If you want to go fast, go alone. If you want to go far, go together.

Contributions of European Chemistry for the Transition to a Sustainable Future

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Institut für Technische und Makromolekulare Chemie

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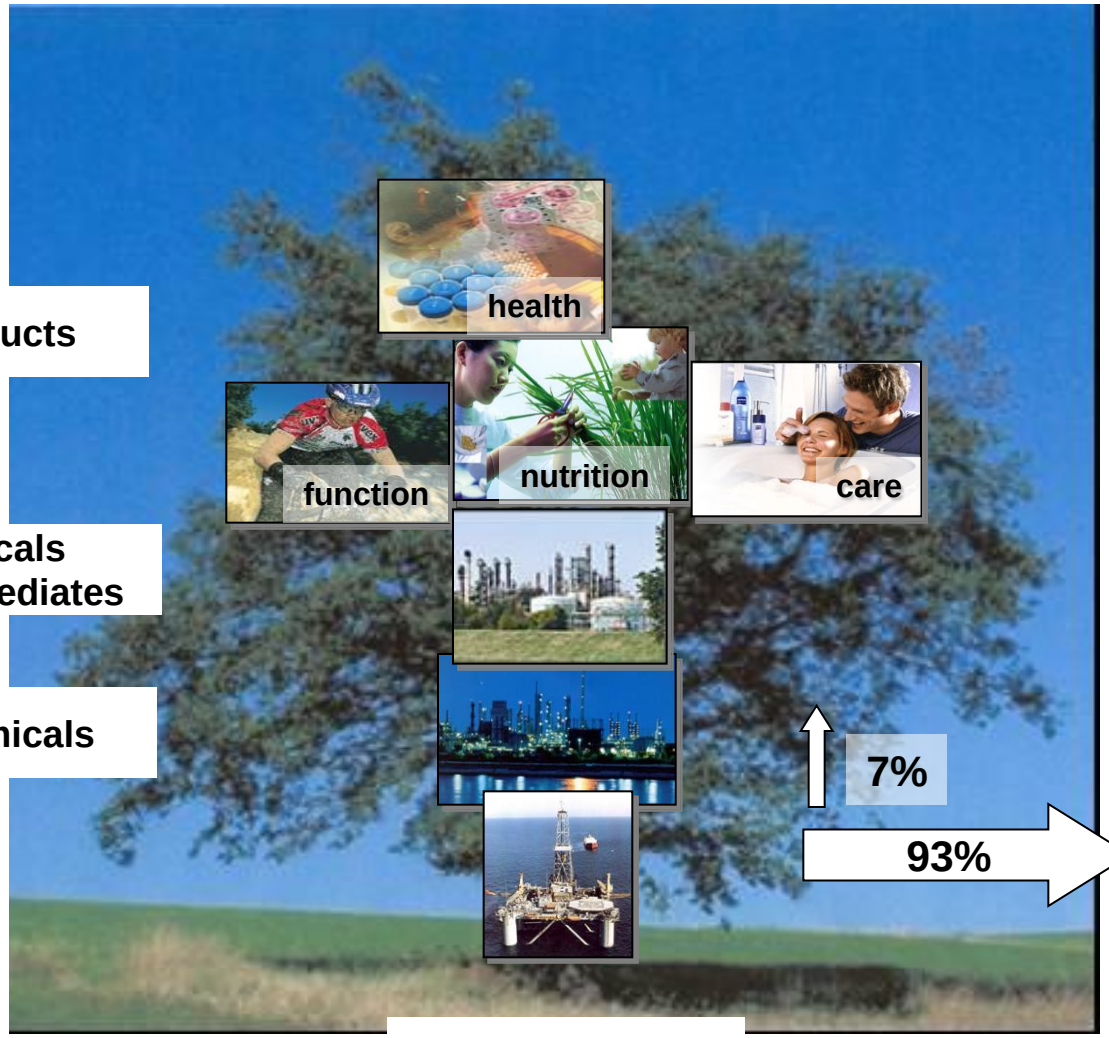


> 10^5 final products

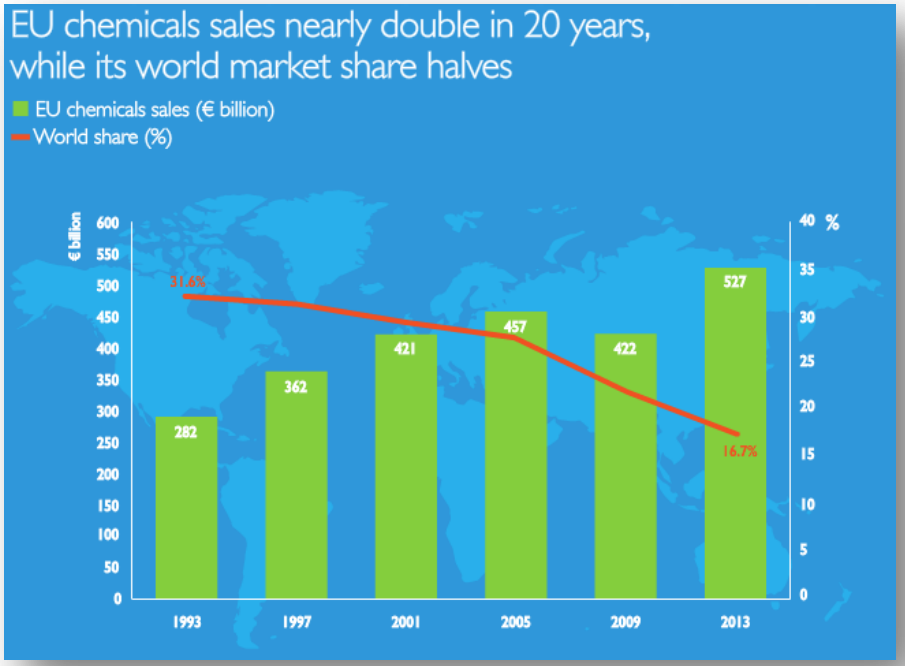
10^2 bulk chemicals and key intermediates

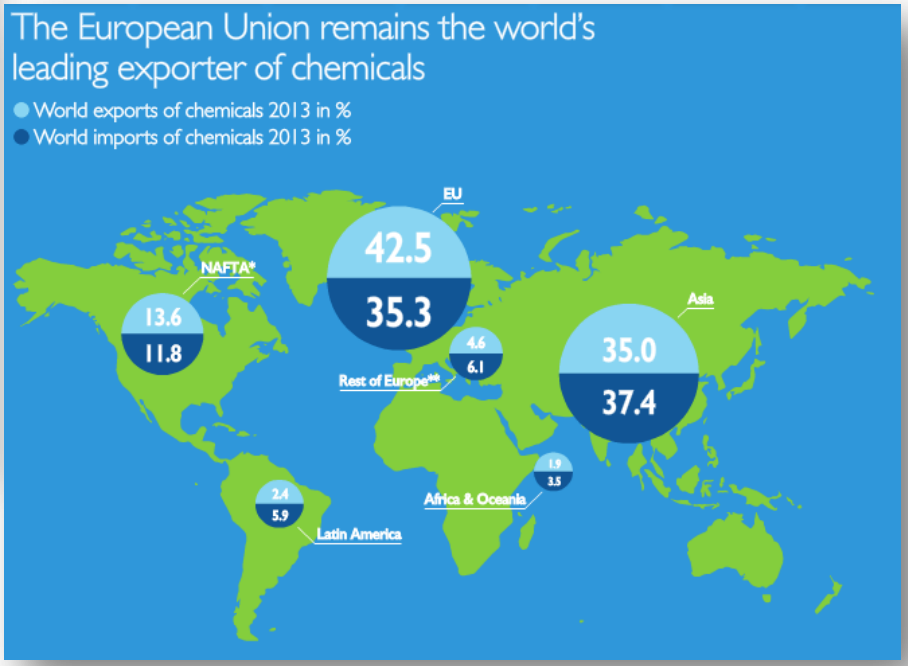
10^1 basic chemicals

petroleum

fuels
transportation
storage

energy

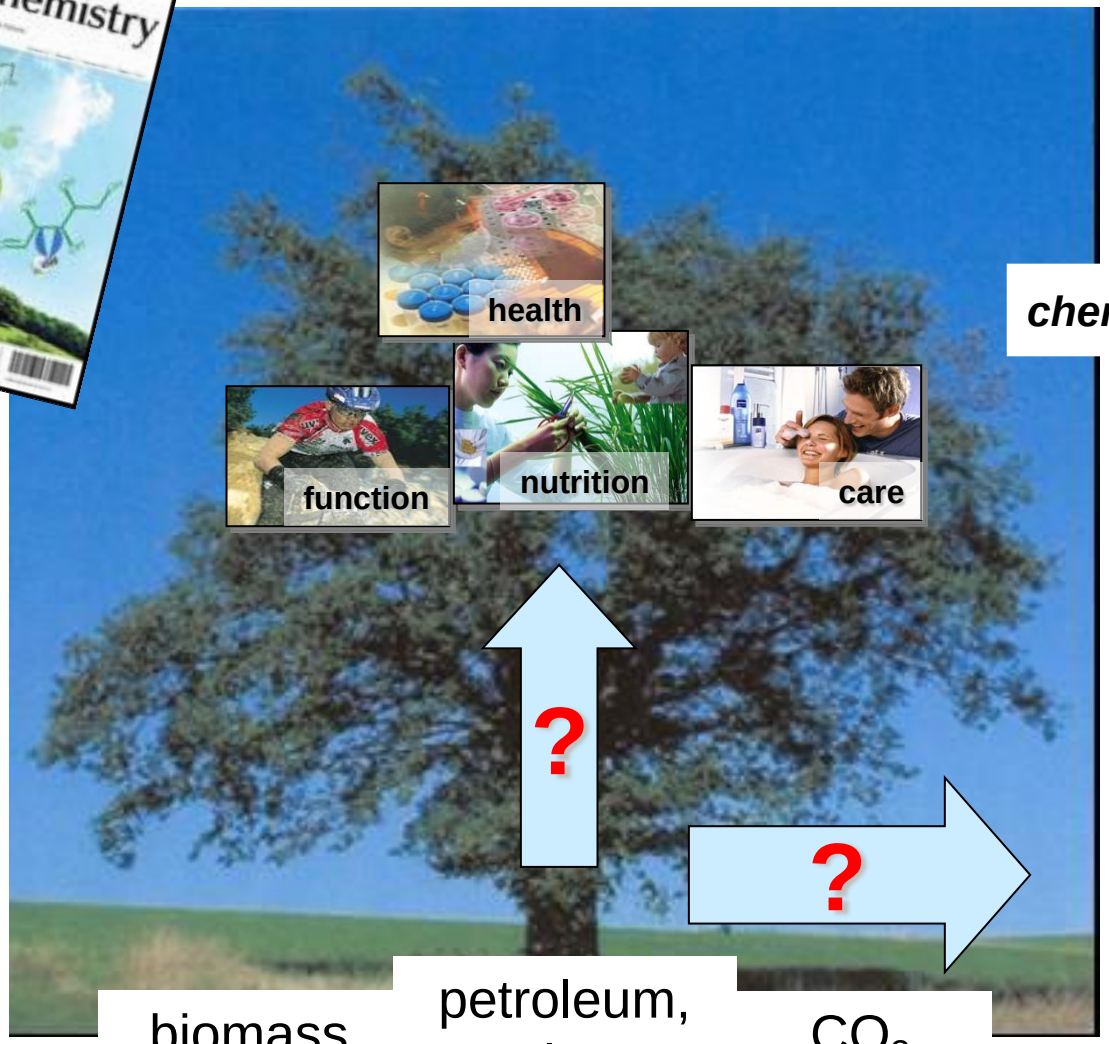




- 527 billion € sales
- 42,5 % export
- 1,75 million employees
- increasing global competition

Sources:
Eurostat and Cefic Chemdata Interational (2014)
European Chemistry Report, VCI (2015)

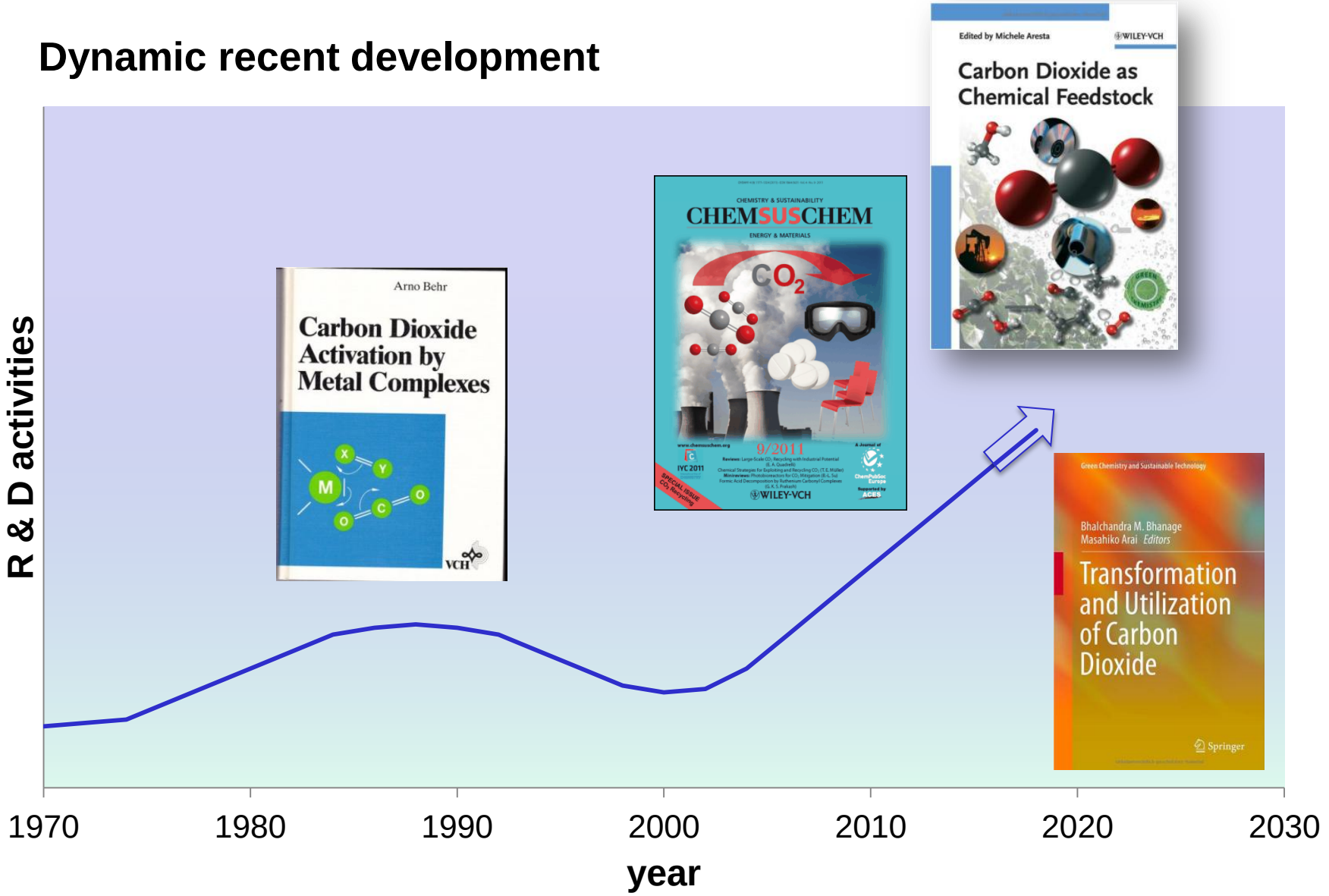
Royal Society of Chemistry
IF = 6.8

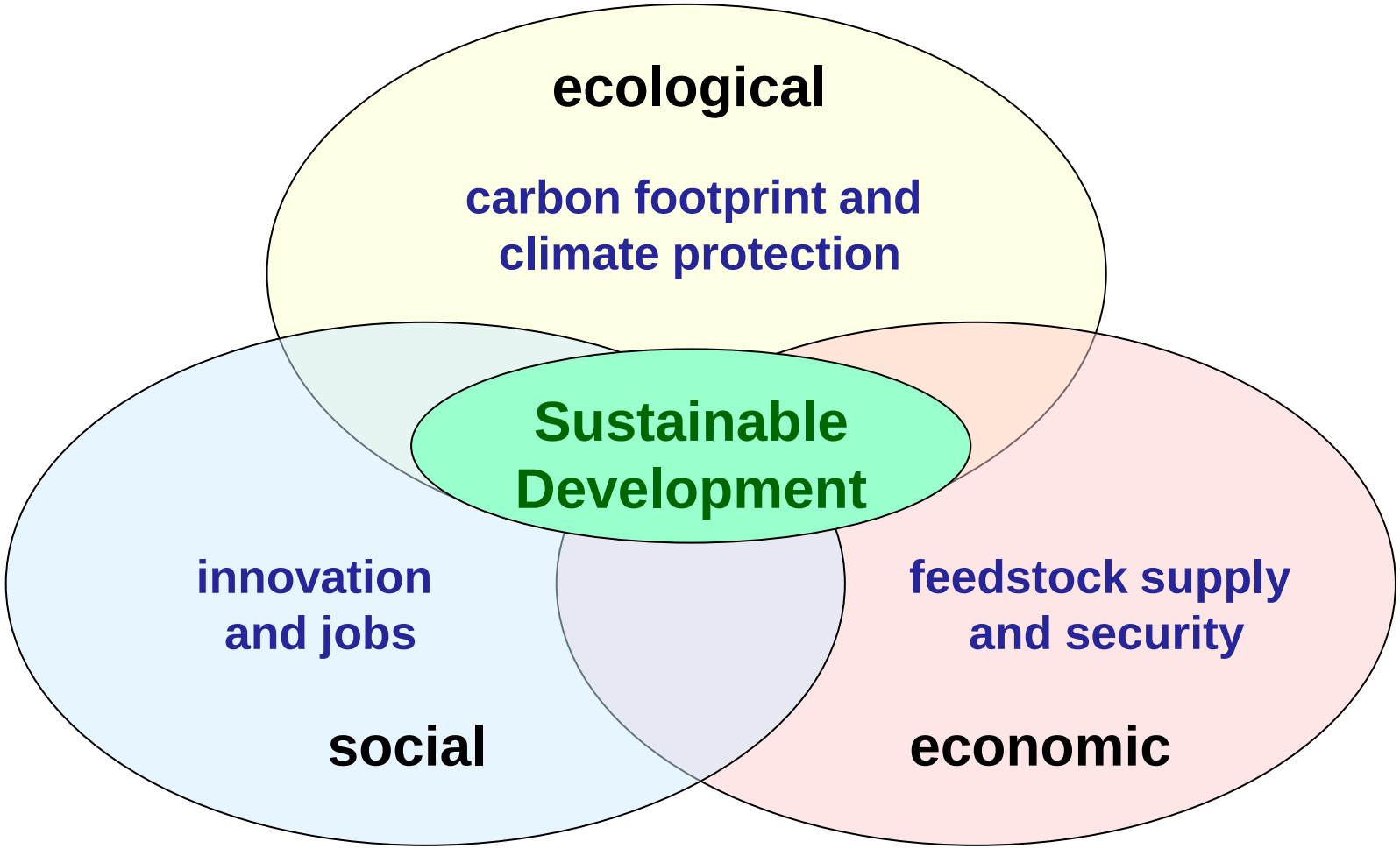


chemical products

energy carrier

Dynamic recent development





=> What is the potential contribution of CO_2 as carbon feedstock?

- Anthropogenic emission[1]:
  35.3 Gt CO_2 per year
- Power plants
  e.g. Niederaußem (Germany)[2]:
  28 Mt/year
- Chemical Processes
  e.g. ethylen oxide[3,4]:
  up to 200 kt per plant and year
- Other industrial sources:
  steel, cement, biogas, ……

CO_2 source	partial pressure
natural wells	1 – 30 bar
fermentation	0.9 – 0.95 bar
carbonates	0.2 – 0.5 bar
flue gases	0.09 – 0.11 bar
ethylen oxide production	0.8 – 0.95 bar
hydrogen-production	1.0 – 1.2 bar

Winnacker-Küchler, *Chemische Technik, Bd. 4*, (Eds. R. Dittmeyer, W. Keim, G. Kreysa, A. Oberholz), Wiley-VCH, [5]2005.

1) Emission Database for Global Atmospheric Research EDGAR, 2013.
2) Umweltbundesamt Workshop 28. - 29.05.2009.
3) European IPPC Bureau, LVOC BAT Document, 2003.
4) Ullmann's Encyclopedia of Industrial Chemistry, DOI: 10.1002/14356007

Bundesministerium für Bildung und Forschung

„Dream Production“: Polyurethane from CO_2

Scrubbing and supply of CO_2

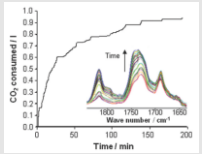
VORWEG GEHEN

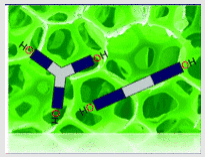
Process development and conversion of CO_2

Bayer Technology Services

Production and testing of polyurethanes with CO_2

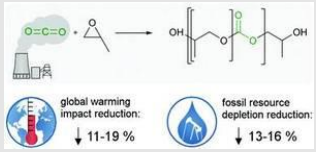
Bayer MaterialScience





cat® Catalytic Center

RWTH AACHEN UNIVERSITY



Fundamental research

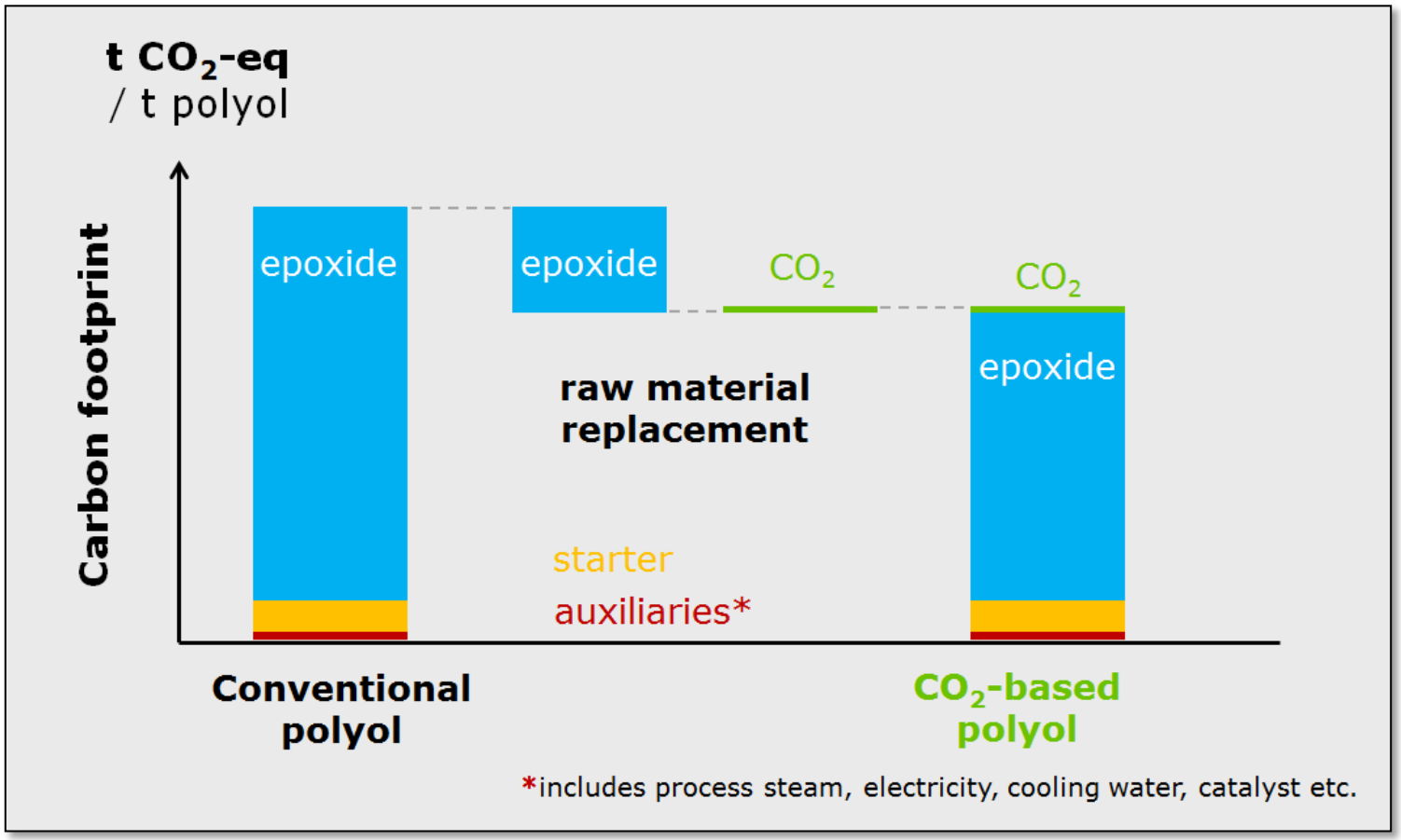
Life Cycle Assessment

J. Langanke, A. Wolf, J. Hofmann, K. Böhm, M. A. Subhani, T. E. Müller, W. Leitner, C. Gürtler, *Green Chem.*, **2014**, *16*, 1865-1870.

- New production plant to be built at Bayer site Dormagen, Germany
- Investment of 15 million Euros

- Production capacity of 5,000 tons / year
- Production start planned in 2016
- Permission process started

Photographs courtesey of Bayer MaterialsSciences



global warming
impact reduction:

↓ 11-19 %

fossil resource
depletion reduction:

↓ 13-16 %

N. von der Assen, A. Bardow,
Green Chemistry, **2014**, *16*, 3272 - 3280.

Excess Renewable Energy

CO_2

+ H_2

HCO_2H

+ H_2

- H_2O

H_2CO

+ H_2

H_3COH

+ H_2

- H_2O

CH_4

Chemical Value Chain

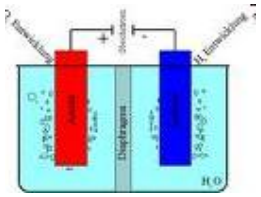
Energy Content

carbon dioxide	formic acid	form-aldehyde	methanol	methane

$$4\,H_2 + CO_2 \longrightarrow CH_4 + 2\,H_2O$$

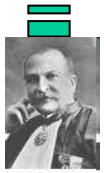
Methane for energy storage

http:/merkur-online.de



http:/membres.multimania.fr

$4\,H_2 + CO_2$



$CH_4 + 2\,H_2O$

http://www.wintershall.com

$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$

http://rwe.com

H_2 from renewable energy via electrolyis of water

Catalytic conversion of CO_2 to methane

Natural gas infrastructure and power plants

CH_3OH

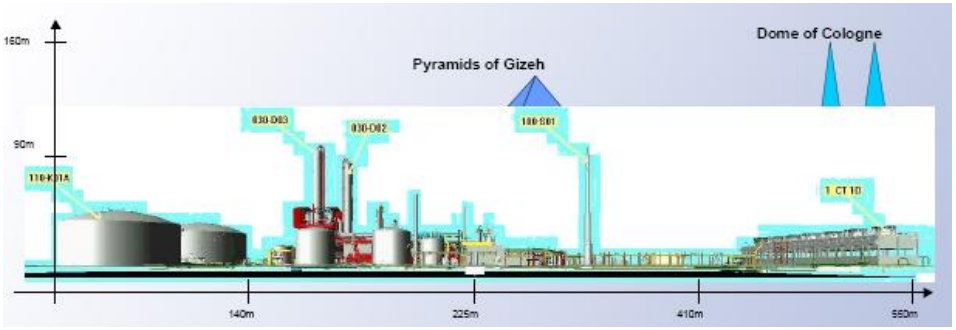
Fossil fuel based MeOH

$CO\ (g) + 2H_2\ (g) \rightleftharpoons CH_3OH\ (g)$

$CO_2\ (g) + 3H_2\ (g) \rightleftharpoons CH_3OH\ (g) + H_2O\ (g)$

$Cu/ZnO/Al_2O_3$
50 – 100 bar, 200 – 300 ˚C
50 Mt/a

- **Worldscale plants**
- **Capacities > 1 Mt/a (each plant)**



Courtesy of L. Plass (Lurgi)

CO_2 based MeOH

$CO_2\ (g) + 3H_2\ (g) \rightleftharpoons CH_3OH\ (g) + H_2O\ (g)$

$\Delta_R H^0 = -58$ kJ/mol

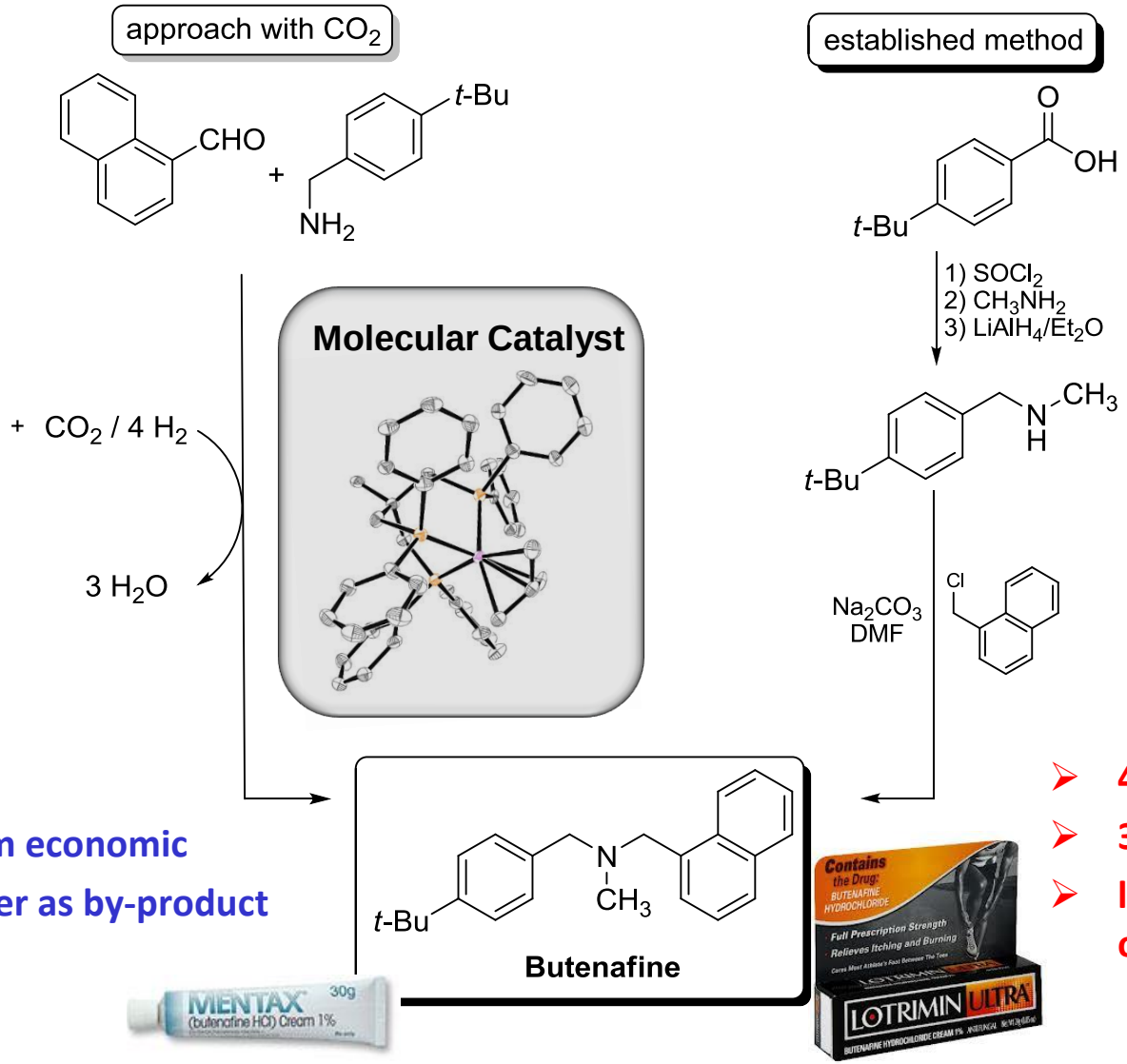
New catalysts and process concepts needed

- **Local solutions; Iceland: geothermal energy**
- **4 kt/a**

www.carbonrecycling.is

M. Aresta, A. Dibendetto, *Dalton Trans.* **2007**, 2975-2992.

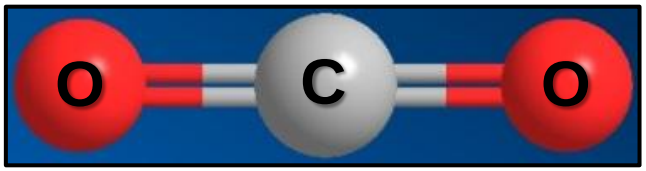
“Green Chemisty” using CO_2/H_2



- 1 step
- 85% atom economic
- only water as by-product

- 4 steps
- 35% atom economic
- large amounts of waste

K. Beydoun, G. Ghattas, K. Thenert, J. Klankermayer, W. Leitner, *Angew. Chem.* **2014**, *53*, 11010–11014.

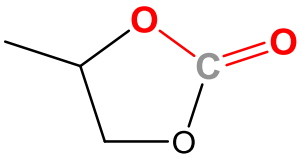


incorporation

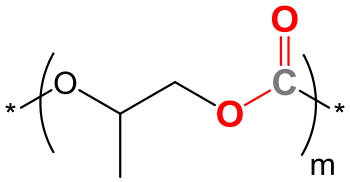
hydrogenation

carbon source

energy storage

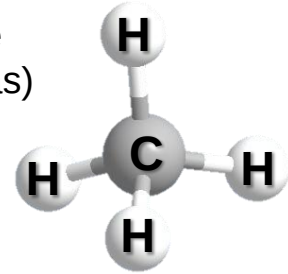


cyclic carbonate
(solvent)

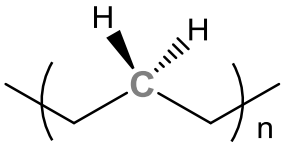


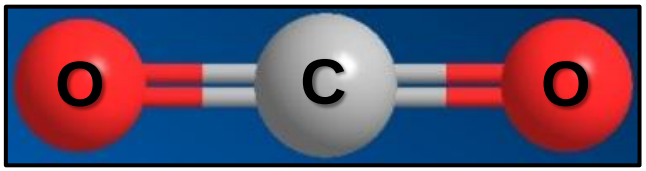
poly-carbonate
(plastic)

methane
(natural gas)



hydrocarbon
(fuel)





incorporation

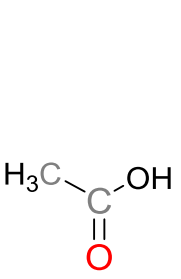
CO_2 + H_2

hydrogenation

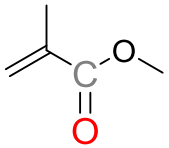
carbon source

energy storage

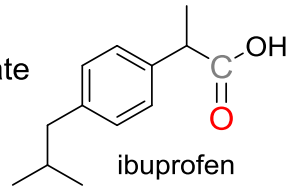
energy harvest



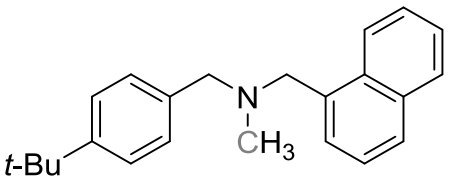
acetic acid



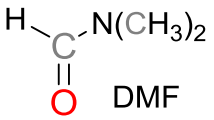
methyl methacrylate



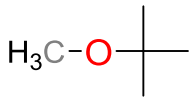
ibuprofen



butenafine



DMF



MTBE

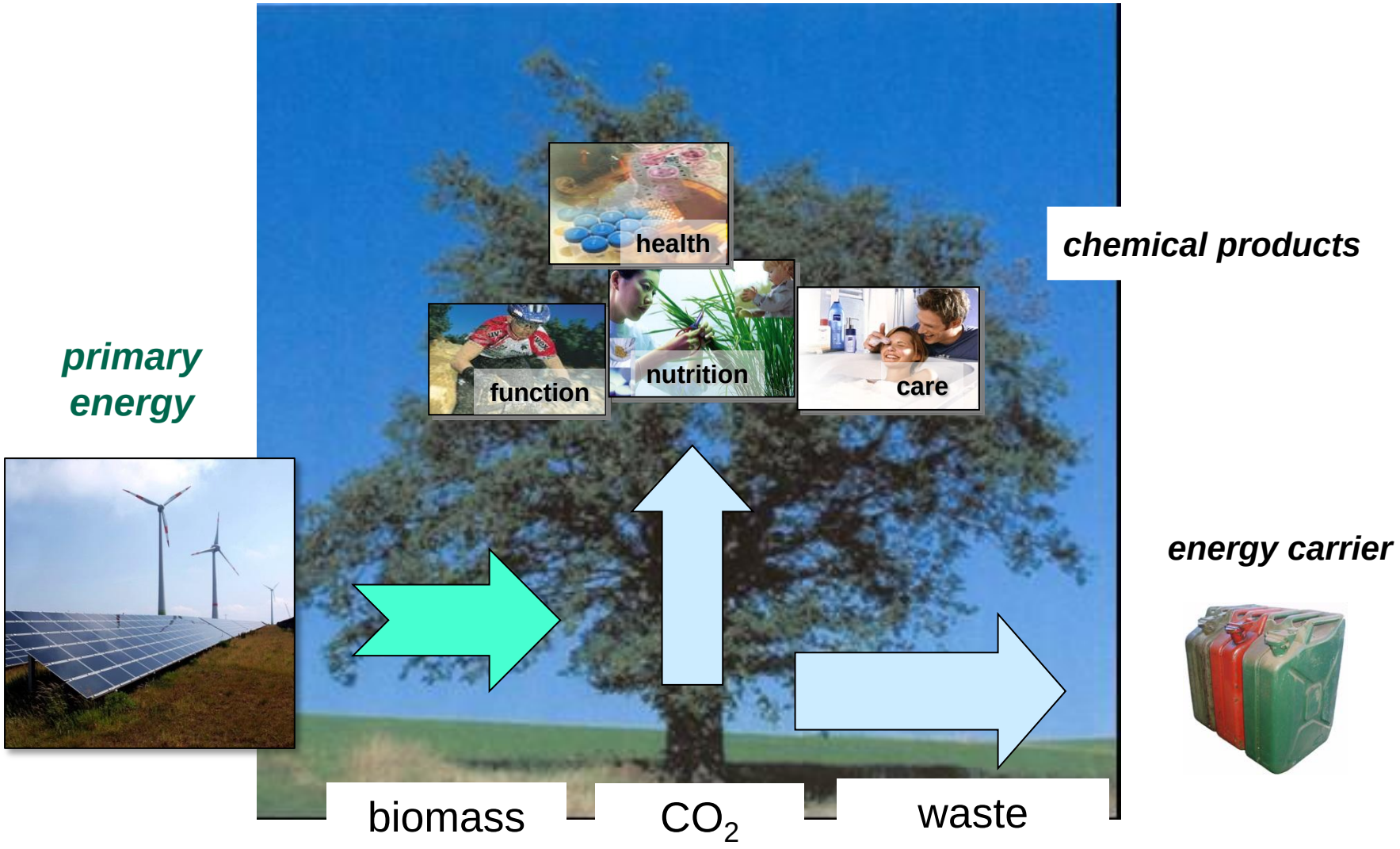
building blocks, solvents, cosmetics, agro-chemicals, pharmaceuticals,…..

Use of CO_2 as feedstock **can**…

- …reduce the carbon footprint of chemical production
- … open novel „green“ chemical transformations
- …“harvest“ renewable energy into the material value chain
- … facilitate decentralized production

Use of CO_2 as feedstock **requires**…

- …progress in catalysis research
- …interdisicplinary solutions between natural & engineering sciences
- …interaction of academia and industry


health
function
nutrition
care
chemical products
primary energy
energy carrier
biomass
CO_2
waste


RAMONES