# The 2nd Life of Mixed Coloured PET Bottles

Fachhochschule Köln
Cologne University of Applied Sciences

42 Engineering


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# The 2nd Life of Mixed Coloured PET Bottles - Outline

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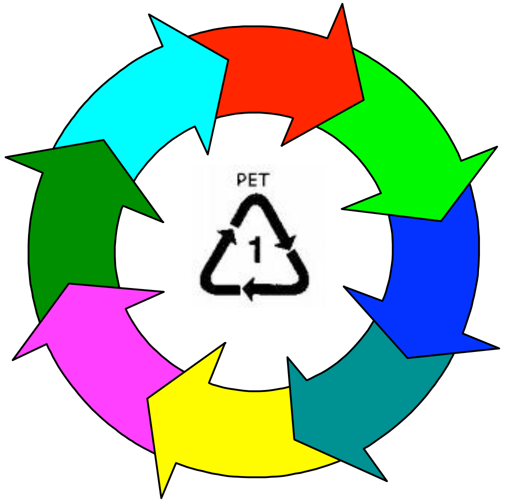
## Background



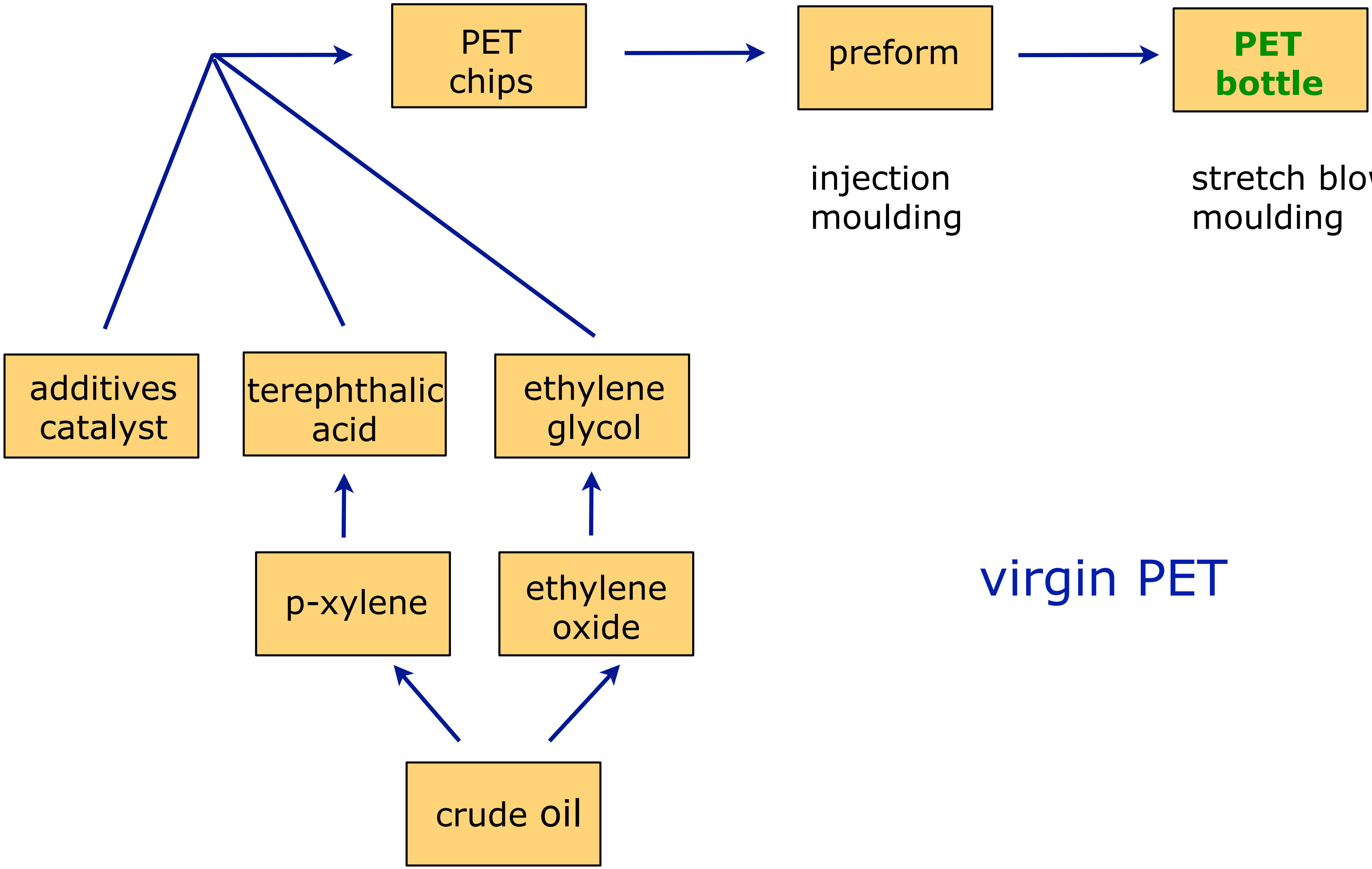

## Challenge

## Solution

DMT EG Residue

# Background - PET Pathways

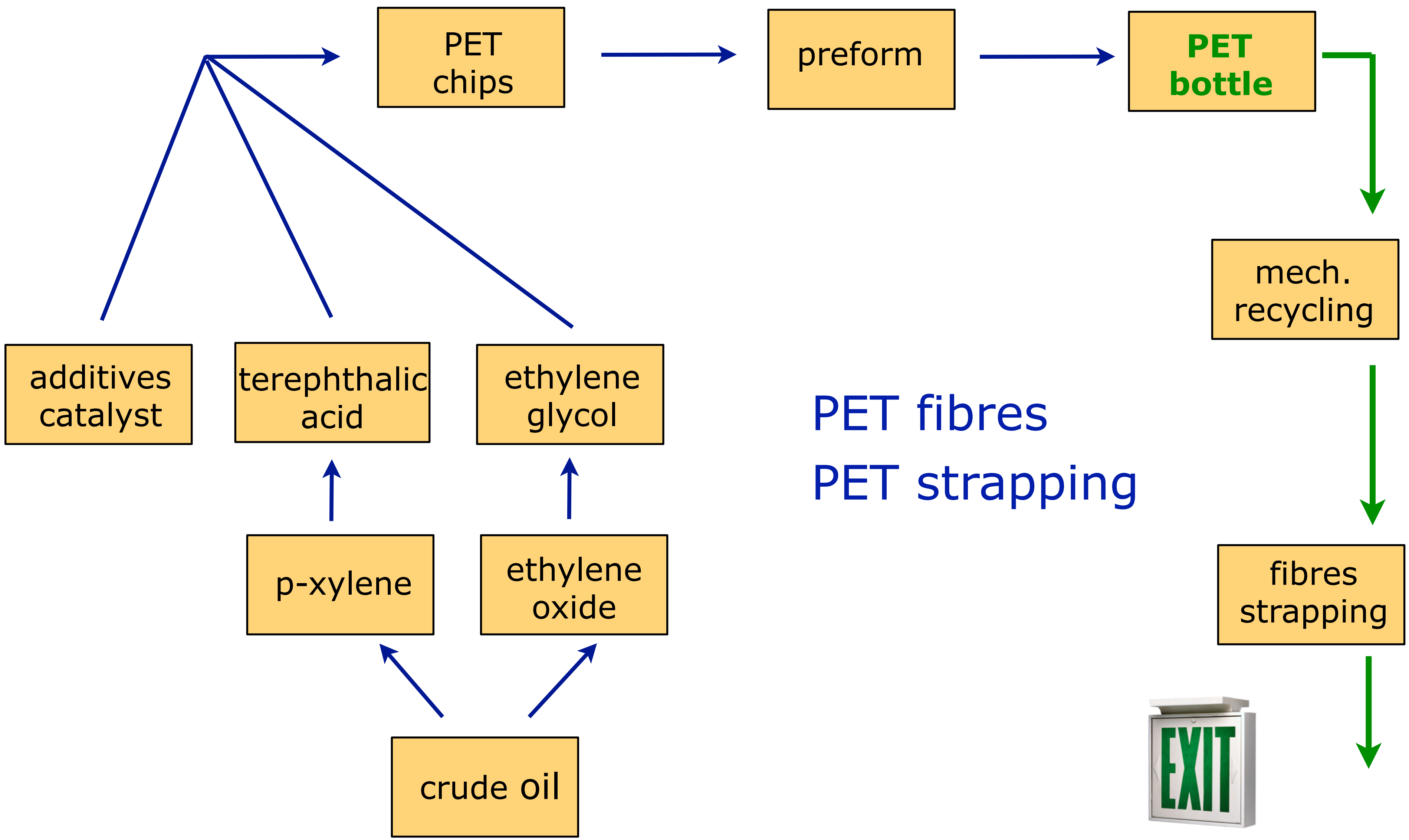





virgin PET

# Background - PET Pathways





# Background - PET Pathways

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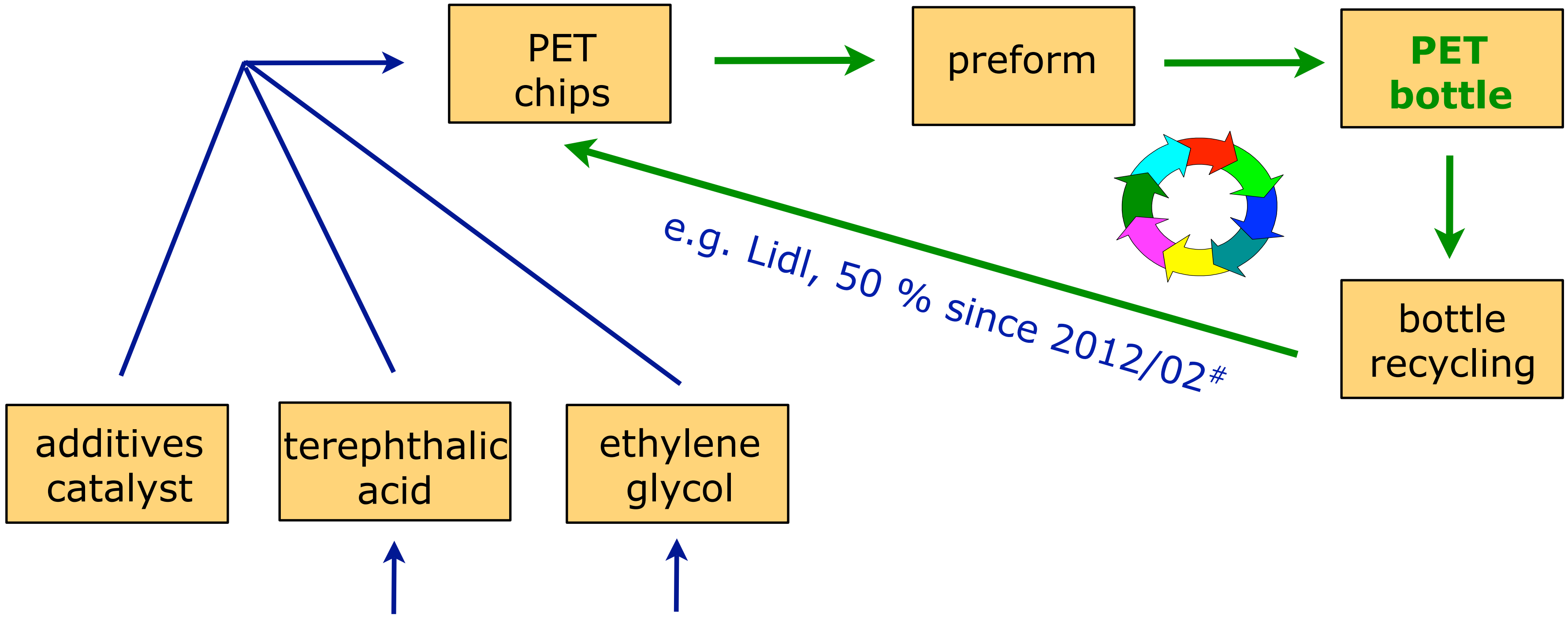
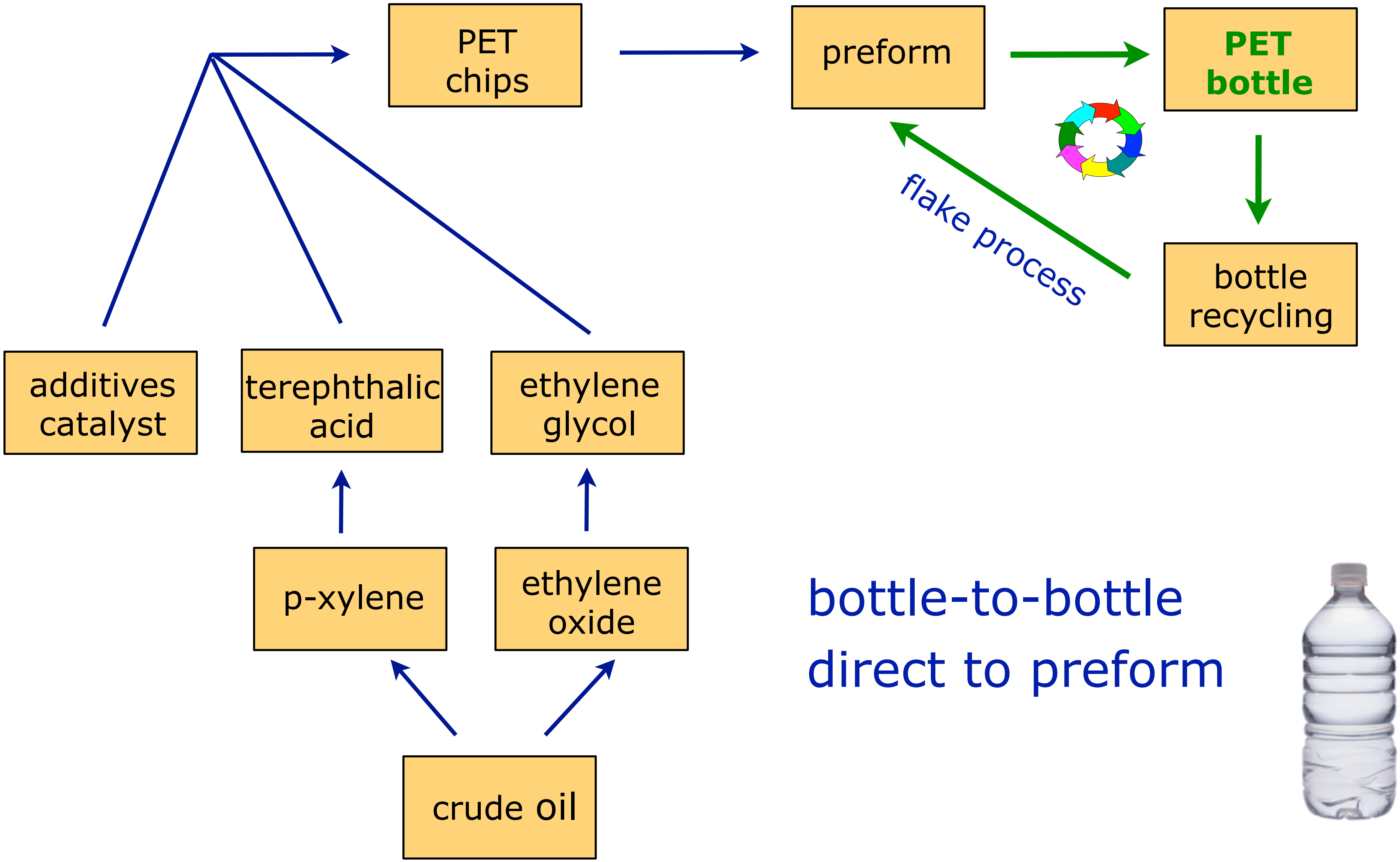



bottle-to-bottle
via chips

#www.lidl.de

# Background - PET Pathways




bottle-to-bottle

direct to preform

# Background - PET Pathways

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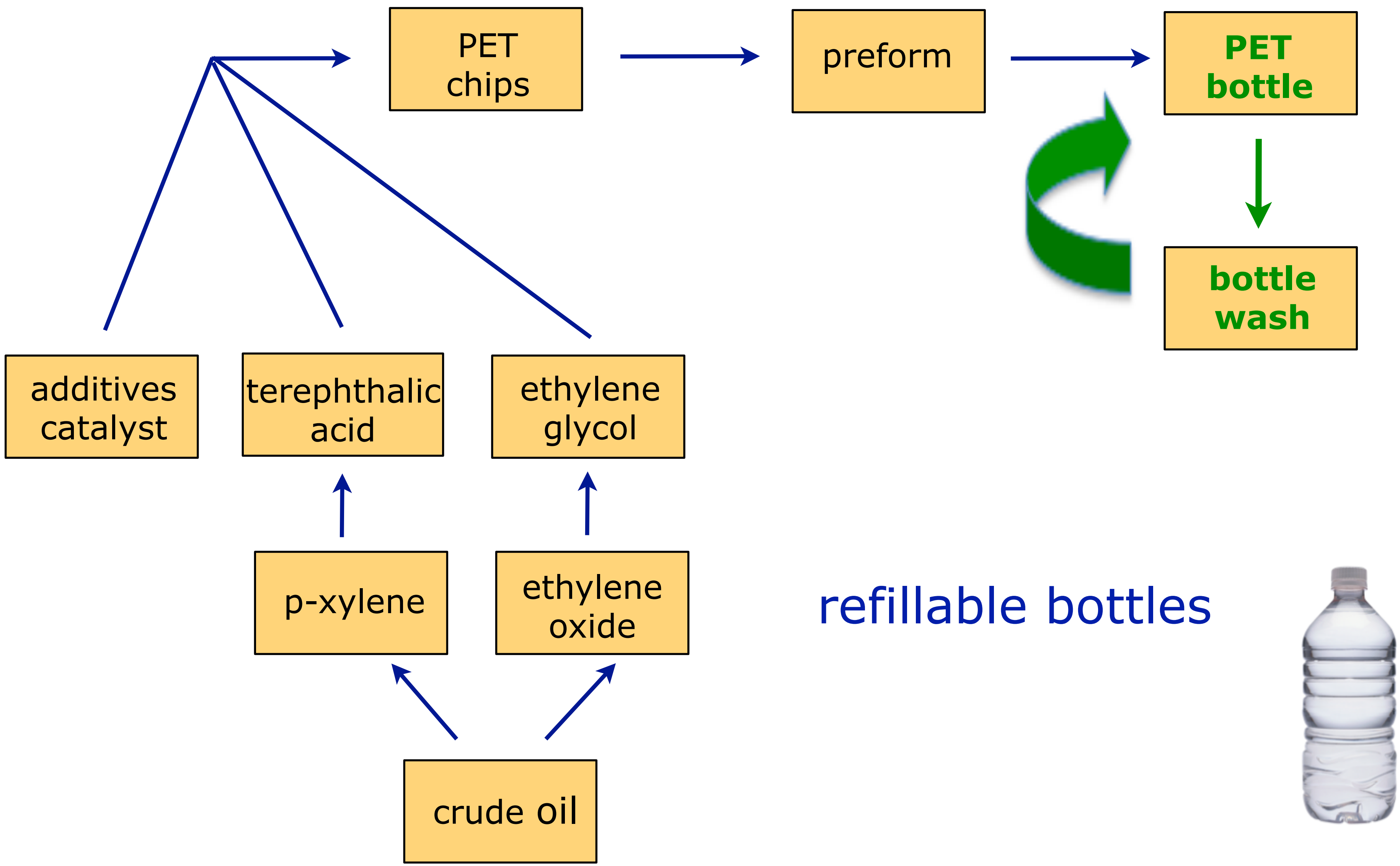

# Background - PET Pathways

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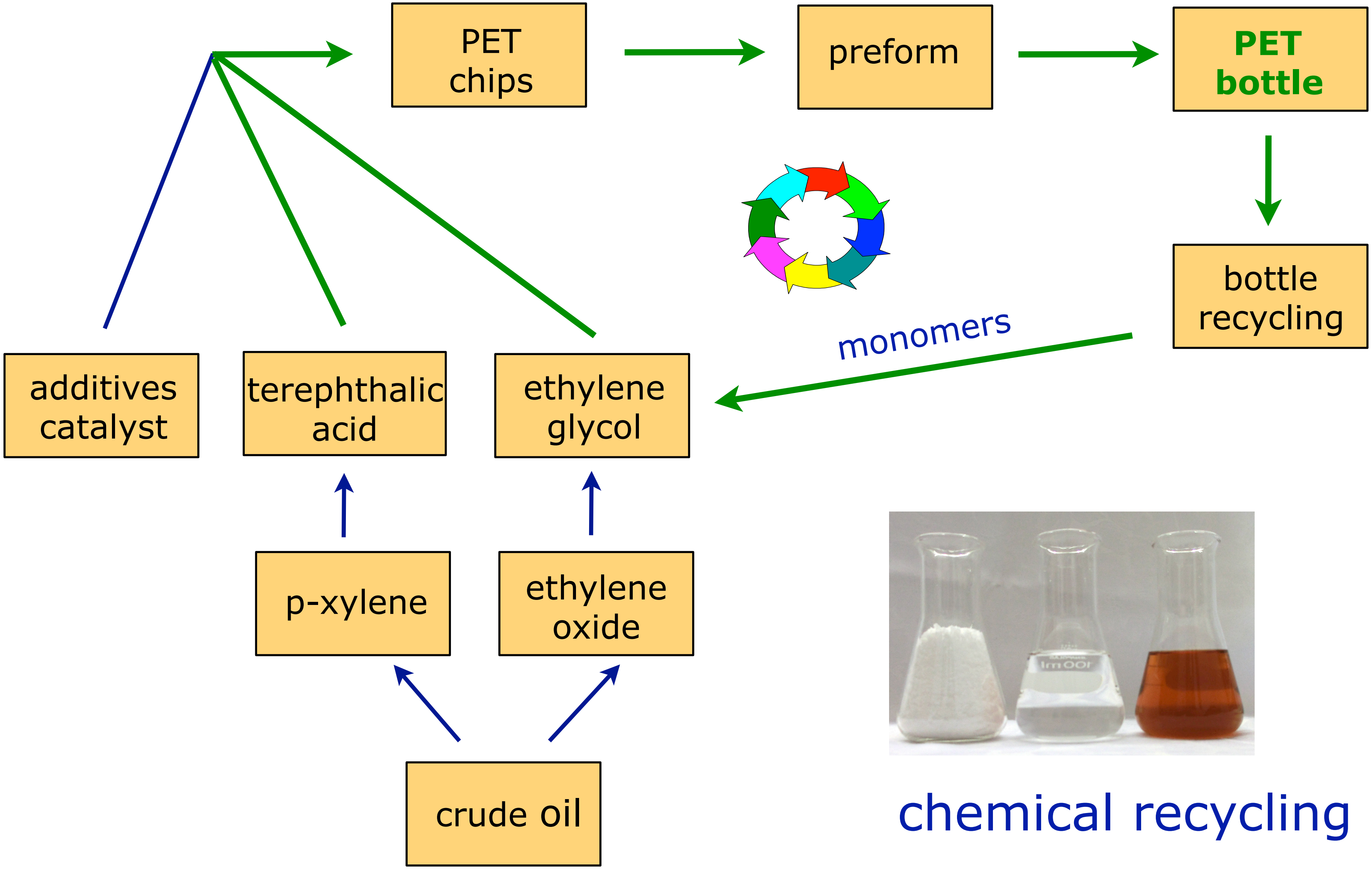

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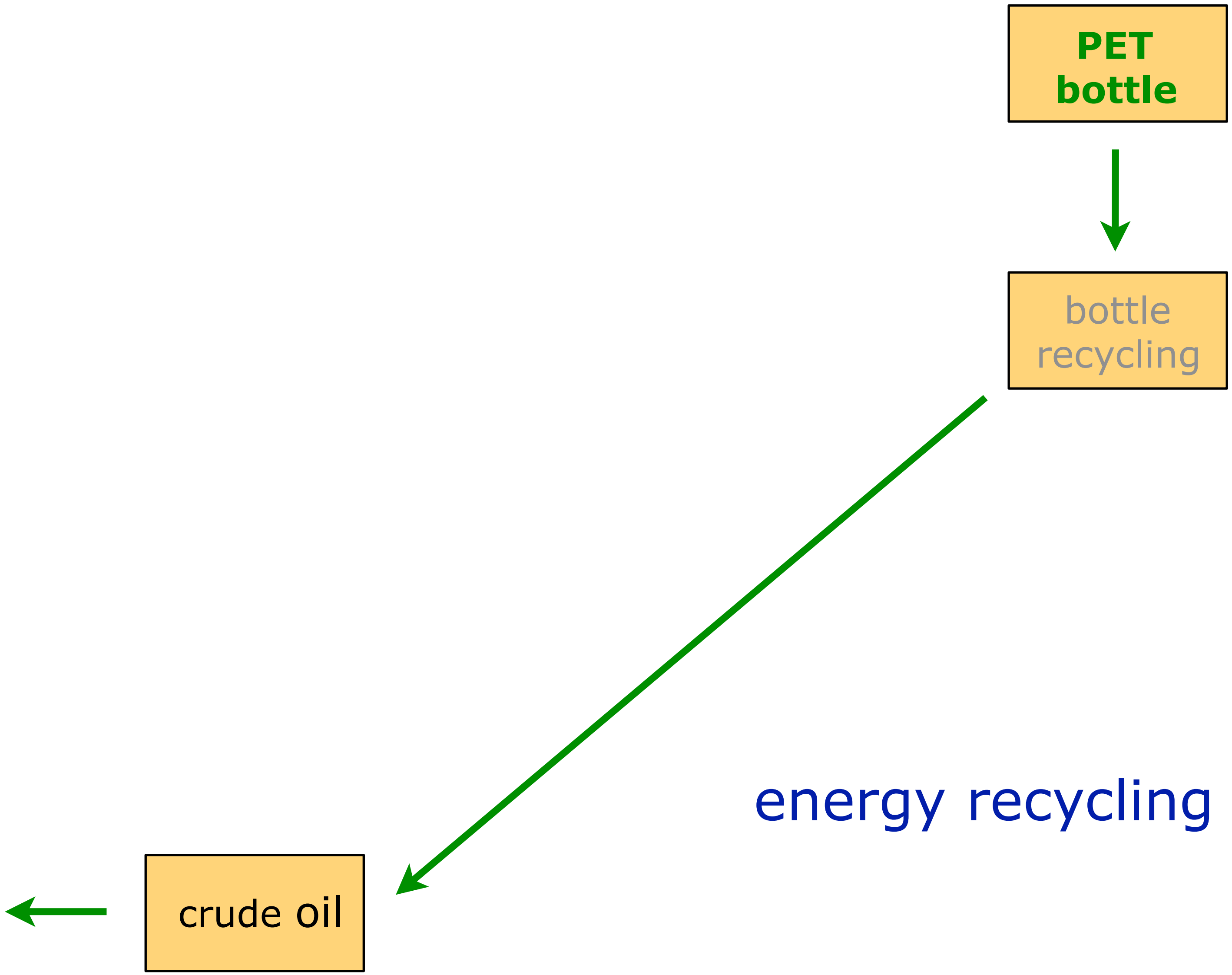

# Background - PET Pathways



**PET bottle**

bottle recycling

energy recycling

crude oil

# State-of-the-Art PET Recycling Processes

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Recycling of clear PET bottles is a well established technology.

PET bottle recycling is fulfilling our society's demand for a safe and sustainable beverage packaging material.

Mixed coloured bottles are commonly exported and processed into staple fibres.

Multi-layer bottles are often incinerated.

www.ohl-eng.com

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# State-of-the-Art PET Recycling Processes

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Bottle-to-bottle state-of-the-art recycling processes comprise the following main process steps:

- pre-sorting
- caustic wash
- size reduction
- thermal treatment for decontamination
- thermal treatment for IV adjustment
- melt filtration and granulation

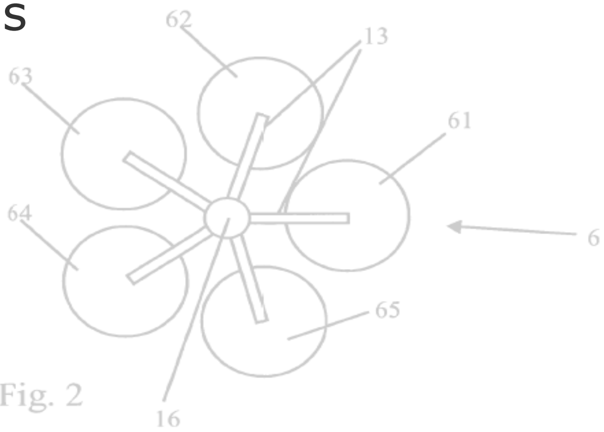


Fig. 2

These mainly mechanical and thermal recycling processes differ in design philosophy, apparatus design as well as process conditions.

… but they are not capable to handle mixed coloured feed stock and multi-layer bottles.

DE 10 2005 013 701 A1 2006.09.28

# The Challenge - Mixed Coloured Flake

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PET
PETnology

# Colorants and Vapour Pressure

PET colorants are specifically designed to match the polymer’s chemistry.

They have to be as non-volatile as possible because the migration of colorants into the beverage has to be strictly avoided.

If bottles or flake of any colour like blue, green, red, or black are heated up to a temperature of approx. 210 °C, some of the colorants can be found on the surface areas of equipment and pipes.

Nevertheless, after process times of approx. 2-3 h still only very small colour changes of the flake are detected.

From these observations it can be concluded that the colorants can be evaporated but the rate is much too small for technical applications.

# Colorants and Vapour Pressure

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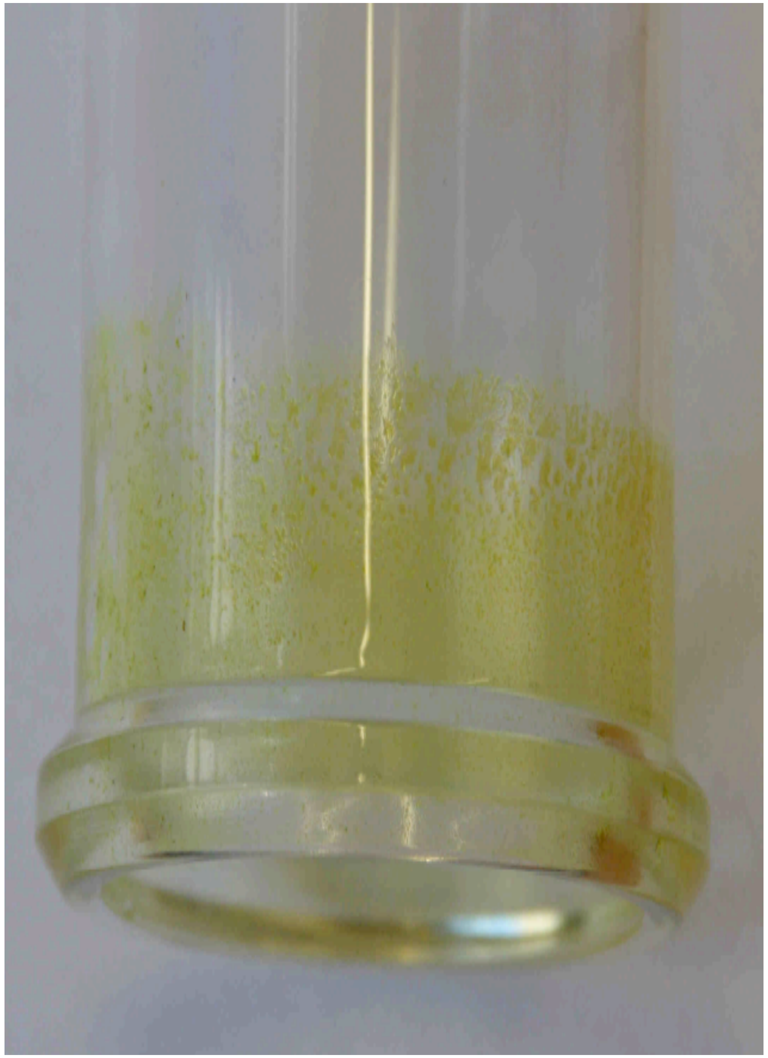
„Saskia blue"



„Saskia green"

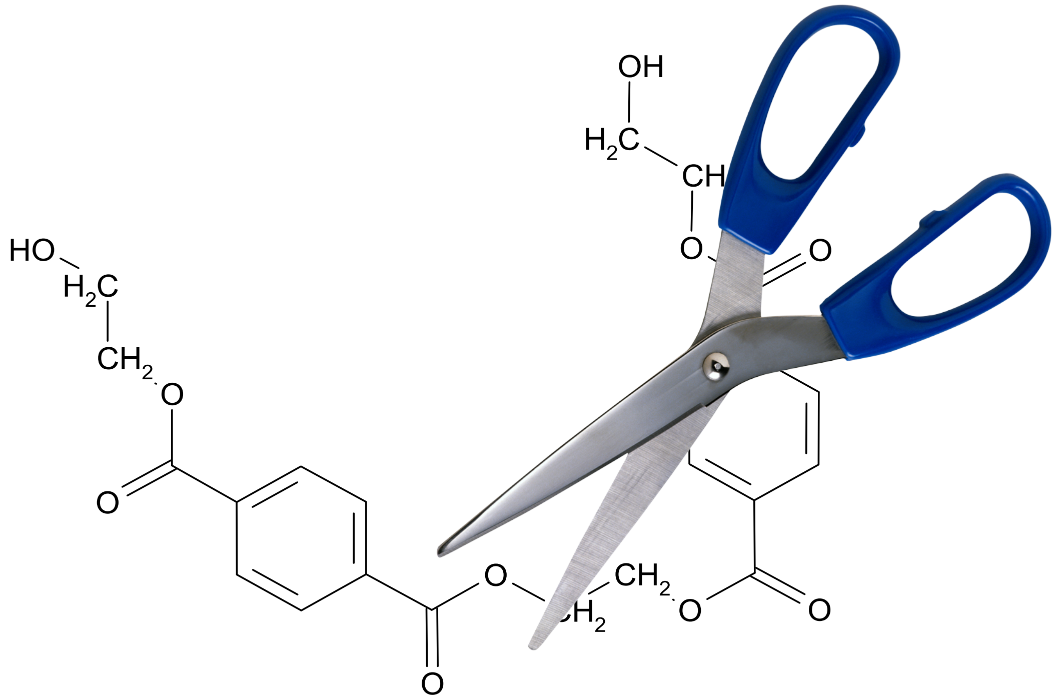
# Shifting Back the Equilibrium to the Monomers



As a step-growth polymer, PET can easily be converted into the monomers from which the polymer was formed.

Alcohols like methanol and ethylene glycol or water can be added in excess to solid or molten PET.

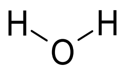
At elevated temperatures, alcohols or water, act as "chemical scissors" cutting the PET polymer chain down to fragments such as low molecular weight PET or the respective monomers.

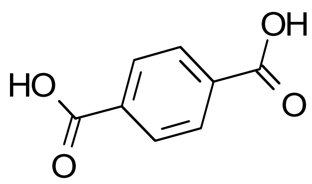


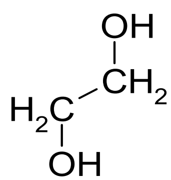
# Shifting Back the Equilibrium to the Monomers

$H_2O \longleftrightarrow$ TPA + EG **Hydrolysis**

PET +



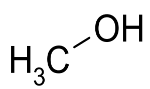


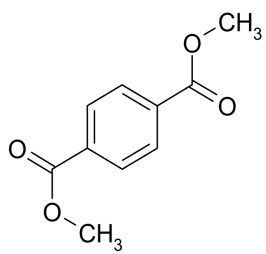


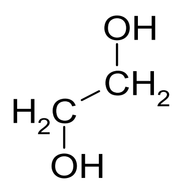
# Shifting Back the Equilibrium to the Monomers

PET +

| | | | |
|---|---|---|---|
| $H_2O$ | $\longleftrightarrow$ | TPA + EG | **Hydrolysis** |
| $CH_3OH$ | $\longleftrightarrow$ | DMT + EG | **Methanolysis** |



# Shifting Back the Equilibrium to the Monomers

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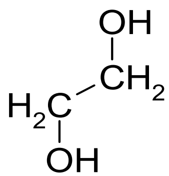
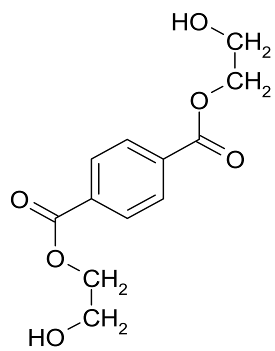
| | | | | |
|---|---|---|---|---|
| PET + | $H_2O$ | $\longleftrightarrow$ | TPA + EG | **Hydrolysis** |
| | $CH_3OH$ | $\longleftrightarrow$ | DMT + EG | **Methanolysis** |
| | $HOC_2H_4OH$ | $\longleftrightarrow$ | BHET | **Glycolysis** |



# Shifting Back the Equilibrium to the Monomers

PET +

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| $HOC_2H_4OH$ | $\longleftrightarrow$ | BHET | **Glycolysis** |
| NaOH | $\longrightarrow$ | NaOOC  COONa + EG | **Saponification** |

# Purification by Standard Unit-Operations



The objective of chemical recycling is to change the properties such, that the recycling product is suitable for purification by standard unit operations of the process industry.

Filtration and adsorption

- low viscosity and tailor made adsorbents

Distillation

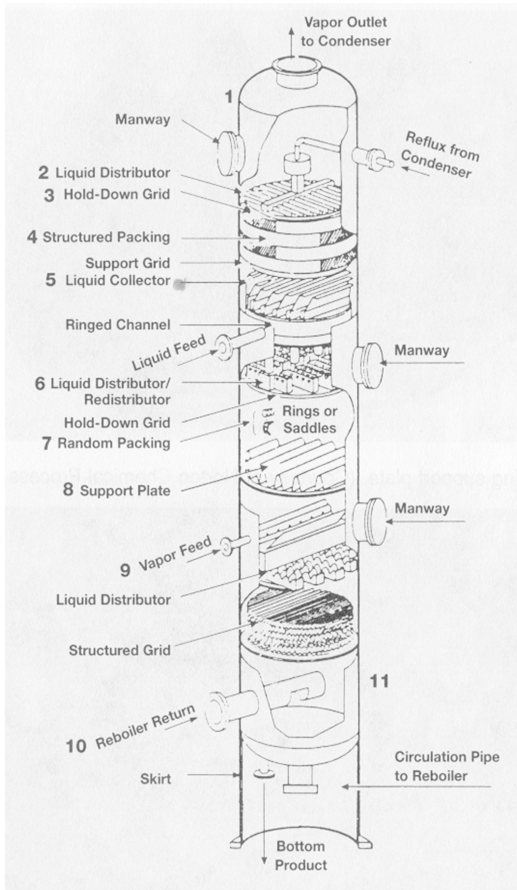
- differences in vapour pressure and boiling temperature, respectively

Extraction

- low viscosity, different solubilities

Melt crystallisation

- differences in melting temperature
- suitable crystal formation




*Chemical Engineering*, 5 (1984)

# Mixed Coloured Flake Recycling



Two technologies are developed to cope with the recycling of mixed coloured and multi-layer PET bottles.

One pathway is glycolysis, followed by adsorption, filtration, melt phase polycondensation and direct filament spinning.

The other pathway comprises glycolysis, followed by methanolysis and monomer purification by distillation, and melt crystallisation.

The products of the latter process are the PET monomers dimethylterephthalate (DMT) and ethylene glycol (EG).

# From Coloured Flake to Filament Yarn by Direct Spinning

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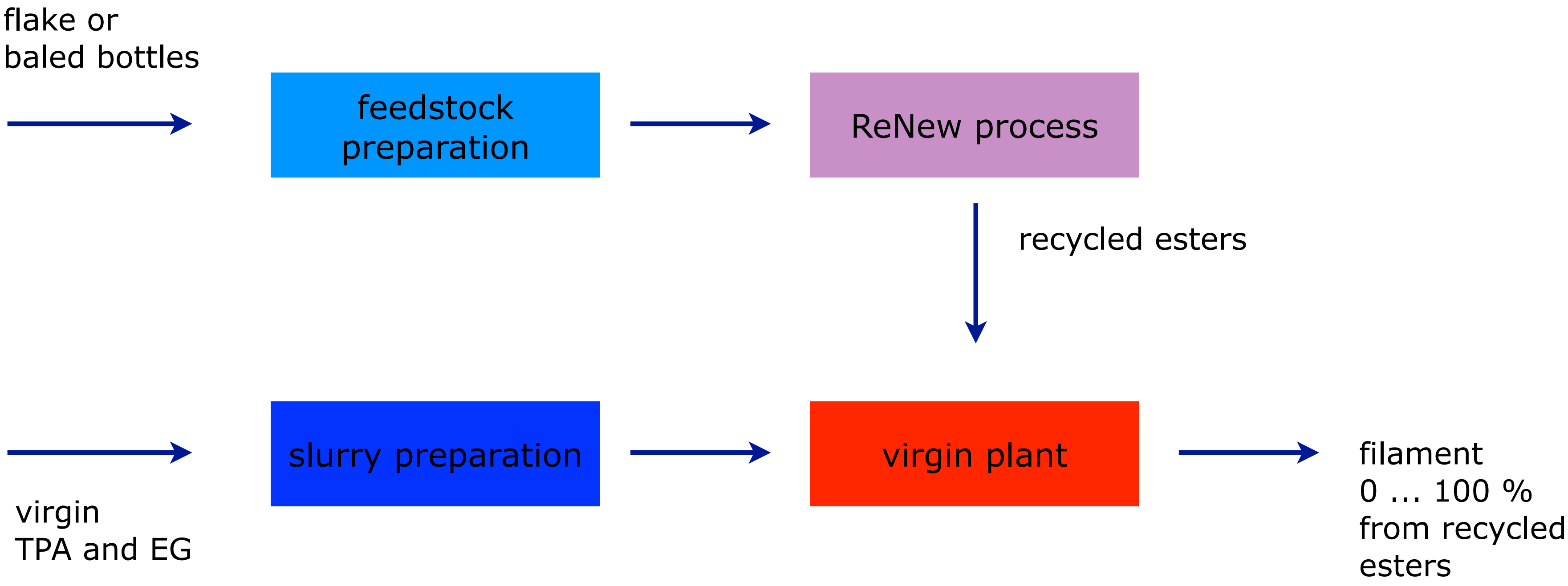


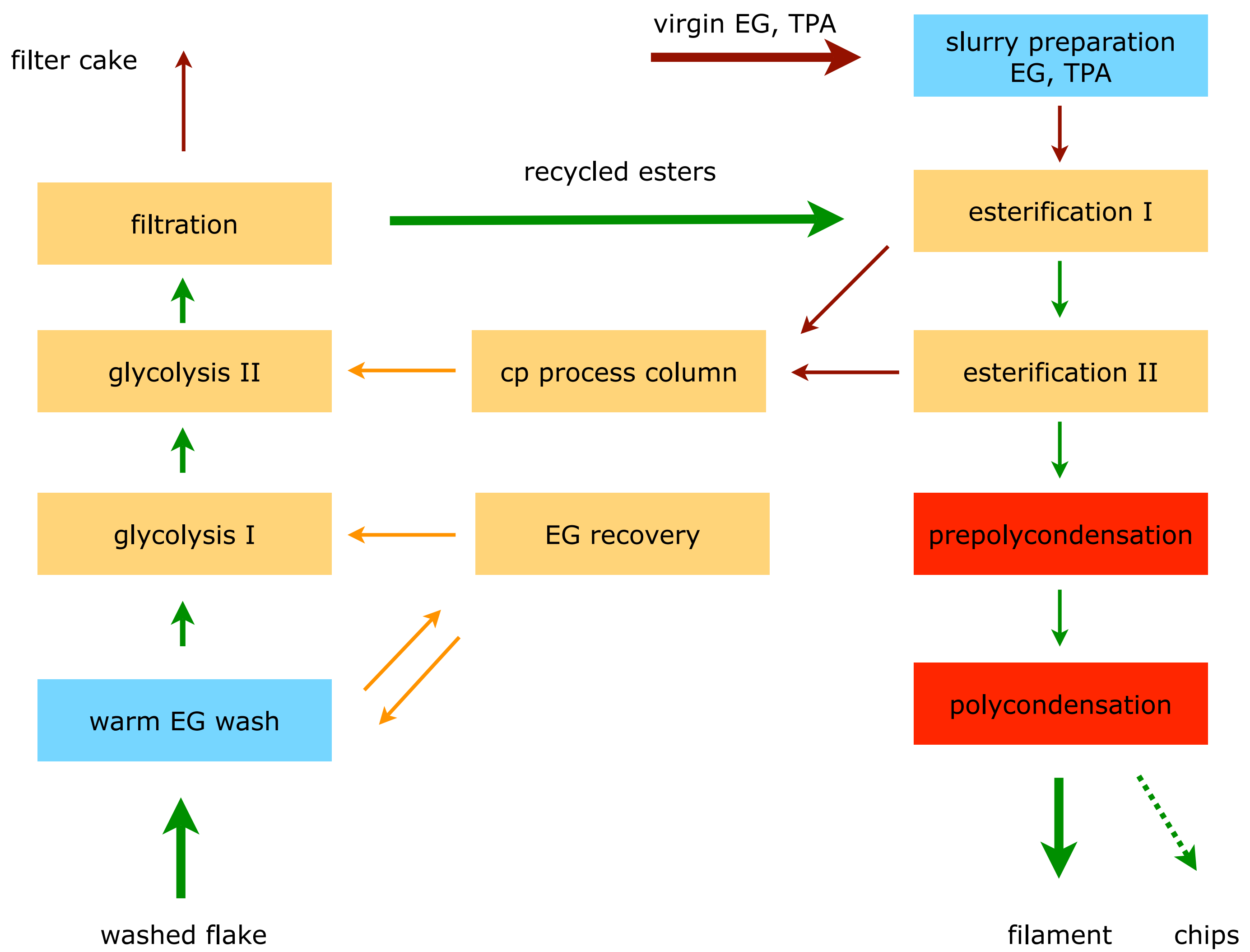

## Technology:

Base patents by Simon West (Melbourne, Australia)

Engineering by AQUAFIL Engineering GmbH (Berlin, Germany)

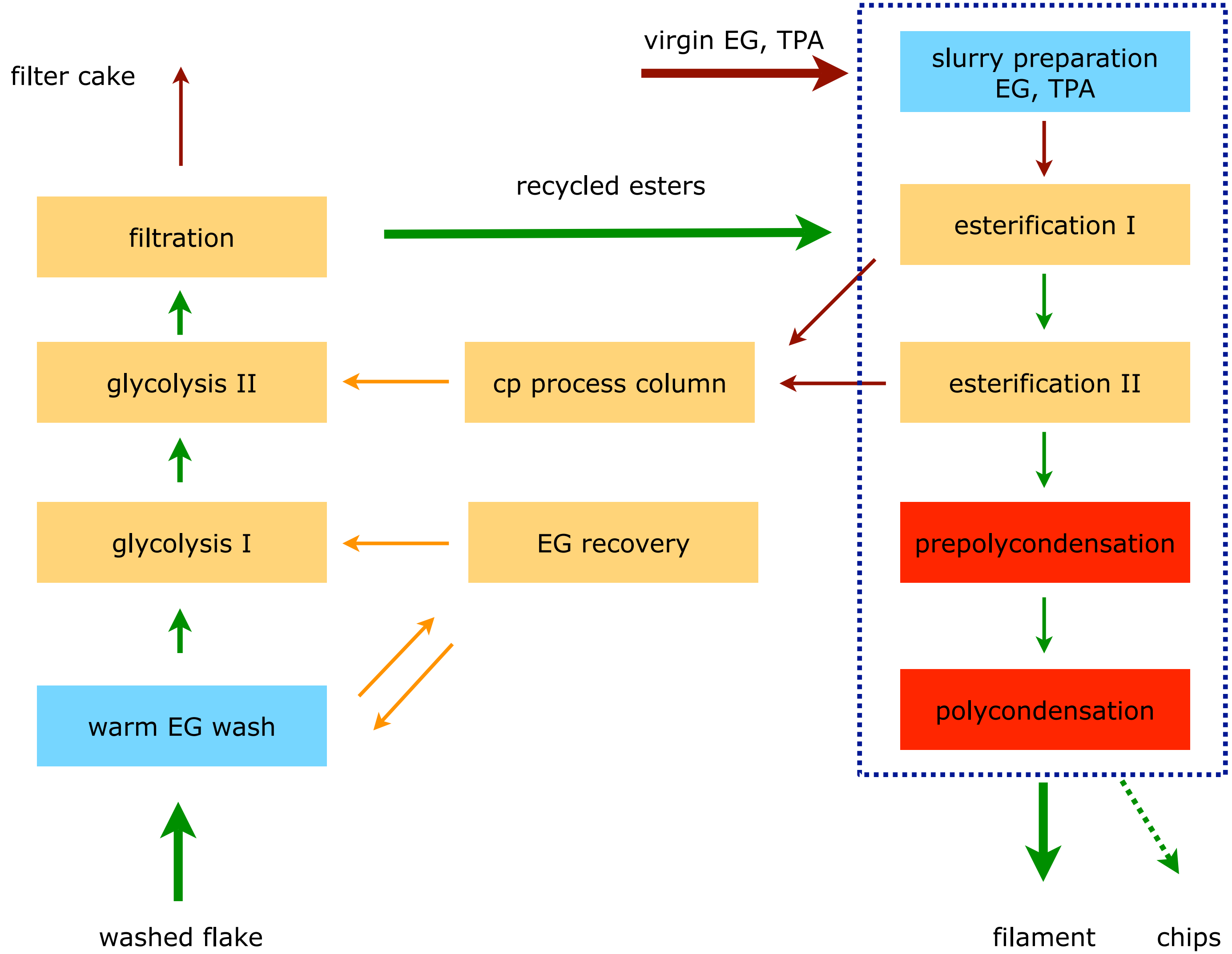
Production plant and technology licensing by PerPETual Global (Nashik, India)

# Glycolysis, Polycondensation and Direct Spinning




The Nashik polycondensation plant is a continuous direct spinning polycondensation plant (operating 24/7) with a capacity of 30,000 tpy filament yarn.

# Glycolysis, Polycondensation and Direct Spinning

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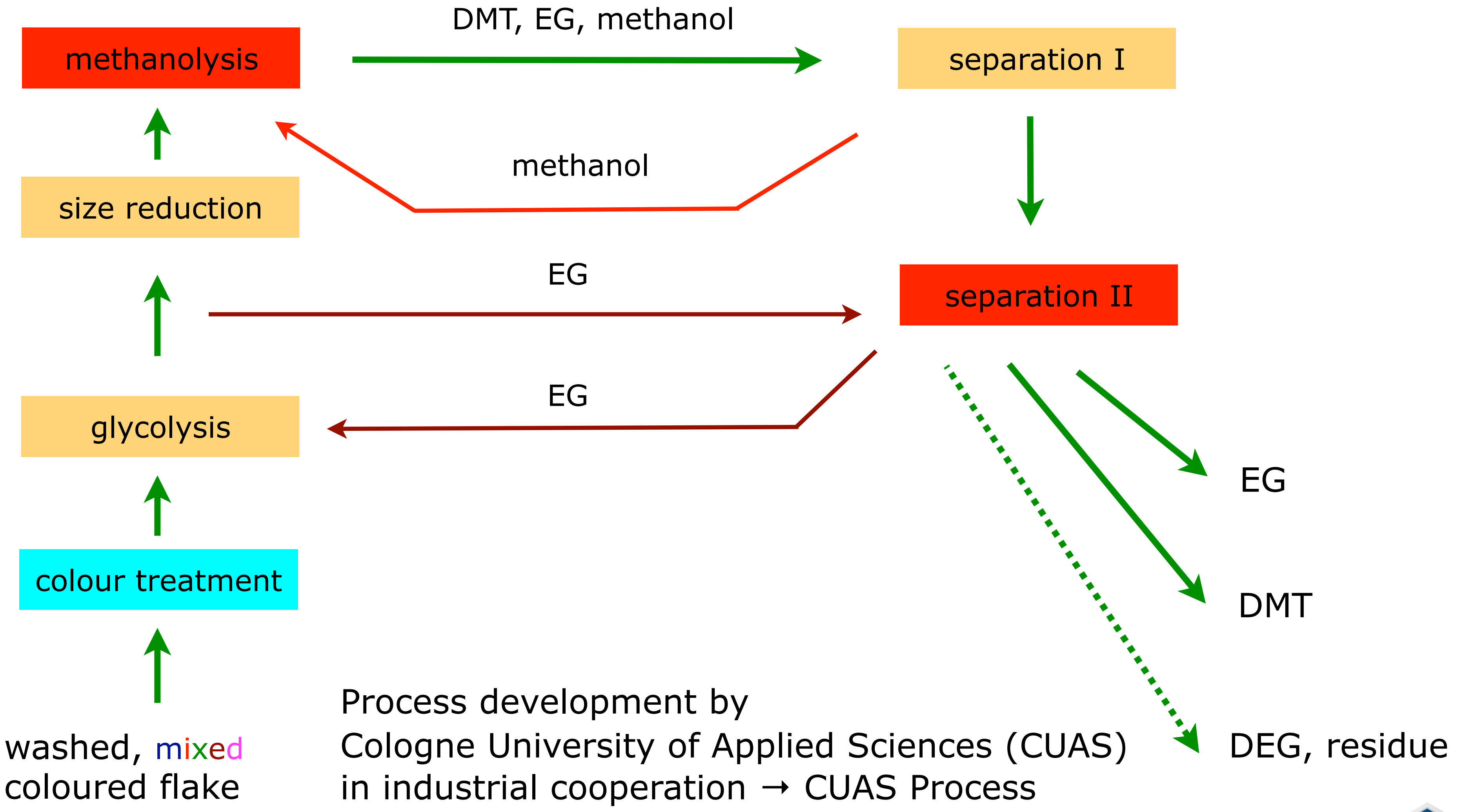
# DMT and EG from Mixed Coloured Flake



A chemical recycling process for mixed coloured flake was developed by CUAS.




Process development by
Cologne University of Applied Sciences (CUAS)
in industrial cooperation → CUAS Process

# Cost Estimation for the CUAS Process

Process economics was calculated for a 20,000 tpy capacity, using the equipment factored method - class 4 estimate:

| | Primary Characteristic | Secondary Characteristic | | | |
|---|---|---|---|---|---|
| **ESTIMATE CLASS** | **LEVEL OF PROJECT DEFINITION** Expressed as % of complete definition | **END USAGE** Typical purpose of estimate | **METHODOLOGY** Typical estimating method | **EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a] | **PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b] |
| **Class 5** | 0% to 2% | Concept Screening | Capacity Factored, Parametric Models, Judgment, or Analogy | L: -20% to -50%<br>H: +30% to +100% | 1 |
| **Class 4** | 1% to 15% | Study or Feasibility | Equipment Factored or Parametric Models | L: -15% to -30%<br>H: +20% to +50% | 2 to 4 |
| **Class 3** | 10% to 40% | Budget, Authorization, or Control | Semi-Detailed Unit Costs with Assembly Level Line Items | L: -10% to -20%<br>H: +10% to +30% | 3 to 10 |
| **Class 2** | 30% to 70% | Control or Bid/ Tender | Detailed Unit Cost with Forced Detailed Take-Off | L: -5% to -15%<br>H: +5% to +20% | 4 to 20 |
| **Class 1** | 50% to 100% | Check Estimate or Bid/Tender | Detailed Unit Cost with Detailed Take-Off | L: -3% to -10%<br>H: +3% to +15% | 5 to 100 |

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

[b] If the range index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%. Estimate preparation effort is highly dependent upon the size of the project and the quality of estimating data and tools.

AACE International Recommended Practice No. 18R-9, 2005

# Cost Estimation for the CUAS Process

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# Sensitivity Analysis by Monte Carlo Simulation

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Sensitivity analysis

- Cost estimation - a prediction into the future
- Input parameters may change and are uncertain

Monte Carlo Analysis

- All input parameters with defined distribution function, e.g.: uniform, triangle, normal ...
- Simultaneous variation of input parameters
- Repeated calculation of spread sheet (1,000 times, 10,000 times,...)
- Output of calculation results given by distribution functions, with most probable result
- 90 % probability that the result falls within a certain range
- Tornado-Analysis: Graphical representation of regression sensitivities
- Software e.g. Crystal Ball or @Risk (Excel extension)

# Sensitivity Analysis by Monte Carlo Simulation

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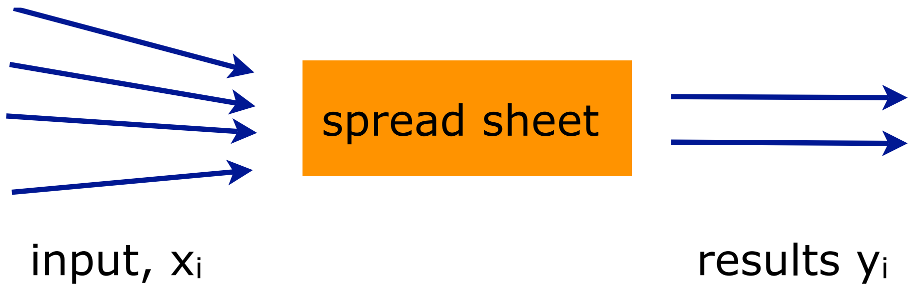


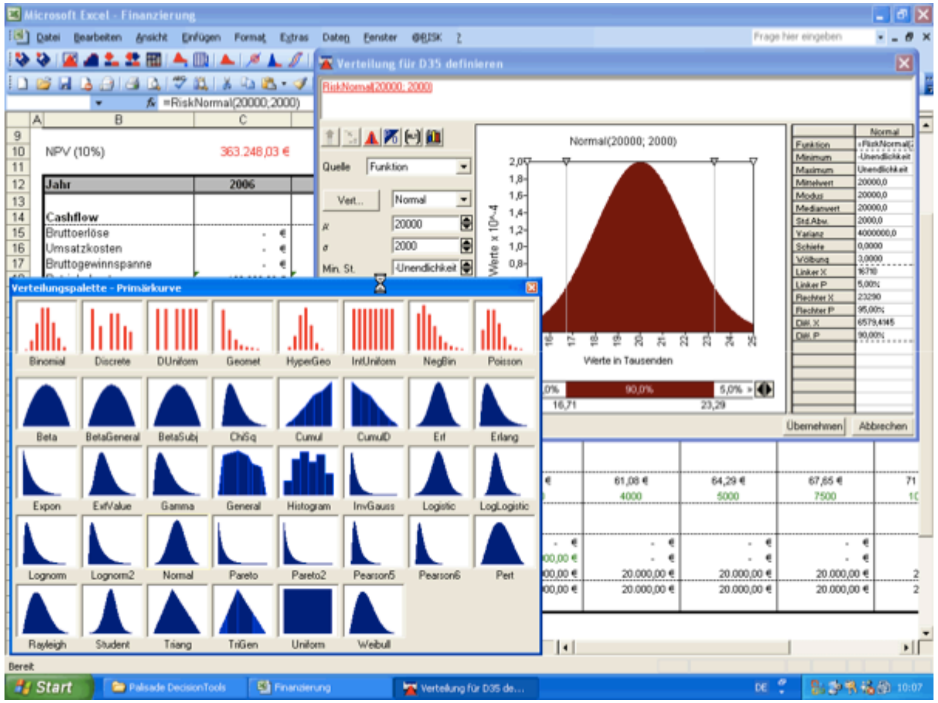


John William Waterhouse - The Crystal Ball

# Cost Estimation CUAS Process – Input Data

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## Process

- Recycling of mixed coloured PET flake
- glycolysis and methanolysis,
  colour removal, distillation, and melt crystallisation
- Capacity: 20,000 tpy

## Products

- Dimethyl terephthalate, DMT, polycondensation quality
- Ethylene glycol, EG, polycondensation quality

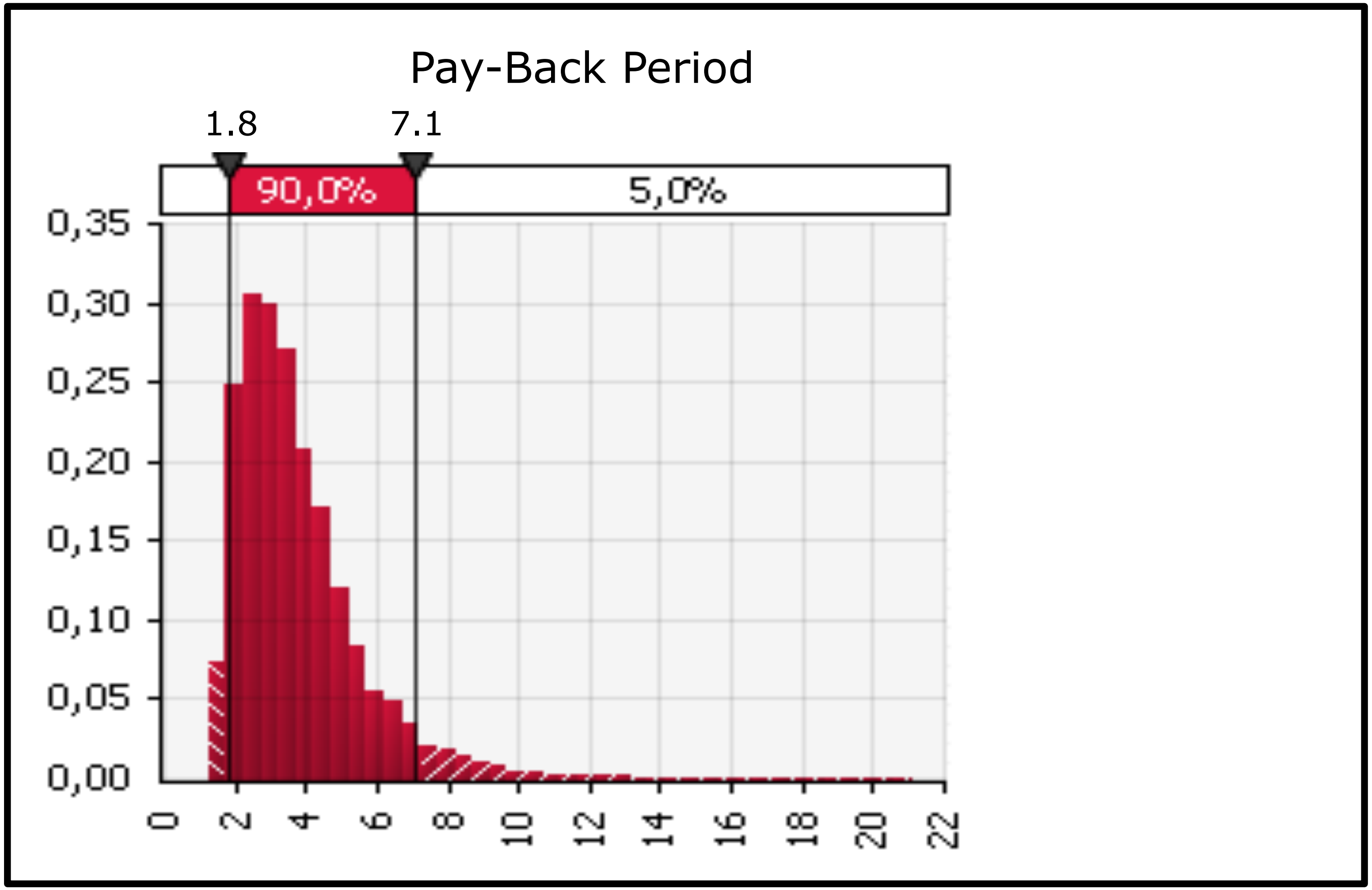
## Variation of Input Parameters

- Feed cost mixed coloured flake: ± 20%
- Feed cost methanol: ± 10%
- Fixed capital investment (class 4 estimate): -30 to + 50%
- Labour cost: ± 20 %
- Energy demand: ± 20 %
- Marked value rDMT: ± 10%
- Marked value rEG: ±10 %

# Cost Estimation – Pay-Back Period

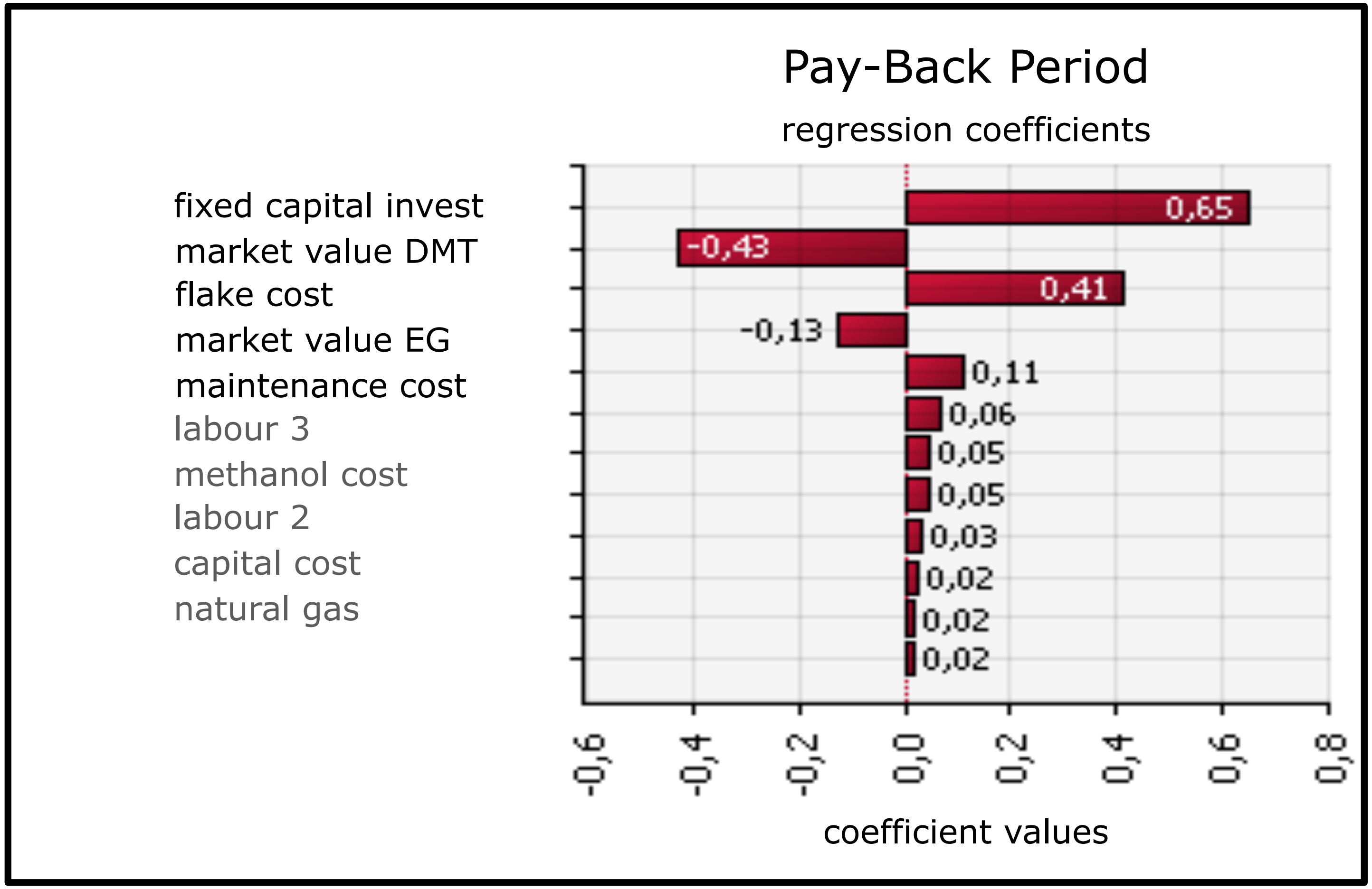
Most probable value: 3.0 years

90 % chance within the interval of 1.8 - 7.1 years



# Pay-Back Period, Regression Coefficients





# Cost Estimation – Production Cost

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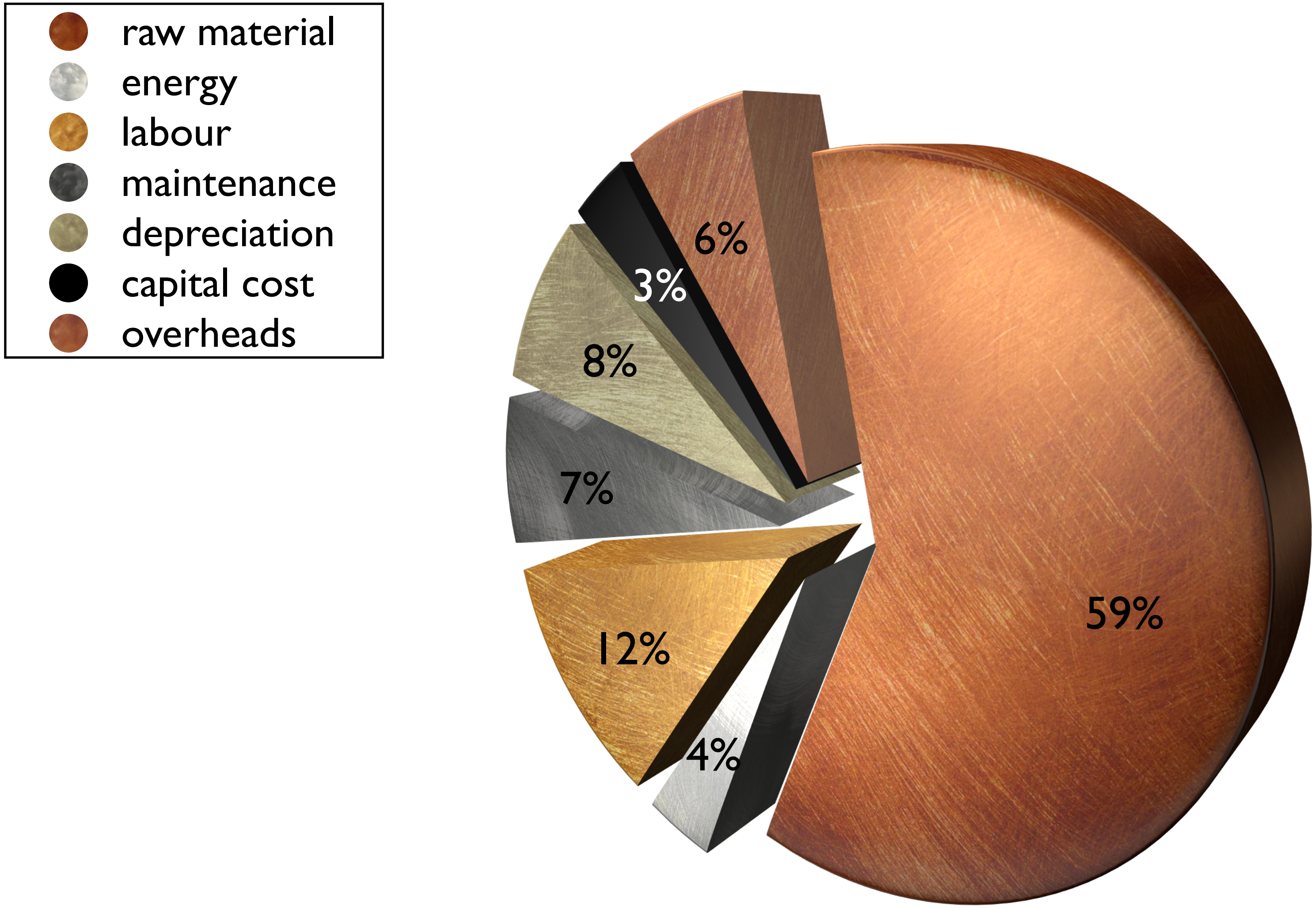

# Future Processing of Mixed Coloured PET Flake?

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## Post Consumer PET Bottles

- Presorting, removal of multi-layer and pigmented bottles
- Removal of cups and labels
- Size reduction

gold | silver | white

$TiO_2$

## Mixed Coloured Flake

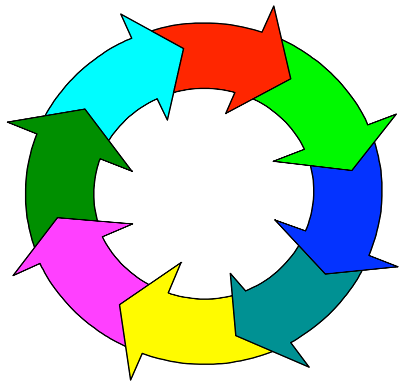
- Caustic wash
- Colorants removal

## Clear Flake

- Drying
- Crystallisation
- Decontamination
- IV adjustment

## Preform

## Recycling PET bottle



# Conclusions

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## Recycling of Mixed Coloured PET Bottles

- Chemical recycling
- Back to the monomers
  - ethylene glycol, EG
  - dimethyl terephthalate, DMT
- Colour removal in two steps
  - any known colorants
  - any known pigments
- Can handle multi-layer bottles
- Monomer purification by standard unit-operations
  - distillation
  - melt crystallization
- Competitive cost

# Conclusions



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## Thank you for your attention!