Plastics Performance Overview

-A Primer on Thermoplastic Polymer Resins-

Presented by

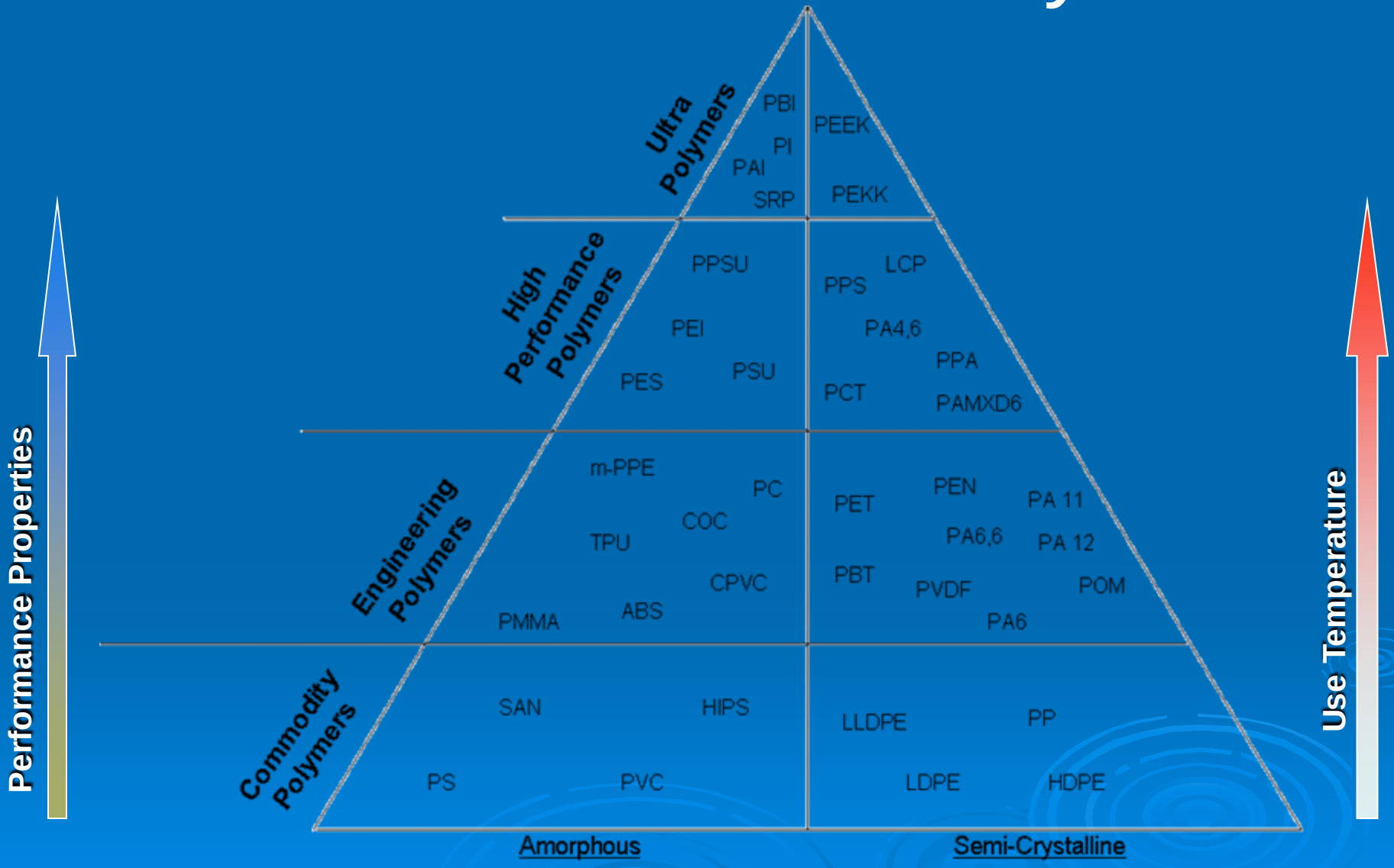
China Array Plastics LLC

Contents:

- Plastics Performance Pyramid
- Key of Polymer Acronyms
- Performance vs. Cost **Trends
- Individual Ultra, High Performance Polymer, and Select Engineering Resin Profiles

**Pricing Estimates Stated Herein are Derived From
Plastics Technology ®, Plastics News®, and other Reputable Public Sources during 4Q 2007.
They are Estimates Only, and are United States prices.

Plastics Performance Pyramid



Polymer Classes

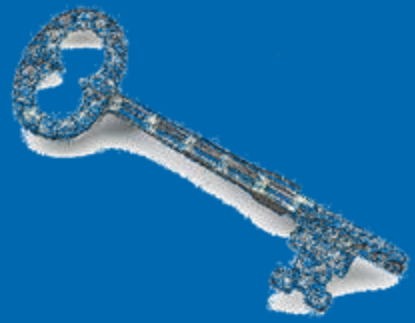
- **Amorphous** - The polymer is arranged randomly on the molecular level
  - General Attributes
    - Low Shrinkage
    - Low Warp
    - Usually Transparent/Translucent
    - Poor Impact
    - Poor Chemical Resistance
    - Low Ductility
    - Lower Heat Resistance vs. Crystalline
    - Lower Creep Resistance vs. Crystalline
- **Crystalline** - The polymer is arranged in a regular order on the molecular level
  - General Attributes
    - Good Chemical Resistance
    - Good Ductility
    - Poor Shrinkage
    - Good Stiffness
    - Poor Warpage
    - Good Barrier
    - Better Heat Resistance vs. Amorphous
    - Better Creep Resistance vs. Amorphous

Thermoplastic Classifications
-General Trends

- Commodity
  - High Volume
  - Low Cost
  - Low Stiffness
  - Low FR (Flammability Resistance)
  - Low Temperature Resistance
  - Poor Chemical Resistance
- High Performance
  - Low-Medium Volume
  - High Cost
  - High Stiffness
  - Inherently FR
  - High Temperature Resistance
  - Good Dimensional Stability
  - High Chemical Resistance
- Engineering
  - High Volume
  - Moderate Cost
  - Good Stiffness/Impact
  - Low FR, Good Chemical Resistance
  - Moderate Temperature Resistance
  - Good Dimensional Stability
- Ultra
  - Low Volume
  - Very High Cost
  - Very High Stiffness & Hardness
  - Inherently FR
  - Extreme Temperature Resistance
  - Very High Chemical Resistance
  - Wear & Fatigue Resistance

Plastics Key

Commodity	
HDPE	High Density Polyethylene
HIPS	High Impact Polystryrene
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
SAN	Styrene Acrylonitrile



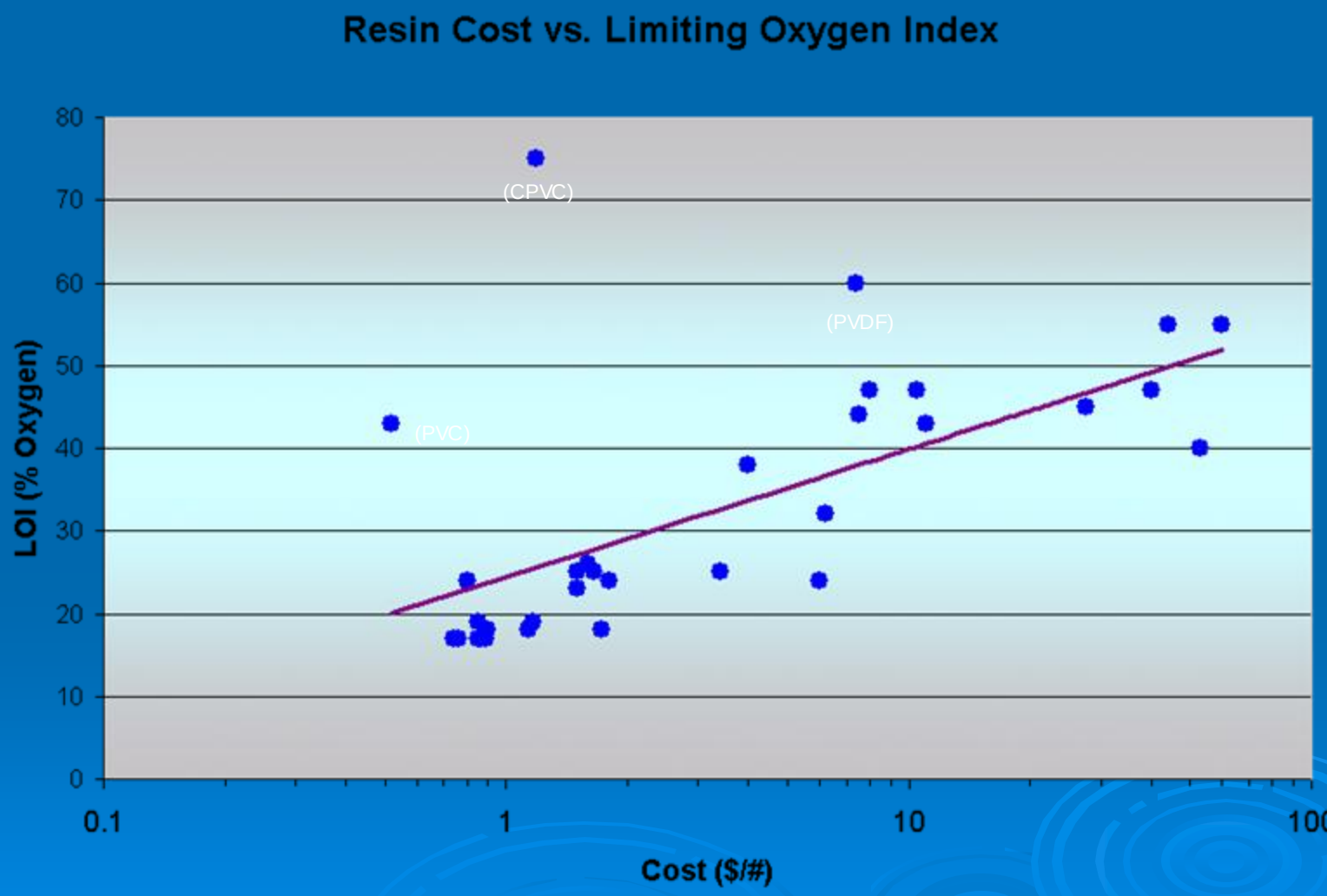
High Performance	
LCP	Liquid Crystal Polymer
PA4,6	Polyamide 4,6
PAI	Polyamideimide
PAMXD6	Polyarylamide
PBI	Polybenzimidazole
PCT	Polycyclohexylene dimethyl terephthalate
PEEK	Polyetheretherketone
PEI	Polyetherimide
PEKK	Polyetherketoneketone
PES	Polyethersulfone
PPS	Polyphenylene sulfide
PPSU	Polyphenylsulfone
PPA	Polyphthalamide
PSU	Polysulfone
SRP	Self Reinforced Polyphenylene
TPI	Thermoplastic Polyimide

Engineering	
ABS	Acrylonitrile Butadiene Styrene
COC	Cyclic Olefin Copolymer
CPVC	Chlorinated Polyvinylchloride
m-PPE	Polyphenyleneether
PA 11	Polyamide 11
PA12	Polyamide 12
PA6	Polyamide 6
PA6,6	Polyamide 6,6
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PEN	Polyethylene 2,6-naphthalenedicarboxylate
PET	Polyethylene Terephthalate
PMMA	Polymethyl methacrylate
POM	Polyoxymethylene
PVDF	Polyvinylidinedifluoride
TPU	Thermoplastic Polyurethane

Limiting Oxygen Index (LOI)

- LOI expresses the minimum percentage (by volume) of oxygen necessary for a material to undergo flammable combustion
  - Atmospheric air is about 21% oxygen
    - A material's LOI increasing beyond 21 is an indication of increasing resistance to fire
- Some polymers have a high LOI and thus are considered inherently flame retardant
  - This performance is often reflected in higher pricing
    - Exceptions include some halogen containing polymers

Price/Performance Trends

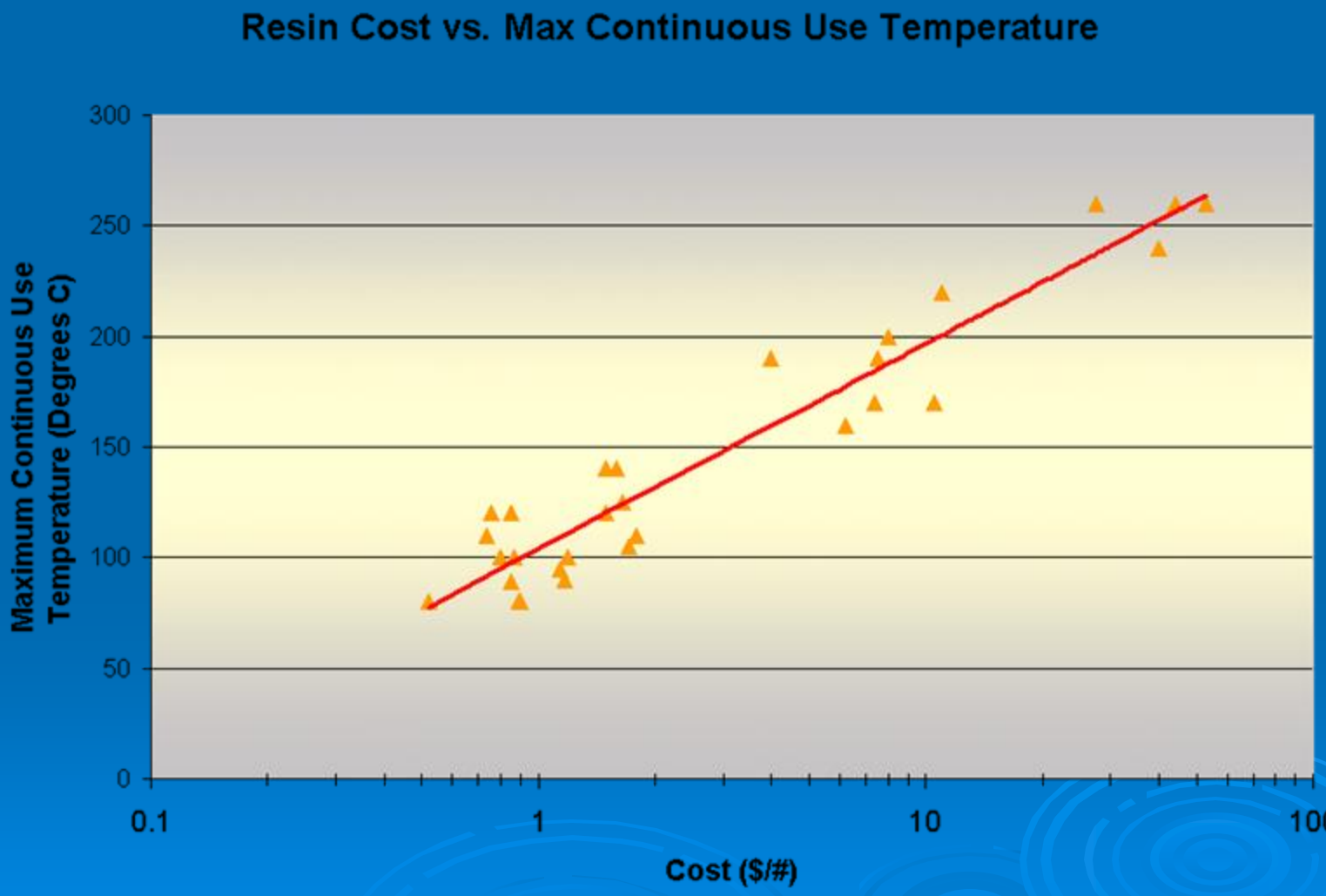


= lb.

Continuous Use Temperature

- The continuous use temperature is used to indicate the maximum temperature at which a material may be exposed to for a given long period of time leading to a property loss of 50%
  - Property is usually tensile strength or impact (Tensile Herein)
  - Run for 500-20,000 hrs – Not indefinitely
    - All polymers are organic and thus will break down eventually
  - Key design parameter for demanding applications such as underhood automotive, aerospace, and other industries
  - As continuous use temperature increases so does the cost of the resin

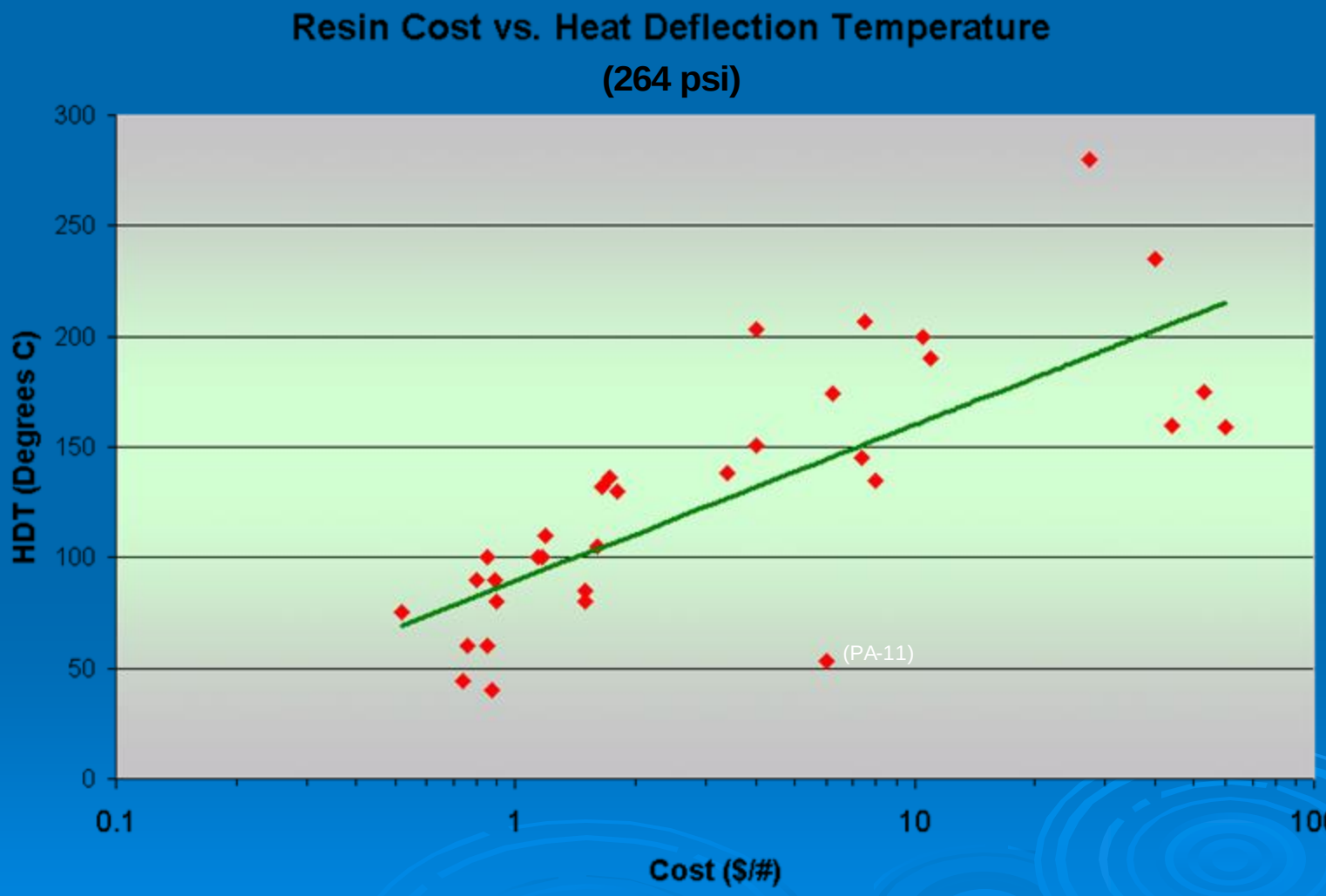
Price/Performance Trends



Heat Distortion Temperature

- Heat Distortion Temperature indicates the temperature at which a material deflects a certain distance under a specified load
  - Generally run at 66 psi and 264 psi
  - Used as a design parameter to determine if a part will deform during use or post molding operations that entail elevated temperatures
  - Higher HDT materials generally command a premium price

Price/Performance Trends



SRP

(Self Reinforced Polyphenylene)

{Injection Molded Grade}

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - Very High Stiffness
    - Good Chemical Resistance
    - LOI of 55%
  - Maintains Mechanical Properties up to 300° C
  - Machinable to Tight Tolerances
  - Very High Wear Resistance
  - Very low Shrinkage
  - Dimensional Stability
  - Intrinsic FR and Low Smoke
  - Good UV and Gamma Resistance
- **Targeted Applications and Markets**
  - Automotive Components
  - Aerospace
  - Electronics/Circuit Boards
  - Medical Devices
  - Bolts and Fasteners
  - Coatings and Composites
- **High Temperature Polymer**
  - Melt Process Temp of ~370-390° C
  - Continuous use Temp. of ~260° C
  - Heat Distortion Temp. (264psi) 159° C
- **Major Resin Producers**
  - Solvay
- **Intermediates**
  - Biphenyl
  - Benzoyl Chloride

PEEK

(Polyetheretherketone)

- **Key Properties & Performance Characteristics**
  - Semi-Crystalline (Opaque)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 55
  - Maintains Mechanical Properties up to 300° C
  - Very High Wear Resistance
  - Good Fatigue Resistance
  - BioCompatible
  - Inherent Low Flammability and Low Smoke
  - High Flow
  - Ability to Sterilize – (Autoclave &Radiation)

- **High Temperature Polymer**
  - Melt Process Temp of ~380° C
  - Continuous use Temp. of ~260° C
  - Heat Distortion Temp. (264psi) 160° C

- **Major Resin Producers**
  - Victrex
  - Solvay

- **Intermediates**
  - 4,4' diOH benzophenone
  - 4,4 difluorobenzophenone

- **Targeted Applications and Markets**
  - Bearings & Bushings
  - Gears
  - Aerospace
  - Electronics/Circuit Boards
  - Medical Implants
  - Tubing

PEKK

(Polyetherketoneketone)

- **Key Properties & Performance Characteristics**
  - Crystalline (Opaque)
    - High Stiffness
    - LOI of 40
  - Very High Purity
  - Bio-implantable Grades
  - Higher Tg than PEEK (162C vs. 142C)
  - Compressive Strength (30,000 psi) higher than PEEK
  - Slower crystallization than PEEK resulting in less warpage
  - Very Good Chemical Resistance
- **Targeted Applications and Markets**
  - Bio-medical
  - Fuel Cell (Functionalized)
  - Pumps
  - High Temperature Applications
- **High Temperature Polymer**
  - Melt Process Temp of 380° C
  - Continuous use Temp. of - 260° C
  - Heat Distortion Temp. (264psi)- 175° C
- **Major Resin Producers • Intermediates**
  - Oxford Performance Materials
  - Diphenyl ether
  - Isophthaloyl chloride

TPI

(Thermoplastic Polyimide)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent & Opaque Grades)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 47
  - Maintains Mechanical Properties up to 230° C
  - Low Friction / High Wear Resistance
  - Low Metals Content (High Purity)
  - High Chemical Resistance
  - Low Shrinkage and High Dimensional Stability
  - Inherent low flammability and low smoke
  - Ability to Sterilize – (Autoclave &Radiation)
  - No need for "Post Curing" (Optional)
- **Targeted Applications and Markets**
  - Military
  - Aerospace
  - Electronics/Electrical
  - High Performance Fibers
  - Automotive Components
- **High Temperature Polymer**
  - Melt Process Temp of ~390° C
  - Continuous use Temp. of ~240° C
  - Heat Distortion Temp. (264psi) 235° C
- **Major Resin Producers**
  - Mitsui (DuPont Distributes)
  - GE
- **Intermediates**
  - Mitsui: Diamine and a tetracarboxylic dianhydride
  - 1,3-bis(4-aminophenoxy)benzene
  - GE: Diamino Benzimidizole
  - Dianhydride

PBI

(Polybenzimidazole)

- **Key Properties & Performance Characteristics**
  - Amorphous
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 58
  - Maintains Mechanical Properties up to 500° C
  - Low Friction / High Wear Resistance
  - Extreme Hardness
  - Good Fatigue Resistance
  - Extremely High Compressive Strength
  - Large Elastic Recovery / Ductile Failure
  - Low Mechanical Hysteresis
  - Must be Processed via Sintering Process
    - (Injection Moldable Blends Available)

- **High Temperature Polymer**
  - Melt Process Temp of ~510° C
  - Continuous use Temp. of ~310° C
  - Heat Distortion Temp. (264psi) 435° C

- **Major Resin Producers**
  - PBI Performance Products

- **Intermediates**
  - Tetra-aminobiphenyl
  - Diphenyl isophthalate

- **Targeted Applications and Markets**
  - Fuel Cell Membranes
  - Chemical/Petroleum Industry
  - Aerospace
  - Electronics/Electrical
  - Military
  - High Performance Fibers

PEI

(Polyetherimide)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - High Stiffness
    - LOI of 47
  - Maintains Mechanical Properties up to 200° C
  - Very High Strength
  - Low CLTE
  - Extremely Low Shrinkage
  - Inherent low flammability & Low Smoke
  - Good Chemical Resistance
  - Autoclavable (repeated)
- **Targeted Applications and Markets**
  - Optics Housings
  - Automotive Underhood
  - Electronics/Electrical
  - Medical Reusables
  - Electronics Connectors
- **High Temperature Polymer**
  - Melting Process Temp of ~350-340° C
  - Continuous use Temp. of ~170° C
  - Heat Distortion Temp. (264psi) 200° C
- **Major Resin Producers**
  - GE
- **Intermediates**
  - Bis-Phenol A
  - Phthalic Anhyd.
  - M-Phenylene Diamine

PAI

(Polyamideimide)

- **Key Properties & Performance Characteristics**
  - Amorphous (Opaque)
    - High Stiffness
    - LOI of 45
  - Maintains Mechanical Properties up to 260° C
  - Excellent Cryogenic Properties
  - Very High Strength
  - Low CLTE
  - Very Low Shrinkage
  - Inherent low flammability & low smoke
  - Good Fatigue Resistance
  - Moderate Chemical Resistance
- **Targeted Applications and Markets**
  - Gears, Bushings, and Bearings
  - Automotive Connectors
  - Electronics/Electrical
  - Aerospace
- **High Temperature Polymer**
  - Melting Process Temp of ~315-360° C
  - Continuous use Temp. of ~260° C
  - Heat Distortion Temp. (264psi) 280° C
- **Major Resin Producers**
  - Solvay
- **Intermediates**
  - Trimelletic Anhydride
  - Aromatic Amines

PSU

(Polysulfone)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - High Stiffness
    - Moderate Chemical Resistance
    - LOI of 32
  - Maintains Mechanical Properties up to 174° C
  - Inherent low flammability (Self Extinguishing)
  - Food Contact
  - High Toughness & Strength
  - High Melt/Thermal Stability
  - Low Environmental Stress Cracking
- **Targeted Applications and Markets**
  - Printers
  - Appliances
  - Automotive connectors
  - Electronics/Circuit Boards
  - Pipes and Fittings
  - Faucets

- **High Temperature Polymer**
  - Melt Process Temp of ~325-360° C
  - Continuous use Temp. of 140-160° C
  - Heat Distortion Temp. (264psi) 174° C

- **Major Resin Producers**
  - BASF
  - Solvay Udel®
  - LG
- **Intermediates**
  - 4,4' dichlorophenyl sulfone
  - Bis Phenol A

PES

(Polyethersulfone)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 38
  - Inherent low flammability
  - Electrical properties at high temperatures
  - Excellent toughness
  - Environmental Stress Cracking Resistant
  - Food Contact Applications

- **High Temperature Polymer**
  - Melt Process Temp of ~360° C
  - Continuous use Temp. of 190° C
  - Heat Distortion Temp. (264psi) 203° C

- **Major Resin Producers**
  - BASF
  - Solvay

- **Targeted Applications and Markets**
  - High Intensity Lighting
  - Appliances
  - Electronics/Circuit Boards
  - Membranes Filters
  - Face Shields
  - Housings

- **Intermediates**
  - 4,4' diOH phenylsulfone
  - 4,4' dichlorophenyl sulfone

PPSU

(Polyphenylsulfone)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 44
  - Inherent low flammability
  - Electrical properties at high temperatures
  - Excellent toughness
  - Autoclavable
  - Environmental Stress Cracking Resistant
  - Hydrolytic Stability

- **Targeted Applications and Markets**
  - High Intensity Lighting
  - Appliances
  - Electronics/Circuit Boards
  - Automotive Housings
  - Sterilizable Trays and Housings

- **High Temperature Polymer**
  - Melt Process Temp of ~370° C
  - Continuous use Temp. of 190° C
  - Heat Distortion Temp. (264psi) 207° C

- **Major Resin Producers**
  - Solvay
  - BASF

- **Intermediates**
  - Diphenyl ether
  - 1,4 benzene sulfonyl chloride

LCP

(Liquid Crystal Polymer)

- **Key Properties & Performance Characteristics**
  - Crystalline (Oriented) (Opaque)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 43
  - Maintains Mechanical Properties up to 200° C
  - High Wear Resistance
  - Inherent low flammability Very High Flow
  - Ability to Sterilize – (Autoclave & Radiation)
  - Extremely Fast Cycle Times
  - Low CLTE and Shrinkage

- **High Temperature Polymer**
  - Melt Process Temp of ~290-380° C
  - Continuous use Temp. of ~150-204° C
  - Heat Distortion Temp. (264psi) 190° C

- **Targeted Applications and Markets**
  - Cameras & Priners
  - Telecom
  - Aerospace
  - Electronics/Circuit Boards
  - Medical/Dental
  - Automotive
  - Barrier Applications

- **Major Resin Producers**
  - Solvay
  - DuPont
  - Sumitomo
  - Polyplastics

- **Intermediates**
  - Various aryl hydroxy acids, biphenols, e.g. Vectra: p-OH benzoic acid, 6-OH napthanoic acid

PPS

(Polyphenylenesulfide)

- **Key Properties & Performance Characteristics**
  - Semi-Crystalline (Opaque)
    - High Stiffness
    - Excellent Chemical Resistance
    - LOI of 47
  - Maintains Mechanical Properties up to 150° C
  - High Wear Resistance
  - Thermal Conductivity
  - Inherent low flammability
  - High Flow
  - Radiation Resistant
  - Food Contact
- **Targeted Applications and Markets**
  - Underhood Automotive
  - Aerospace
  - Electrical/Electronics
  - Coatings for Chemical and Abrasion Resistance
- **High Temperature Polymer**
  - Melt Process Temp of ~320° C
  - Continuous use Temp. of 190° C
  - Heat Distortion Temp. (264psi) 135° C
- **Major Resin Producers**
  - Chevron Phillips
  - Polyplastics
  - Toray
- **Intermediates**
  - 4,4' dichlorobenzene

PPA

(Polyphthalamide)

- **Key Properties & Performance Characteristics**
  - Semi-Crystalline (Opaque)
    - High Stiffness
    - Very Good Chemical Resistance
    - LOI of 25
  - Maintains Mechanical Properties up to 140° C
  - Low Coefficient of Friction
  - Low Moisture absorption
  - Good Hydrolytic Stability
  - Ease of processing for High Temp Material

- **Targeted Applications and Markets**
  - Connectors and Bushings
  - Automotive Housing
  - Electronics/Circuit Boards – - Lead Free
  - Cell Phone Housings

- **High Temperature Polymer**
  - Melt Process Temp of ~340° C
  - Continuous use Temp. of ~140° C
  - Heat Distortion Temp. (264psi) 138° C

- **Major Resin Producers**
  - DuPont
  - Solvay
  - EMS-Grivory

- **Intermediates**
  - Iso and Tere Phthalic Acids
  - Various ailphatic and/or aromatic amines

PA12

(Polyamide)

- **Key Properties & Performance Characteristics**
  - Semi-Crystalline (Opaque)
    - Low Stiffness
    - Excellent Chemical Resistance
    - LOI of 24
  - Maintains Mechanical Properties up to 125° C
  - Excellent toughness
  - Lowest Nylon Water Absorption (~2%)
  - Hydrolytic Stability
  - Flexible Applications
  - High Barrier Resistance
- **Targeted Applications and Markets**
  - Low Temp. Impact Applications
  - Sporting Goods
  - Electronics/Circuit Boards
  - Precision moldings
  - Tubings and Hoses
  - Wire & Cable
  - Medical

- **High Temperature Polymer**
  - Melt Process Temp of ~270° C
  - Continuous use Temp. of 100° C
  - Heat Distortion Temp. (264psi) 53° C
- **Major Resin Producers • Intermediates**
  - Arkema
  - Degussa
  - EMS-Grivory
  - Ube
  - PA12: COT

*similar grades as well

PA11

(Polyamide)

- **Key Properties & Performance Characteristics**
  - Semi-Crystalline (Opaque)
    - Low Stiffness
    - Excellent Chemical Resistance
    - LOI of 24
  - Maintains Mechanical Properties up to 150° C
  - Excellent toughness
  - Good Abrasion Resistance
  - Low Nylon Water Absorption (~2.5%)
  - Hydrolytic Stability
  - Flexible Applications
  - High Barrier Resistance
  - Bioderived polymer
- **Targeted Applications and Markets**
  - Gears & Cams
  - Fluid Tubing
  - Powder Coatings
  - Tubings and Hoses
- **High Temperature Polymer**
  - Melt Process Temp of ~270° C
  - Continuous use Temp. of 125° C
  - Heat Distortion Temp. (264psi) 53° C
- **Major Resin Producers**
  - Arkema
- **Intermediates**
  - 11-aminoundecanoic acid Castor oil

COC

(Cyclic Olefin Copolymer)

- **Key Properties & Performance Characteristics**
  - Amorphous (Transparent)
    - Optical Transparency
    - Extremely Low Birefringence
    - LOI of ---
  - Maintains Mechanical Properties up to 170° C
  - Very High Refractive Index
  - Very Low Shrinkage and Warpage
  - Good Chemical Resistance
  - High Moisture Barrier
  - Non-toxic Combustion Products
  - Excellent biocompatibility
  - FDA Food Contact and USP Class VI Approved
- **Targeted Applications and Markets**
  - Optical Lens Applications
  - Optical Sensors and Lasers
  - Micro Fluidic Structures
  - Medical Devices
  - Packaging Films and Blisters
  - Lab Ware

- **Moderate Temperature Polymer**
  - Melt Process Temp of ~250-320° C
  - Continuous use Temp. of --° C
  - Heat Distortion Temp. (264psi) 151° C

- **Major Resin Producers**
  - TOPAS Inc
  - Mitsui

- **Intermediates**
  - Ethylene
  - Norbornene

PVDF

(Polyvinylidinedifluoride)

- **Key Properties & Performance Characteristics**
  - Crystalline (Opaque)
    - Extremely Low Birefringence
    - LOI of 60
  - Maintains Mechanical Properties up to 170° C
  - Melt Processable Fluoropolymer
  - Good Radiation Resistance
  - Good Chemical Resistance
  - Piezoelectric Properties
  - High UV Resistance
  - Inherently Low Flammability and Smoke
  - Very High Purity
- **Targeted Applications and Markets**
  - Fluid Transfer Systems
  - Pump Assemblies
  - Membranes
  - Premium Wire Insulation
  - Bearings
  - Metal Coatings
- **Moderate Temperature Polymer**
  - Melt Process Temp of ~220-270° C
  - Maximum use Temp. of -170° C
  - Heat Distortion Temp. (264psi) 125° C
- **Major Resin Producers**
  - Arkema
  - Solvay Solexis
- **Intermediates**
  - 1,1-difluoroethene

-End-