Solutions for a Better Tomorrow

Coloring of Mechanical Recycled Materials, Challenges & Solutions

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Agenda

- **Introduction**
  - Color and composition of PCR
- **Challenges coloring mechanical recycled polymers**
  - Why do we need solutions?
- **PCR Color Optimization & Prediction Tool**
  - How to support customers developing colored products with PCR
- **Batch-batch variation of PCR**
- **Using special effects with PCR**

Introduction

- **Brand owners have commitments to use more recycled material in their products**
  - Packaging with minimum of 30% PCR; ultimate target 100%
  - Appliances, Transportation and Consumer Goods with recyclate content for lower CO_2 footprint
  - Recyclate content can depend on regulatory or industry targets

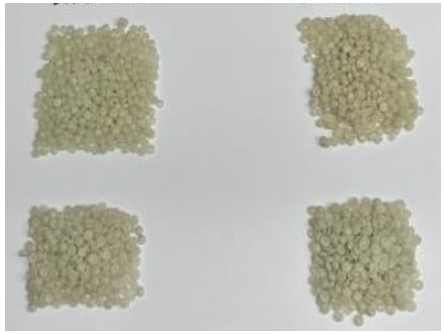
- **Wide color variation of recycled polymers provides challenges for brand owners and material producers to develop & supply consistent colored products.**
  - Regulatory requirements and physical properties for the application also need to be considered

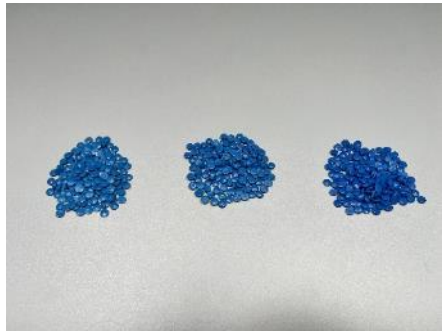
- **Mechanical recycled polymers are available from multiple sources**
  - Pre-consumer recyclate (PIR) – e.g., traceable industrial sources
  - Post-consumer waste recyclate (PCR) – e.g., mixed household waste

Color and Composition of PCR

- **PCR can vary significantly in color and composition**
  - Different sources of feedstock
  - Sorted into multiple polymer and color fractions
  - Same visual color can have wide range of pigment content; especially grey produced with mixed color fraction
  - Homogenized by compounding and blending

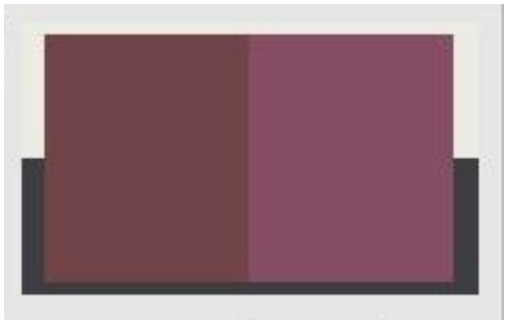
PCR Color	Ash Content	Non-polymer content	Impact on color vs. virgin polymer
Natural	< 1%	Silica, $CaCO_3$	Neutral affect; yellowness affects natural or white colors
White / Ivory	2 – 7%	TiO_2, $CaCO_3$	High white pigment content not suitable for dark colors
Grey	1 – 10%	TiO_2, $CaCO_3$, Carbon Black, mixed pigments	Variable grey shades; not suitable for light or vibrant colors
Black	1 – 10%	Carbon Black, Talc, $CaCO_3$, mixed pigments	Black color difficult to convert to other colors; NIR detection
Blue	1 - 5%	TiO_2, $CaCO_3$, organic pigments	Specific to blue articles





Challenges coloring mechanical recycled polymers

- **Existing color targets are not always possible in recycled materials**
  - More difficult to achieve desired colors and special effects compared to virgin polymer
  - New color recipes have to be developed for each quality of recycled material
- **Batch-Batch variation of recycled material**
  - Material from same source can be different depending on feedstock composition
  - Color recipes can need adjustment for each batch
- **PCR availability**
  - Limited availability of prime PCR grades
  - Need to work with all quality of PCR
- **Complexity**
  - Color development
  - Managing materials, PCR and Color Masterbatch
- **Cost**
  - Color matches and molding trials
  - Higher coloring costs



***Polybatch* 5670 in PCR Ivory & Grey**

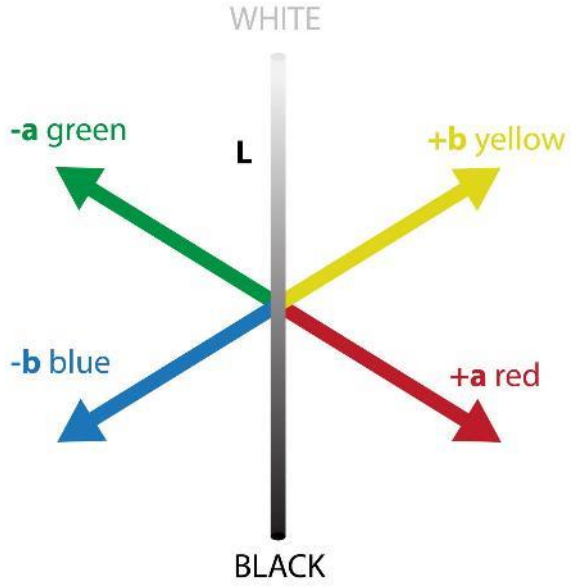
***Polybatch* 4012 in PCR Ivory & Grey**

Why do we need solutions?

- **Allow designers to understand and simulate the effect on color when using PCR**
  - Color capability is already considered in design phase
  - Which colors & cannot can be achieved using preferred PCR quality?
  - Determine maximum PCR content possible and use of blends
- **Reduce the complexity and costs of product development**
  - Fewer color matches and molding trials
  - Faster color development process
- **Understand how batch-batch color variation of chosen PCR will affect color specification**
  - Color masterbatch development to mitigate variation
  - Allow for color specification to be managed in supply chain
    - Determine realistic color specification (DE) limits
- **Maximise PCR usage and utilisation of all qualities of available PCR**
  - Limited availability of color selected PCR
  - Solutions required for Grey and mixed color PCR

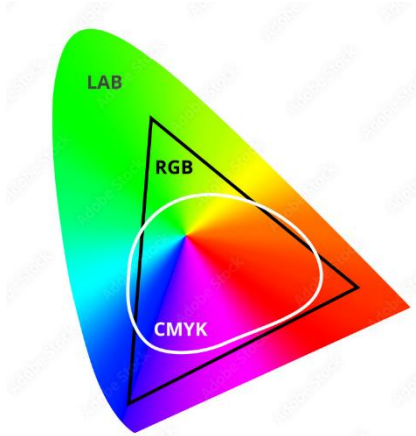
Lyondellbasell PCR Color Optimisation Tool

- **Digital solution to predict and visualise the influence of PCR on the target color**
  - Calibrated with multiple PCR grades to simulate effect on color when replacing virgin polymer
  - Enables specific color matching in selected PCR source
  - Allows for color simulation with different blend ratios of PCR



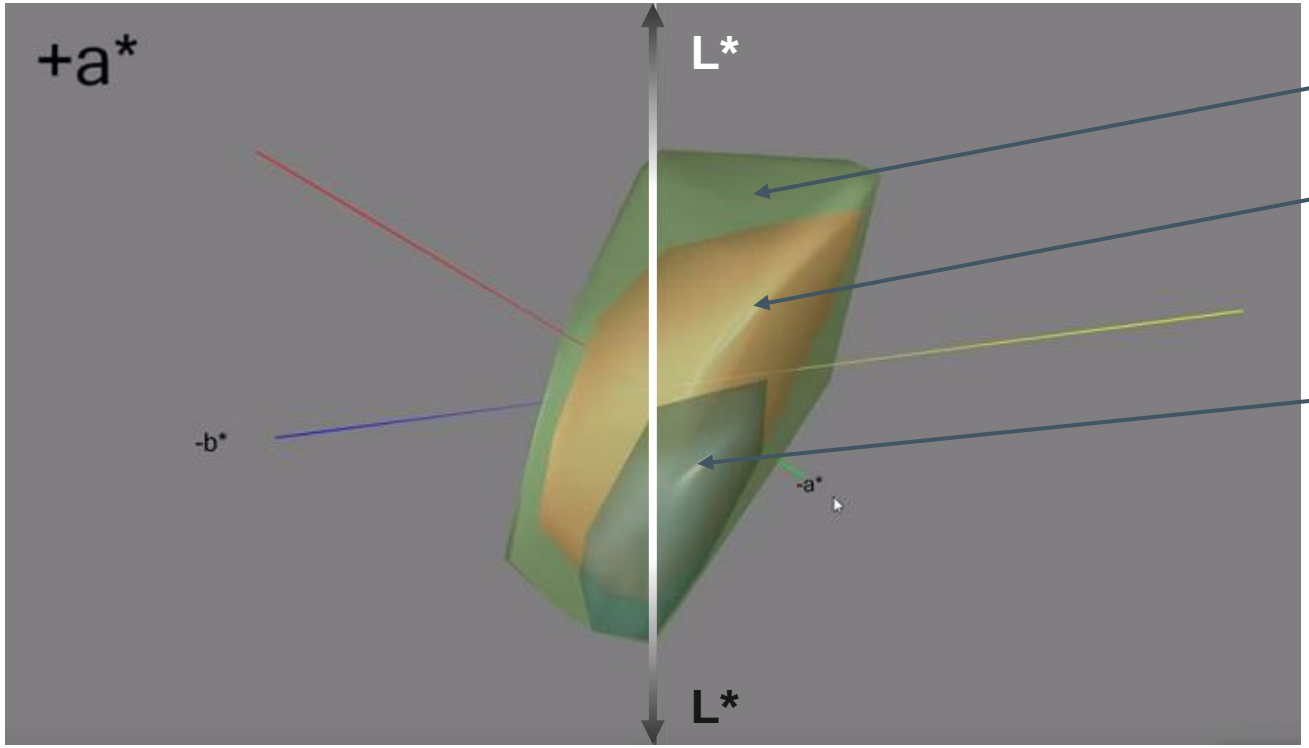
- **Coloring of plastics is usually measured and communicated using LAB values**
  - L = lightness / darkness
  - a = red → green
  - b = yellow → blue

- **Color Gamut can be used to visualise the portion of the color space which can be depending on:**
  - Pigment color set and concentration
  - Substrate e.g. polymer or PCR type



PCR Color Optimisation Tool

- **Digital visualization of working color space (gamut) for different polymer and PCR**
  - Comparison of PP Homopolymer with Ivory and Grey PCR



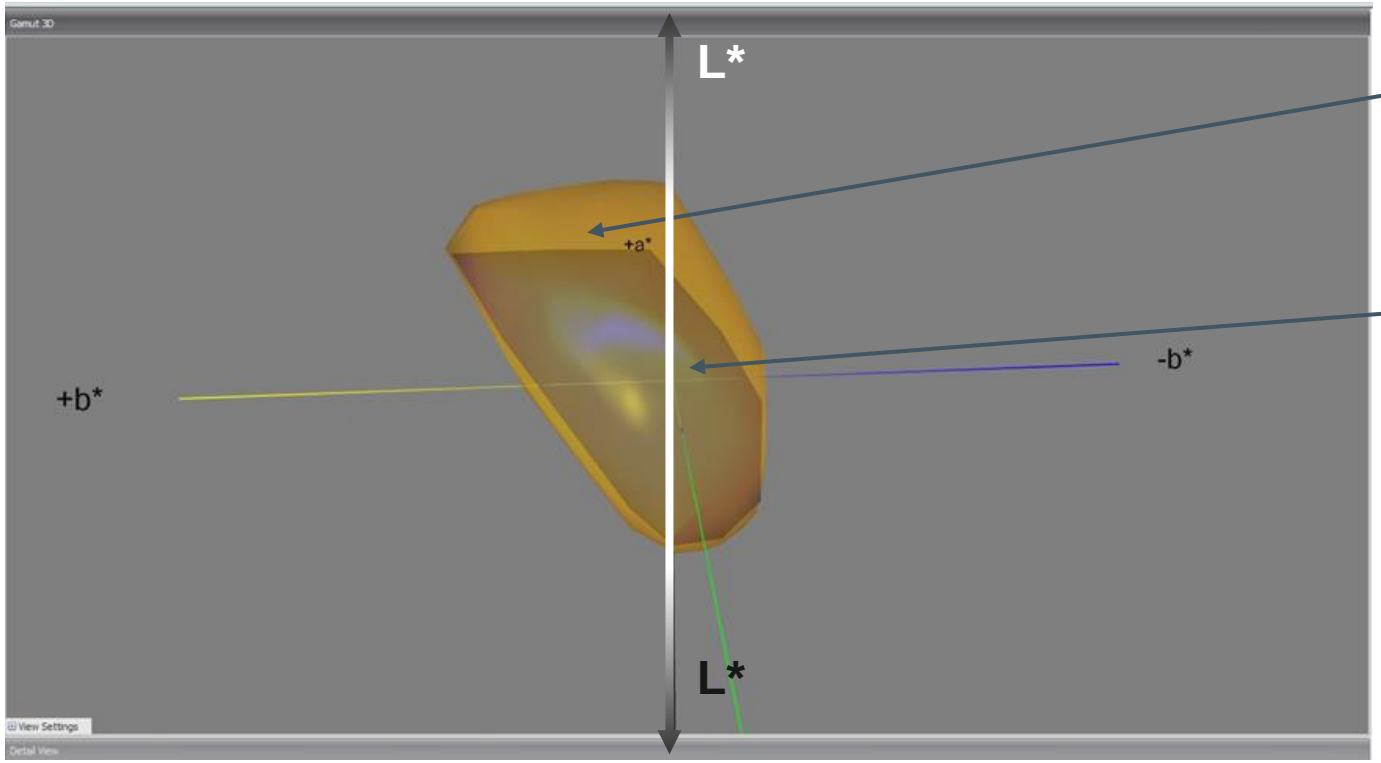
PP Homopolymer

*Circulen*Recover PP Ivory

*Circulen*Recover PP Grey

PCR Color Optimisation Tool

- **Pigment concentration can adjust the color space for a selected polymer or PCR**
  - Digital visualization of color space with different pigment concentration limits (2% → 4% total pigments)
    - Simulation of using higher concentration of pigments to overcome inherent color of PCR
    - Pigment concentration can be limited by processing, physical properties and cost

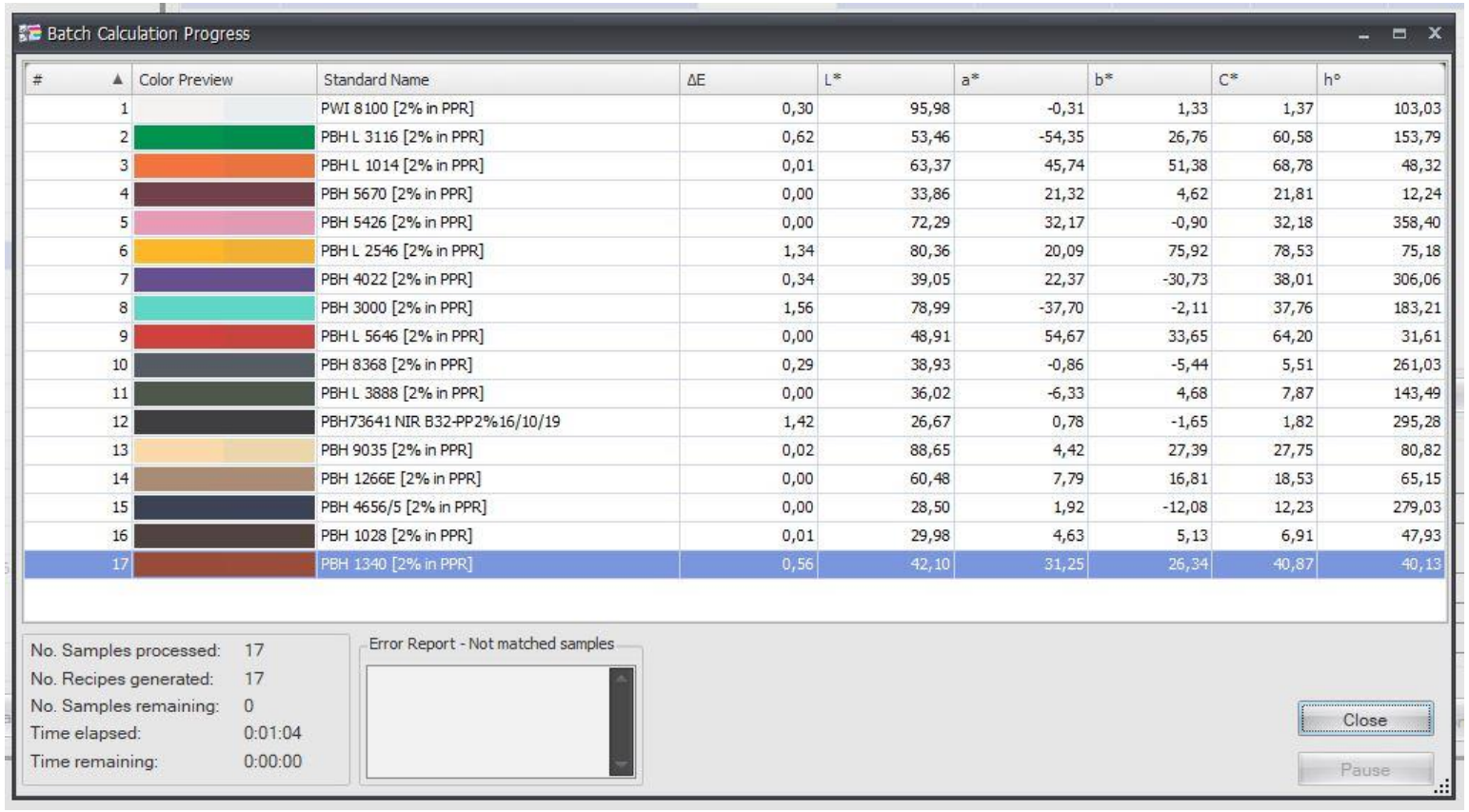


Pigment concentration limit = 4%
In *Circulen*Recover PP Ivory

Pigment concentration limit = 2%
In *Circulen*Recover PP Ivory

PCR Color Optimisation Tool – Batch Calculation

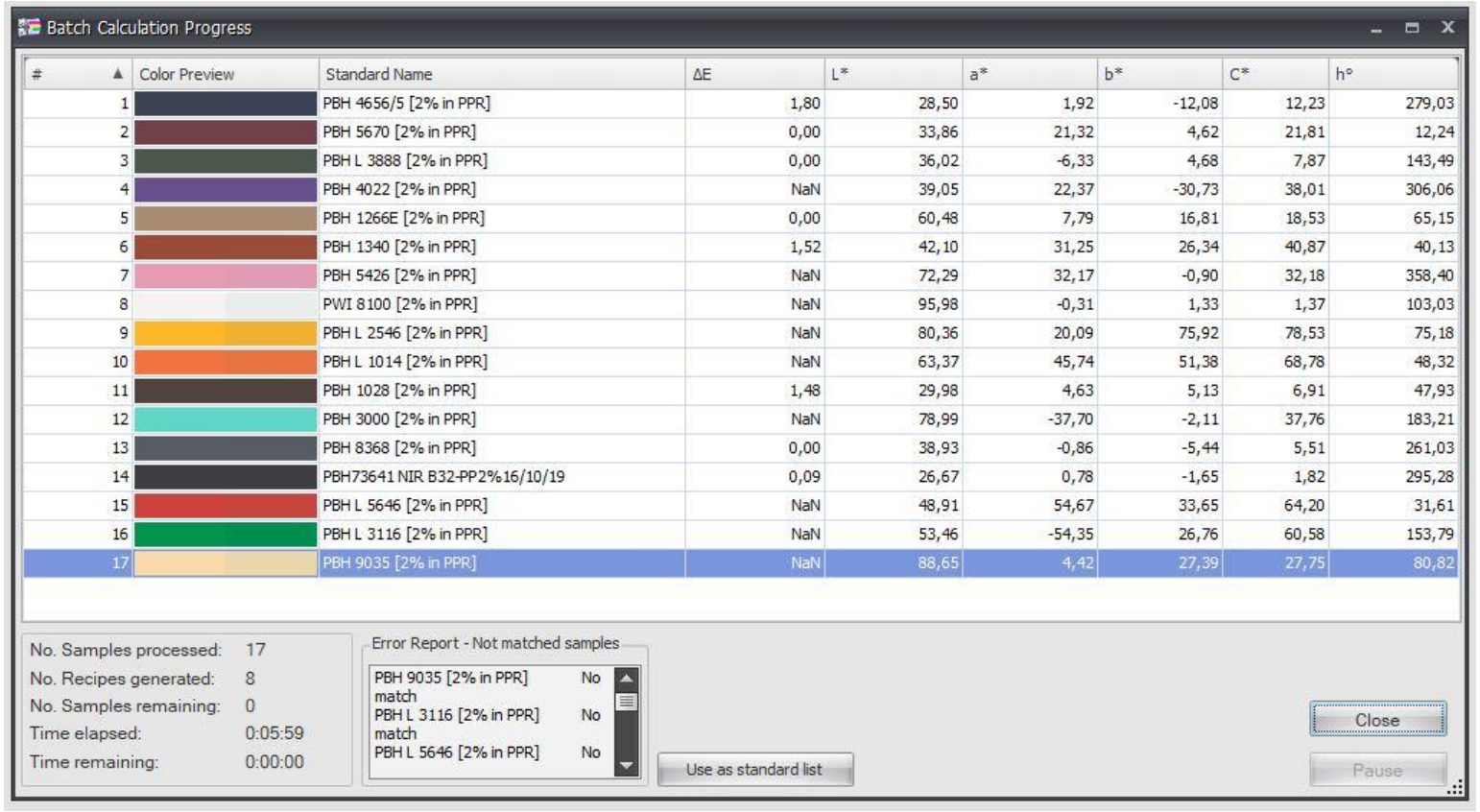
- **Batch calculation allows set of brand colors to be analysed with different PCR polymers**
  - Determine which colors can (or cannot) be achieved when replacing virgin polymer with PCR, or alternative PCR sources
    - Calculate DE possible for selected PCR and pigment concentration
      - Example of standard color range in *Circulen*Recover PP Ivory with 2% pigment concentration limit
      - Possible to achieve all colors with CMC DE target <2.0



#	Color Preview	Standard Name	ΔE	L*	a*	b*	C*	h°
1		PWI 8100 [2% in PPR]	0,30	95,98	-0,31	1,33	1,37	103,03
2		PBH L 3116 [2% in PPR]	0,62	53,46	-54,35	26,76	60,58	153,79
3		PBH L 1014 [2% in PPR]	0,01	63,37	45,74	51,38	68,78	48,32
4		PBH 5670 [2% in PPR]	0,00	33,86	21,32	4,62	21,81	12,24
5		PBH 5426 [2% in PPR]	0,00	72,29	32,17	-0,90	32,18	358,40
6		PBH L 2546 [2% in PPR]	1,34	80,36	20,09	75,92	78,53	75,18
7		PBH 4022 [2% in PPR]	0,34	39,05	22,37	-30,73	38,01	306,06
8		PBH 3000 [2% in PPR]	1,56	78,99	-37,70	-2,11	37,76	183,21
9		PBH L 5646 [2% in PPR]	0,00	48,91	54,67	33,65	64,20	31,61
10		PBH 8368 [2% in PPR]	0,29	38,93	-0,86	-5,44	5,51	261,03
11		PBH L 3888 [2% in PPR]	0,00	36,02	-6,33	4,68	7,87	143,49
12		PBH73641 NIR B32-PP2%16/10/19	1,42	26,67	0,78	-1,65	1,82	295,28
13		PBH 9035 [2% in PPR]	0,02	88,65	4,42	27,39	27,75	80,82
14		PBH 1266E [2% in PPR]	0,00	60,48	7,79	16,81	18,53	65,15
15		PBH 4656/5 [2% in PPR]	0,00	28,50	1,92	-12,08	12,23	279,03
16		PBH 1028 [2% in PPR]	0,01	29,98	4,63	5,13	6,91	47,93
17		PBH 1340 [2% in PPR]	0,56	42,10	31,25	26,34	40,87	40,13

PCR Color Optimisation Tool – Batch Calculation

- **Batch calculation used to compare change in PCR for brand colors**
  - Example of standard color range changing to *Circulen*Recover PP Grey with 2% pigment concentration limit
    - Only possible to achieve 8 colors with CMC DE target <2.0
    - *Not possible to correct other colors to meet specification!*



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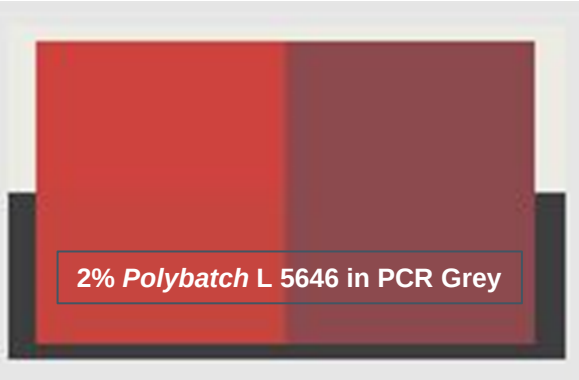
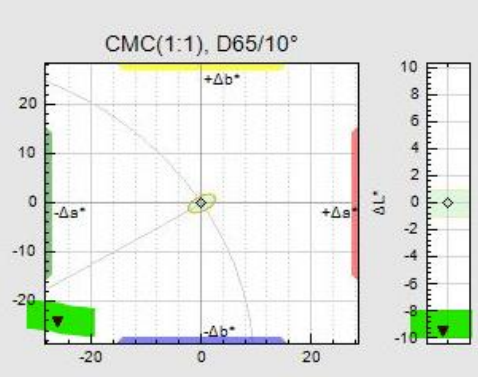
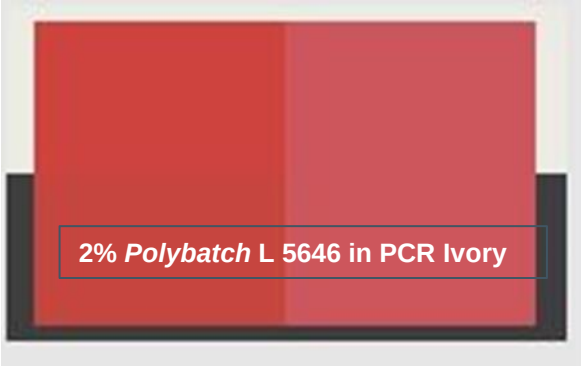
17		PBH 9035 [2% in PPR]	NaN	88,65	4,42	27,39	27,75	80,82

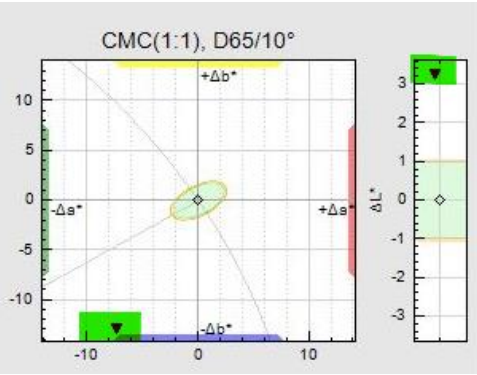
PCR Color Optimisation Tool

- **Example of *Polybatch* L 5646 red masterbatch**
  - Color comparison with PCR Grey or PCR Ivory versus virgin PP at 2% masterbatch dilution
  - PCR Grey – DE = 16.7
  - PCR Ivory – DE = 7.6
  - Using Color Optimization Tool recipe for 100% PCR Ivory can be adjusted to achieve DE of <0.5 (good visual color)



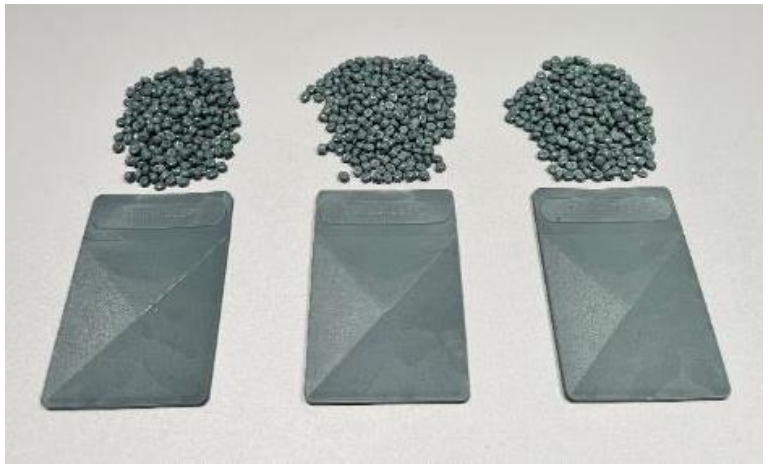






PCR Batch-Batch Color variation

- **Example of *Circulen*Recover HD5603 Silver**
- **Measurement of color range for typical Low → High 'L' value batches**
  - Comparison of L*a*b values versus mid range batch
  - **DL range from -1.96 to 1.22**
  - **DE CMC = 1.6 and 1.8**
- Can color masterbatch be developed to meet the customer specification allowing for batch-batch variation?

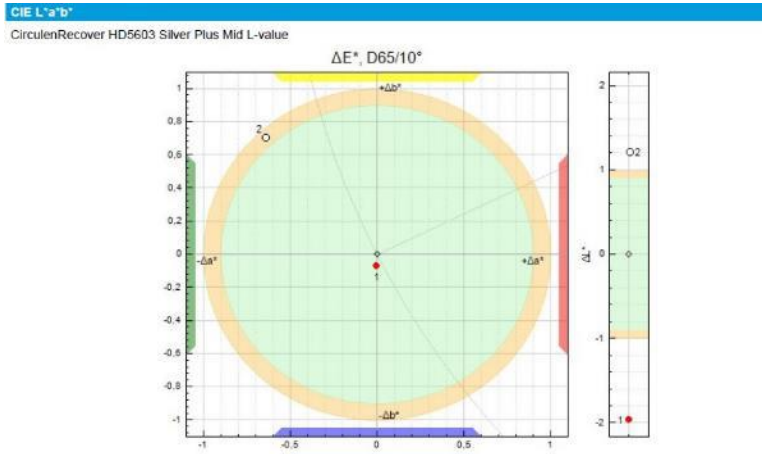


Job Results

CirculenRecover HD5603 Silver Plus Mid L-value

Name	Spectrum Condition	Thickne	Concentratio	L*	a*	b*	C*	h°
CirculenRecover HD5603 Silver Plus Mid L-value	CM-3600A (d/8, 10nm, 31, SCI, 11)	3,00	100,00	51,0	-4,6	-2,3	5,1	206,1
CirculenRecover HD5603 Silver Plus Low L-value	CM-3600A (d/8, 10nm, 31, SCI, 11)	3,00	100,00	49,1	-4,6	-2,3	5,1	206,8
CirculenRecover HD5603 Silver Plus High L-value	CM-3600A (d/8, 10nm, 31, SCI, 11)	3,00	100,00	52,2	-5,2	-1,5	5,5	196,4

Name	Memo	ΔL*	Δa*	Δb*	ΔC*	ΔH*	ΔE*	CMC	ΔE00
CirculenRecover HD5603 Silver Plus Mid L-value	100 %								
CirculenRecover HD5603 Silver Plus Low L-value	100%	-1,96	0,00	-0,07	0,03	0,06	1,97	1,79	1,97
CirculenRecover HD5603 Silver Plus High L-value	100%	1,22	-0,64	0,71	0,34	-0,89	1,55	1,59	1,57



PCR Batch-Batch Color variation – Blue Color Example

- **4% *Polybatch* EB402230 NIR + 50% *Circulen*Recover HD5603 Silver**
- **Measurement of color coordinates for Low → High 'L' value range batches**
  - Comparison of L*a*b values versus mid range batch
  - **DL range from -0.16 to 0.10**
  - **DE CMC = 0.23 and 0.95**
- **Good visual color obtained, same masterbatch used in different PCR batches**

Job Results

MB EB402230 NIR in 50% MID SPEC L-value

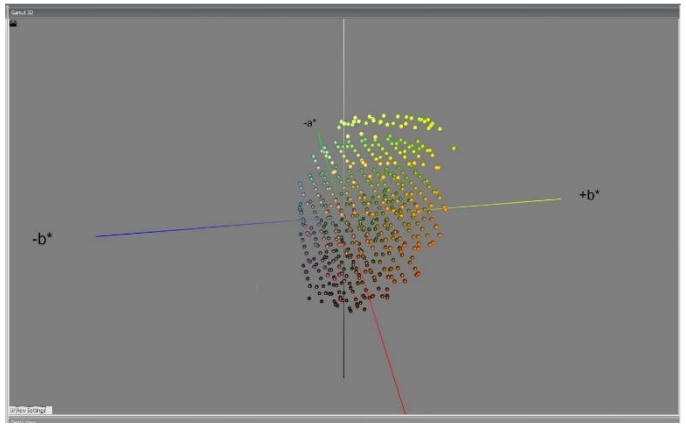
Name	Spectrum Condition	Thickne	Concent	L*	a*	b*	C*	h°
MB EB402230 NIR in 50% MID SPEC L-valu	CM-3600A (d/8, 10nm, 31, SCI, 11)	1,50	4,00	33,8	0,3	-22,8	22,8	270,8
MB EB402230 NIR in 50% LOW EXT L-value	CM-3600A (d/8, 10nm, 31, SCI, 11)	1,50	4,00	33,9	-0,3	-21,6	21,6	269,1
MB EB402230 NIR in 50% HIGH EXT L-valu	CM-3600A (d/8, 10nm, 31, SCI, 11)	1,50	4,00	33,6	0,5	-22,8	22,8	271,1

Name	Memo	ΔL*	Δa*	Δb*	ΔC*	ΔH*	ΔE*	CMC	ΔE00
MB EB402230 NIR in 50% MID SPEC L-valu									
MB EB402230 NIR in 50% LOW EXT L-value		0,10	-0,65	1,26	-1,26	-0,66	1,42	0,95	0,66
MB EB402230 NIR in 50% HIGH EXT L-valu		-0,16	0,15	0,01	-0,01	0,15	0,22	0,23	0,19

Benefits of PCR Color Optimisation Tool to Customers

- **Color matching system optimised to include recycled polymer**
  - PCR and other recyclates calibrated in database to use as destination polymer
  - Allows use of existing pigment databases and customer color references

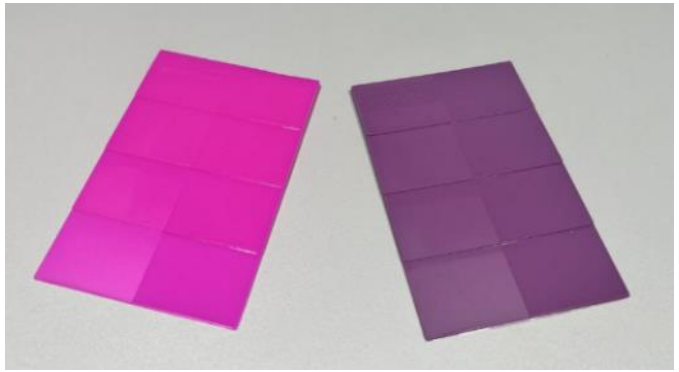
- **How can we support Customers & Brand Owners**
  - Digital visualisation of brand colors when using PCR
  - Prediction of which brand colors are possible with different PCR quality
  - Calculate maximum PCR content for specific color using different PCR quality
  - Batch calculation of brand colors to support PCR allocation
  - Reduced complexity and costs of product development
    - Faster color development process
    - Fewer color matches and molding trials
    - Cost prediction of color matches to meet target color
  - Manage batch-batch variation of PCR
    - Visualisation of color effect with batches from lower and upper limits
    - Development of masterbatch to mitigate color variation
    - Specification setting, determine realistic DE limits



Using Special Effect Colors with PCR

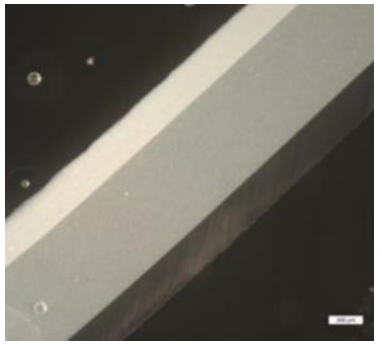
- **Special effect pigments like Pearlescent, Metallic and Fluorescent are influenced by the PCR color**
  - Transparent polymer is required to maximise the special effect
  - TiO_2 pigment content in PCR reduces light transmission and limits pearlescent effect

- **How to achieve special effects with PCR?**
  - Compromise the PCR content when special effect pigments are required
    - Allow for blends with virgin polymer to improve color and transparency
  - Selective use of Natural PCR
  - Design with alternative special effects which complement look of PCR
    - Stone, marble, particle effects with contrasting color
  - Use multi-layers for film extrusion and blow molding in flexible or rigid packaging
    - Special effect can be applied in outer (visual layer) with virgin polymer or natural PCR
    - Allows use of lower PCR quality in core layers to hide color variation



Fluorescent Pink in virgin PP and PCR Grey

Metallic Gold in virgin PP, PCR Ivory and PCR Grey



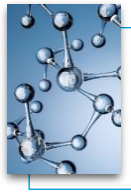
Masterbatch & Color Concentrates

Applications

- **Packaging**
- **Building & Construction**
- **Transportation**
- **Consumer Goods**
- **Appliances**
- **Agriculture**

We deliver…

Specialized color competence and masterbatch technology centers



Innovative solutions to exactly meet customer application requirements

One-Stop shop for color and additive masterbatches

Raw materials harmonization to ensure consistent quality and supply, worldwide

Sustainability is a core value and a driver

Solutions for Coloring of Recycled Polymers

- **Lyondellbasell Color Optimisation Tool can be used to support customers & brand owners**
  - Color simulation with different PCR
  - Extensive database of pigments, polymer and PCR
  - Reduce the complexity and costs of product development
- **Extensive Color Knowledge & Experience**
  - Different polymers and recyclates
  - Special effects
  - Multiple applications & processing techniques

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Solutions for a Better Tomorrow

Thank you !