Materials Fire Test Forum Meeting
FAA Technical Center, Atlantic City Airport, NJ 08405
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Micro- and Bench-Scale Fire Growth Parameters

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Objective:

Compare Fire Behavior of Materials For Regulatory Purposes

- Single physically based parameter
- Independent of test conditions
- Reproducible (COV < 5%)
- Obtained by standard methods

Microscale Combustion Calorimeter
ASTM D7309

Bench Scale Method Using ASTM E1354 Cone Calorimeter

Key Experimental Parameters

- Heat release rate per unit area, *dQ/dt* (W/m^2)
- Total heat release by combustion, Q_c (J/m^2)
- External heat flux, *EHF* (W/m^2)
- Time-to-ignition, t_{ign} (seconds)

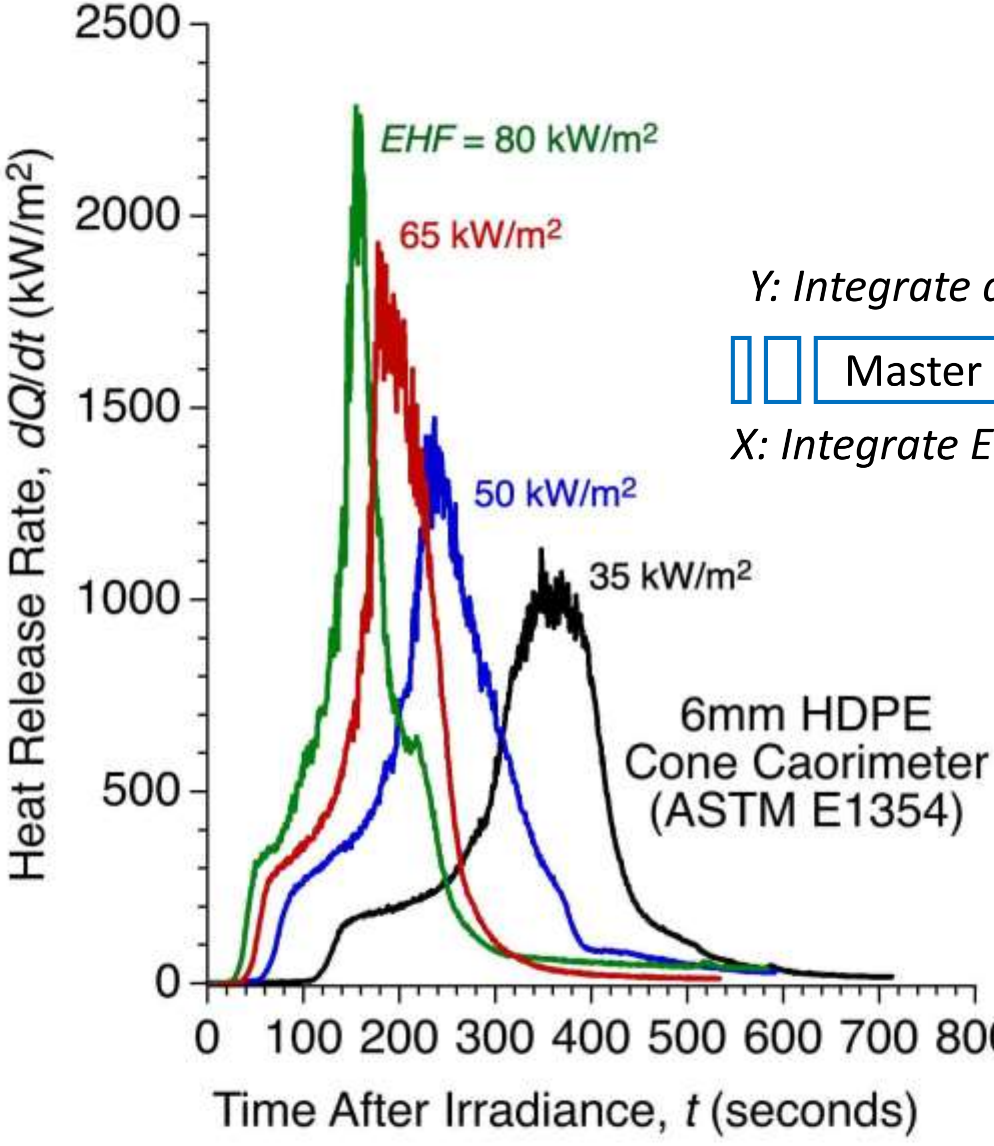
Derived Properties*

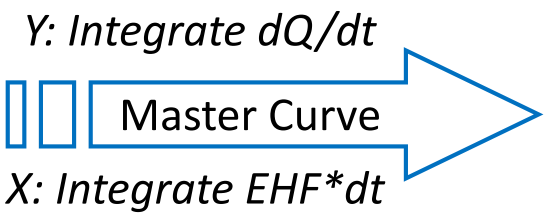
- **Heat Release Parameter (HRP)** $= \frac{\Delta Q}{\Delta E} = \frac{H_c}{H_g} = \frac{Effective\ Heat\ of\ Combustion}{Effective\ Heat\ of\ Gasification}$

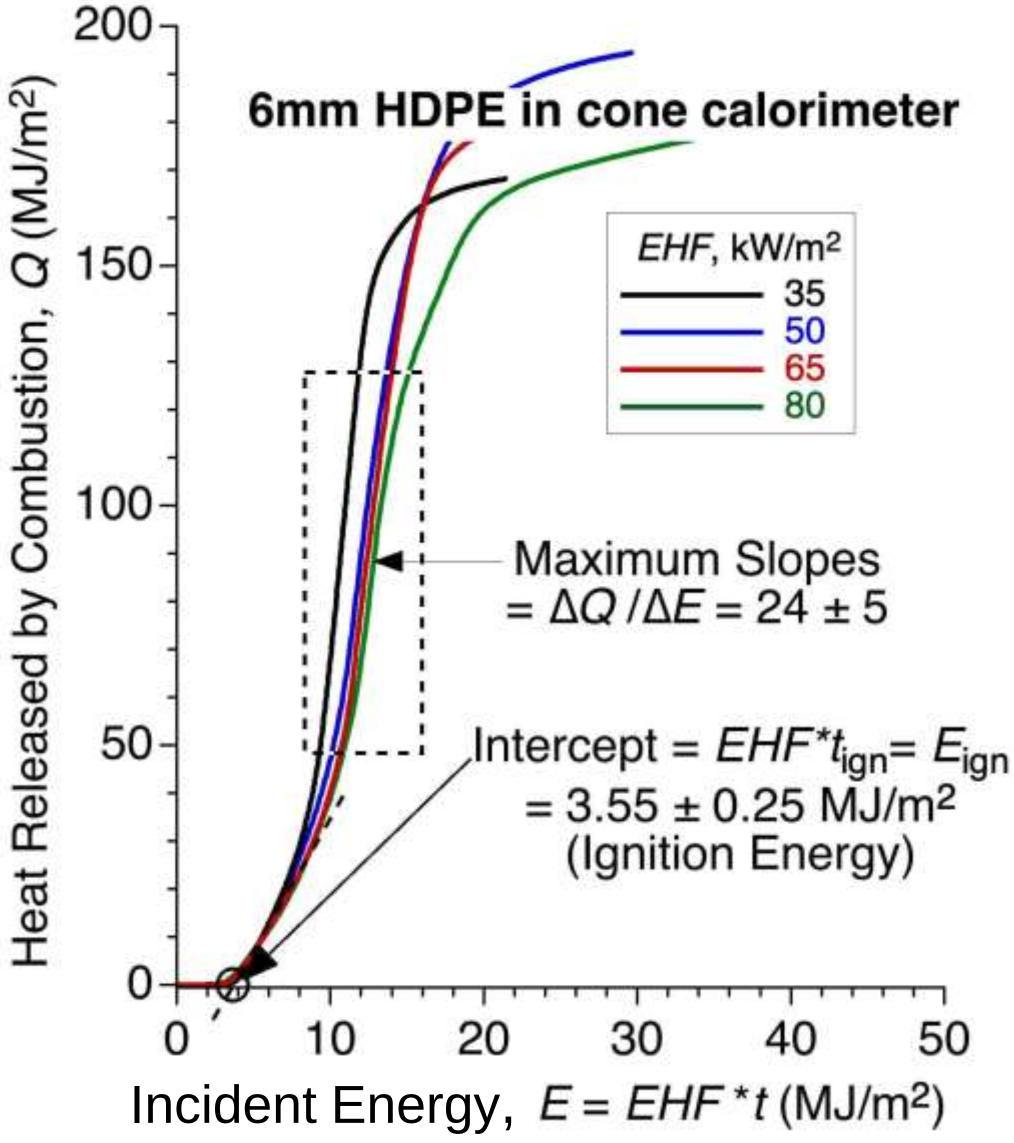
- **Ignition Energy** $(E_{ign}) = EHF * t_{ign} = \rho c_p \delta (T_{ign} - T_0)$

*R.E. Lyon, "Comparing Fire Behavior of Materials," 19th Meeting on Fire Retardant Polymeric Materials (FRPM23) EMPA, Zurich, Switzerland, 26-29 June 2023.

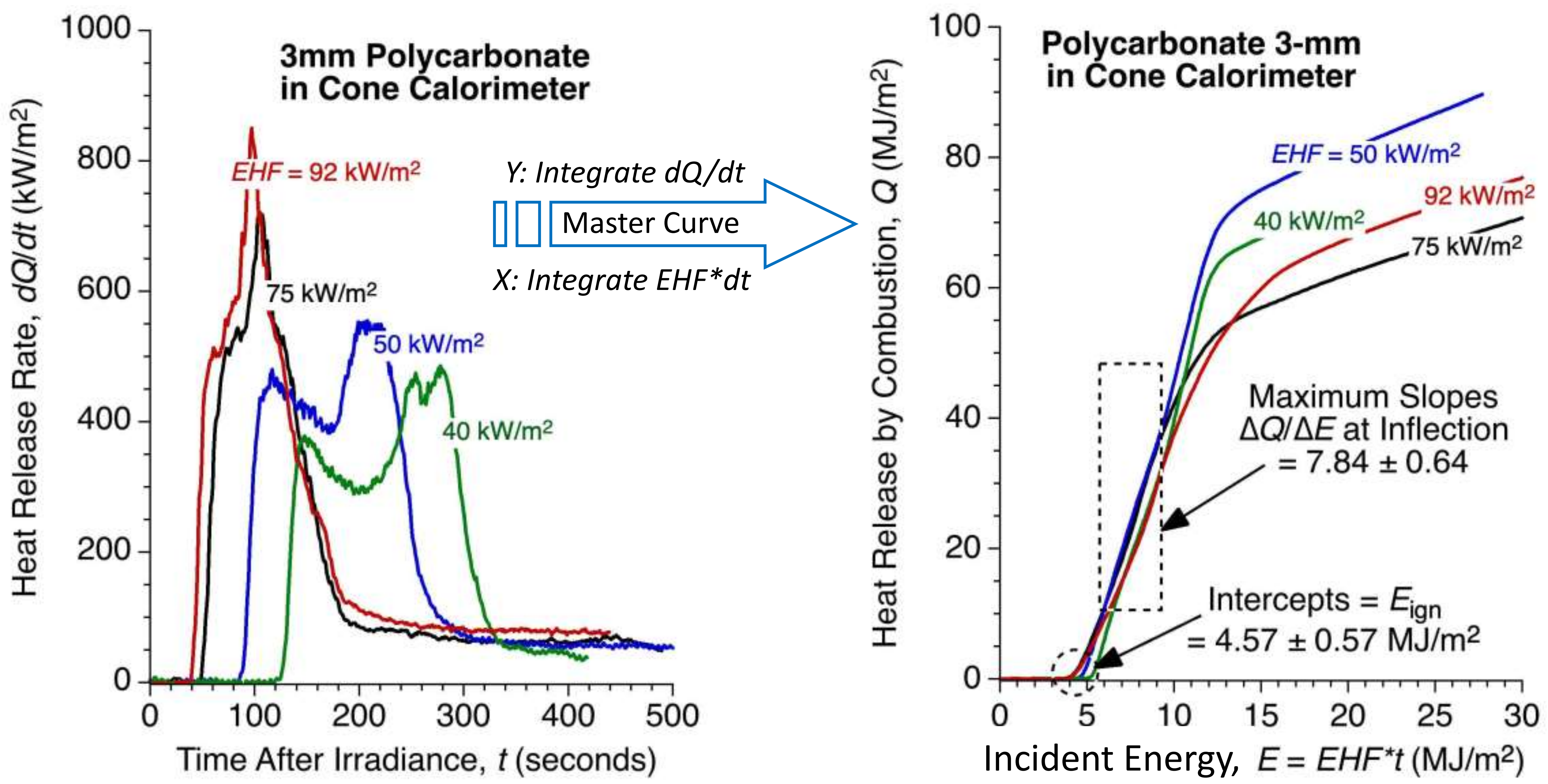
Master Curve of Combustion Energy (*Q*) *versus* Incident Energy (*E*)



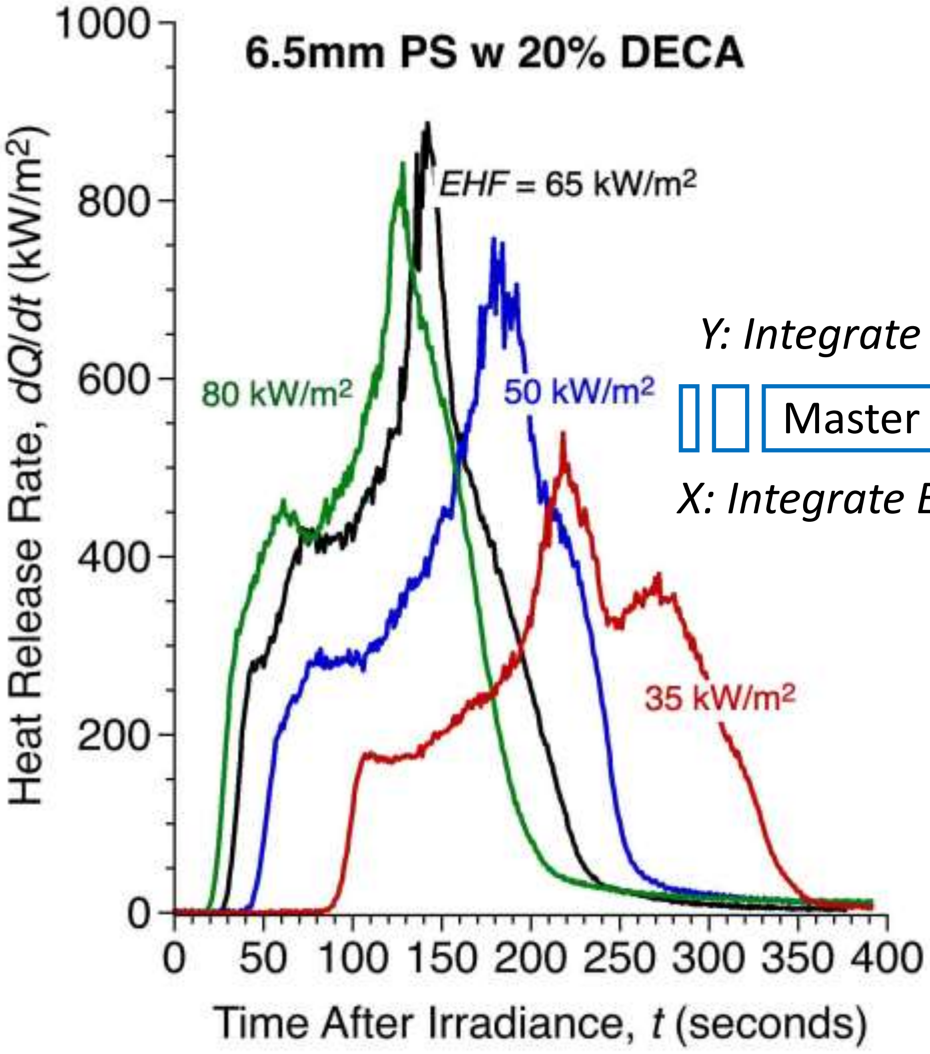


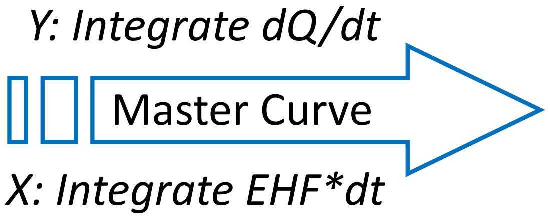


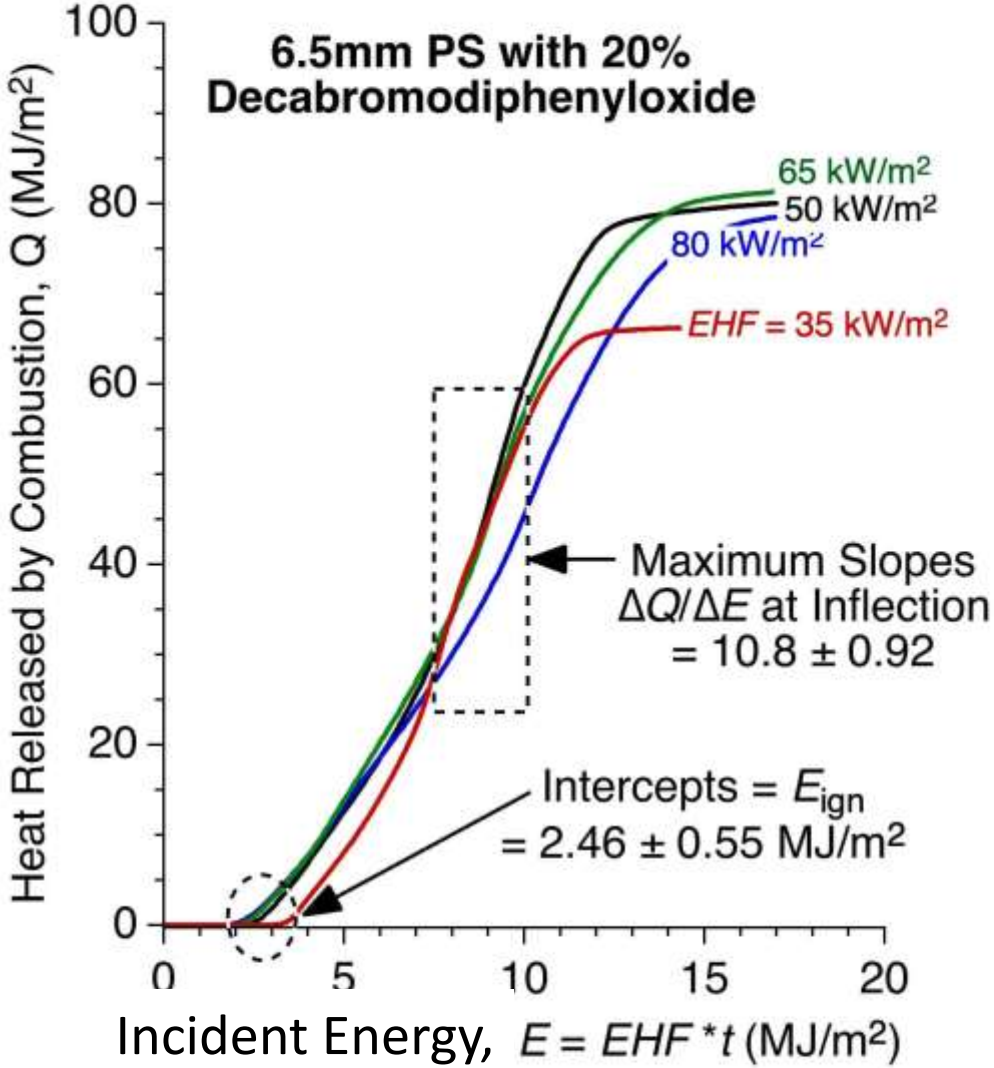
Master Curve Shows *HRP*, E_{ign} are Independent of Heat Flux



HRP, E_{ign} Should Also be Independent of Sample Thickness if Burning is Localized in a Pyrolysis Zone of Depth δ







Measured Ignition Energies E_{ign} Approximate Theoretical Values

- $Time\ to\ ignition = t_{ign} = \frac{\rho c_p \delta (T_{ign} - T_0)}{EHF}$
- $Ignition\ Energy = E_{ign} = EHF * t_{ign}$
  $= \rho c_p \delta \left(T_{ign} - T_0\right)$

Theoretical E_{ign} ≈ 3 MJ/m^2

Measured E_{ign} = 3.6 ± 2.3 MJ/m^2 (n = 27)

- $FGP = \frac{\Delta Q / \Delta E}{E_{ign}} = \frac{HRP}{E_{ign}}$ = **Heat Release Potential / Ignition Resistance**

ρ = density = 1100 ±100 kg/m^3

c_p = heat capacity = 1500 ±200 J/kg-K

δ = pyrolysis zone depth = 1-4 mm

T_{ign} = ignition temperature = 400 ± 50°C

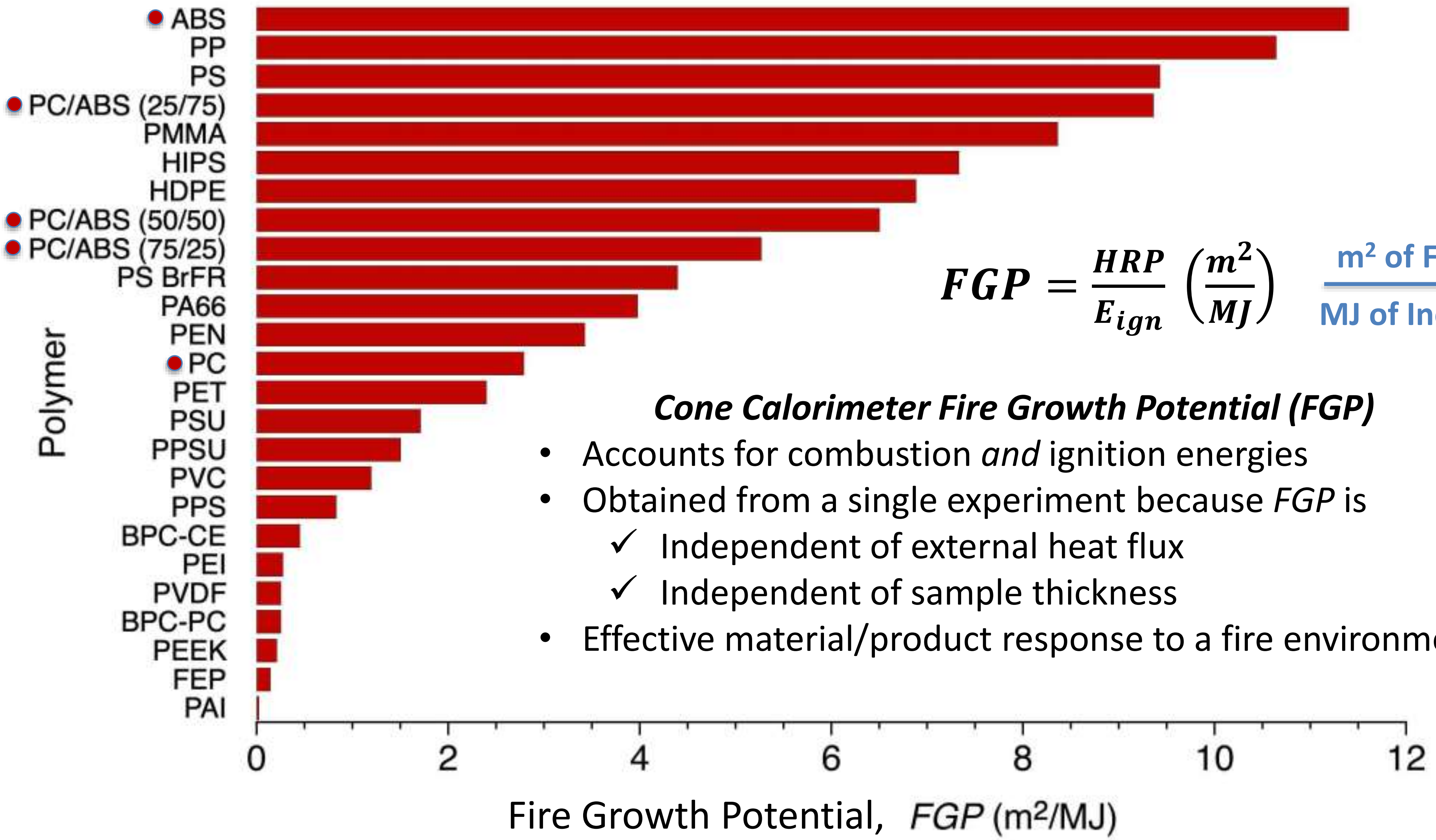
T_0 = ambient temperature = 25°C

EHF = external heat flux (10-100 kW/m^2)

H_c = Specific Heat of combustion (J/kg-gas)

H_g = Specific Heat of gasification (J/kg-gas)

Fire Growth Potentials Are Consistent With Material Fire Performance



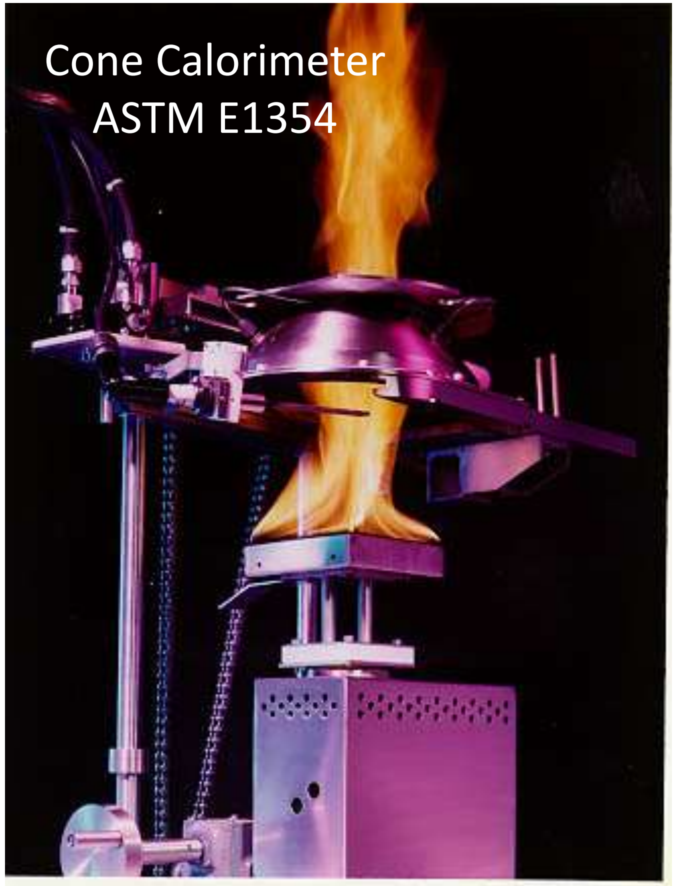
$$FGP = \frac{HRP}{E_{ign}} \left(\frac{m^2}{MJ}\right)$$

$\frac{\text{m}^2\text{ of Fire Growth}}{\text{MJ of Incident Energy}}$

Cone Calorimeter Fire Growth Potential (FGP)

- Accounts for combustion *and* ignition energies
- Obtained from a single experiment because *FGP* is
  - ✓ Independent of external heat flux
  - ✓ Independent of sample thickness
- Effective material/product response to a fire environment

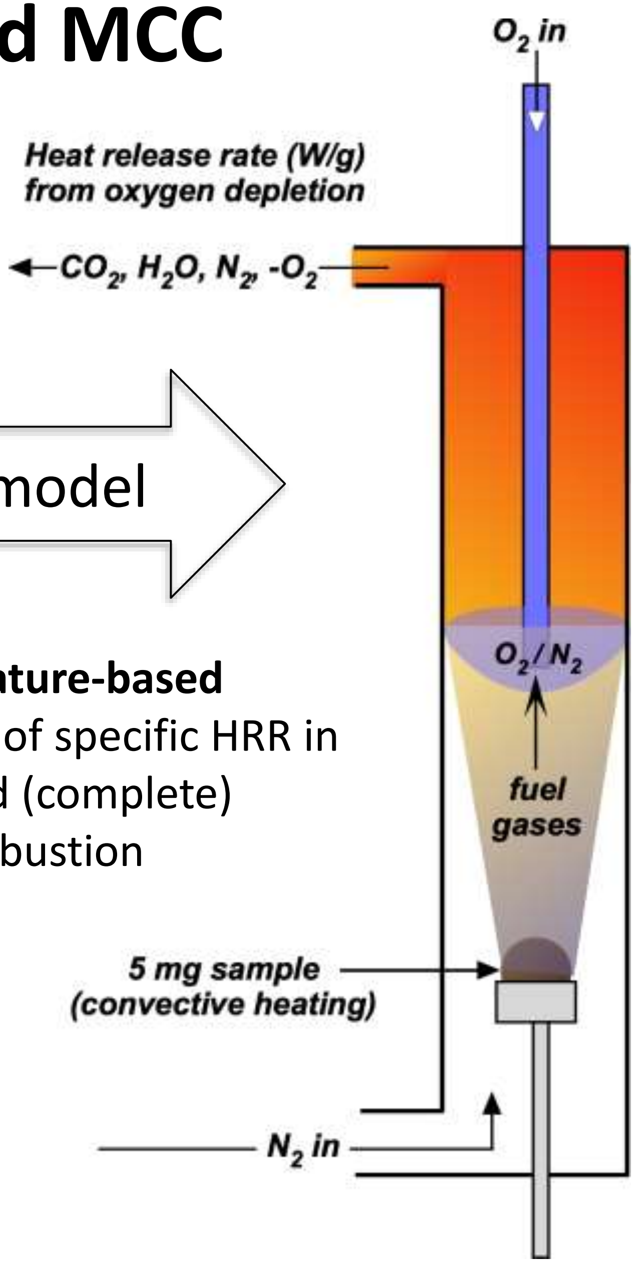
Relationship Between Cone and MCC



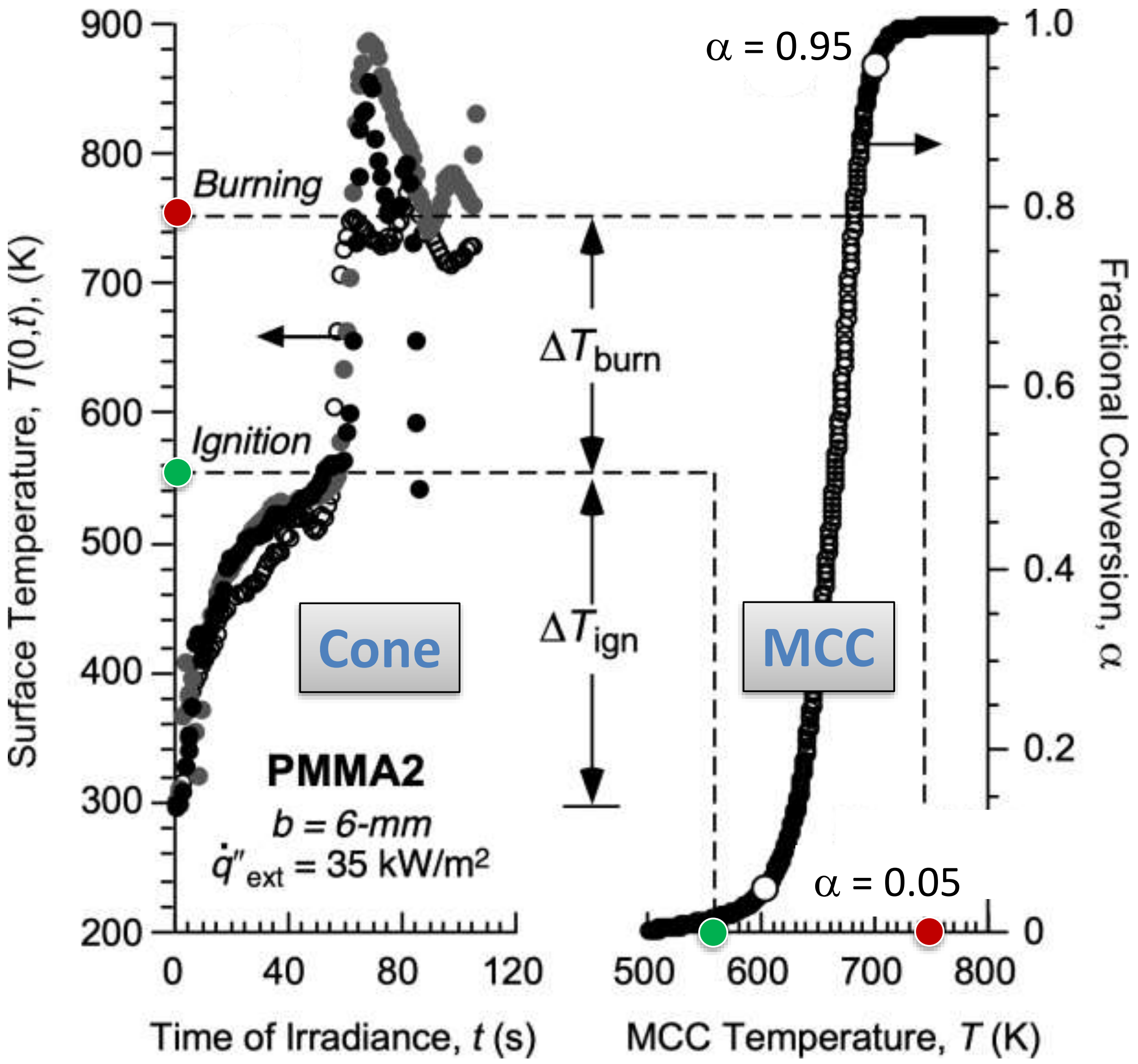
Time-based measurement of areal HRR in diffusion flame (incomplete combustion)

Physical burning model

Temperature-based measurement of specific HRR in premixed (complete) combustion



Time-Temperature Correspondence (Non-Charring)



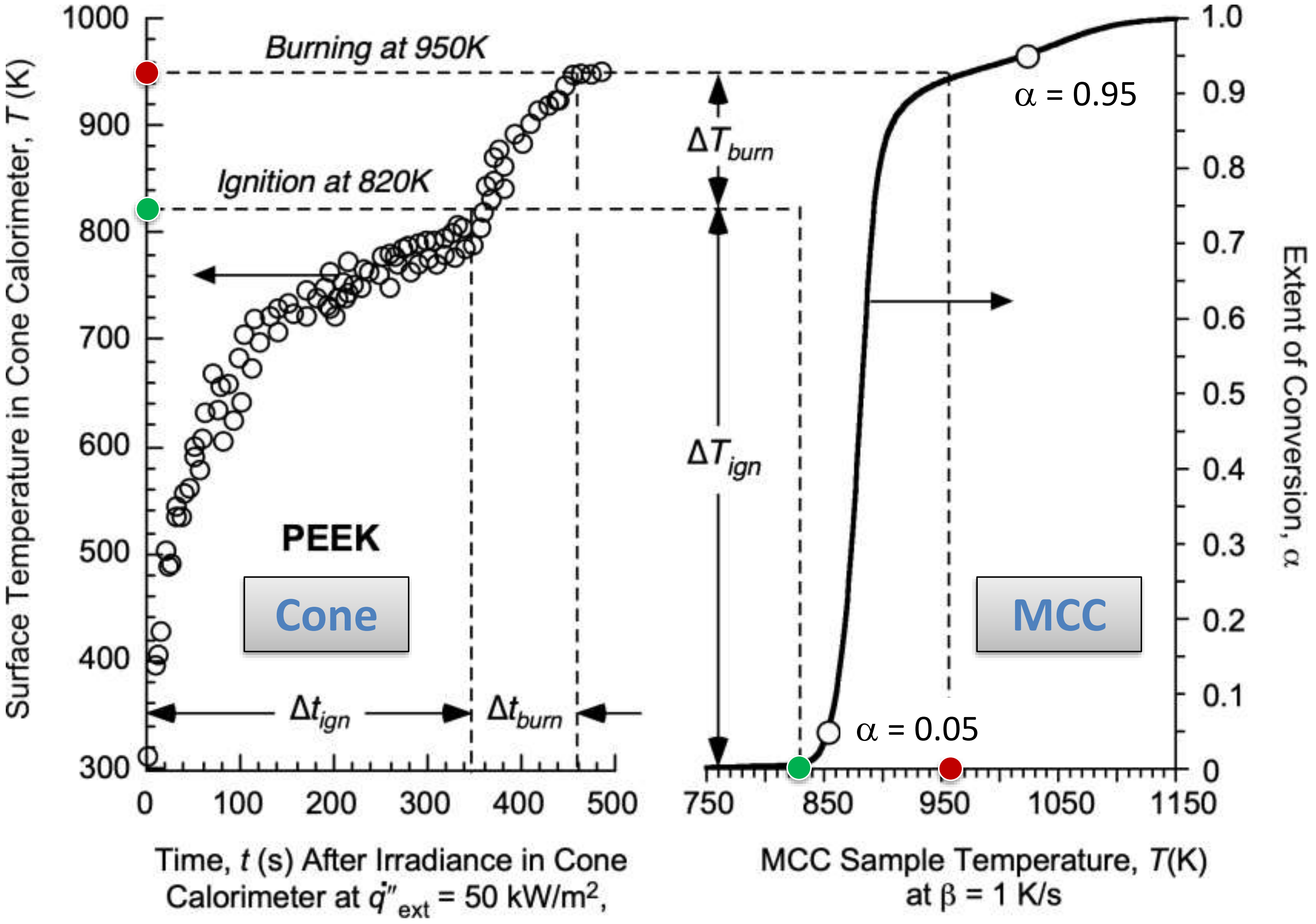
Burning Temperature

Cone	MCC
T_{burn}	$\approx T_{95\%}$

Ignition Temperature

Cone	MCC
T_{ign}	$\approx T_{5\%}$

Time-Temperature Correspondence (Charring)



Burning Temperature

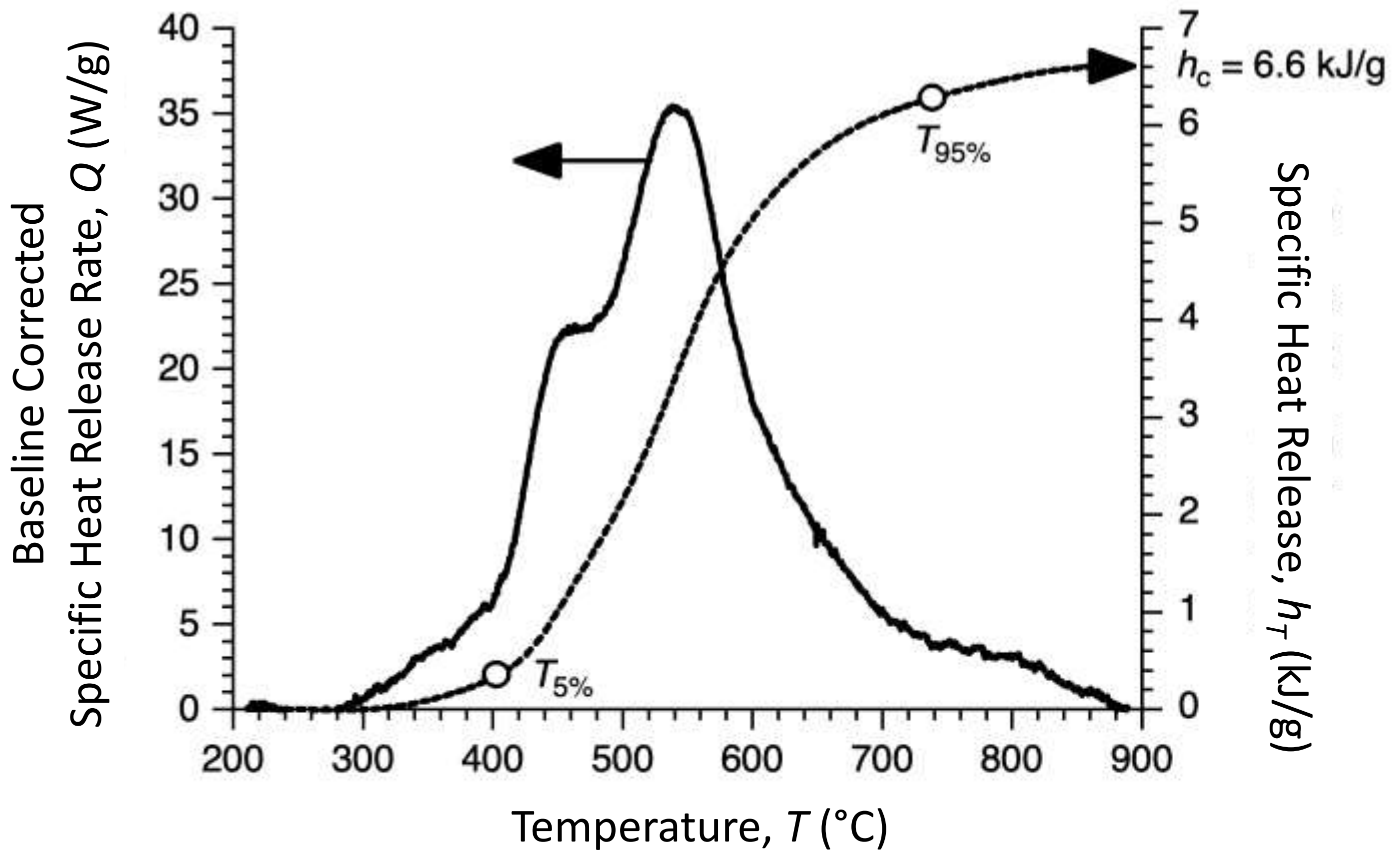
Cone	MCC
T_{burn}	$\approx T_{95\%}$

Ignition Temperature

Cone	MCC
T_{ign}	$\approx T_{5\%}$

Fire Growth Capacity (FGC) is Microscale Metric for FAA Similarity

R.E. Lyon, A Molecular-Level Fire Growth Parameter, *Polymer Degradation & Stability,* 186 (April 2021)



Since,

$T_{5\%}$ (MCC) ≈ T_{ign} (cone)

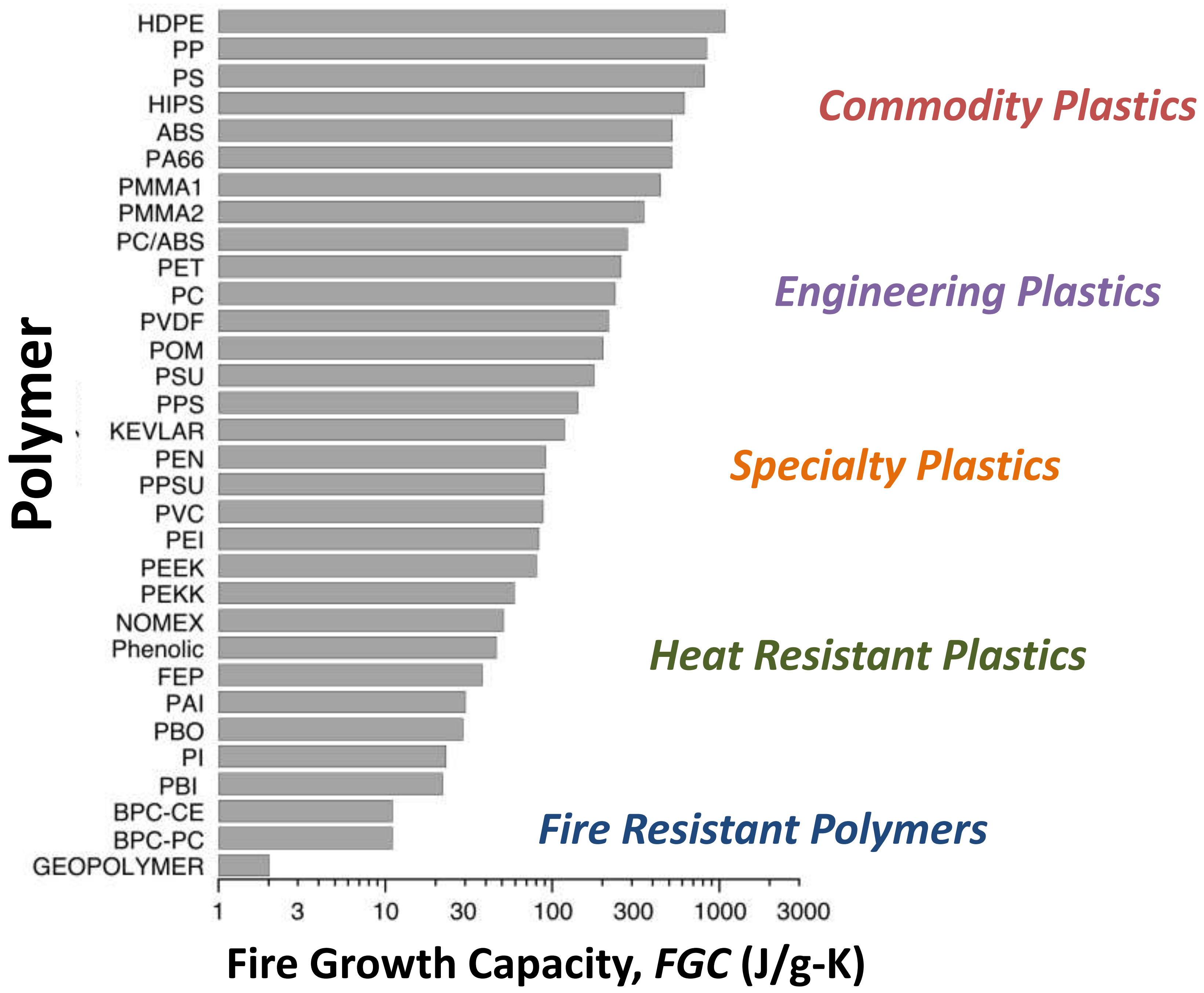
and

$T_{95\%}$ (MCC) ≈ T_{burn} (cone)

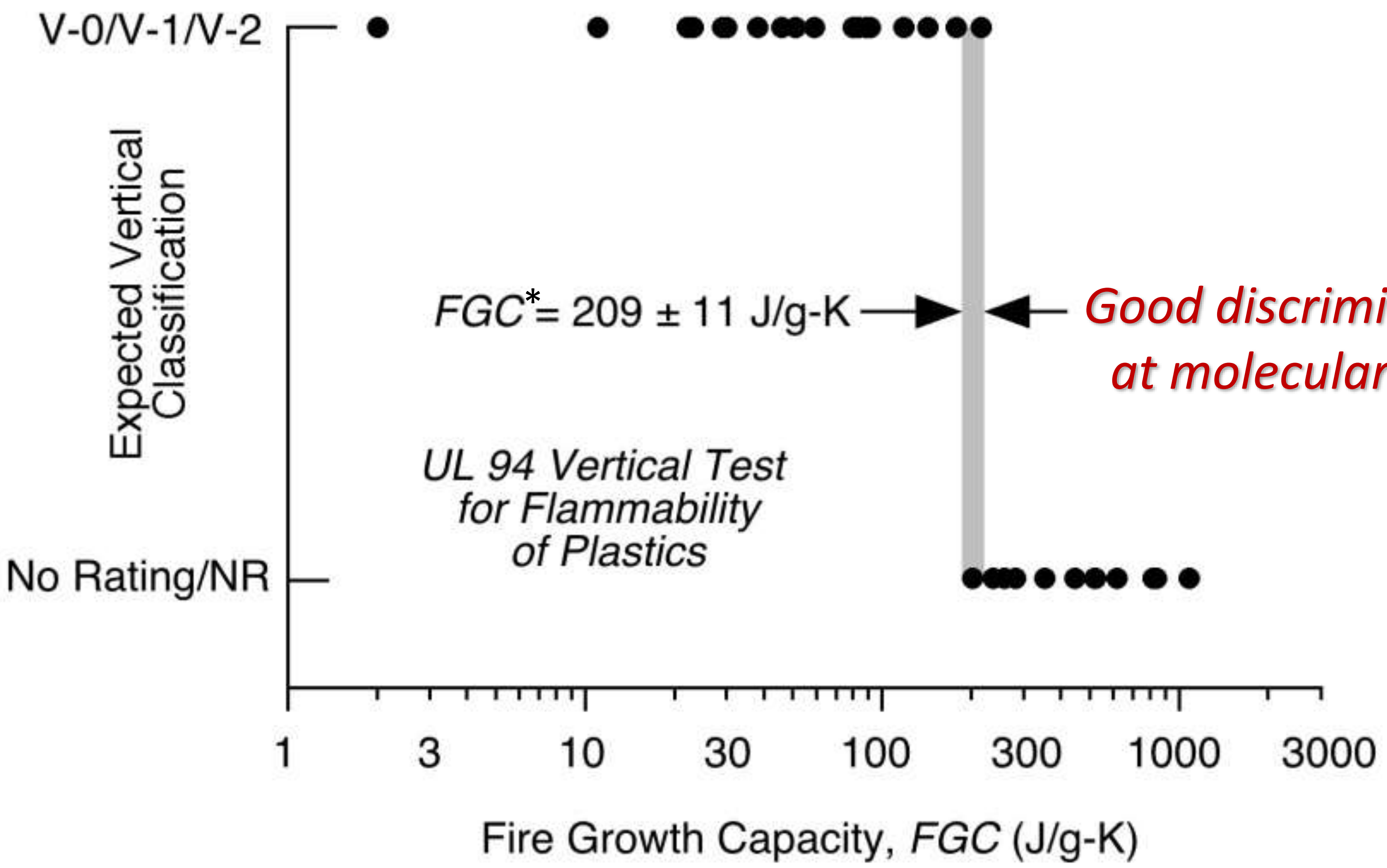
Heat Release Rate ***Ignitability***

$$FGC = \frac{h_c}{T_{burn} - T_{ign}} + \frac{h_c}{T_{ign} - T_0}$$

$$\approx \left(\frac{h_c}{T_{95\%} - T_{5\%}}\right)\left(\frac{T_{95\%} - T_0}{T_{5\%} - T_0}\right)$$

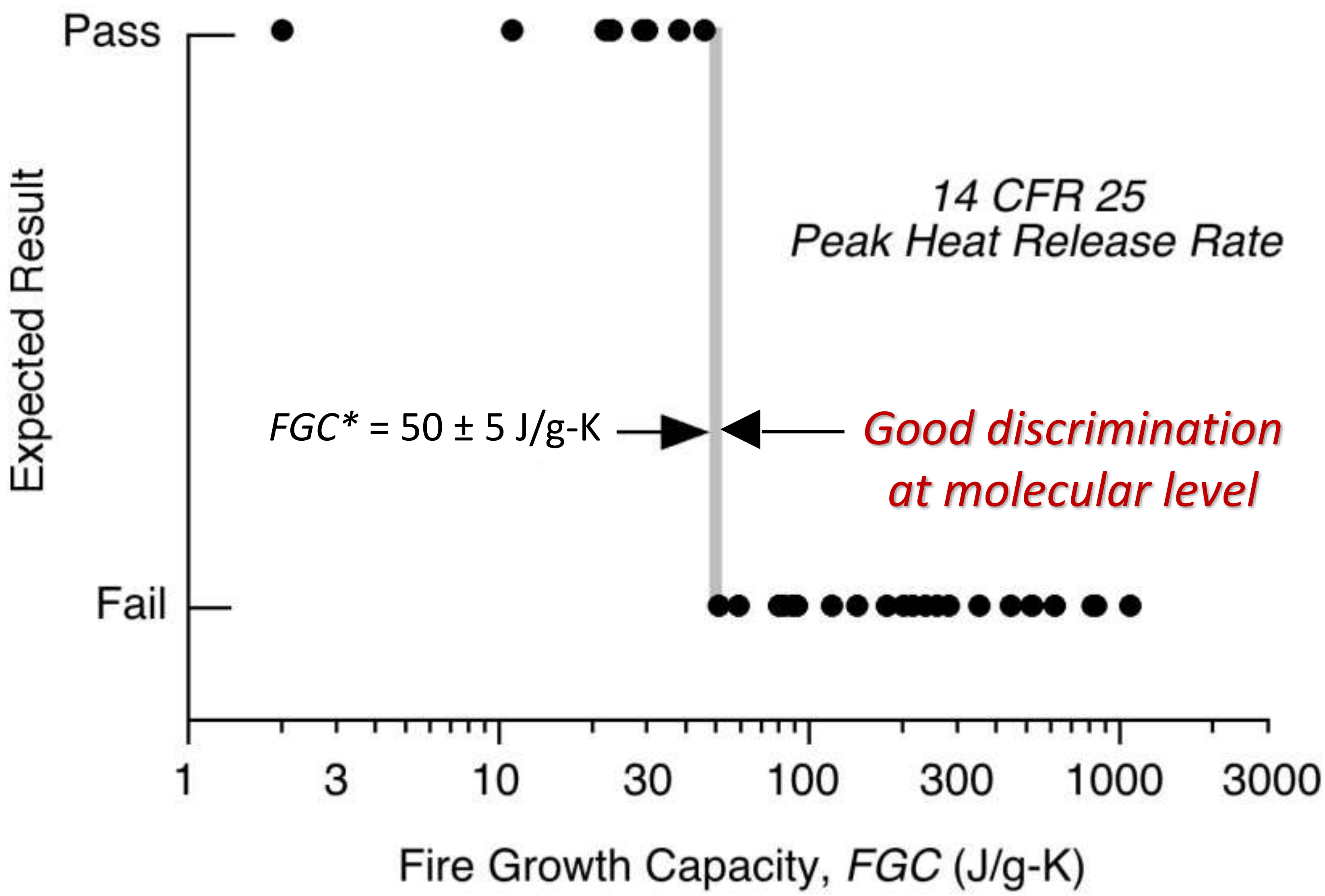

Polymer
HDPE
PP
PS
HIPS
ABS
PA66
PMMA1
PMMA2
PC/ABS
PET
PC
PVDF
POM
PSU
PPS
KEVLAR
PEN
PPSU
PVC
PEI
PEEK
PEKK
NOMEX
Phenolic
FEP
PAI
PBO
PI
PBI
BPC-CE
BPC-PC
GEOPOLYMER
1
3
10
30
100
300
1000
3000
Fire Growth Capacity, FGC (J/g-K)
Commodity Plastics
Engineering Plastics
Specialty Plastics
Heat Resistant Plastics
Fire Resistant Polymers

FGC and Upward Flame Spread in Bunsen Burner Test (UL 94 V or ASTM D3801)

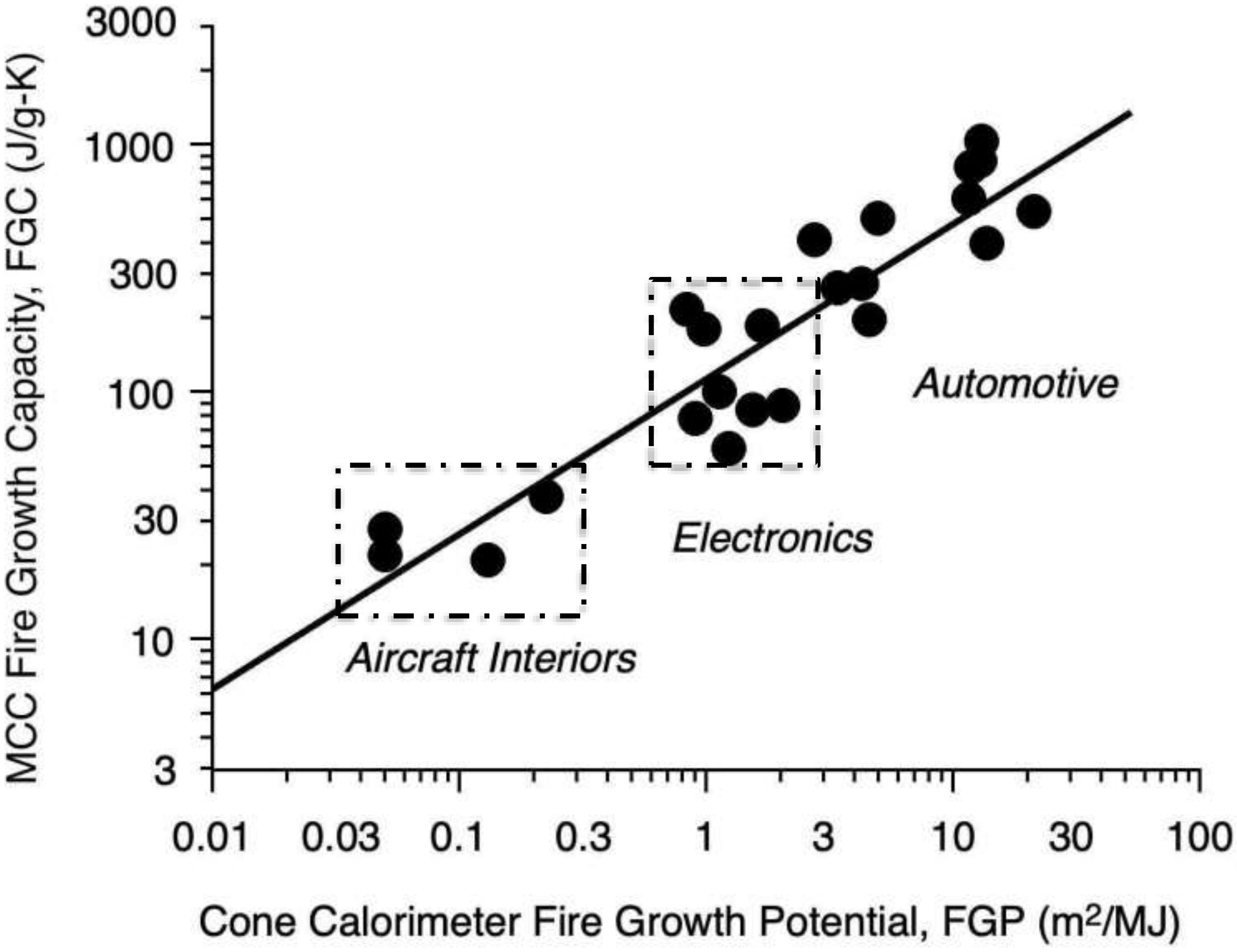


Good discrimination at molecular level

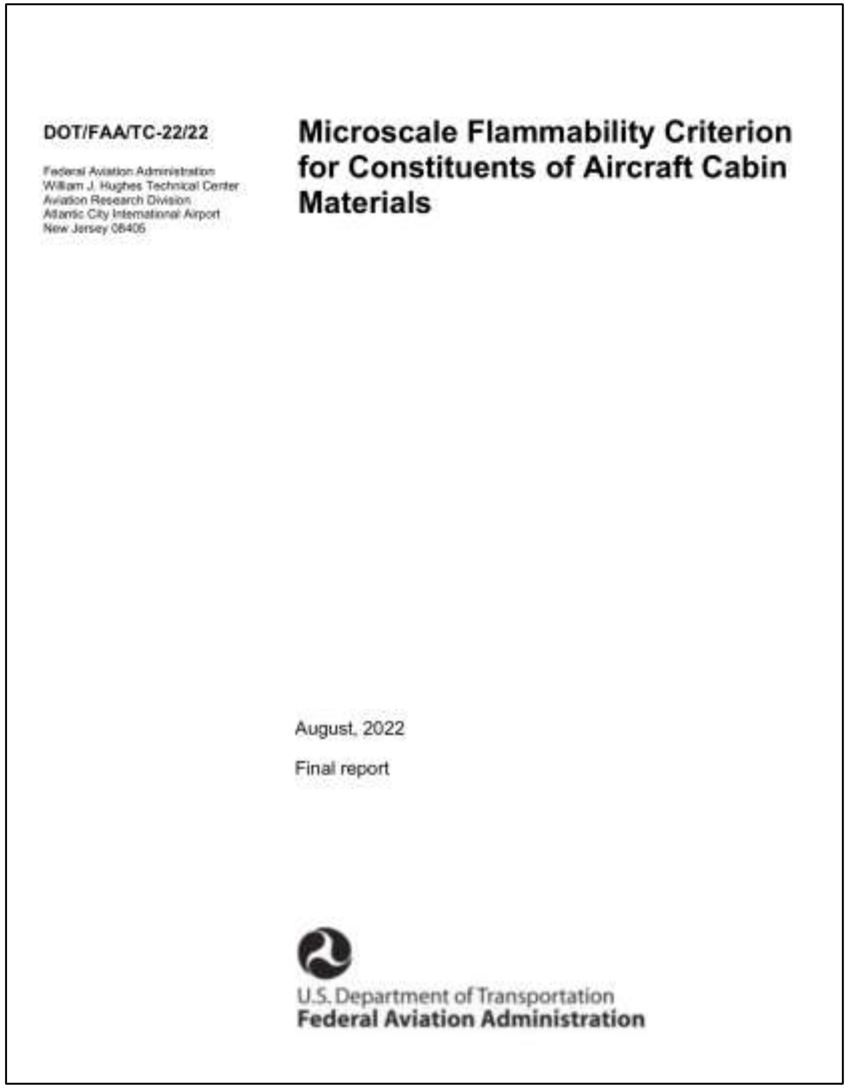
FGC and Heat Release Rate in OSU Fire Calorimeter (14 CFR 25 or ASTM E906)



Microscale Combustion Calorimeter *FGC* ∝ Cone Calorimeter *FGP*



MCC Criterion for Equivalent 14 CFR 25 Flammability



DOT/FAA/TC-22/22

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Microscale Flammability Criterion for Constituents of Aircraft Cabin Materials

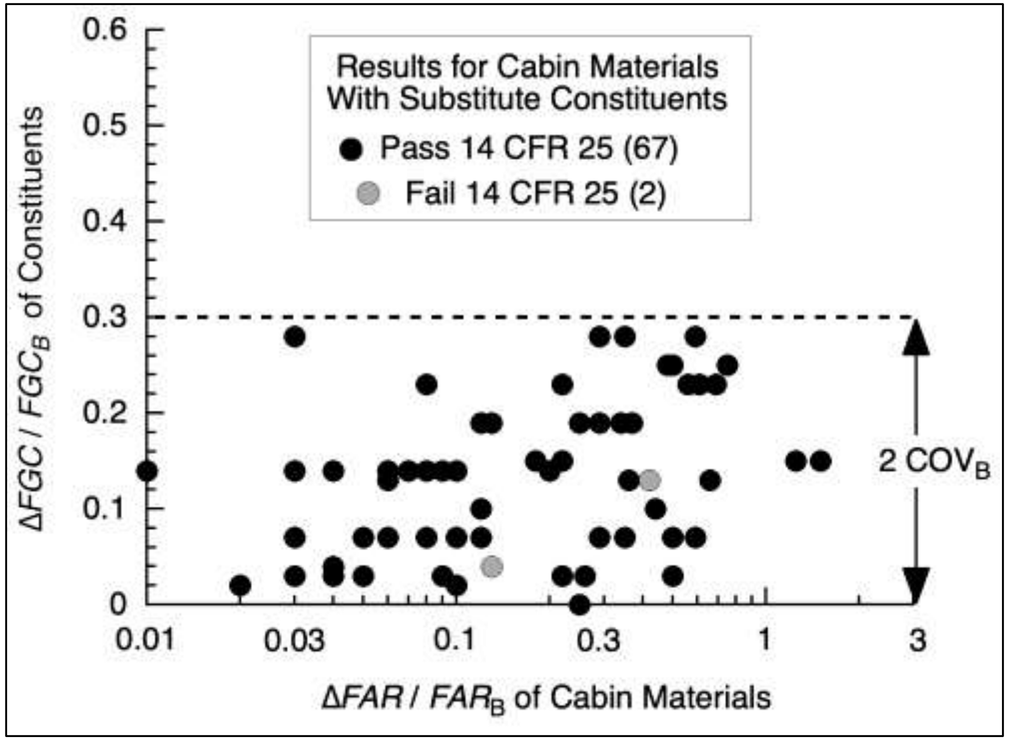
August, 2022

Final report

U.S. Department of Transportation
Federal Aviation Administration

$$\frac{\Delta FGC}{FGC_{certified}} \leq 0.3$$

Correctly predicts FAR Passing Results for Component Substitutions 97% of the Time



Data for 69 materials in FAA/Industry Study

Current ASTM D20.30.03 Plastics/Thermal Properties/Combustion Ballot to Add Baseline Correction to MCC Standard

INTERNATIONAL Designation: D7309 – 21b

ITEM 24

Date: 15 Sept 2023

To: Subcommittee D20.30 and Main Committee D20 members (concurrent ballots)

Tech Contact: Frederick Schall, fpschall@comcast.net / +1 847 373 9662

Work Item #: WK87880

Ballot Action: Revision of Revision of D7309-21B/Standard Test Method for Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry.

Rationale:

This item was previously balloted as WK83409 on D20 Main Committee ballot D20 922-06) Item 17 closing 24 October 2022. This version resolves all negatives received on the balloted item.

The microscale combustion calorimeter signal is susceptible to thermal and temporal fluctuations when no test specimen is present. This is called baseline drift and can cause significant error in flammability characteristics if left uncorrected. This ballot provides methods for correcting the calorimeter signal for baseline drift to improve reproducibility and repeatability of test results and giving specific instructions for performing calculations with and without baseline correction.

The entire standard is presented for clarity. Only clauses containing revisions shown as ~~strikethrough~~ and underlined text are subject to ballot.

Standard Test Method for

Determining Flammability Characteristics of Plastics and Other Solid Materials Using Microscale Combustion Calorimetry[1]

This standard is issued under the fixed designation D7309; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

Conclusions

ASTM E1354 Cone Calorimeter Fire Growth

- Large (4-in x 4-in) sample is mounted horizontally = no melting, dripping or swelling problems.
- *Fire Growth Potential FGP* (m^2/MJ) has units of square meters of burning surface area per mega-Joule of incident energy.
- *Product Fire Hazard, PFH = FGP * THR* (dimensionless) where *THR* (MJ/m^2) is the total heat release (fire load) of cabin materials, constructions, insulation blankets, thermoformed parts, textiles, wiring, etc.
- **Reproducibility of *FGP* is ±20% based on ASTM interlaboratory study of Q_c.**

ASTM D7309 Microscale Combustion Calorimeter Fire Growth

- Small (milligram) sample in cup = no melting, dripping or swelling problems.
- *Fire Growth Capacity FGC* (J/g-K) is a molecular-level parameter that is the total heat release and ignitability of small (milligram) samples of materials.
- Differences of less than 30% between certified and substitute materials are not seen in FAR fire tests.
- **Reproducibility of *FGC* is ±4% based on preliminary ASTM interlaboratory study.**