample = 1/16-inch (2 mm)

THERMOSET POLYMERS

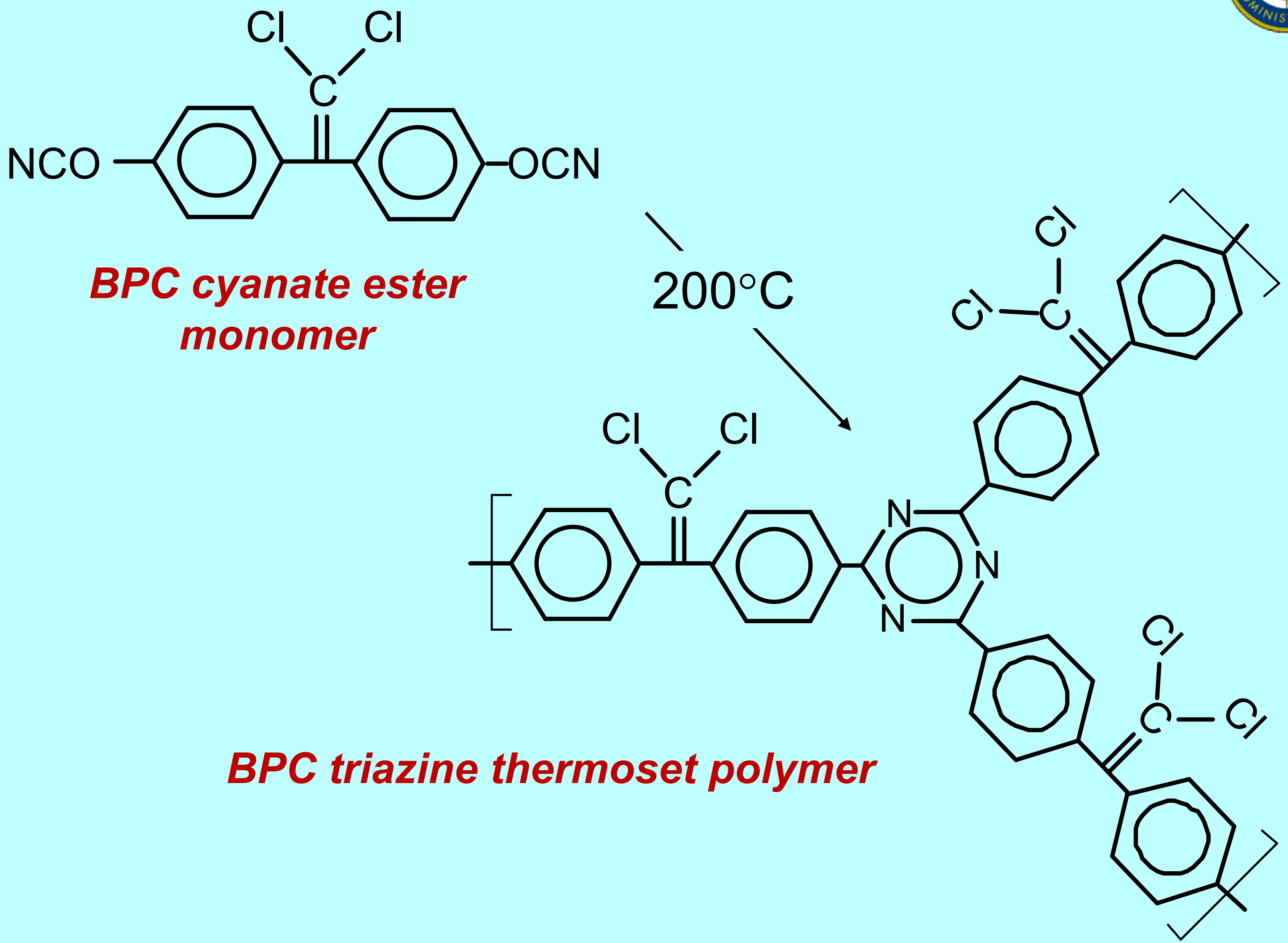
BPC Epoxy (Pacific Epoxy)

BPC Cyanate Ester (Vantico)

BPC Epoxy-Cyanate Ester Blends

Benzoxazines (Case Western)

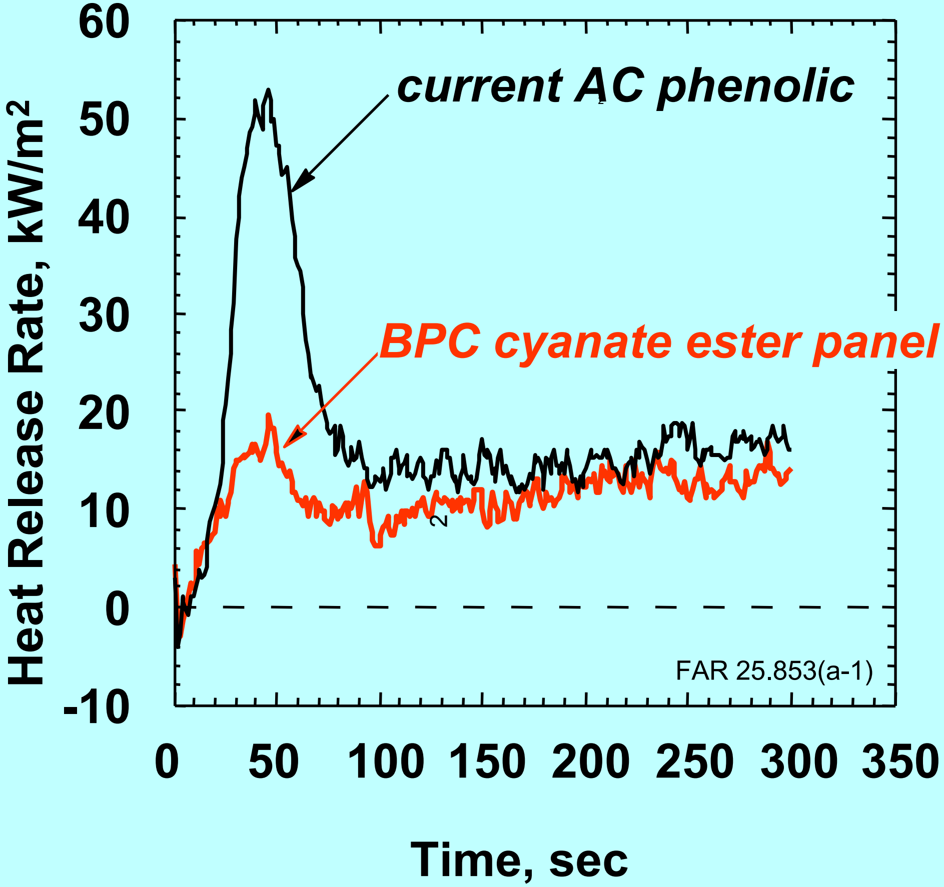
CYANATE ESTER: Polymerization Reaction

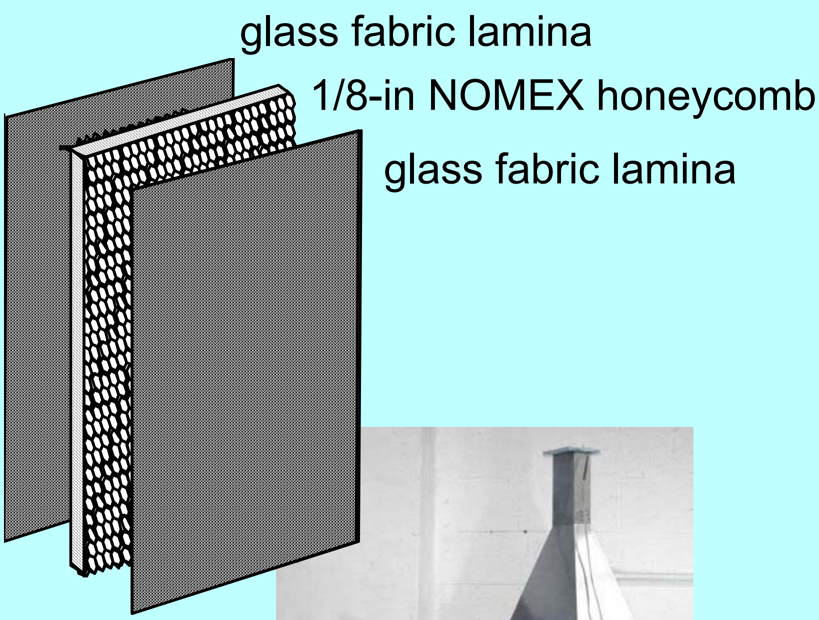


BPC cyanate ester monomer

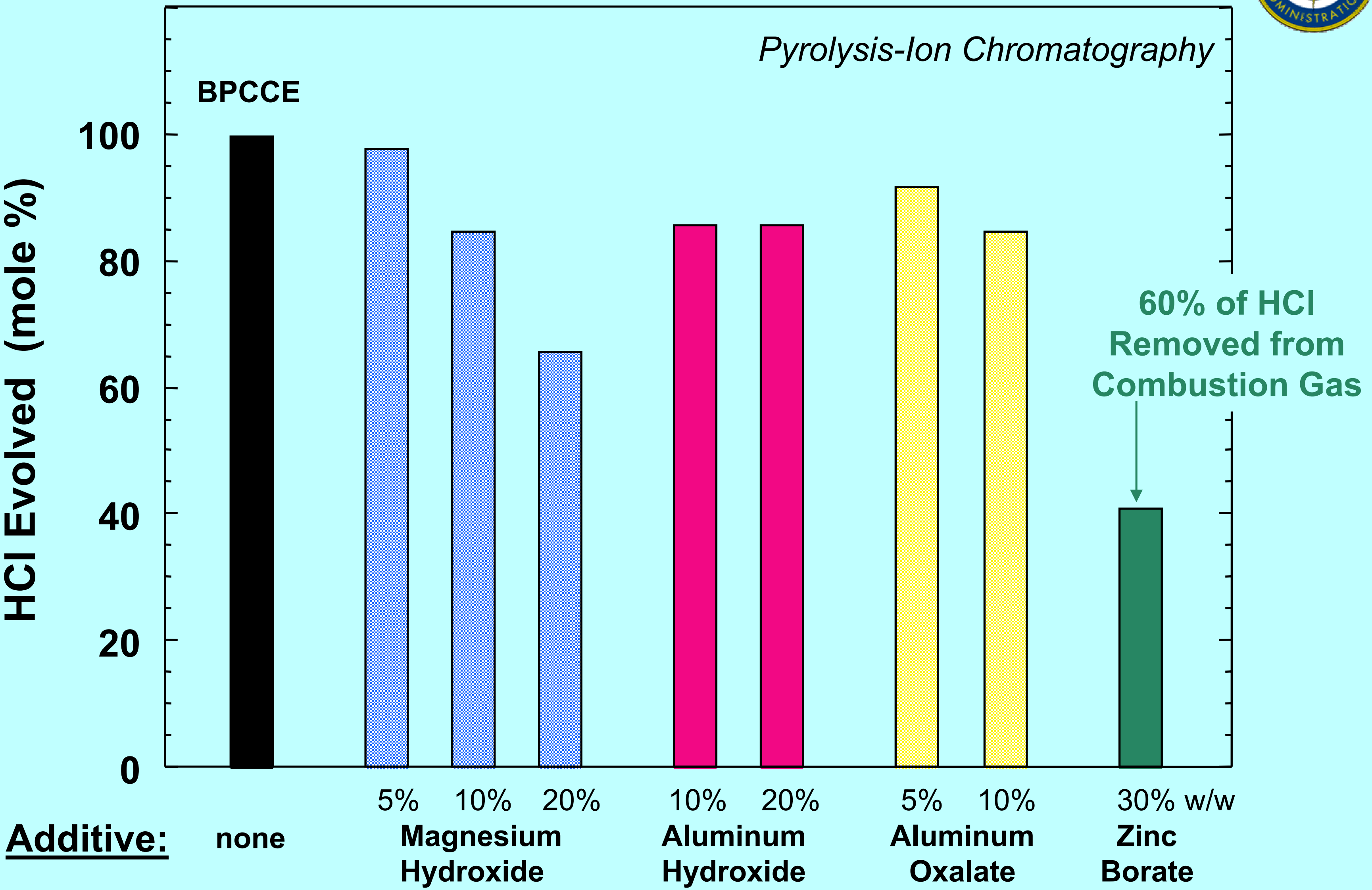
BPC triazine thermoset polymer

BPC CYANATE ESTER: FAA Heat Release Rate Test

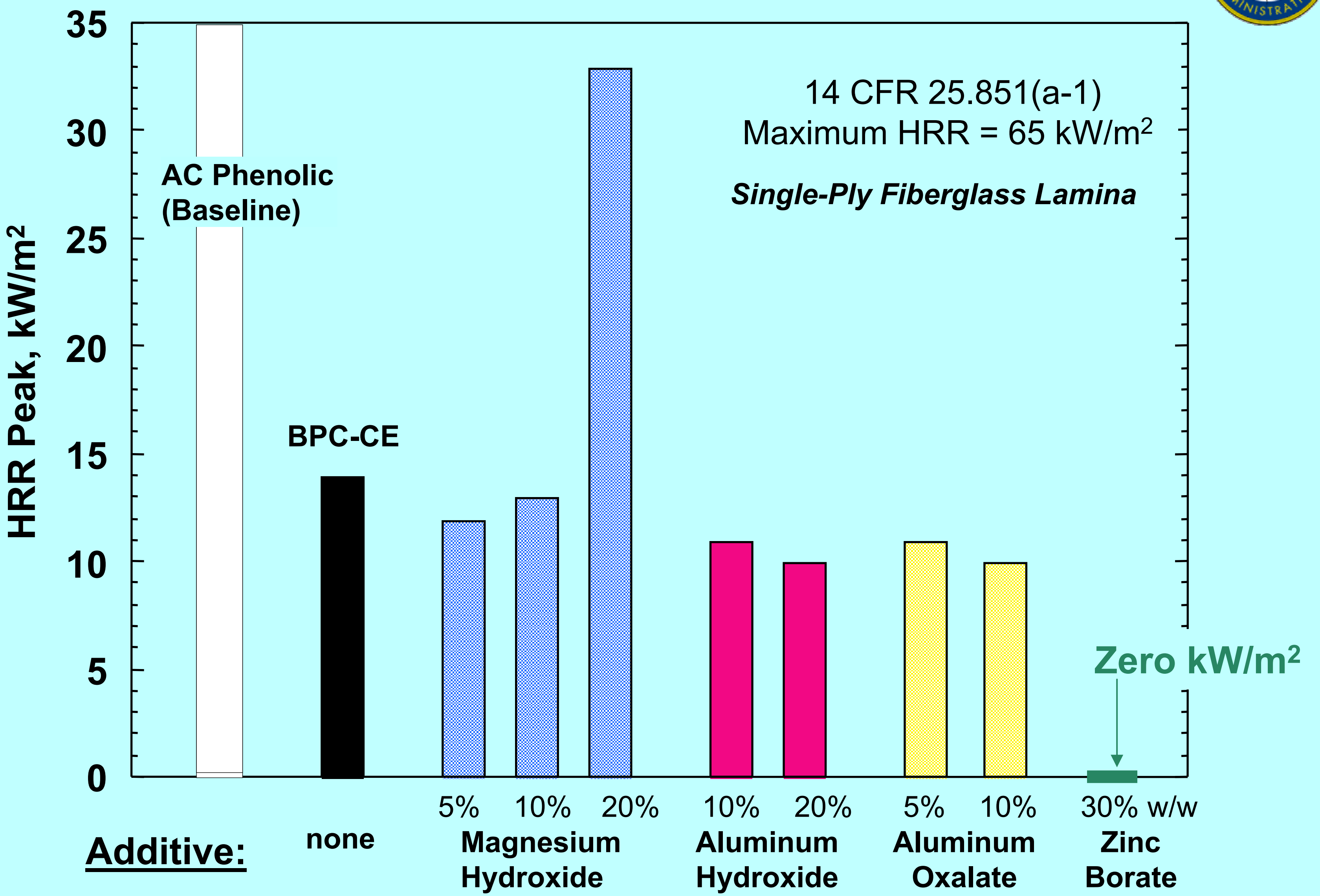




BPC-CE: Effect of Additives on HCl in Combustion Gas

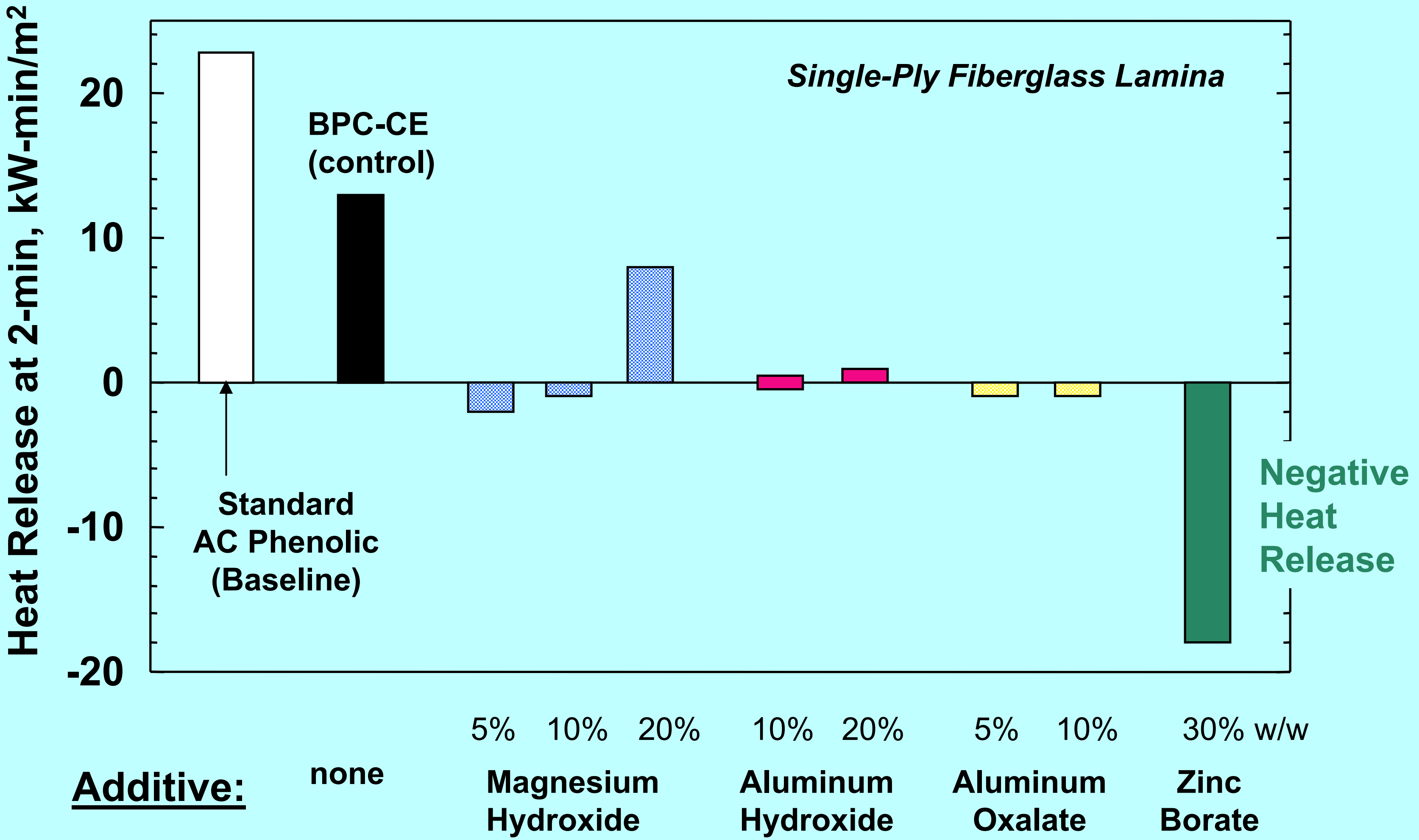


BPC-CE: Effect of Additives on Peak HRR in OSU



BPC-CE: Effect of Additives on 2-minute HR in OSU

14 CFR 25.851(a-1) Maximum HR = 65 kW-min/m²



BPC-CE STRUCTURAL COMPOSITES

Only VARTM resin to pass all NAVY submarine fire performance requirements:

Fire Test/Characteristic	Requirement (MIL-STD-2031)	Composite Resin		
		BPC-CE	Phthalo-nitrile	Silicone
Time to ignition (s) at irradiance:				
25 kW/m^2	> 300	**pass**	pass	pass
50 kW/m^2	> 150	**pass**	pass	pass
75 kW/m^2	> 90	**pass**	pass	pass
100 kW/m^2	> 60	**pass**	pass	pass
Peak/Average Heat Release Rate (kW/m^2) at irradiance:				
25 kW/m^2	< 50/50	**pass**	pass	pass
50 kW/m^2	< 65/50	**pass**	pass	pass
75 kW/m^2	< 100/100	**pass**	pass	pass
100 kW/m^2	< 150/120	**pass**	pass	pass
Smoke Obscuration, D_{max}/D_s (avg):	< 200/100	**pass**	N/A	pass
Combustion Gas Toxicity ($CO/CO_2/HCN/HCl$):		**pass**	N/A	pass
Mechanical Properties		**good**	good	poor
Cure Temperature		**< 200°C**	> 375°C	N/A

J. Koo, et. al., SAMPE 2001

FIRE RESISTANT TEXTILE FIBERS

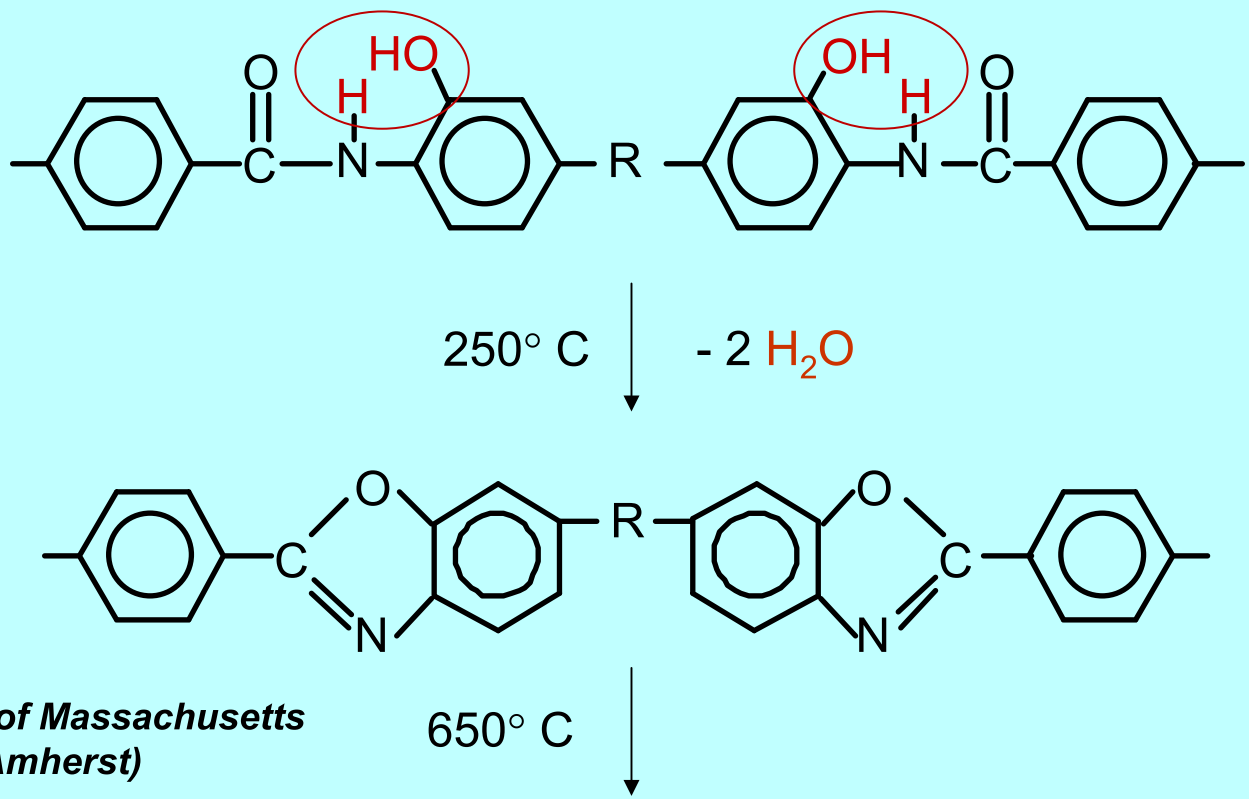
Polyimides (U. of Akron)

Polyhydroxyamides (U. of Mass/Amherst)

Polyphosphazenes (Penn State)

FIBERS & FILMS

Non Halogen / Fire Smart Polyhydroxyamides (PHA's) are Precursors to Heat Resistant Polybenzoxazoles (PBO's)



PHA

PBO

University of Massachusetts (Amherst)

75% Char, HRC = 40 J/g-K; (40 kW/m^2 Peak HRR CFR 25.853)

FIRE RESISTANT ELASTOMERS

Polysilphenylenes (U. of Mass/Amherst)

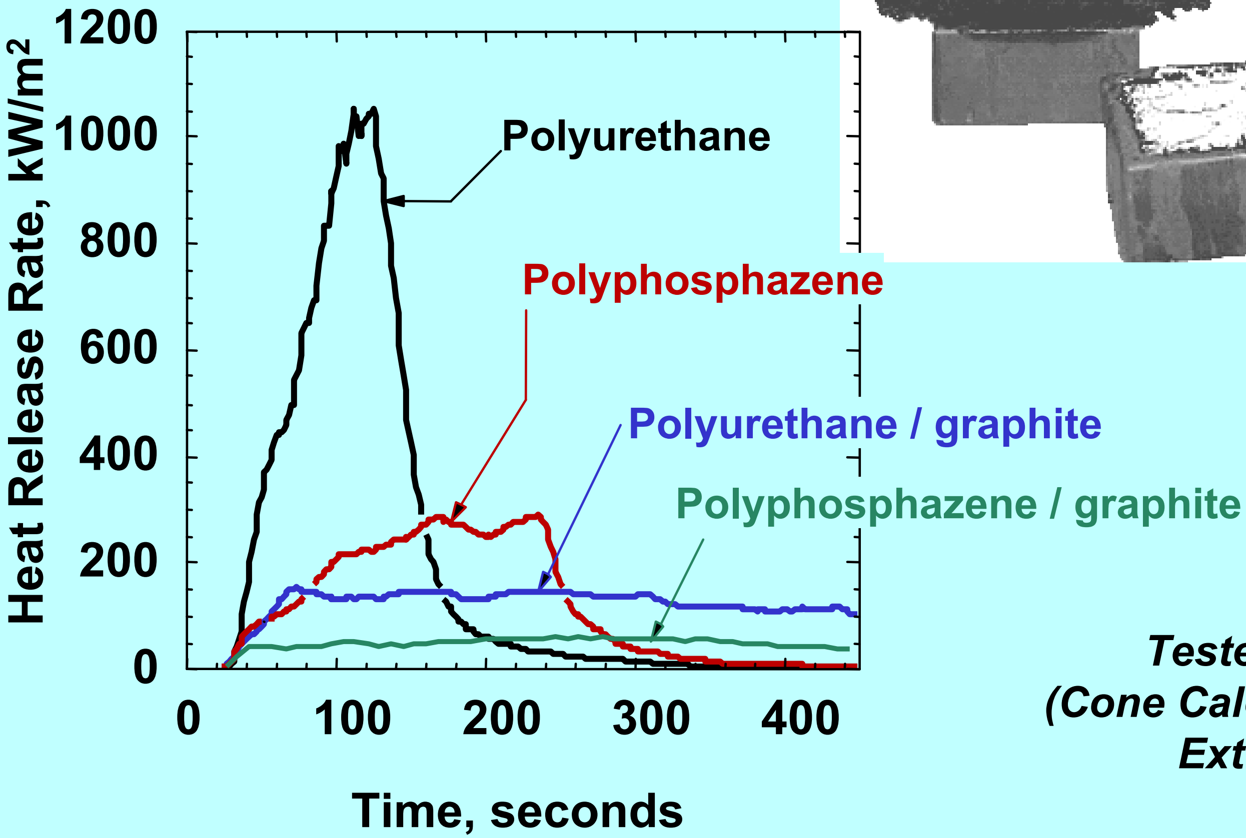
Polyphosphazenes (Penn State)

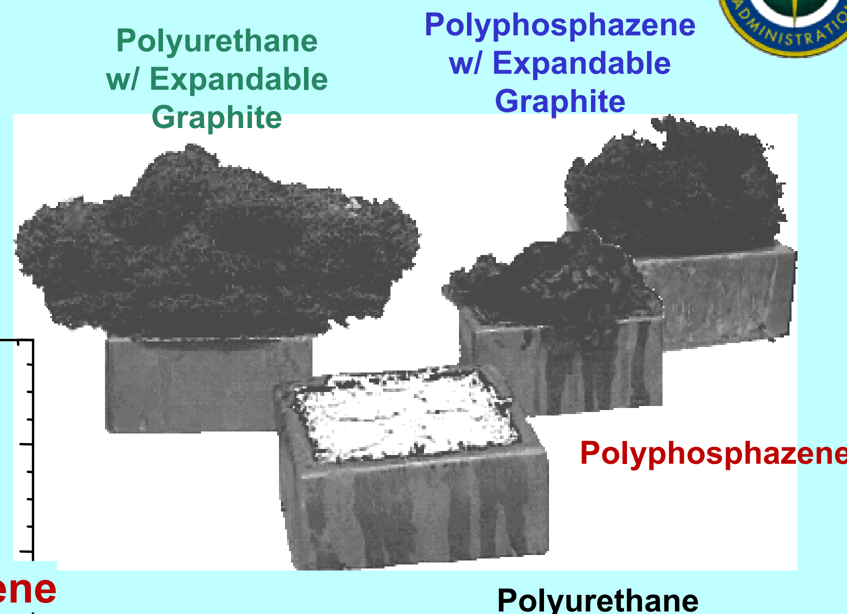
PPZ Polyurethane (Penn State)

BPC Polyurethane (U. Mass/Amherst)

FIRE RESISTANT ELASTOMERS

20% w/w Expandable Graphite Added to 6-mm Thick Solid Rubber





Tested by ASTM 1354 (Cone Calorimeter) @ 50 kW/m² External Heat Flux

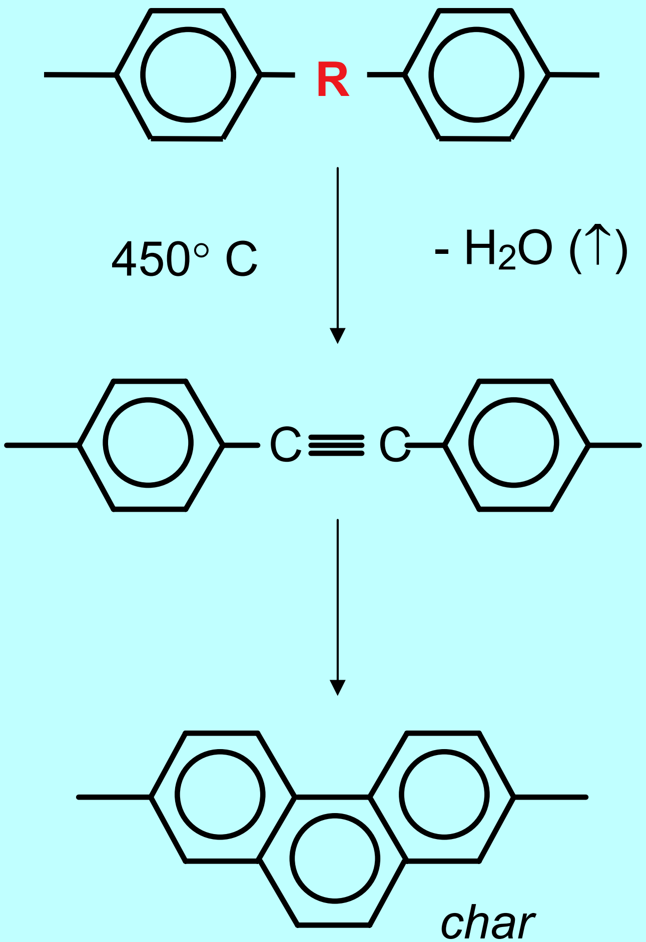
CURRENT RESEARCH

- NON-HALOGEN FIRE SMART POLYMERS
- MOLECULAR MODELING OF POLYMER DECOMPOSITION
- NUMERICAL MODELING OF SOLID BURNING
- HIGH THROUGHPUT SCREENING OF FLAME RETARDANTS
- TECHNOLOGY TRANSFER
  - ✓ Scale Up Fire Smart Polymers
  - ✓ Commercialize Micro Scale HRR Calorimeter

CURRENT RESEARCH: Non Halogen / Fire Smart

R = Novel H,C,O Group

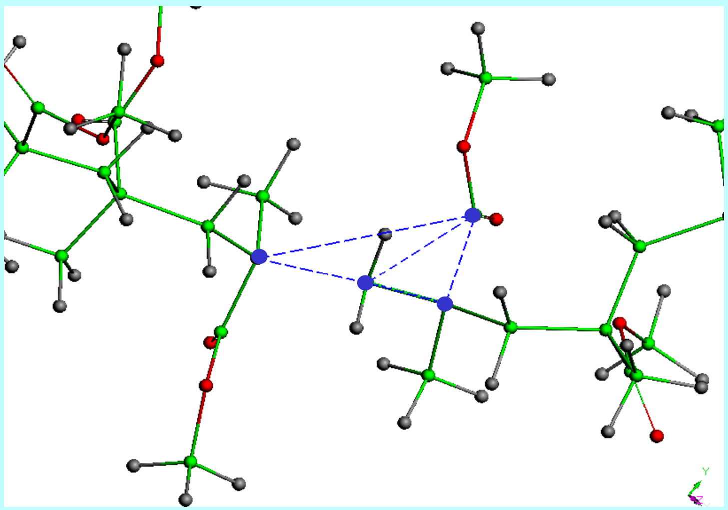
Polyarylate From-	HRC (J/g-K)	Char (%)	Calc. Peak HRR 14 CFR 25.853 (kW/m^2)
BP-A	460	25	
BP-R	80	40	(50 ±10)
BP-C	30	50	

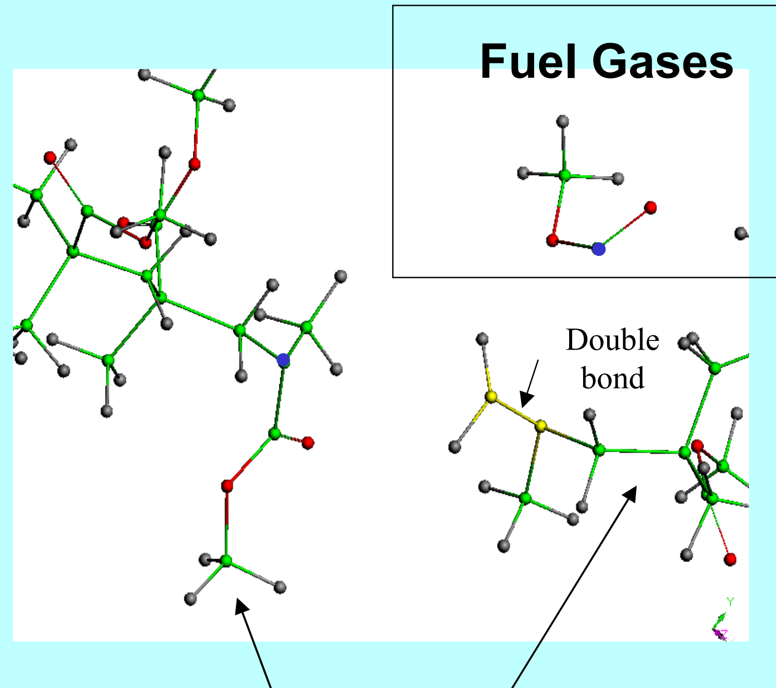


University of Massachusetts (Amherst)
PATENTS PENDING

CURRENT RESEARCH: Molecular Modeling

Reactive Molecular Dynamics (RMD) Predicts Rate And Type Of Fuel Species Generated In A Fire From Chemical Structure Of Polymer





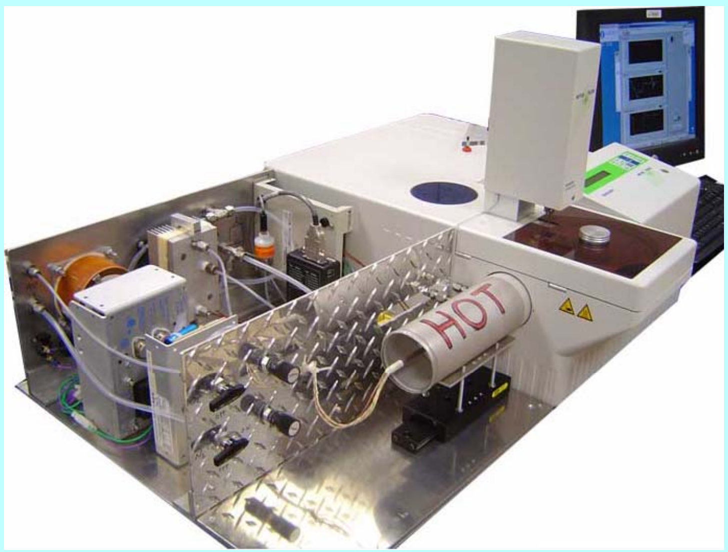
● chemically reactive atom

Decomposing Polymer

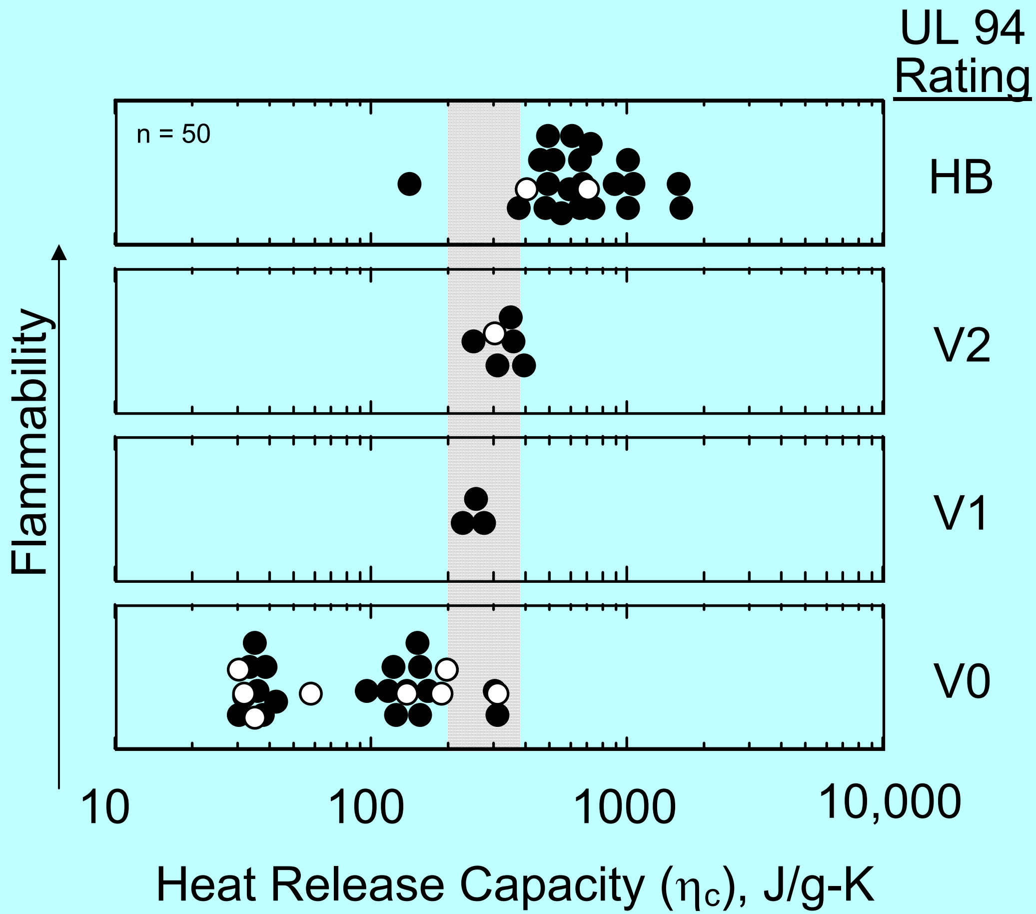
Oligomers

CURRENT RESEARCH: High Throughput FR Test

AUTOMATED MICRO HRR TEST PREDICTS FLAMMABILITY



TGA- Combustion Test



ACKNOWLEDGEMENTS: Research Partners

OTHER U.S. AGENCIES

- NIST
- U.S. Navy
- NASA Langley
- U.S. Army
- National Science Foundation

UNIVERSITIES

- Case Western Reserve
- Cornell University
- Penn State University
- Richard Stockton College of NJ
- Rutgers University
- Rice University
- University of Akron
- University of Maryland
- University of Massachusetts
- University of South Carolina
- Virginia Polytechnic University

CORPORATIONS

- Boeing Commercial Airplane Group
- BP Amoco Polymers
- Ciba Specialty Chemicals
- Dow Corning
- Dow Chemical Company
- Dupont Company
- Eikos Inc.
- Foster Miller Co.
- General Electric/GE Plastics
- Galaxy Scientific Corporation
- Monsanto Chemical Company
- Omega Point Laboratories
- Pacific Epoxy, Inc.
- Schneller, Inc.
- Solvay Advanced Polymers, Inc.
- Titeflex Corporation
- UCAR Carbon Company
- VANTICO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