INNOVATION DIRECTIONS AND DRIVERS IN AUTOMOTIVE POLYOLEFINS

PREPARED BY:

Bob Eller
Robert Eller Associates LLC
Phone: +1-330-670-9566
Email: bobeller@robertellerassoc.com
Web Site: www.robertellerassoc.com

May, 2017
PAPERES/INNOVATION PRESENTATION
TODAY’S OBJECTIVES

- Identify future materials and processes that will drive automotive PP
- Identify strategies and examples for addressing the driving forces
- Examine the auto PP innovation process
- The auto PP supply chain and points for innovation or resistance to change
- Examine how the connected/autonomous car could shape PP innovation
- Identify the potential roles for carbon-based solutions

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
AUTO POLYOLEFIN OPPORTUNITY TARGET ZONE EXAMPLES

AUTO SYSTEMS TARGETS

- INTERIOR RIGIDS
  - IP
  - DOOR MODULE
    - CARRIER
  - CONSOLE
- HVAC
  - AIR DUCTS
  - GASKETS
- INTERIOR FLEXIBLES(a)
  - AIRBAG DOORS
    - SKINS
    - SEVERAL PROCESSES
  - COATED FABRIC
  - FLOOR SYSTEMS
  - ACOUSTIC
    - CARPET BACKING
    - MATS
- TRUNK
- INTERIOR BEAD FOAMS
- OTHER
  - FASCIA
  - PANELS
  - TRIM

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
Note:
- Indicates recent share gain, “smart” coatings could enter several material types
  (a) Polyurethane dispersion (PUD) coated fabrics gaining share, improved TPO grades and SEBS may challenge
  (b) Growth process
  (c) Modify conventional injection to provide textile or leather look without extra step

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
MATURITY CURVE FOR INTERIOR TPEs AND TPOs

INTRODUCTION

MIN-FILLED PP

CELLULOSIC REINFORCEMENT

SGF-PP

LGF AND CF-PP(SEVERAL FORMS)

P-TPVs IN IP SKINS(VIA INJECTION, THERMOFORMING)

SMART SURFACES

FOAMED INJECTION MOLDING WITH GOOD SURFACE

NANOCHELLOSE REINFORCEMENT

AUTONOMOUS TECHNOLOGY RESPONSE

BIO-TPEs?

TPO COMPOUNDS

DEMAND VOLUME

MARKET INTRODUCTION

GROWTH

MATURE

SATURATION (ORGANIC GROWTH)

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
### IMPROVEMENT TARGET EXAMPLES

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>NOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart skins</td>
<td>Luminescent skins, lighting function, transparent windows(b), sensing</td>
</tr>
<tr>
<td>Indentation recovery</td>
<td>Important for contact surfaces(a)</td>
</tr>
<tr>
<td>Airbag door score read-through</td>
<td></td>
</tr>
<tr>
<td>Tailoring haptics</td>
<td>Via surface coating/additives/surface texture</td>
</tr>
<tr>
<td>Performance requirements</td>
<td>- Abrasion resistance; Chemical resistance</td>
</tr>
<tr>
<td></td>
<td>- Stain cleaning; Denim (blue dye cleanability)(d)</td>
</tr>
<tr>
<td>China interior emissions req’t’s</td>
<td>Becoming more severe(c)</td>
</tr>
<tr>
<td>Moving into hand wrap</td>
<td>Requires different stiffness/compression requirements</td>
</tr>
<tr>
<td>More leather-like look</td>
<td>Via TPO skins</td>
</tr>
<tr>
<td>Structural/conductives</td>
<td>Reinforcements (nanocellulose, carbon fiber)</td>
</tr>
</tbody>
</table>

(a) Door trim panel, armrest, console cover
(b) Display, lighting, switching/sensing functions
(c) Interior emission requirements in China are currently more severe than U.S. or Europe
(d) Req’ts increased at GM/Ford 1-2 years ago (compromise between blue dye and coffee stain cleanability)

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
The HMI Evolution/Smart Surfaces (ADAS→ connected vehicle role):
- Buttons→touch screens→ smart materials, thin film technologies, incorporate into skins
- Wi-Fi interiors: technology drivers for voice activation, need for better acoustics

Convenience, Comfort, Luxury:
- Trim materials: soft touch, luxury feel/look, even lower gloss
- Continued VOC reduction
- improved ergonomics

Stronger, Lighter, and Parts Consolidation:
- Stronger/lighter materials: weight reduction
- Parts integration(especially electronics), “smart” materials/surfaces where feasible
- Role for nanocellulose reinforcement

Environmental, Recycling:
- Today: Lower oil/gas price challenge recycle efforts /fuel economy
- Continued drive for sustainability
- Government directives: likely to weaken

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
AN AUTOPLASTIC INNOVATION FRAMEWORK

- Plastic-related innovation has been disruptive to established incumbent technologies

- Most have been substitutions for incumbent technologies:
  - TPO fascia for chromed steel bumpers
  - TPO IP skin for PVC skins or hard, non-skinned IPs
  - D-LFT processes

- Some autoplastic innovations have resulted in systems shifts:
  - TPO fascia → honeycomb energy absorbers
  - PP/PE bead foams in trunk tool kit/spare tire carriers

- Most PP innovations have been internal to auto systems design. Some future substitutions will be in response to external driving forces, for example:
  - Connected/autonomous car → sensing, switching, communications → systems reconfigurations
  - Fuel economy regulations (changing)
  AND/OR

- Introduction of new/evolving enabling materials or processes (for example):
  - Carbon forms (graphene, fibers)
  - Injection molded soft touch/textile-like surfaces

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
SELECTIVE 3D MOLDING: ROLE IN AUTO?

- Weight save potential
- Putting resin where structural requirements dictate
- Deposition via sintering (suited for some TPEs e.g. SEBS, PP powders?)

SOURCES: PHOTOS: PLASTICS TECHNOLOGY MAGAZINE 042017;
COMMENTS: ROBERT ELLER ASSOCIATES LLC, 2017
CONSUMER NEEDS/WANTS:
Plastic opportunities shifting with autonomous/connected car

TECHNICALLY FEASIBLE?

MATERIALS AVAILABILITY
MEET SAFETY/ CAFE STANDARDS
FABRICATION PROCESSES

HARMONY BETWEEN INTERIOR COMPONENTS

LAUNCH TIMING

COMMERCIAL VIABILITY

GOOD DESIGN

GOV’T DIRECTIVES/STANDARDS

HAS PROFITABILITY BEEN DRIVEN OUT OF THE SUPPLY CHAIN ELEMENT?

LOW PROFITABILITY ➔ SUPPLY CHAIN CONSOLIDATION AND ACQUISITIONS

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
<table>
<thead>
<tr>
<th>BASE COMP’D.</th>
<th>ENHANCER</th>
<th>TO OBTAIN</th>
<th>APPLICATIONS</th>
</tr>
</thead>
</table>
| TPO, PP, Composites | - Carbon nanotubes (CNTs)  
- Graphene | - Conductivity              | - Smart surfaces  
- Sensors  
- Touch sensors (replace membrane switches) |
| TPO, PP     | - Blowing agent  
- Additives     | - Foam structure            | Trim panels                                                                |
| TPO, PP     | - Compounding  
- Tooling     | - Surface decoration        | Trim panels                                                                |
| PP          | - Nanocellulose  
- Carbon fiber | Mechanical properties       | Semi-structural                                                             |
| PP          | Natural fibers               | - Adequate mechanicals     | Door trim  
- Overhead structures                                                          |

ROBERT ELLER ASSOCIATES LLC, 2017
## Materials Status: What’s Happening with Interior Polyolefins and TPEs

<table>
<thead>
<tr>
<th>Feature</th>
<th>Plastic or TPE Type</th>
<th>Status/Current Matl’s</th>
<th>Note/Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft touch</td>
<td>SBC, TPO</td>
<td>Current(a)</td>
<td>Composition shift, 2-shot molding</td>
</tr>
<tr>
<td>Silky feel</td>
<td>SBC, s-TPV(b)</td>
<td>- Silicone-based</td>
<td>- Steering wheel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- s-TPV was first</td>
<td>- Other locations</td>
</tr>
<tr>
<td>Better seals</td>
<td>SBC, TPV</td>
<td>Improving</td>
<td></td>
</tr>
<tr>
<td>Improved c’set</td>
<td>SBC, o-TPV</td>
<td>Still targeting</td>
<td>Seals, gaskets; multiple markets</td>
</tr>
<tr>
<td>Lower hardness w/o</td>
<td>TPU, TPO, SBC</td>
<td>- TPO starting</td>
<td>Coated fabrics</td>
</tr>
<tr>
<td>compromise</td>
<td></td>
<td>- TPU difficult</td>
<td></td>
</tr>
<tr>
<td>Smart surfaces</td>
<td>TPO, ETPs, conductives</td>
<td>Starting</td>
<td>Sensing and controls. Integrating printed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>circuits/electronics into moldings(c)</td>
</tr>
<tr>
<td>Scratch resistance</td>
<td>TPO, PP compounds</td>
<td>Steady gains</td>
<td>Has been a long term target</td>
</tr>
<tr>
<td>3D structural printing</td>
<td>ETPs, TPEs</td>
<td>Starting (MIT, others)</td>
<td>Vibration damping/structure control</td>
</tr>
<tr>
<td>Leather look/feel</td>
<td>SBC, TPU, TPO</td>
<td>Getting there slowly</td>
<td>IP, door trim, coated fabrics</td>
</tr>
</tbody>
</table>

Note:
(a) Via coatings, some materials innovations/fabrication process innovation
(b) Via silicone-based s-TPV. Note combination of soft touch and silky feel
(c) For example from TactoTek
MOS= Metal-organic framework

SOURCE: GRAPHENICS
CARBON FIBER/PP HAS UNIT STIFFNESS ADVANTAGE

Note: CF Nylon is nearest competitor
(a) specific bending stiffness = $E^{1/3}$/density

SOURCE: LYONDELLBASELL
<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ride piggyback on auto/non auto developments</td>
<td>- Smart devices</td>
</tr>
<tr>
<td></td>
<td>- Autonomous vehicle</td>
</tr>
<tr>
<td>Replace over-engineered systems</td>
<td>- GF/PA;</td>
</tr>
<tr>
<td></td>
<td>- GF-PP replaced by SGF-PP</td>
</tr>
<tr>
<td>Modify during molding</td>
<td>Foam, 3D printing of complex shapes</td>
</tr>
<tr>
<td>3D molding</td>
<td>Recent 3D Ford large part</td>
</tr>
<tr>
<td>New reinforcements</td>
<td>Carbon fiber</td>
</tr>
<tr>
<td>Direct to market</td>
<td>- Catalloy;</td>
</tr>
<tr>
<td></td>
<td>- Post reactor compounding</td>
</tr>
<tr>
<td></td>
<td>- Reduce fabrication steps/combine parts</td>
</tr>
<tr>
<td>Benefit from equipment supplier developments</td>
<td>- At press additions (fibers, additives)</td>
</tr>
<tr>
<td></td>
<td>- Multi-shot, multi-layer</td>
</tr>
<tr>
<td>New functionalities</td>
<td>- Softell;</td>
</tr>
<tr>
<td></td>
<td>- Conductivity</td>
</tr>
<tr>
<td></td>
<td>- Piezoelectric effects</td>
</tr>
<tr>
<td>Recognize need to “shape” new markets</td>
<td>Inner panels for exterior components</td>
</tr>
</tbody>
</table>

**SOURCE:** ROBERT ELLER ASSOCIATES LLC, 2017
### EXAMPLE OF INNOVATION/PRODUCT IMPROVEMENT STRATEGIES IN INTERIOR SKINS

<table>
<thead>
<tr>
<th>STRATEGY</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solve a performance problem: Need to pre-score for passenger airbag</td>
<td>Formulate skin and structure to rupture upon deployment w/o scoring</td>
</tr>
<tr>
<td>Target a high priced incumbent</td>
<td>TPO skin with leather-like grain via in mold graining (IMG) and formulation</td>
</tr>
<tr>
<td>Successful imitation of key peripheral features</td>
<td>- Easy wrap (like leather)</td>
</tr>
<tr>
<td></td>
<td>- Real stitches</td>
</tr>
</tbody>
</table>

**SOURCE:** ROBERT ELLER ASSOCIATES LLC, 2017 BASED ON HAARTZ NEW PRODUCTS (SEE NEXT SLIDES)
DEPLOY® For Instrument Panels

No need to pre-score for PAB - Utilizes Clean Break Technology

NO AIRBAG SCORE LINE VISIBLE
SKINS INNOVATION EXAMPLE: REPLACING HIGH END INCUMBENT

Alura® Elite  TPO Synthetic Leather

- Excellent option for replacing leather in Instrument Panel and Door applications
- Ease of wrapping around contours
SKINS INNOVATION EXAMPLE: IMPROVE LUXURY FEEL

**Soft-Tek® - Soft and Luxurious**

- Premium PU Topcoat
- Soft TPO Skin
- Soft XLPP Foam

**Soft TPO Laminates**
- Superior grain reproduction
- Leather like effects using IMG
- Stitch pattern detail
COCKPIT/INSTRUMENT PANEL DESIGN SIMPLIFICATION WILL DRIVE:
- PLASTIC FABRICATION AND SKINS TECHNOLOGIES
- INSTRUMENTATION/SENSING; PLASTICS FABRICATION SUPPLY CHAIN SHIFT

(a) Note, for example, Panasonic acquisition of Ficosa

SOURCE: ROBERT ELLER ASSOCAITES LLC, 2017
INSTRUMENT CLUSTER: TARGET FOR SIMPLIFICATION

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
• Acoustics
• Shielding
• “Windows”/transparent sections in the surface
• Lighting
• Image projection
• Sensing/smart surfaces
• Smart touch
• Damping
• Conduction
• Signaling/data transmission

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
EXAMPLES OF IMSE AUTOMOTIVE APPLICATION AREAS

- Illumination & control solutions in curved decorative panels
- Force and capacitive sensing integration for enhanced applications, preventing unintentional activations
- Illumination adjustment

SOURCE: TACTO TEK, 2017
AUTOPLASTIC SUPPLY CHAIN: UNDER PRESSURE; RECONFIGURING

- GLOBAL COMPETITION
- OFFSHORE COMPETITION
- SHIFT TO LOWER COST MFG. COUNTRIES
- SELLOFF OF NON-CORE BUSINESSES (CONSOLIDATION)
- VEHICLE MIX SHIFT (a)

RESINS/ADDITIVE

COMPONUNDER

TIER 1

TIER 2, 3 SUPPLIERS

OEM ASSEMBLY

RESIN SUPPLIER SHIFT TO LOW COST MONOMER REGIONS

PRICE COMMODITIZATION

IN-LINE COMP’DG. BY TIER 1s

ELIMINATE/REDUCE THE INEFFICIENCIES:
- MULTIPLE STEPS
- EXCESSIVE LOGISTICS
- SCRAP GENERATION
- INEFFICIENT PROCESS TECHNOLOGIES
- LABOR COSTS REDUCTION → ROBOTIZATION
- OVER-GLOBALIZATION?

ELIMINATION OF EXTRA STEPS

PRESSURES PASSED DOWN THE SUPPLY CHAIN PRICING PRESSURES

(a) VEHICLE DEMAND SHIFT TO LARGE VEHICLES

GLOBAL SPECIFICATIONS

MANUFACTURING LOCATION SHIFT

INCREASED EUROPEAN/ JAPANESE INFLUENCE

WHO DRIVES INNOVATION/CAPTAIN OF THE SUPPLY CHAIN

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017

LB/LB AUTOPLASTIC SUPPLY CHAIN 050417
<table>
<thead>
<tr>
<th>NAFTA/EUROPE</th>
<th>FLOW</th>
<th>ASIA</th>
<th>NOTE/EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 OEMs</td>
<td></td>
<td>TO BENEFIT FROM HIGH GROWTH POTENTIAL</td>
<td></td>
</tr>
<tr>
<td>2 RESIN SUPPLIERS/</td>
<td></td>
<td>TO FOLLOW OEM CUSTOMERS</td>
<td></td>
</tr>
<tr>
<td>COMPOUNDERS/MOLDERS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 TECHNOLOGY FLOW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 DOMESTICS</td>
<td></td>
<td>TECHNOLOGY BARRIERS ARE POROUS</td>
<td></td>
</tr>
<tr>
<td>5 VIA ACQUISITION/</td>
<td></td>
<td>ASIAN OEMs</td>
<td>TOYOTA, KIA</td>
</tr>
<tr>
<td>GREENFIELD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 SERVE WESTERN</td>
<td></td>
<td>ASIAN RESIN SUPPLIERS AND COMPOUNDERS</td>
<td>IS COST ADVANTAGE TRANSFERABLE?</td>
</tr>
<tr>
<td>OEMs:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- BUSINESS WON IN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- EXPLOIT COST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- VIA ACQUISITIONS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
• Paths to market:
  - Greenfield
  - Tolling
  - Distribution of imported compounds
  - Follow the customer

• Forces driving supplier transplants to NAFTA:
  - Access Western markets
  - Learn Western business/marketing skills
  - Access Western distribution channels (in some cases via tolling)
  - Employ large cash holdings from years of profitable operations in China
  - In some cases, serve existing customers in West that were developed in China
  - Access to rich, stable Western markets
  - Need for “global” presence

• Regional compounders expanding globally

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
INTERIOR PROCESSES/MATERIALS: FUTURE DIRECTION EXAMPLES

MATERIALS:
- Natural fiber reinforcement
- Cellulosic nano reinforcements
- Role for graphenes/graphene-based foams
- Role for carbon fibers
- Smart textiles/skins/molded surfaces/thin film sensors

PROCESSES:
- 3D printing/molded structures
- Smart/Luminescent coatings
- Slush molding of SBCs
- Skins injection processes

BROADER FUNCTIONS:
- Lighting/display
- Sensing/switching
- Voice activation
- Shielding

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
EVOLUTION VIA NEW MATERIALS/PROCESSES/FUNCTIONS

- DIRECT p-TPVs
- IN-MOLD PROCESSES
- NEW FOAMING METHODS
- SKINS
- SOFT TOUCH
- SILKY TOUCH
- MULTI-LAYER STRUCTURES
- ACOUSTIC MAT’LS.
- IMPROVED BODY SEALS

- PROCESS COST SAVE
- LUXURY
- SMART FUNCTIONS
- RENEWABLE SOLUTIONS
- LOW VOC
- LIGHTING
- SENSORs
- TOUCH SWITCHES
- BIO-PLASTICS
- NATURAL FIBER REINFORCEMENTS
- GRAPHENE
- CNTs
- IMSE
- PLASTICIZER SHIFT
- ELIMINATE PLASTICIZERS/OILS

- CURRENT INTERIORS
- STRUCTURE WITH WEIGHT SAVING
- DOOR TRIM
- OVERHEADS

- NANOCELLULOSICS
- CARBON FIBER/GLASS REINFORCEMENT
- NATURAL FIBERS
- 3D MOLDING

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
• Autonomous/semi-autonomous cars/EVs will create opportunities for new generations of PP compounds and TPOs capable of:
  - integrating electronics
  - providing display, sensor and switching functions
  - operating as “smart surfaces”
  - improving acoustics
  - acting as display surfaces

• The major drivers/opportunity frontiers are:
  - weight save (eased by regulations shift?)
  - the HMI interface (new control/sensing modes (voice, light, motion, touch))
  - luxury look and feel (haptics)
  - process improvement: replace inefficient component fabrication technology
  - role for 3D composite manufacturing: new materials/process combinations
  - electrical/electronic architecture
  - new generation fillers/reinforcements (nanocellulosics, carbon fibers)
  - improved conductive materials (graphenes, carbon nanotubes)

SOURCE: ROBERT ELLER ASSOCIATES LLC, 2017
SUMMARY (Cont’d.)

• Continued competition in skins:
  - inter-materials; inter-process competition
  - role in cockpit design evolution

• TPO skins gaining share on basis of:
  - cost
  - in-house compounding (to produce p-TPVs) and radiation crosslinking
  - controlling rheology
  - new fabrication technologies
  - controlling airbag deployment

• Skin/foam technologies: evolving to meet higher standards/improved performance
Robert Eller Associates LLC
CONSULTANTS TO THE PLASTICS AND RUBBER INDUSTRIES