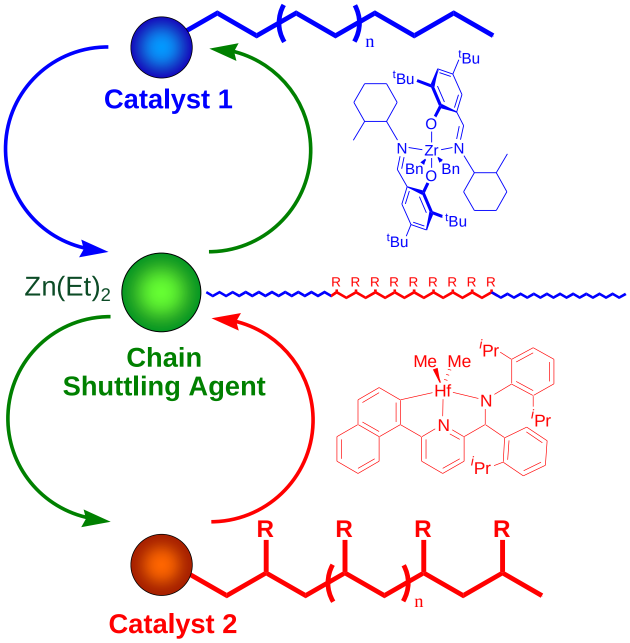
NOMINATION FOR THE 2012
PRESIDENTIAL GREEN CHEMISTRY CHALLENGE AWARD

INFUSE™ OLEFIN BLOCK COPOLYMERS

DECEMBER 31, 2011



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INFUSE™ OLEFIN BLOCK COPOLYMERS

SIGNIFICANT MILESTONES

- Grew 2011 global business by 58% vs. 2010 while creating value for customers and for Dow.
- Demonstrated commercial prime rates competitive with best-in-class elastomer production in 2011.
- Delivered 3rd party reviewed Life Cycle Assessment vs. Styrenic block copolymers in 2011.
- Grew business by meeting diverse needs of over 85 customers around the world, substituting a number of other existing polymers including SEBS, TPV and f-PVC from 2008-2011.
- No increase to the existing manufacturing footprint while implementing new-to-the world polymeric materials via unique catalyst technology. 2007-2011 (and on-going as we will not need to build a plant)

CATEGORY ELIGIBILITY

This entry is **Not Eligible** for awards in either the academic or small business categories.

AREA OF FOCUS

The design of greener chemicals. A secondary focus is the use of greener reaction conditions and greener synthetic pathways.

DEVELOPMENTAL ACTIVITIES IN THE UNITED STATES

Catalyst development occurred in Midland, Michigan and Freeport, Texas. The product R&D and scale-up occurred/is occurring in Freeport, Texas. Manufacturing is done in Freeport, Texas. The Freeport production facility is used to source U.S. customer needs, as well as their global needs. The OBC technology was developed to be produced in the existing polyolefin elastomer configuration for efficient and synergistic capabilities, lower carbon footprint and speed-to-market to meet customer needs vs. adding additional assets.

ABSTRACT

INFUSE™ Olefin Block Copolymers (OBCs) are produced via a patent-pending shuttling process that represents a new-to-the-world innovation in catalyst technology, delivering breakthrough performance by bringing new combinations of properties. The unique block architecture enables our customers to expand into a wide range of innovative market applications currently served by high performance thermoplastic elastomers, thereby adding value to fabricators and end-users alike. OBCs have highly differentiated material properties that break the traditional relationship of flexibility and heat resistance while providing significantly improved compression set and elastic recovery properties versus other polyolefin plastomers and elastomers. Importantly, OBCs also maintain the ease of formulation and processing that is expected from a polyolefin.

Sustainable Chemistry benefits include:

- Atom Efficiency – More efficient chemistry, due to improved selectivity - with less by-products, less extractables and less volatiles (nearest competitor SEBS requires significant resources to strip catalyst after polymerization).
- Reduced Toxicity/Risk – Unique block architecture allows high performance from a polyolefin and enables customers to substitute for materials like PVC and styrene-based polymers with regulatory or deselection issues (which also often require additives to achieve the required properties).
- Minimized Auxiliary Substances – Converted a stepwise polymerization into a swift catalytic process. The complex chain shuttling dual catalyst system resembles biochemical pathways where multiple enzymes (catalysts) and substrate transfer (chain-shuttling) combine to achieve the desired synthetic target, in the most efficient and direct manner possible.
- Reduced Energy Requirements – Polymer is produced in a less energy-intensive process compared to incumbent engineering polymer technology, as processing steps like catalyst and volatile stripping are eliminated. In addition, for the plastic fabricator, the molecular weight distribution of OBCs affords lower processing temperatures, hence, reduced energy usage during end product production vs. competitive resins.
- Cradle to Cradle – Better recycling/end-of life management due to compatibility of OBCs with disparate plastic waste streams. This compatibilization feature actually can enhance the quality of the recycled stream.
- Broad Impact – Applicability is wide as the technology can be used in a very large number of applications; in addition, value chain economic benefits are great, thereby enhancing market selection.

This revolutionary material was created using INSITE™ Technology – another example of how Dow continues to invest in innovative solutions and next-generation possibilities that deliver value to customers.

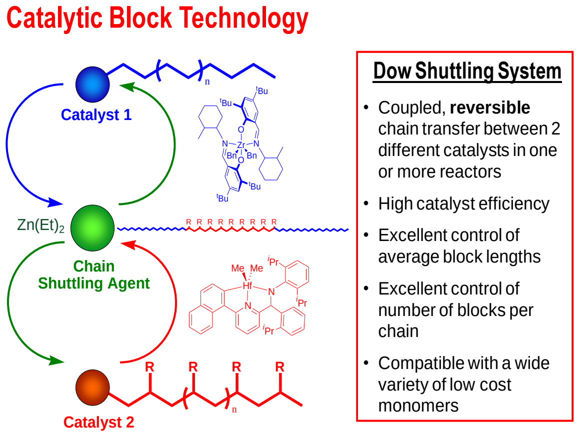
DESCRIPTION OF THE NOMINATED TECHNOLOGY

The Catalytic Block Technology developed by The Dow Chemical Company provides a revolutionary way to make block copolymers, resulting in the novel INFUSE Olefin Block Copolymers. These block copolymers have chains with alternating blocks of “hard” (highly rigid) and “soft” (highly elastomeric) segments. Olefin Block Copolymers offer breakthrough performance for a number of reasons.

For one, they are produced via a patented shuttling process that represents a new-to-the-world innovation in catalyst technology. Prior to this invention, attempted block copolymers of simple olefins such as ethylene, propylene, and alpha-olefins were only laboratory curiosities, made via a cost-prohibitive batch process similar to the manner in which other types of block copolymers (i.e., styrene butadiene styrene [SBS] and styrene ethylene butylene styrene [SEBS]) are produced. In these prior processes, one initiator was required to produce a single polymer molecule. With the new Dow technology, polyolefin block copolymers can be made catalytically in Dow’s current continuous solution process, which gives design freedom to produce these unique materials.

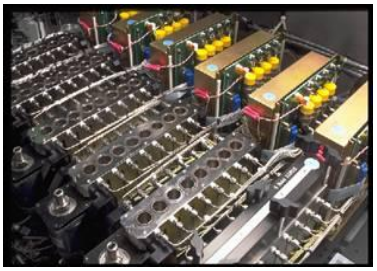
OBCs also have highly differentiated material properties that break the traditional relationship of flexibility and heat resistance while providing significantly improved compression set and elastic recovery properties versus other polyolefin plastomers and elastomers. In essence, OBCs offer breakthrough material performance by having both the flexibility of polyolefin plastomers and elastomers and the heat resistance of high density polyethylene.

Dow’s High Throughput capability played a key role in the project, enabling the discovery of the dual-catalyst chain shuttling chemistry (reversible chain transfer between different catalysts is the key and unique part of the Dow invention). These High Throughput reactors are nearly 1/200th the size of conventional reactors and therefore require less raw materials and produce far less waste. The small-scale reactions are also conducted in parallel, and were coupled with extensive molecular and kinetic modeling, making the discovery and optimization process far more efficient. These High Throughput workflows enabled Dow to progress from conceptualization to commercial launch of INFUSE™ OBCs in less than 2 years.



Dow Shuttling System

- Coupled, **reversible** chain transfer between 2 different catalysts in one or more reactors
- High catalyst efficiency
- Excellent control of average block lengths
- Excellent control of number of blocks per chain
- Compatible with a wide variety of low cost monomers



Catalytic block technology allows for the coupled, reversible chain transfer between different catalysts operating in tandem in one or more reactors. With such catalyst systems, high efficiency is obtained, allowing for the catalytic production of block polyolefins. Unlike living or anionic polymerization systems, catalytic block technology enables many polymer chains to be produced from each catalyst, with all of the sophisticated control of polymer microstructure and branching that advanced polyolefin catalysts allow. Tuning catalyst combinations and chain shuttling agents (CSAs) allows for precise control of average block lengths, individual block composition, and block distributions. In addition, this technology enables the production of block copolymers from monomers not normally associated with block copolymers, including ethylene and propylene.

A few strategies for preparation of stereoblock polyolefins have been reported in the recent literature. Olefin-based block copolymers have been made using living coordination polymerization catalysts. These catalysts, like living anionic, cationic, or radical polymerization processes, can be used to achieve precise structural control in block copolymer synthesis through sequential monomer addition strategies. However, living polymerization processes are uneconomical because they produce only one polymer chain per catalyst molecule and operate in a batch polymerization process. In addition, the low reaction temperatures typically required to achieve living behavior with these systems inhibit the synthesis of materials containing more than one semicrystalline block because of premature precipitation of the polymer.

To circumvent the problems associated with previous strategies for the preparation of polyolefin block copolymers, we pursued the synthesis of these materials via a technique that we call “chain shuttling polymerization”. We define chain shuttling as the passing of a growing polymer chain between catalyst sites, such that portions of a single polymer molecule are synthesized by at least two different catalysts. Likewise, a chain shuttling agent (CSA) is a component such as a metal alkyl complex that facilitates this transfer. This approach can thus be used to prepare block copolymers from a common monomer environment by using a mixture of catalysts of different selectivities, namely stereoselectivity or monomer selectivity. Under the right conditions, efficient chain shuttling produces a linear multiblock copolymer that features alternating hard and soft blocks.

One key to forming differentiated block copolymers via chain shuttling is finding a monomer or combination of monomers that, on the basis of their arrangement in the polymer chain, can give rise to both hard and soft materials. Ethylene-based polymers that incorporate varying fractions of α-olefin fit this criterion. Polyethylenes (PE) with low co-monomer content are semicrystalline (hard) materials with melting temperatures (Tm) approaching 135°C, whereas PEs with high levels of comonomer are amorphous (soft) materials with very low glass transition temperatures (Tg < –40°C). To this end, we required a mixed catalyst system capable of producing these different types of polymer in a common reaction environment. A further important requirement is that each of the catalysts undergoes chain shuttling with a common chain shuttling agent.

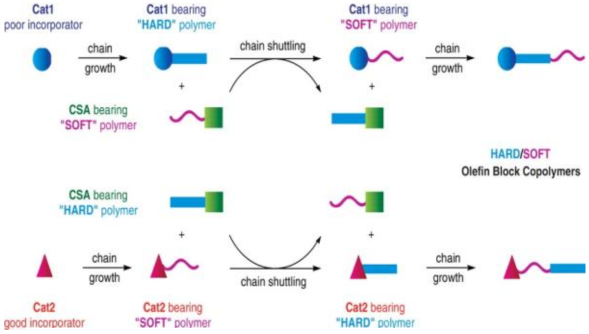


Figure 1. Depiction of the likely chain shuttling mechanism in a single reactor, dual-catalyst approach.

This process (Fig. 1) requires one catalyst, Cat1, with high ethylene selectivity to form hard polymer chains. Meanwhile, a good incorporator of comonomer, Cat2, grows soft amorphous chains in the same reactor because of its dramatically different monomer selectivity. In the absence of chain shuttling, a polymer blend is produced with none of the advantageous properties of block copolymer architecture. In the presence of an effective CSA, however, polymer chains are swapped between catalysts before the chains terminate. To understand this swapping phenomenon, it is instructive to follow the lifetime of a representative polymer chain. The chain may begin growing on Cat1 as a hard polymer. The chain is then exchanged onto a CSA, where it is held for some period of time without growing. The dormant polymer chain may then return to another molecule of the same catalyst and lengthen the hard segment or it may shuttle to a molecule of Cat2, from which subsequent chain growth results in formation of a polymer chain with both soft and hard blocks. The process may be repeated any number of times during the lifetime of the chain before chain termination occurs via a usual mechanism such as hydrogenolysis. A statistical analysis of this chain shuttling phenomenon reveals multiblock copolymers with a most probable distribution of block lengths and number of blocks per chain. This microstructure is distinctly different from materials made with living polymerization techniques, which ideally have a Poisson distribution of block lengths and a precise number of blocks. Furthermore, the synthesis of these olefin block copolymers is not stoichiometrically limited by Cat1, Cat2, or CSA.

Furthermore, this approach enables precise control over polymer microstructure. Despite the differences in monomer selectivity between the two catalysts, fast rates of chain shuttling and judicious selection of process variables produce copolymers with homogeneous molecular weight and composition distributions. The overall composition, i.e., the hard-to-soft polymer ratio, can be easily controlled by the relative amount of the catalysts used. The comonomer content of the individual hard and soft blocks can be tailored by reactor feed or catalyst modifications. Finally, the average length of the blocks, which is a function of the relative rates of chain growth and shuttling, can be controlled simply by adjusting the ratio of concentrations of CSA and monomer ([CSA]/[C_2H_4]).

Selection of CSA and catalysts is critical. It is well established in olefin polymerization that growing chains can be transferred from the catalyst to an added main-group metal in exchange for an alkyl group (i.e., chain transfer to metal). This transfer is most often irreversible, leading to the termination of the growing chain and the initiation of a new polymer chain. However, the synthesis of block copolymers via chain shuttling requires this polymer chain transfer to be reversible. The main-group centers cannot act as a final repository for “dead” polymer chains; instead, they must serve as a reservoir of “live” chains that are intermittently reattached to catalyst centers for further growth. Chien and Brintzinger have independently claimed preparations of stereoblock PPs using reversible chain transfer between two catalyst centers with different stereoselectivities. However, polymer fractionation revealed that the samples were largely blends of isotactic and atactic PPs, with at most a small fraction of block copolymer. For single-catalyst systems, this process has been used to prepare long-chain metal alkyls and has more recently been described as “catalyzed chain growth”. Gibson et al. have discussed the effects of catalyzed chain growth on molecular weight distribution, reporting that a Poisson distribution of molecular weights (Mw /Mn = 1, where Mw is the weight-average molecular weight and Mn is the number-average molecular weight) is expected under these conditions instead of the Schulz-Flory distribution (Mw/Mn = 2), observed when chain termination occurs. This behavior provides an easy means of probing the capabilities of a catalyst system for chain shuttling polymerization.

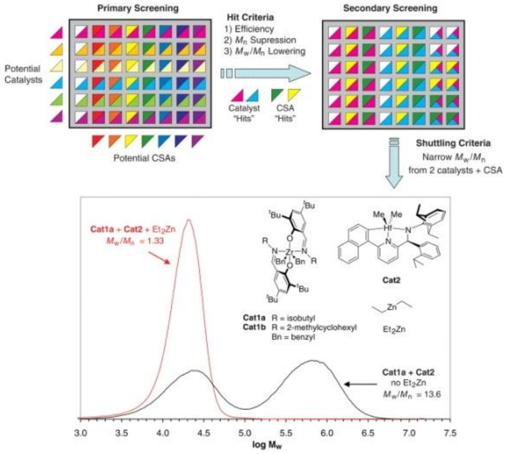


Figure 2. High-throughput screening protocol and selected data from the chain shuttling screen.

Given the multitude of olefin polymerization catalysts, it was daunting to identify a pair of catalysts with substantially different monomer selectivities that are also capable of chain shuttling. Furthermore, the chosen system also needs to operate at a high solution-reaction temperature (T ≥ 120°C) to prevent undesired polymer precipitation. We therefore adopted a high-throughput method to expedite this discovery process. The technique uses a parallel screen of the effects of metal alkyl reagents on the molecular weight and molecular weight distributions of polyethylenes produced by catalyst/CSA combinations. These criteria provide a simple test for finding catalyst/CSA combinations suitable for use in our dual-catalyst system.

Polymerizations are conducted in a parallel grid of individual computer-controlled reactors with robotic addition of reagents and real-time monitoring, coupled with high-throughput characterization techniques. Primary screening involves a broad screen of several catalysts in combination with many potential shuttling agents. Combinations that result in good efficiency, lower molecular weight (Mn), and narrower molecular weight distribution (Mw/Mn), are considered hits. These hits are then subjected to a secondary screen, including individual catalyst and dual-catalyst/CSA combinations. Structures of Cat1a, Cat1b, Cat2, and the CSA are depicted. Shuttling for this trio is demonstrated by the coalescence of the bimodal molecular weight distribution by adding Et_2Zn to the dual-catalyst system.

To begin the selection process, we first selected representative examples from a broad variety of catalyst structure types known to have high polymerization rates. Two examples are shown in Fig. 2. Ethylene polymerizations were then carried out with these catalysts, in combination with a number of potential CSAs using high-throughput screening techniques. By using an array of robotically manipulated individual polymerization reactors combined with rapid polymer characterization methods, we conducted and evaluated more than 1600 individual polymerizations over a three-week period, a feat that would have taken several months using conventional techniques.

Catalyst efficiency, estimated by polymer yield, eliminated several of the potential CSAs due to their inhibition of polymerization. For those combinations that produced a sufficient amount of polymer for characterization, the molecular weight and molecular weight distribution of the polyethylene were then compared with a control polymer prepared with no added CSA. A reduction in Mn in combination with a narrowing of the molecular weight distribution (Mw/Mn) indicated a “hit” for chain shuttling behavior. A zirconium bis(phenoxyimine) catalyst, Cat1a, and a hafnium pyridylamide, Cat2, displayed significant differences in monomer selectivity and also showed characteristics of chain shuttling by using diethylzinc (Et2Zn) as the CSA. Similar bis(phenoxyimine) catalysts have also been shown to exhibit characteristics of catalyzed chain growth. Also, whereas catalyzed chain growth on aluminum and magnesium has been well-documented, only recently has this phenomenon been claimed to occur on zinc.

After this dual-catalyst/CSA combination was identified, a secondary screening process was conducted to further validate the shuttling capability of these hits. This process involved evaluation of both individual catalyst/CSA combinations, as well as mixed catalyst experiments in the high-throughput reactor. Individual catalysts were screened to evaluate the effect of different catalyst/CSA ratios on Mn and Mw/Mn. Dual-catalyst experiments provided further confirmation of the shuttling behavior of this system. A mixture of Cat1a and Cat2 produced a copolymer with a 1-octene content intermediate between those afforded by the individual catalysts, indicating that both catalysts were active in the polymerization. The copolymer had a high molecular weight (Mw = 446,000 g/mol) and a broad, bimodal molecular weight distribution (Mw/Mn = 13.6), indicating a large difference in propensities of the two catalysts for chain termination or transfer (Fig. 2). Introduction of Et_2Zn as the CSA resulted in the formation of copolymers with lower molecular weight and extremely narrow molecular weight distributions. The addition of 50 equivalents of Et2Zn to the total catalyst metal in the mixed catalyst system gave a copolymer with Mw = 20,300 g/mol and Mw/Mn = 1.33. The resulting copolymer was again of intermediate comonomer composition, indicating that both catalysts were active. This observation of a very narrow molecular weight distribution copolymer produced by a mixture of catalysts with drastically different molecular weight capability and monomer selectivity indicates fast rates of chain shuttling with this dual-catalyst CSA system.

The dual-catalyst process described above can be conducted in either a batch or in a continuous-polymerization reactor, but there are marked differences between the two. First, the catalyst onset and decay profiles are not an issue in a continuous process, because catalysts are continuously supplied and removed to give steady-state concentrations. In contrast, different catalyst deactivation rates in a batch system can lead to polymer inhomogeneities. For example, if Cat2 dies faster than Cat1, the total polymer may contain whole chains of hard polyethylene. A second, more subtle difference is that shuttling occurs more efficiently in a continuous process. Typical CSAs begin as simple metal alkyl species such as Et_2Zn. The initial chain-transfer event with Et_2Zn involves exchange of an ethyl moiety for a polymer chain, which initiates growth of a new polymer chain but does not produce any polymer blockiness. Statistically, this event predominates over chain shuttling early in the course of the reaction. Only later in the reaction is the concentration of zincpolymeryl species sufficient to enable true chain shuttling. In a continuous process, the reactor is populated with a steady-state concentration of these zinc-polymeryl species. Because the volume of the reactor is large compared with the volume of the continuous feed, the ratio of zinc-polymeryl species to fresh Et_2Zn is very high. Thus, polymeryl interchange predominates over ethyl-for-polymeryl exchange. In addition, the zinc alkyl compounds exhibit higher thermal stability than many catalysts. At high reactor temperatures, catalyst molecules often deactivate before exiting, but the zinc species continue to participate in chain shuttling throughout their entire residence time.

To realize the full potential of chain-shuttling polymerization for making ethylene-based block copolymers, experiments were conducted with this dual-catalyst chain shuttling system in a continuous solution polymerization reactor. A series of ethylene-octene copolymers of similar melt index (i.e., molecular weight) were produced with a composition of ∼30 weight percent (wt %) hard blocks and 70 wt % soft blocks. The level of Et_2Zn, reported in Table 1 as a $[Zn]/[C_2H_4]$ molar ratio, was systematically varied to study the effects of the ratio on polymer microstructure.

Table 1. Process details and properties of ethylene-octene block copolymers from the chain shuttling system in a continuous process.

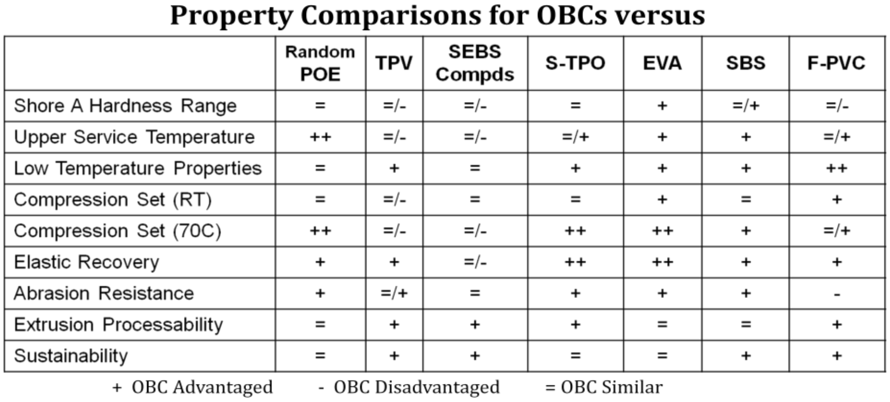
Sample	**Description**	**Catalyst package**	**$[Zn]/[C_2H_4]$ * ($\times 10^3$)**	**Density (g/cm^3)**	**Efficiency (kgP/gM)**	**M_w † (g/mol)**	**M_w/M_n †**	**Chains per Zn ‡**	**Chains per (Hf + Zr) ‡**	**T_m § (°C)**	**ΔH_f § (J/g)**
1	Soft PE	Cat2 + Et_2Zn	1.87	0.862	95.2	110,000	1.97	2.7	230	37	32
2	Hard PE	Cat1b + Et_2Zn	2.07	0.938	127	65,000	1.95	4.6	2,200	124	184
3	Blend	Cat1b + Cat2	—	0.890	258	137,300	13.8	—	3,600	125	90
4	Low CSA	Cat1b + Cat2 + Et_2Zn	0.56	0.883	261	129,000	3.22	12	820	124	68
5	Mid CSA	Cat1b + Cat2 + Et_2Zn	1.40	0.883	244	118,500	2.23	3.6	630	121	69
6	High CSA	Cat1b + Cat2 + Et_2Zn	2.39	0.879	118	104,600	1.97	1.9	260	120	60

* The $[Zn]/[C_2H_4]$ ratio is defined as the molar ratio of CSA to ethylene in the reactor. † Determined by GPC relative to polystyrene standards. ‡ Chains per Zn was calculated by using the zinc feed and polymer production rates and the number-average molecular weight of the resulting copolymer corrected for comonomer content. Similarly, chains per (Hf + Zr) was estimated by using the total catalyst metal feed. § Melting point (T_m) and heat of fusion (ΔH_f) were determined by differential scanning calorimetry (DSC).

The set of experiments was begun with only Cat2 to produce a copolymer with a density of 0.862 g/cm3 by adjusting monomer feed rates and catalyst and cocatalyst flows. Molecular weight control was achieved with a mixture of Et_2Zn and hydrogen, which were adjusted to reach a Mw of 110,000 g/mol (sample 1). Cat2 feed was then stopped, and Cat1b was introduced to the reactor under identical reactor conditions. The higher ethylene selectivity of this catalyst resulted in an increase in the measured polymer density to 0.936 g/cm3. The large difference in comonomer content between these two copolymers, made under similar reaction conditions, demonstrates the substantial difference in the monomer selectivity of the two catalysts. The molecular weight of this hard comonomer–poor material was also much lower, indicative of faster chain termination (primarily by reaction with H2) for this catalyst system. Et_2Zn feed was maintained, but some hydrogen was removed to give a polymer with Mw = 65,000 g/mol (sample 2).

These two baseline polymerizations provided an estimate of the catalyst ratio necessary to achieve the desired composition for the dual-catalyst product; an overall density of ∼0.88 g/cm^3 was targeted to give the desired copolymer composed of 30% high-density material. As a control, a mixture of Cat1b and Cat2 was added to the reactor under the same process conditions with no Et_2Zn, giving a reactor blend of the two component copolymers with an overall density of 0.89 g/cm^3. Hydrogen was added to give a polymer with Mw = 137,300 g/mol (sample 3), which was a simple blend of hard and soft PE made independently by the two catalysts. Et_2Zn was then added to induce chain shuttling between the two catalysts. Products were produced at three different levels of blockiness, controlled by the ratio of concentrations of Et_2Zn to ethylene ($[Zn]/[C_2H_4]$). Sample 6 was made with the highest Et_2Zn level possible, while still achieving the desired molecular weight.

The technology was developed to drop fit into an existing manufacturing plant, requiring limited changes to the equipment and allowing a swing operation to meet the production needs for these and other products. That "repurposing" of existing assets led to significant resource savings.



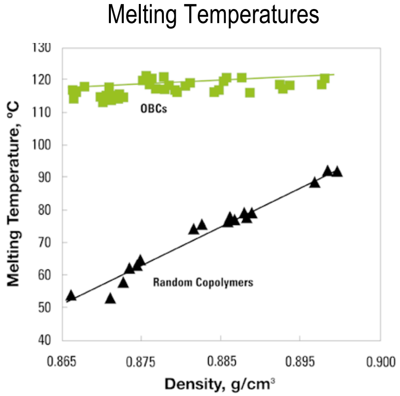
Property Comparisons for OBCs versus

	Random POE	TPV	SEBS Compds	S-TPO	EVA	SBS	F-PVC
Shore A Hardness Range	=	=/-	=/-	=	+	=/+	=/-
Upper Service Temperature	++	=/-	=/-	=/+	+	+	=/+
Low Temperature Properties	=	+	=	+	+	+	++
Compression Set (RT)	=	=/-	=	=	+	=	+
Compression Set (70C)	++	=/-	=/-	++	++	+	=/+
Elastic Recovery	+	+	=/-	++	++	+	+
Abrasion Resistance	+	=/+	=	+	+	+	-
Extrusion Processability	=	+	+	+	=	=	+
Sustainability	=	+	+	=	=	+	+

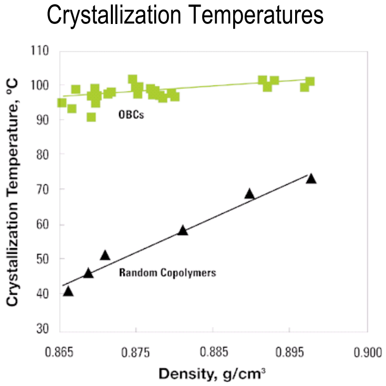
+ OBC Advantaged - OBC Disadvantaged = OBC Similar

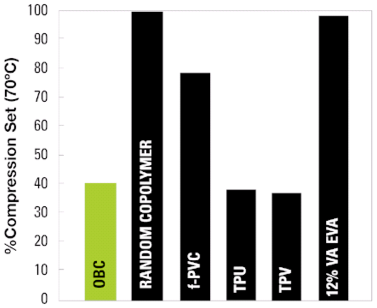
OBCs have a unique property balance not possible with current random olefin copolymers and blends because the technology enables independent control of modulus and heat resistance. Thus, the novel polymer structure shatters the traditional relationships between these properties, which can provide a range of performance properties that are very unique to Olefin Block Copolymers.

One can see the melting and crystallization temperatures of ethylene-octene OBCs versus random ethylene-octene copolymers in figures on the right. Melting and crystallization temperatures for OBCs are up to 50°C higher. The higher melt temperature indicates superior heat resistance. The higher crystallization temperatures enable OBCs to be injection molded and extruded with faster set-up characteristics which helps to reduce energy consumption at customer production locations. The combination of the properties enables OBCs to be used in applications previously reserved for crosslinked polyolefins, styrenic block copolymers (SBCs), thermoplastic polyurethanes (TPUs), or flexible polyvinyl chloride (f-PVC).



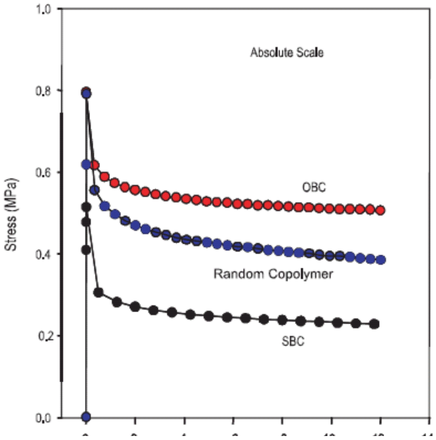
Measured by DSC at 10°C/min.





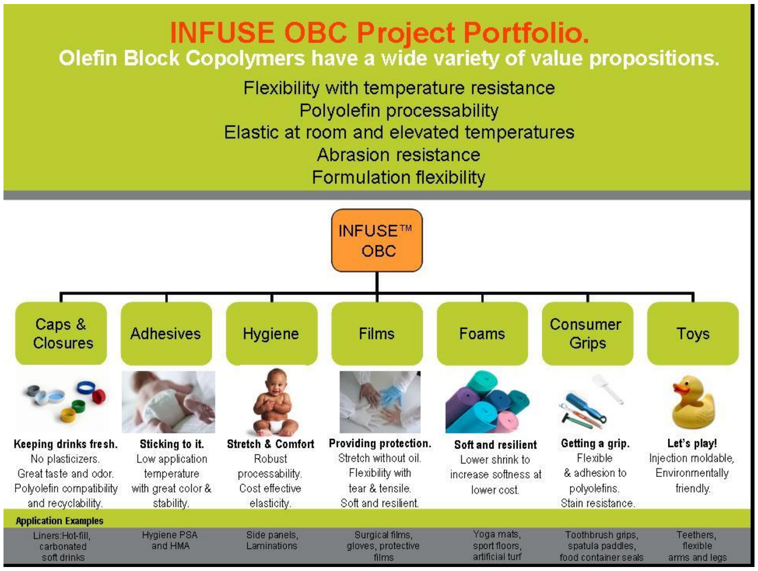
Compression Set (lower is better)

The compression set (elastic recovery under compressive deformation) at 70°C for OBCs and a range of competitive materials is shown in on the left. Notably, compression set of OBCs is similar to the high performance thermoplastic elastomers such as thermoplastic vulcanizates (TPVs) and TPU. Low compression set properties are critical for applications such as gaskets/profiles, footwear, and many automotive applications. This allows the marketplace to move to a new simple, clean polymer solution.



Stress Relaxation Performance
at Body Temperature, 50% Strain

The stress relaxation performance at body temperature for OBCs, random copolymers, and styrenic block copolymers (SBCs) are shown in the figure on the right. OBCs show less stress relaxation versus the two comparative polymers. Lower stress relaxation is indicative of higher holding force and is critical in elastic film and fibers used in hygiene and medical applications (e.g., diapers). This allows for down-gauging of product thickness and less overall material usage while still meeting performance requirements.



INFUSE OBC Project Portfolio.

Olefin Block Copolymers have a wide variety of value propositions.

Flexibility with temperature resistance
Polyolefin processability
Elastic at room and elevated temperatures
Abrasion resistance
Formulation flexibility

INFUSE™ OBC

Caps & Closures	Adhesives	Hygiene	Films	Foams	Consumer Grips	Toys
Keeping drinks fresh. No plasticizers. Great taste and odor. Polyolefin compatibility and recyclability.	**Sticking to it.** Low application temperature with great color & stability.	**Stretch & Comfort** Robust processability. Cost effective elasticity.	**Providing protection.** Stretch without oil. Flexibility with tear & tensile. Soft and resilient.	**Soft and resilient** Lower shrink to increase softness at lower cost.	**Getting a grip.** Flexible & adhesion to polyolefins. Stain resistance.	**Let's play!** Injection moldable, Environmentally friendly.
Application Examples						
Liners:Hot-fill, carbonated soft drinks	Hygiene PSA and HMA	Side panels, Laminations	Surgical films, gloves, protective films	Yoga mats, sport floors, artificial turf	Toothbrush grips, spatula paddles, food container seals	Teethers, flexible arms and legs

Due to the unique balance of flexibility, heat resistance, compression set, and processability, OBCs have market opportunities in hoses & tubes; profile extruded products (weather-stripping for automotive; appliance, furniture, and building & construction gaskets); crosslinked foams for industrial, consumer, and footwear applications; closure liners for caps; and interior automotive parts. Due to the elastic recovery and stress relaxation performance of OBCs, elastic films and fibers are a market segment of interest for the hygiene and medical industry. Due to compatibility with polypropylene and polyethylene, low glass transition temperature, and excellent injection molding processability, impact modification of polypropylene for automotive and rigid packaging present significant market potential for OBCs. It's new technology to suit many application requirements across multiple market segments.

Life Cycle Assessment

Finally, in consideration of the sustainability of the polymer in application, a Life Cycle Assessment was performed internally by the Dow Environmental Health & Safety Department, with assistance from the Dow Plastics R&D Department. It was peer reviewed by a third party following ISO standards 14040 and 14044. The objective of this study was to produce a “cradle-to-gate” Life Cycle Assessment (LCA) comparing the potential environmental impacts of DOW™ Ethylene/1Octene polyolefin (olefin block copolymers, OBC) with a few typical generic styrene/butadiene (SBS / SEBS) systems. Done in accordance with ISO standards, the comparison includes example compounds based on these copolymers with white mineral oil and polypropylene. The target application under consideration is hot-filled cap liners.

LCA Study Findings

A comparison of the impact assessment results is shown in the table below. The values given are percentages relative to the impact of the E-O polyolefin copolymer.

	Polyolefin compound	**SBS compound**	**SBS copolymer**	**SEBS compound**	**SEBS copolymer**
Acidification	109%	138%	173%	163%	235%
Eutrophication	159%	193%	184%	218%	247%
GWP, IPCC	91%	121%	174%	147%	240%
Photochemical oxidation	102%	130%	170%	155%	232%
Water	109%	147%	193%	206%	342%
CED	94%	1-5%	127%	120%	163%

Pink cells indicate an impact up to 50% higher than the E-O polyolefin baseline, and are interpreted as being significantly greater than the baseline. Red cells show impact values of more than 50% above the baseline, and are interpreted as being significantly greater than the baseline. Green cells show impacts that are less than 10% above the baseline, and are interpreted as performing similarly to the baseline.

LCA Study Results

1. The DOW™ E-O polyolefin is significantly advantaged in the six impact categories compared to the styrene/butadiene based copolymers, with >50% advantage in most comparisons (red cells in table above).
2. The DOW™ E-O polyolefin is also advantaged compared to the SBS and SEBS compounds in the six impact categories (the exception being CED for the SBS compound), though the advantage is not as large as for the neat copolymers [more pink boxes (<50% advantage) in the table].
3. The DOW™ E-O polyolefin compound is also advantaged in comparison with the SBS and SEBS compounds in the same way.

LCA Study Considerations

1. As a “cradle to gate” LCA, the use and end-of-life phases are not included. These phases are assumed to be essentially identical for the products being studied.
2. The life cycle impact assessment (LCIA) results of these impacts are relative expressions and do not predict actual impacts on human health or the environment, exceeding of thresholds, safety margins or risks.
3. Since the densities are about the same, equal masses are used in the filler cap application. Thus, the functional unit is defined to be 1 kg of “ready-to-use” polymer or polymer compounds. These materials can be used interchangeably by volume or mass in applications such as hot-filled cap liners, where the material needs to fill a certain space.
4. When comparing results, differences of at least +/- 10% in energy use and global warming potential are considered significant at the 90% confidence level. Differences less than this are treated as equivalent.
5. Sensitivity analyses conducted around the age of the SBC process models and the source of the styrene dataset showed that these did not change the trends of the results.

LCA Study Summary

Based on the findings generated from the tests performed for this study, users or potential users of sytrenic block copolymers (SBCs) who are looking to improve the sustainability profiles of their products may consider switching to INFUSE™ Olefin Block Copolymers (OBCs). The latter show significant performance improvements per kilogram in the areas of energy use, greenhouse gas generation, water use, eutrophication, photochemical oxidation and acidification.

REFERENCES

- Please refer to www.dow.com/infuse/lit for links to papers describing this technology.