Covestro

We will be fully circular

Chemical recycling technologies for PC

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Forward-looking statements

This presentation may contain forward-looking statements based on current assumptions and forecasts made by Covestro AG.

Various known and unknown risks, uncertainties and other factors could lead to material differences between the actual future results, financial situation, development or performance of the company and the estimates given here. These factors include those discussed in Covestro's public reports, which are available on the Covestro website at www.covestro.com.

The company assumes no liability whatsoever to update these forward-looking statements or to adjust them to future events or developments.

Covestro – leading in the world of plastics

Strong

- €10.7 bn in sales
- 16,500 employees[1]

Useful

- Plastics, pre-products and solutions
- For many industries

Global

- 33 production sites globally
- Close to customers and partners

Innovative

- 1,200+ employees in research and development
- 80 years of ideas and inventions

Financial year 2020
[1]calculated as full-time equivalent (FTE)

Our purpose – for a brighter world

“We want to make the world a brighter place”

Preserving the environment

Advancing society

Creating value

Our vision – promote circular economy

Circular economy enables a climate neutral future

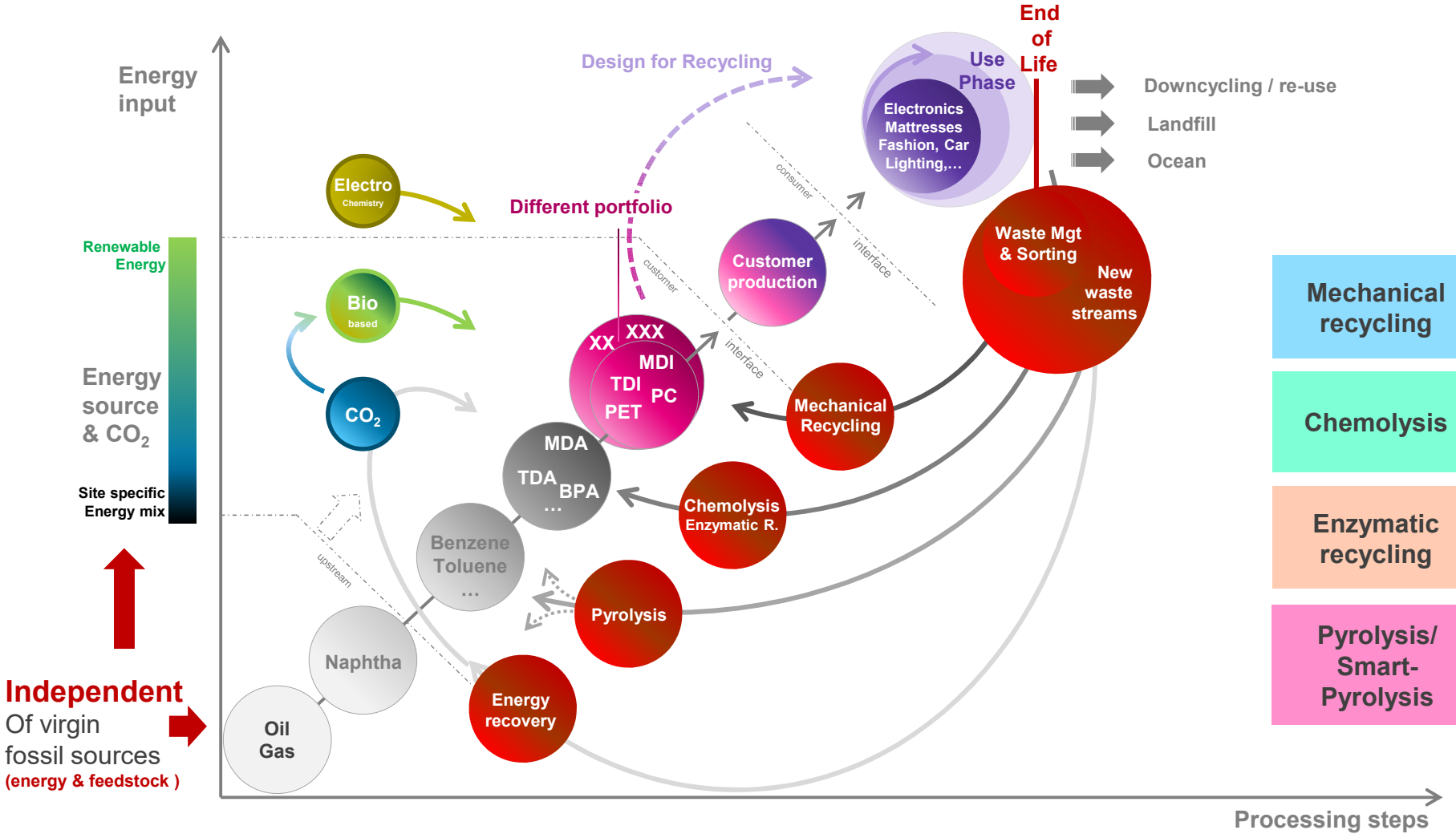
- Circular economy is the key to resource conservation, climate and environmental protection
- Plastics are a driving force for implementing circular economy

We want to become fully circular

- We want to contribute to make circular economy the global guiding principle …
- … and anchor it across the whole company

How can we move from a linear to a circular economy?

Using recycling technologies, bio-based materials and C1-chemistry



Mechanical recycling	A process in which materials are recycled into “new” raw materials without changing the basic structure of the material itself: suitable for thermoplasts like PCS
Chemolysis	A process in which organic substances are broken down into smaller molecules through chemical processes and prepared for further use.
Enzymatic recycling	A process in which waste is broken down into its components with the help of enzymes and prepared for further use.
Pyrolysis/ Smart-Pyrolysis	A process in which waste is broken down without oxidizing agents such as oxygen, at temperatures between 600 and 800ºC (pyrolysis) and 300- 500 °C (smart pyrolysis).

How can we move from a linear to a circular economy?

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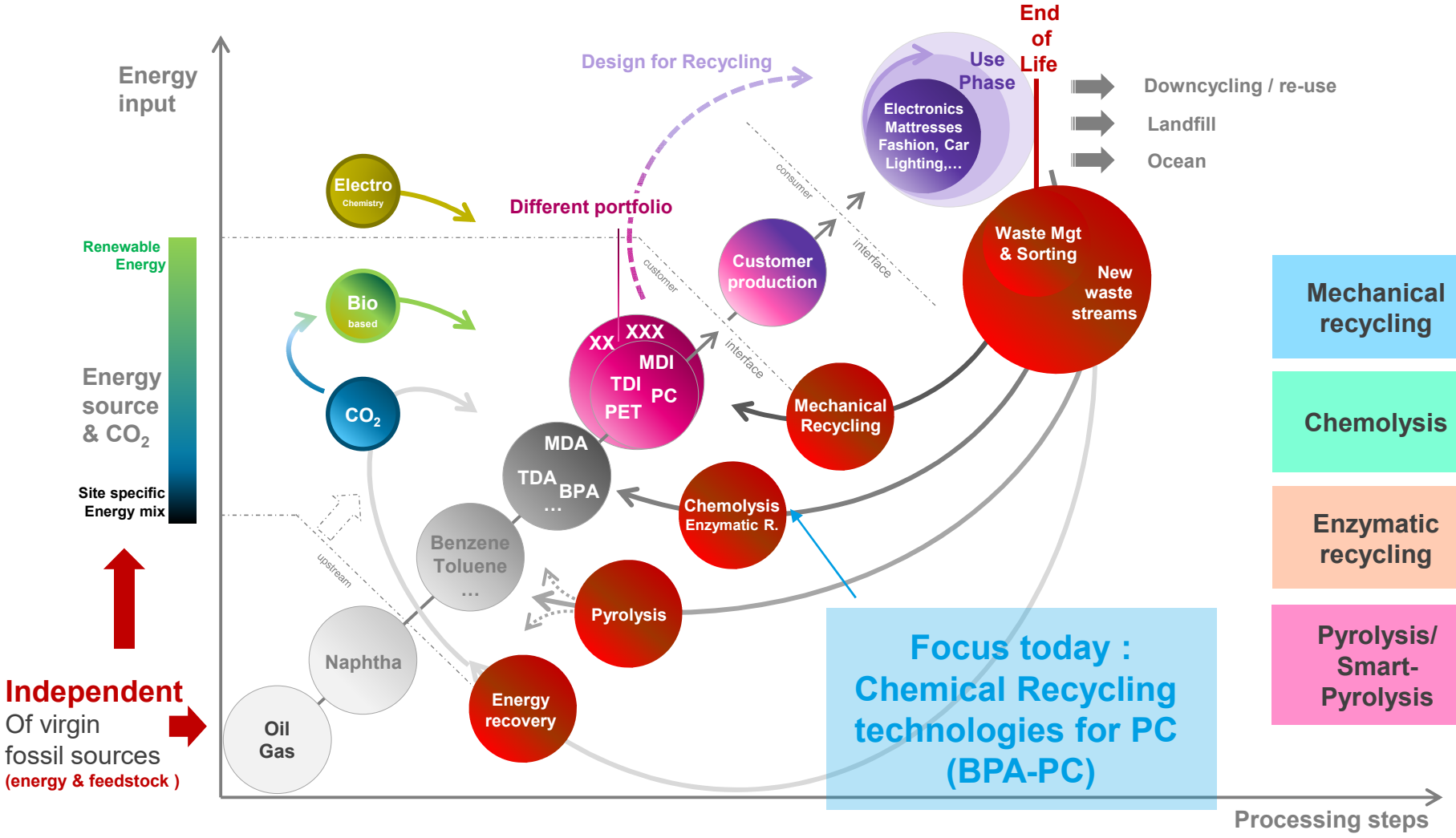

Focus today : Chemical Recycling technologies for PC (BPA-PC)

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Segment Polycarbonates

Product

Polycarbonate is a high-tech material – very robust, break-proof and light-weight. It can be flexibly shaped and is available in all colors.

It is an excellent substitute for traditional material such as glass or metal.

This allows for a wide variety of application possibilities ranging from vehicles to electronic devices as well as lenses or large roofs.

Covestro develops and produces the granules for polycarbonate parts.

Facts and figures

€3.0	28%
sales in bn (rounded)	share of group sales

Polycarbonates were first developed by the predecessor company of Covestro in 1953.

The global demand is likely to grow by around 4% annually.[1]

Key customer industries:

Sample applications

For trendy smartphones

For bright buildings

For light-weight cars

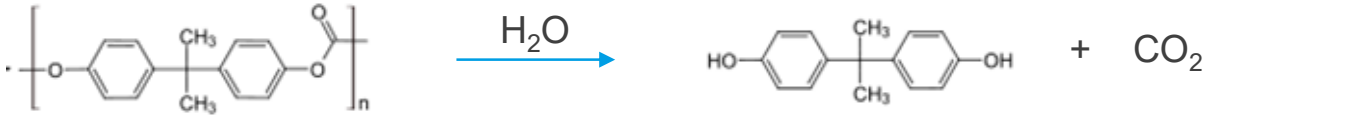
For safe medical products

Financial year 2020
[1]Compound Annual Growth Rate (CAGR) 2020-2025e according to Covestro estimates

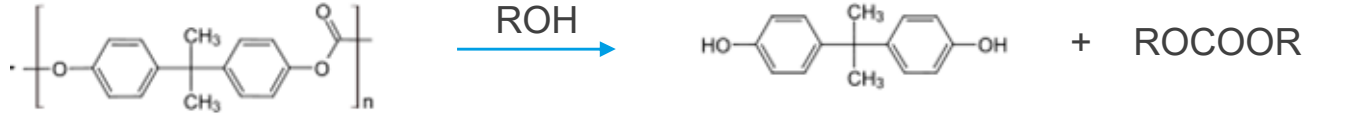
Chemical Recycling technologies for PC

General overview of different technologies described in literature / patents

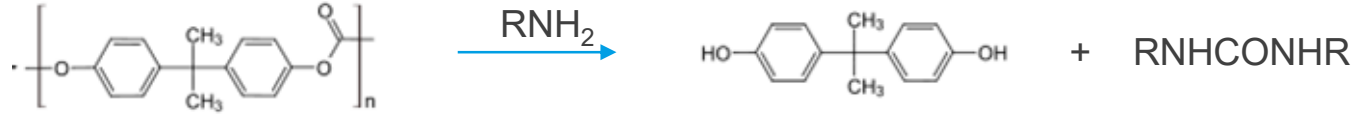
1. Hydrolysis:



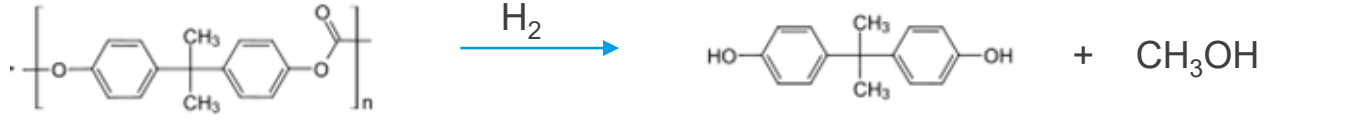
2. Alcoholysis:



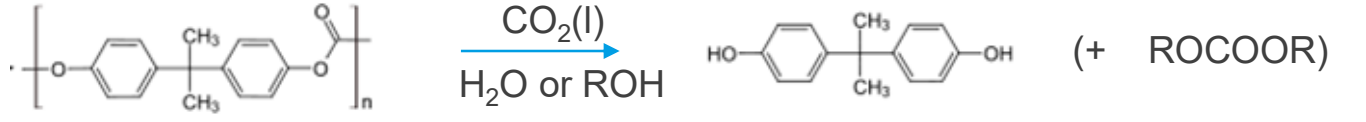
3. Aminolysis:



4. Hydrogenolysis:



5. Supercritical CO_2:



Chemical Recycling technologies for PC

Hydrolysis technology in literature / patents

1. Hydrolysis:

PC hydrolysis reaction conditions :

- High temperatures: (> 200 deg C) *[ref: S.E. Hunter, P.E. Savage J. Org. Chem. 2004, 69, 14, 4724–4731]*
- Use of catalyst: such as (earth)alkali oxides or hydroxides

  [ref: G. Grause, K. Sugawara, T. Mizoguchi and T. Yoshioka, Polym. Degrad. Stab., 2009, 94,1119-1124]

  [ref: F.-S. Liu, Z. Li, S.-T. Yu, X. Cui, C.X. Xie and X.P. Ge, J. Polym. Environ., 2009,17, 208-211]
- Use of ionic liquids *[ref: X. Song, F Liu, L. Li, X. Yang, S. Yu, X. Ge, J. Hazard. Mater., 2013, 244-245, 204-208]*

Remarks:

- Often solvent needed to dissolve PC
- CO_2 is not chemically captured
- Side reactions of BPA possible under the above conditions

Chemical Recycling technologies for PC

Alcoholysis technology in literature / patents

2. Alcoholysis:

PC alcoholysis reaction conditions:

- Low(er) temperatures [< 200 deg C] *[ref: patents DE4220412A1, DE4312037A1]*
- Use of catalyst such as NaOH, KOH *[ref: patents DE4220412A1, DE4312037A1]*
  or KF, NaF, LiCl, NaCl, LiBr ,NaBr, KBr, NaI, KI *[ref: C. Alberti and S. Enthaler, Asian J. Org. Chem. 2020, 9, 359 –363]*
- Use of ionic liquids *[ref: F.-S. Liu, L. Li, S. Yu and X.P. Ge, J. Hazard. Mater., 2011 ,189, 249-255]*

Remarks:

- Often solvent needed to dissolve PC
- CO_2 can be captured as carbonate
- Different mono-alcohols can be used: CH_3OH, C_6H_6OH *[ref: patents DE4220412A1, DE4312037A1]*
- Di-alcohols, such as $C_2H_6O_2$ could lead to the formation of cyclic carbonates *[ref: A.Oku, S. Tanaka, S. Hata., Polymer, 2000, 41, 6749-6753]*

Chemical Recycling technologies for PC

Aminolysis technology in literature / patents

3. Aminolysis:

PC aminolysis reaction conditions:

- Low(er) temperatures [< 200 deg C] *[ref: USpatent 4885407]*
- H_2O-NH_3 is a good depolymerization agent for PC *[ref: USpatent 4885407]*
- An extra catalyst can be added to improve reaction with some amines

  [ref: S. Hata, H. Goto, E. Yamato and A. Oku, Polymer, 2002, 43, 2109-2116]
- Use of ionic liquids *[ref: F. Iannone et al., J Mol. Catal. A: Chem, 2017, 426,107-116]*

Remarks:

- Solvent needed to dissolve PC
- CO_2 can be captured chemically (such as urea when using NH_3) *[ref: USpatent 4885407]*

Chemical Recycling technologies for PC

Hydrogenolysis technology in literature / patents

4. Hydrogenolysis:

PC hydrogenolysis reaction conditions:

- Low(er) temperatures [< 200 deg C], higher pressure 45 bar *[Ref: C. Alberti et al., Chemistryselect, 2019,4, 12268-12271]*
- Metal catalyst needed such as a Ruthenium complex *[Ref: C. Alberti et al., Chemistryselect, 2019,4, 12268-12271]*

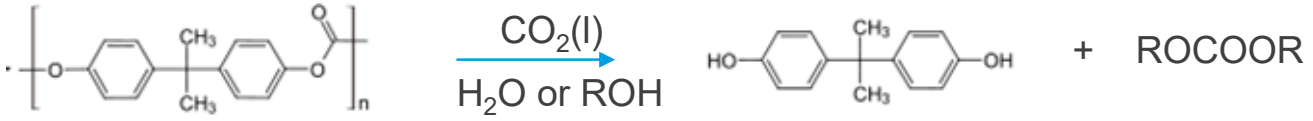
Remarks:

- Solvent needed
- Expensive catalyst
- Reduction reaction of PC by H_2 into BPA and methanol

Chemical Recycling technologies for PC

Supercritical CO_2 technology in literature / patents

5. Supercritical CO_2:



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PC supercritical reactions:

- High temperatures (> 200 degC) and pressures needed *[ref: patent EP 1 439 158 A1]*
- No extra catalyst needed *[ref: patent EP 1 439 158 A1]*

Remarks:

- Solvent needed when using water
- Alcohols used: CH_3OH and C_6H_6OH forming dimethylcarbonate and diphenylcarbonate respectively
- Excess CO_2 needs to be compressed for re-usage

Chemical Recycling technologies

Challenges in chemical recycling of polycarbonates

1. A clean PC waste source is needed – impurities could influence the chemical recycling process
2. Non-pure PC types containing additives, fillers need extra process steps
3. Suitable work-up of depolymerized PC needed to retrieve BPA and other chemicals with acceptable quality
4. Extra process steps will increase investment and operational costs
5. The global warming potential of the PC recycling process should be evaluated

THANK YOU FOR YOUR ATTENTION!

QUESTIONS ?