Everything you wanted to know about polyethylene but were afraid to ask

Ian Gibbons, Matthew Botros, Chris Gick
September 16, 2013
Closures: A Large and Growing Market

North American Market = 1.5 billion lbs

“The world demand for caps and closures is projected to rise 5.3% per year to reach $46 billion in 2016”

Source: Freedonia Group (2013)
Old closures paradigm

PP Applications

- Crystal-clear overcaps
- Living Hinge
- Retort

PE Applications

- CSD
- Hot fill/aseptic
- Hinge
- NCB
- Child Resistant

Applications:

- Bottled water
- Milk/Dairy
- Home/office water

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
New closures paradigm

PP Closures
- Crystal-clear overcaps
- Retort

Neither
- CSD
- Hot fill/aseptic
- Living Hinge
- NCB
- Child Resistant

PE Closures
- Bottled water
- Milk/Dairy
- Home office delivery water
Presentation Outline

Act 1 – The Basics of Polyethylene

Feedstock → Manufacturing → PE Key Parameters → Additives

Caps & Closures Performance
Act 2 – Polyethylene Market Dynamics

Price Drivers

- Supply
- Demand
- Input Costs
- Inventory
- Import/Export
- Value Creation
Act 1 – The Basics of Polyethylene

Ian Gibbons, Matthew Botros
PE Markets: Why PE is so interesting!
PE Feedstock options

“Oil, Gas and Petrochemicals”
Pipeline Straddle Plant Extraction and Fractionation

Natural Gas to Fuel Markets

- Methane
- Ethane & CO₂
- Propane
- Butane
- Pentane Plus

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Ethylene Manufacturing from Ethane

- Ethane is converted into ethylene (thermal decomposition) at high temperature in a steam furnace or cracker.
- Refrigeration is used to separate the various components, co-products, etc.
- The furnace and auxiliary components are designed to efficiently produce as much Ethylene as possible and as few co-products as possible.
- Co-Products such as Hydrogen, CO₂ etc. can be sold for other uses.

\[ \text{Ethane (C}_2\text{H}_6) \xrightarrow{\text{Temperature}} \text{Ethylene (C}_2\text{H}_4) + \text{H}_2 + \text{Co-products} \]
Ethylene Cracking Facilities
Section Summary

• Basics of polyethylene feedstock
  o Heavy or light feeds
  o Ethylene “building block” same regardless of source
  o Ethylene sites often integrated with polyethylene plants
Part 2

PE Polymerization
Chemistry/Manufacturing
What is Polymerization?

Making large parts from small parts

• Poly - from the Greek word for “many”
• Mer - from the Greek word for “part”
• Polymer - a large molecule built up by the repetition of small simple chemical units
• Polymerization - a chemical reaction which joins the repeating units in the polymer
Brief History of Polymers and PE

1800s  1850s - 1907  1930s  1950s

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Building Blocks of Polyethylene
(Monomer/ Comonomer):

Common Comonomers

- **Ethylene**  A Two carbon-long molecule
  - Formula: $\text{C}_2\text{H}_4$

- **Butene** - A four carbon-long molecule
  - Formula: $\text{C}_4\text{H}_8$

- **Hexene** - A six carbon-long molecule
  - Formula: $\text{C}_6\text{H}_{12}$

- **Octene** - An eight carbon-long molecule
  - Formula: $\text{C}_8\text{H}_{16}$
LDPE Process

High Pressure, Temperature, Ethylene, Catalyst → Reactor → Separator → Recycle

- Blender #1
- Off grade Blender
- Pelletizer

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
General Themes

- Ethylene and a comonomer are added to a reactor with a catalyst
  - Chromium - Hogan and Banks
  - Ziegler-Natta
  - Single Site
- Various reactor designs
- Different comonomers can be added depending on process/performance needs
  - Butene
  - Hexene
  - Octene
HDPE Video
LLDPE Video
Advanced SCLAIRTECH™ Solution Process
Section Summary

- Polyethylene is made by the polymerization of various building blocks
- Ethylene is the core block
- How the ethylene units are put together changes the properties of the PE
- Butene, hexene and octene can be added to further change the characteristics of the PE
- Different manufacturing technologies can be used to make PE
Part 3
Polyethylene Physical Properties

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Presentation Outline

Feedstock ➔ Manufacturing ➔ PE Key Parameters ➔ Additives

Caps & Closures Performance
Key Polyethylene Parameters

Resin Parameters which significantly affect PE end use properties:

1. Density
2. Melt Index (molecular weight)
3. Molecular Weight Distribution
4. Comonomer
1. Density - Crystallization Video
PE classified by density ranges, as defined by ASTM

<table>
<thead>
<tr>
<th>General Category</th>
<th>Type Class</th>
<th>Density Range</th>
<th>Specific PEs in each class</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE</td>
<td>Type I</td>
<td>0.910 - 0.925 g/cc</td>
<td>LDPE or LLDPE</td>
</tr>
<tr>
<td>MDPE</td>
<td>Type II</td>
<td>0.926 - 0.940 g/cc</td>
<td>LDPE or LLDPE</td>
</tr>
<tr>
<td>HDPE</td>
<td>Type III</td>
<td>0.941 - 0.960 g/cc</td>
<td>LLDPE Copolymer</td>
</tr>
<tr>
<td>HDPE</td>
<td>Type IV</td>
<td>&gt;0.961 g/cc</td>
<td>Homopolymer</td>
</tr>
</tbody>
</table>
1. Density - Stiffness

- ASTM:D790 – Flexural Modulus
- ATSM:D792 – Density
1. Density - Measurement

- ASTM D792
- Weight per given volume. Reported in g/cm³
- Density is an indication of degree of crystallinity
- More crystallinity = higher density
- Crystallinity affected by polymer composition
  - high density resins have low %/no comonomer
  - low density resins have high % comonomer
1. Density – Effect on Properties

As Density Increases (with other parameters being constant):

- Hardness
- Stiffness
- Melting Point
- Softening Temperature
- Productivity (Faster Molding Cycles)
- Tensile Yield
- Heat Deflection Temperature
- Shrinkage and Warpage
- Resistance to Permeation

- Impact Strength/Toughness
- Clarity
- Stress Crack Resistance
- Flex Life

\[I \text{NCREASE}\]
\[D \text{ECREASE}\]
2. Melt Index

Indicates **length of polymer chains** – i.e. number of ethylene units joined together

- Wax
  - ~500 monomer units long
- Molding Resin?
  - >50,000 monomer units long
2. Melt Index

Indicator of viscosity – resistance to flow

Indicator of how well polymer flows in a mold
- Large Molecules = Lower flow properties
- Smaller Molecules = Increased flow properties

Measured in grams of polymer flow through mold over fixed time (g/sec)
2. Melt Index - Molecular Weight (MW)

Lower Melt Index = Higher MW

Higher Melt Index = Lower MW
2. Melt Index - Measuring

- ASTM D1238
- 190°C
- Weight is 2.16 kg of MI$_2$
- Weight is 21.6 kg of MI$_{21}$
- Units are g/10 min

2.16kg or 21.6kg

190°C
2. Melt Index - Impact on Viscosity

Higher MI = Lower Viscosity
Lower MI = Higher Viscosity
2. Melt Index - Impact of Temperature

![Graph showing Viscosity vs Shear Rate at different temperatures (230°C, 250°C, 260°C). The graph plots Apparent Viscosity (Pa-sec) on the y-axis against Apparent Shear Rate (1/sec) on the x-axis. Each temperature is represented by a different line color: magenta for 230°C, blue for 250°C, and red for 260°C. The temperatures are marked at specific shear rates and viscosities.]
2. Melt Index - Impact

Molded Part Properties and Processability

As Melt Index Increases:

- Processability
- Energy Efficiency
- Productivity (Faster Molding Cycles)
- Warpage Resistance
- Gloss

Impact Strength
- Tensile Strength
- Stress Crack Resistance
3. Molecular Weight Distribution (MWD)

Measure of uniformity of PE molecular length
- Highly uniform molecules: ‘narrow’ distribution
- Highly variable molecules: ‘broad’ distribution

MWD is independent of both density and MI

![Molecular Weight Distribution Curves](chart.png)
3. Molecular Weight Distribution – Illustration

**Broad MWD (varied chain lengths)**
- Good for blow molding and extrusion
- Increased flow at high shear rates in injection molding

**Narrow MWD (more uniform chain lengths)**
- Typical of injection resins
- Good toughness
- Good gloss, elongation
3. Molecular Weight Distribution – Bimodal vs Unimodal Resins

**Unimodal Resins:**
- Fixed property set
- Work well for most applications
- More common in market

**Bimodal Resins:**
- Ability to tailor properties
- Used in very challenging applications
- Better Processability

![Molecular Weight Distribution Graph](chart.png)

**# of Molecules (count)** vs **Molecular Weight (g/mol)**
3. Molecular Weight Distribution – Impact of Shear on Viscosity

THE RHEOLOGY CURVE

- High Resistance
- Low Resistance

Viscosity (resistance to flow)

Shear Rate

M.I. Range

Narrow MWD

Broad MWD
3. Molecular Weight Distribution – Typical Measurements

**Melt Flow Ratio (MFR)**

- Ratio of two Melt Index values taken using different weights (21.6 kg & 2.16 kg)
- The lower the MFR the narrower the MWD (Linear PE’s only)
- MFR can vary from 20 for very narrow MWD grades to 100 for very broad MWD grades
- Not the same as Melt Flow Rate (MFR) used in PP viscosity measurements
3. Molecular Weight Distribution – Impact

Molded Part Properties and Processability

As MWD broadens:

- Productivity (Faster Molding Cycles)
- Crack Resistance
- Shrinkage

- Impact Strength
- Warpage Resistance
- Gloss
- Elongation
4. Comonomer

- Modifies density (crystallinity)
- Imparts added toughness over homopolymer - Octene > Hexene > Butene
## Basic Performance for Caps and Closures

### Impact of Resin on Closure Physical Properties

<table>
<thead>
<tr>
<th>An Increase in...</th>
<th>Crack Resistance</th>
<th>Impact</th>
<th>Removal / App. Torque</th>
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<td>Worse</td>
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</table>

Relationships assume all other resin properties remain the same, same closure design and same processing conditions.
### Impact of Resin on Closure Processing

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Relationships assume all other resin properties remain the same, same closure design.
Section Summary

1. Density
   - Stiffness of the product
   - Impact resistance

2. Melt Index
   - Processability
   - Toughness

3. Molecular Weight Distribution
   - Processability
   - Shrinkage
   - Toughness

4. Comonomer
   - Toughness
Part 4
Additive Technology
Presentation Outline

- Feedstock
- Manufacturing
- PE Key Parameters
- Additives

- Caps & Closures Performance

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What are Additives?

- Designed to protect the polymer
- Enhances the properties of the polymer beyond what is possible with reaction technology
- They typically make up 0.05 to 0.5 wt% of resin
Additive Types

Stabilizers
- Antioxidants
- UV Stabilizers
- Acid Neutralizers

Modifiers
- Slip Agents
- Antiblock Agents
- Antistatic Agents
- Nucleating Agents
- Fillers

Processing Aids
- Melt Fracture Suppressants
- Lubricants
- Mold Release Agents
End Use Laws/Regulations

Food Contact and Drug Packaging Applications

- USA: Federal Food, Drugs and Cosmetic Act, FDA regulations
- 21CFR
- Canada: Food and Drugs Act, Health Canada Food and Drug Regulations (HPFB)
- EU: Food contact Directives, Regulations
PE Additives - Antioxidants

• All organic compounds degrade – including PE

• Antioxidants reduce the rate of degradation

• Organic materials like PE are susceptible to degradation which could lead to:
  o Poor organoleptics (oxidative degradation)
  o Deterioration in physical properties
  o Premature product failure

• Key focus of protection
  o Heat from processing (short term)
  o Part durability (long term)
Polyethylene Degradation
Antioxidant Types

Two Different Types of Antioxidants

- **Primary:**
  - Free Radical Capping
  - Sacrificial agent
  - Pro

- **Secondary**
  - Hydroperoxide decomposition
  - Sacrificial agent
  - Processing stabilizer
  - Processing and long term stabilizer

The two types act synergistically
“Whole is worth greater than the sum of the parts”
PE Additives - Slip Agent

- Compounds that reduce the frictional forces of the polymer with other surfaces

- Slip agents reduce frictional forces by blooming to the surface of the molded part – e.g. lowers removal torques
Chemical structures of primary amides

erucamide (13-cis-docosenamide, Crodamide ER)

oleamide (9-cis-octadecenamide, Crodamide OR, VR)

stearamide (octadecanamide, Crodamide SR)

behenamide (docosanamide, Crodamide BR)
Variation of CoF with time

Very high CoF resulting in poor slip

Amide molecules homogeneously distributed through amorphous polymer
Variation of CoF with time

Amide molecules begin migrating to surface through amorphous regions of polymer
Variation of CoF with time

CoF reducing, increasing slip of film

Single layer of amide molecules starts to form at film surface
Variation of CoF with time

CoF

time after extrusion

Single layer of amide molecules nearing completion at film surface
Variation of CoF with time

CoF

time after extrusion

Single layer of amide molecules complete, multilayer starting to form
Variation of CoF with time

Maximum slip achieved.

Multilayer of amide molecules complete.

Note some amide molecules still dispersed in film.
Variation of CoF with time

CoF

time after extrusion

CRODA
Nucleating Agents

- PE is a semi-crystalline material
  - Two stages of crystallization
    - Nucleation
    - Crystal growth
- HDPE has a fast rate of auto-crystallization
  - Traditionally, nucleating agents were not very effective because once a HDPE nucleus forms the resulting crystals grow very fast
  - Recent advances in nucleation chemistry
- Foreign materials can initiate crystallization
  - Act as a seed for the crystal to grow on
  - Pigments
    - Uncontrolled, uneven crystallization can result in uncontrolled shrinkage/warpage
- Controlled polymer crystallization: the ordered solidification of molecules from a melt
Nucleating Agents

Cooling

Non-Nucleated

Nucleated

Polymer Melt

No Crystallization

Partially Crystallized

Fully Crystallized

Nucleating Agent

Crystallization Begins

Partially Crystallized

Fully Crystallized

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<tr>
<td>Additives</td>
<td>Complex</td>
<td>Complex</td>
<td>Lower (slip)</td>
<td>Complex</td>
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Relationships assume all other resin properties remain the same, same closure design and same processing conditions.
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Relationships assume all other resin properties remain the same, same closure design.
Section Summary

- Additives provide another “knob” in polymer design
- Antioxidants protect the resin during its lifecycle
- Modifiers change the characteristics of the polymer
  - Slip agents alter the CoF (Torques)
  - Nucleating agents affect crystallinity
Part 5
PE Properties Related to Closures Industry
Presentation Outline

Feedstock → Manufacturing → PE Key Parameters → Additives

Caps & Closures Performance
Key Design Parameters for PE

1. Density
2. Melt Index
3. Molecular Weight Distribution/Modality
4. Comonomer
Environmental Stress Cracking (ESC)

- Slow crack growth of PE parts under stress
- Accelerated when PE in contact with surfactants
- PE resins each have different inherent crack resistance
Chemical Resistance of PE

- PE generally a non-reactive polymer
- Suitable for a vast majority of packaging applications and well suited to food/beverage, pharma, and personal care
- Some watch-out applications
  - Soaps and surfactants
  - Selected chemicals (like aromatic hydrocarbons)
  - Edible oils
Mechanism of ESCR

- Theoretical work by A. Lustiger (Exxon/Mobil)
- Interlamellar failure
- Resistance influenced by interlamellar tie chains
- Constant strain/constant stress test methods

![Diagram of lamella entanglement and disentanglement](image)
Key Design Parameters for PE, continued

Key Parameters

1. Density
2. Melt Index
3. Molecular Weight Distribution/Modality
4. Comonomer

![Diagram showing relationship between Molecular Weight Distribution and key parameters such as Processability and ESCR.](image-url)

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Key Design Parameters for PE, continued

Key Parameters

1. Density
2. Melt Index
3. Molecular Weight Distribution/Modality
4. Comonomer
Polyethylene Background

Process Technology and Catalyst Platforms

Manufacturing process
Solution
Gas phase
Slurry

Reactor Technology
Single reactor
Dual reactors

Catalyst Choice
Single-site
Ziegler-Natta

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Closures: A Large and Growing Market

North American Market = 1.5 billion lbs

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Source: Freedonia Group (2013)
Market Dynamics Favor Polyethylene over Polypropylene

Crude Oil to Natural Gas Price Ratio

Ratio > 8 Favors PE Economics

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## A Closer Look…

### Polypropylene (PP)

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MFR (230°C/2.16kg)</strong></td>
<td>0.2 to &gt; 100 g/10 min</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>Typically 0.900 g/cm³</td>
</tr>
<tr>
<td><strong>Types</strong></td>
<td>Homopolymer, Random &amp; Block Copolymers</td>
</tr>
</tbody>
</table>

### Polyethylene (PE)

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MI (190°C/2.16kg)</strong></td>
<td>up to 150 g/10 min</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>up to 0.967 g/cm³</td>
</tr>
<tr>
<td><strong>Types</strong></td>
<td>HDPE, LLDPE, LDPE, VLDPE</td>
</tr>
</tbody>
</table>

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## Polymer Attributes

<table>
<thead>
<tr>
<th>Property</th>
<th>PP</th>
<th>PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>Higher</td>
<td>High</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Lower</td>
<td>Low - High</td>
</tr>
<tr>
<td>ESCR</td>
<td>Medium</td>
<td>Low - High</td>
</tr>
<tr>
<td>Processability</td>
<td>Good</td>
<td>Low - High</td>
</tr>
<tr>
<td>Organoleptics</td>
<td>Poor</td>
<td>Good - Excellent</td>
</tr>
</tbody>
</table>
PE versus PP – A Direct Comparison

Performance Comparison

ESCR: PE meets requirements for many applications
Shrinkage: PE may be designed to match PP

<table>
<thead>
<tr>
<th>Resin</th>
<th>MI or MFR</th>
<th>Density (g/cc)</th>
<th>B100 (IM) (Hours)</th>
<th>Disk (48 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP Homopolymer</td>
<td>2 MFR</td>
<td>0.905</td>
<td>407</td>
<td>1.45%</td>
</tr>
<tr>
<td>SCLAIR® IG454-A resin</td>
<td>9</td>
<td>0.954</td>
<td>13</td>
<td>1.53%</td>
</tr>
<tr>
<td>SURPASS® IGs153-A resin</td>
<td>1.5</td>
<td>0.953</td>
<td>&gt;1000</td>
<td>1.74%</td>
</tr>
</tbody>
</table>
PE versus PP – Shrinkage Comparison

Effect of Red Pigment on Shrinkage

- PE shrink similar to PP

<table>
<thead>
<tr>
<th></th>
<th>IGs153-A</th>
<th>IGs153-A/Red</th>
<th>IGs153-A/Red/Nucleator</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE shrinkage</td>
<td>1.8%</td>
<td>1.6%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Red pigment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PE versus PP – processability and stiffness

Performance Comparison

**Processability**

![Graph showing processability comparison between Extrusion and Injection processes for different resins.]

**Stiffness**

![Bar chart comparing stiffness of HDPE (0.953), HDPE (0.967), Co-PP, and HPP.]

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Caps & Closure Resins Organoleptic Testing

Can Design Polyethylene Resin with Organoleptic Properties in Mind

- Bottled water: 6.9
- SURPASS® IGs153-A RESIN: 6.0
- Industry benchmark HDPE: 4.7
- PP: 4.2

Better taste

Poor taste
PE Selection Criteria - Critical Steps

Determine Application Requirements
• What are performance requirements of closure?
• Hinge Life? Stiffness? Clarity?

Determine Processing Requirements
• PE melt index typically 1.5 to 3x higher than PP to obtain equivalent flow properties (Use higher multiple for thinner parts with longer mold flow)
• What are cooling requirements? Process vs chilled water? BeCu or Steel gates?
Tying It All Together

- Organoleptics
- ESCR Stress cracking
- Stiffness Toughness
- Shrinkage
- Processing

Polyethylene
Old closures paradigm

PP Applications

- Crystal-clear overcaps
- Living Hinge
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Either
Act 2 – The Basics of Polyethylene

Chris Gick
Part 6
Injection Molding Polyethylene
Basic PE Injection Molding

- Feedstock
- Manufacturing
- PE Key Parameters
- Additives
- Caps & Closures Performance

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Suggested melt temperatures for molding polyethylene resins:

- High Density: 200°-280°C (392°-536°F)
- Linear Low Density: 160°-240°C (320°-465°F)
Melt Temperature - Impact of Viscosity

Viscosity vs Shear Rate

- 230°C
- 250°C
- 260°C

Apparent Viscosity (Pa-sec)

Apparent Shear Rate (1/sec)
Mold Temperature

- Typical mold temperatures used to process PE 5ºC-20ºC (40º-68ºF)
- Higher mold temp often necessary to produce a high surface gloss, especially on thick-walled parts
- Use of a cold mold generally decreases cycle time and increases toughness
  - If mold is too cold, molded-in stress may occur resulting in warpage
  - High ambient temperatures and humidity combined with a cold mold may cause condensation, resulting in splay
Mold Fill Rate

Molded Part Optimal Fill Rate Variables

- geometry of the part
- runner size(s), gate
- melt temperature
- resin grade

When molding thin section parts, high injection rates are usually required to fill the cavity before it solidifies; this also reduces molded-in stresses.
Screw Speed

- Sufficient screw speed should be used so that the time to pump material to the front of the screw will not delay the machine cycle.

- Fast screw speeds generate frictional heat in the plastic and help with melt homogenization.
Ram Forward Time

- Sum of the time required to inject the melt into the mold and the time for the gate to seal

- If the gate is not completely sealed before the injection hold pressure is removed, increased shrinkage, voids and sink marks may occur in the molded part
Injection Pressures

- Typical injection pressures for polyethylene resin ranges from 35 to 130 MPa (5,000 to 19,000 psi)
- Higher viscosity grades will require higher injection pressure to fill thin cross sections or long flow distances to minimize or reduce shrinkage and warpage
Post Molding Shrinkage

Shrinkage Varies With a Number of Factors

- Grade of polyethylene (melt index, MWD and density)
- Pigments and other additives
- Process (injection pressure, melt temperature, mold temperature and gate size)
- Section thickness and molecular orientation due to the melt flow path
• Shrinkage in unfilled PE is higher in direction of flow as compared to the transverse flow direction due to molecular orientation
• Parts made from narrow MWD resins will exhibit a more uniform shrinkage balance than if they were made from broader MWD resins
• Unbalanced or uneven shrinkage may cause part distortion and warpage
# Section Summary PE and PP – Processing Differences

<table>
<thead>
<tr>
<th>Property</th>
<th>Polyethylene</th>
<th>Polypropylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold Longevity</td>
<td>Less Maintenance</td>
<td>More maintenance</td>
</tr>
<tr>
<td>Shrinkage</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Processing Window</td>
<td>Broad</td>
<td>Narrow</td>
</tr>
<tr>
<td>Shear Thinning</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Mold Temperatures</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Gate Insert Material</td>
<td>Beryllium Copper</td>
<td>Steel</td>
</tr>
</tbody>
</table>
Section Summary

- With a few minor differences, polyethylene can be injection molded similarly to other thermoplastics, e.g. polypropylene
- Contact your resin supplier technical service team for additional processing support
## Closures Customer Engagement Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
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<tbody>
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**Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com**
Act 2 - PE Market Dynamics

Chris Gick
September 16, 2013
Polyethylene Market Dynamics

Polyethylene Market

- Demand Growth
- Inventory Changes
- Value Delivery
- Trade Flows
- GDP / IP Growth
- Capacity Changes
- Natural Gas
- Feedstock Prices
- Crude Oil

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Polyethylene Price Drivers

- Energy and feedstock costs
- Supply and demand balance
- Value in product and service offering
- Changes in inventory positions
- One-time events and other factors
The Petrochemical Supply Chain involves the conversion of natural gas and crude oil into ethane and naphtha, respectively. Ethane is then converted to ethylene, which is further utilized to produce other derivatives such as SM/PS, VCM/PVC, MEG/PET, LAOs/Comon, LLDPE, LDPE, HDPE, LLDPE, LDPE, HDPE, and LLDPE. These products are then distributed to converters, and ultimately to customers. The diagram indicates that ethylene accounts for approximately 60% of the demand, with LLDPE, LDPE, and HDPE being significant downstream products. Questions or comments can be directed to Mike Cappelli at cappelm@novachem.com.
PE Price = Cost floor + Margin

- Cost floor driven mainly by feedstock;
  - Crude oil / naphtha sets the cost floor;
  - Petrochemical markets are global – increasingly so – in nature;

- Margins tend to be lower or declining when:
  - There is an excess of capacity and/or operating rates are <90%;
  - Low product / service value;
  - Chain inventories are being depleted, reducing PE demand;

- Margins tend to be higher or increasing when:
  - Demand exceeds capacity or operating rates are >90%;
  - High product / service value;
  - Downstream inventories are being built, increasing PE demand

- Many events can disrupt the status quo, such as weather, geopolitical events, industrial accidents, recession, etc.

- In the medium to long-term, many factors are operating simultaneously, making the application of a “formula” inappropriate
  - In the short term, one factor (e.g. hurricane, war, can dominate temporarily)
High crude to gas ratio affords NA producers using some NGL feedstock the opportunity to earn high margins.

But, the low cost of production for some NA producers is irrelevant as a driver of price.

Price floor is set globally by the marginal (i.e. high) cost of production.
Commodity markets:
- Global in nature, rare exceptions (e.g. gas, ethane in N.A.)
- Marginal high cost producers set the price

2012 demand ~ 285 B lb
- Total capacity ~ 330 B lb
- Total global ethane-based capacity less than 125 B lb
- Ethane based economics only set the price if ethylene demand declines by 160 B lb
Supply and Demand

- Natural Gas
- Ethane "NGLs"
- Crude Oil
- Naphtha "LPGs"

Ethylene
- Other derivatives: SM/PS VCM/PVC MEG/PET LAOs/Comon
- LLDPE LDPE HDPE

~60% of Derivative demand

Converters
- Distributors
- Customers

~60% of Derivativedemand

Questions? Comments? Contact Mike Cappelli at cappelm@novachem.com
Supply and Demand

Global:
- Global oversupply of PE
- So-called “trough” conditions for most of Europe, Asia
- Price floor set by global naphtha cracking economics
- Generally low margins for naphtha-based businesses everywhere

N. America
- Regional oversupply of PE
- Domestic demand is ~74% of capacity in 2013
- Cost advantage supports exports at ~18% of capacity
- Price floor set by global naphtha cracking economics
Product and Service Value

Product value (value in use):

- Production rates in conversion processes
- Attributes in finished products
- Overall conversion cost

Service value

- Supply reliability
- Ease of doing business
- Technical support
Inventory Changes

Modeled underlying demand:

- Retail sales and industrial production
- Changes generally occur slowly, over time
- Affected by generalized macroeconomic trends and events (e.g. recession, changes in growth rate) that precipitate broad builds and depletions

PE consumption

- Driven by underlying demand in medium to longer term
- Can be volatile
- Affected by, and affects, pricing
- “Events” can have dramatic impact

Modeled vs Actual PE Demand
Polyethylene Price Drivers

- Energy and feedstock costs
- Supply and demand balance
- Value in product and service offering
- Changes in inventory positions
- One-time events and other factors
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