

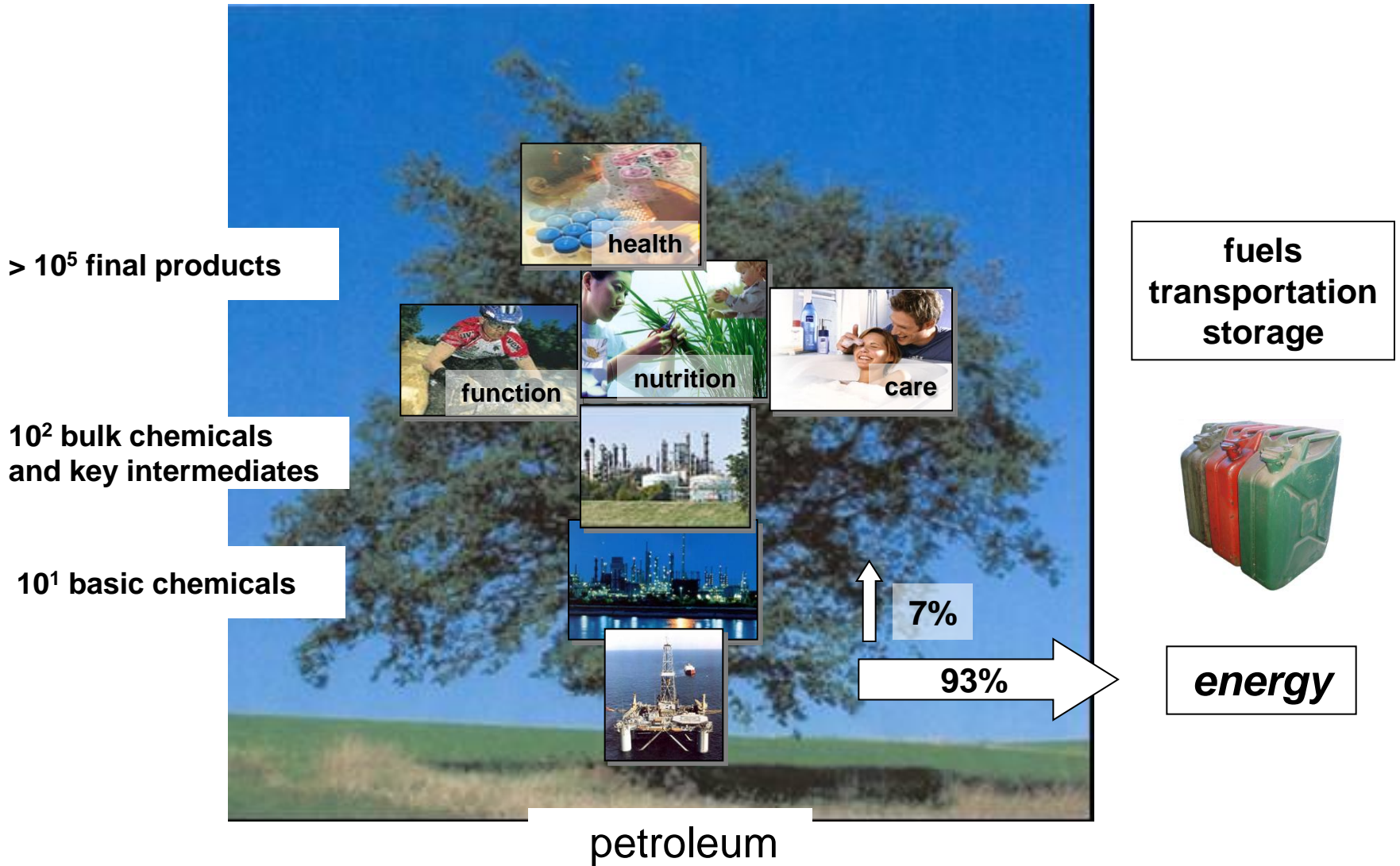
If you want to go fast, go alone. If you want to go far, go together.

Contributions of European Chemistry for the Transition to a Sustainable Future

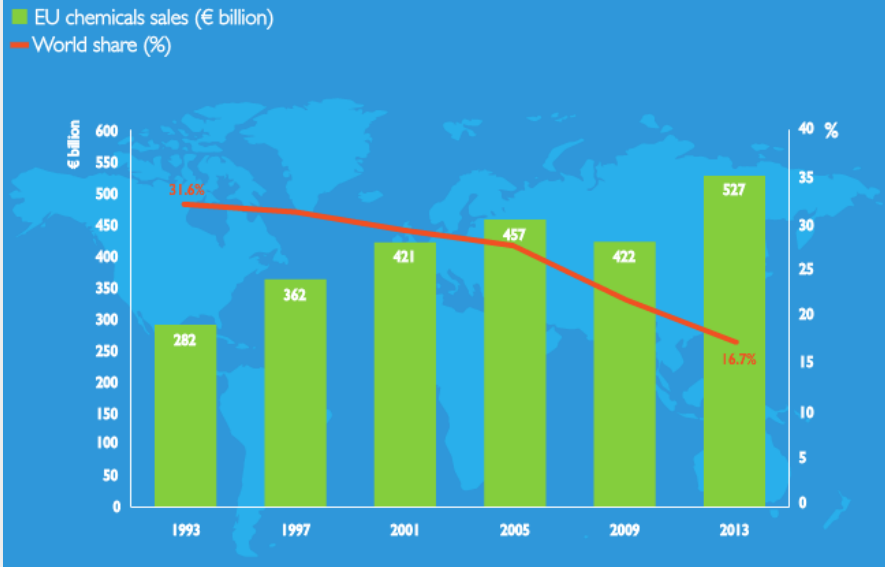
Jürgen Klankermayer & Walter Leitner

ITMC
Institut für Technische und
Makromolekulare Chemie

RWTHAACHEN
UNIVERSITY

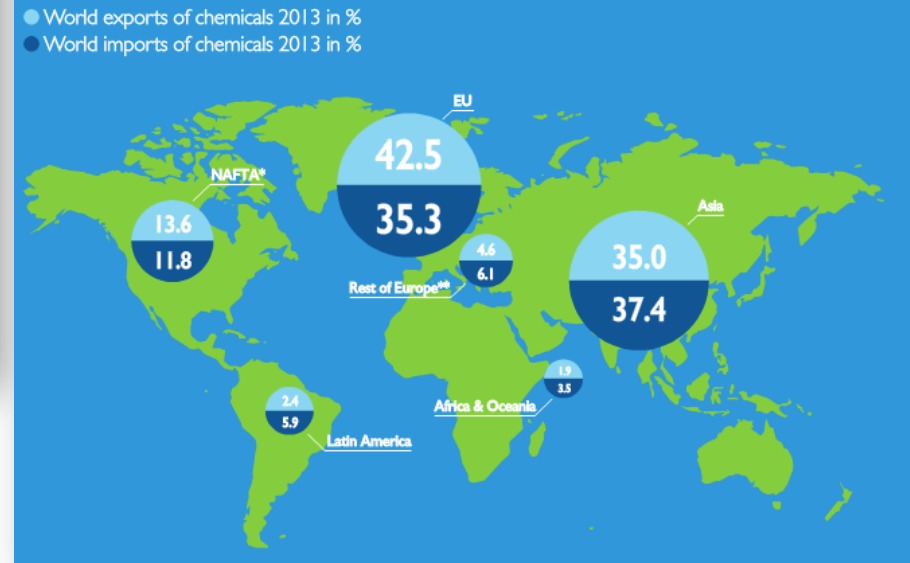


EU chemicals sales nearly double in 20 years, while its world market share halves



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

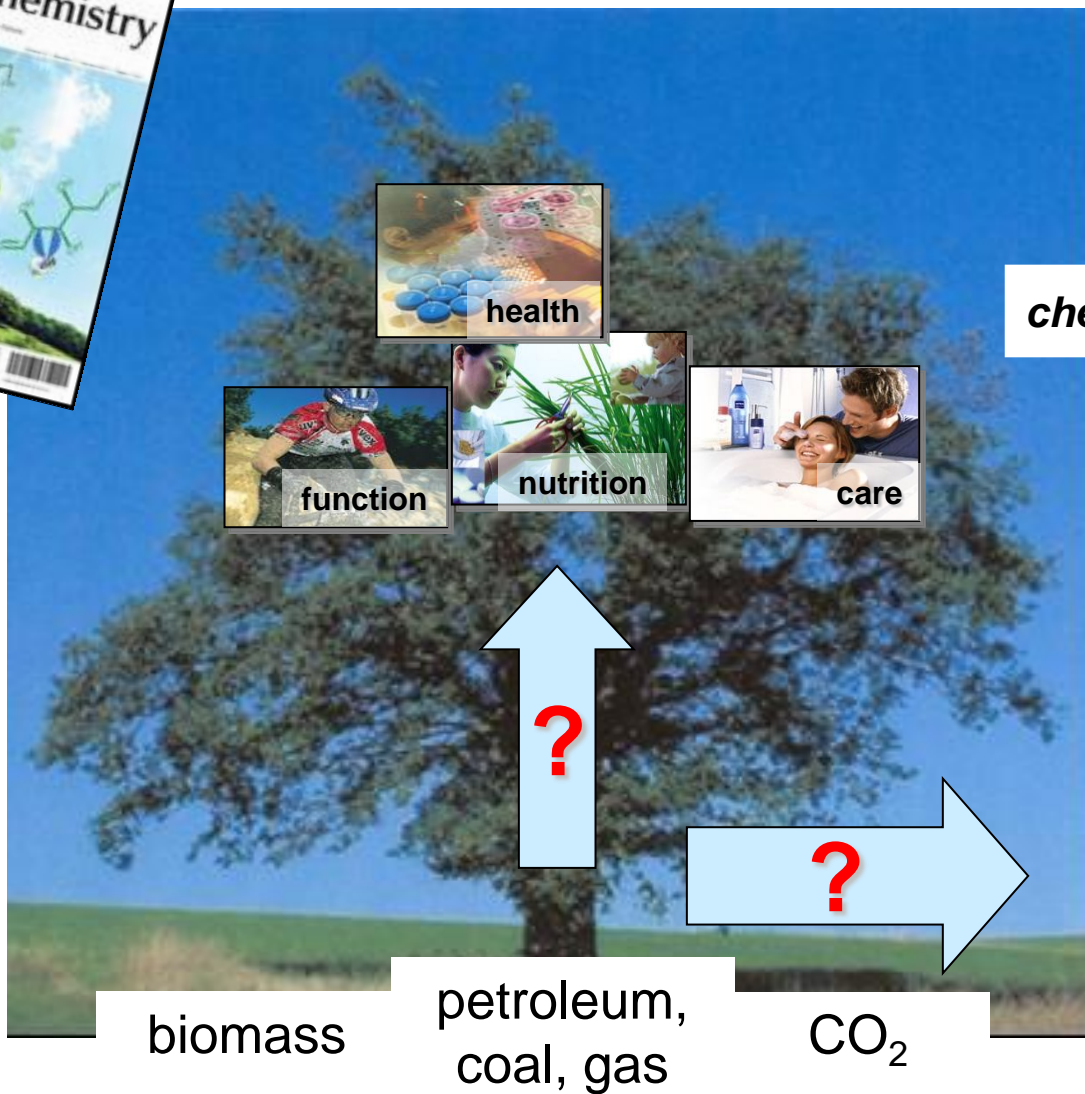
The European Union remains the world's leading exporter of chemicals



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



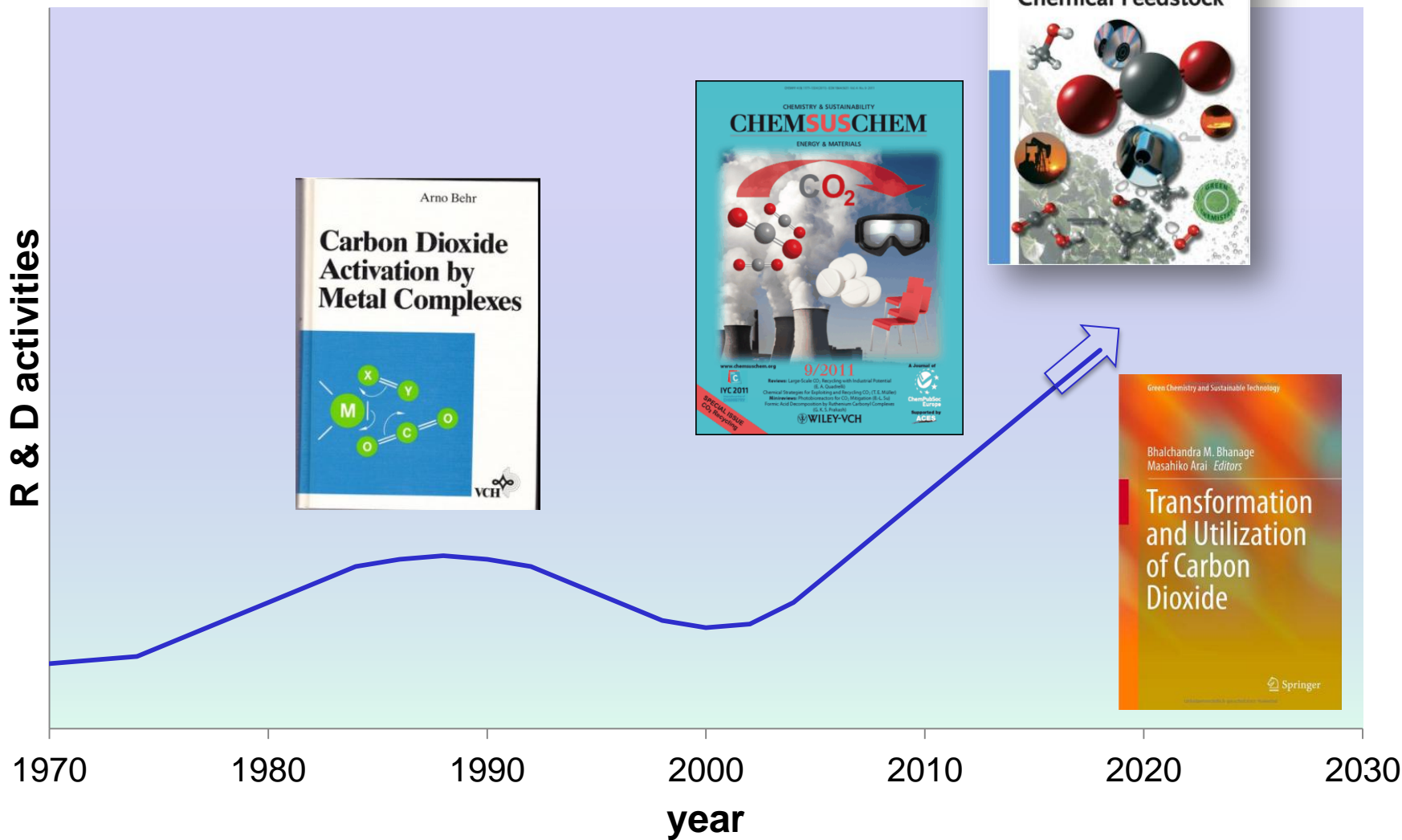
Royal Society
of Chemistry
IF = 6.8

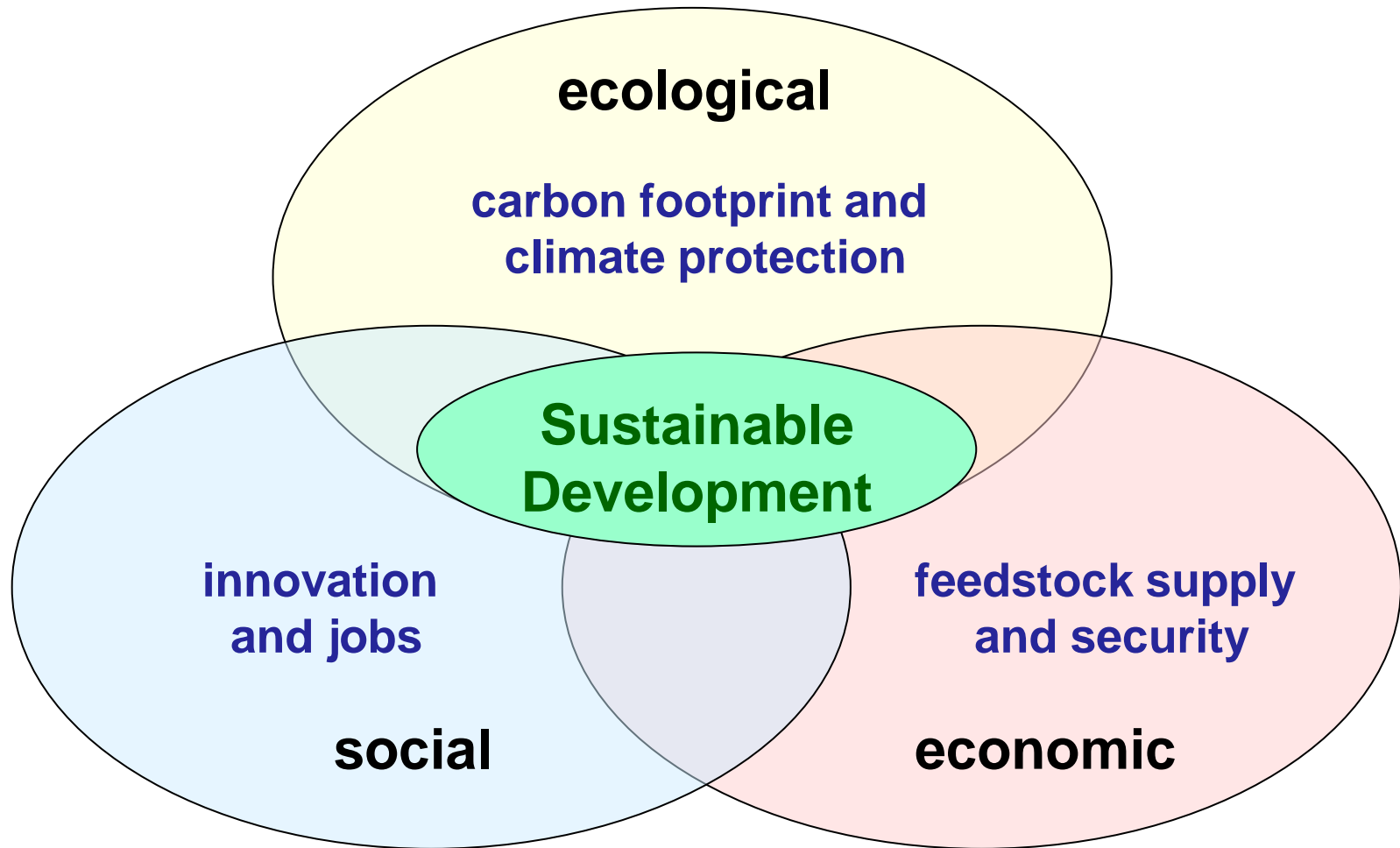


energy carrier



Dynamic recent development





=> What is the potential contribution of CO₂ as carbon feedstock?

- Anthropogenic emission¹:
35.3 Gt CO₂ 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

- 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

Winnacker-Küchler, *Chemische Technik, Bd. 4*,
(Eds. R. Dittmeyer, W. Keim, G. Kreysa, A. Oberholz), Wiley-VCH, ⁵2005.



„Dream Production“: Polyurethane from CO₂




Scrubbing and supply of CO₂

VORWEG GEHEN



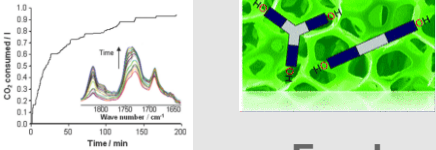
Process development and conversion of CO₂

BAYER Bayer Technology Services



Production and testing of polyurethanes with CO₂

BAYER Bayer MaterialScience

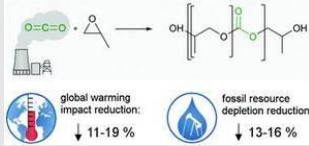


Fundamental research



COT[®]
Catalytic Center

RWTHAACHEN
UNIVERSITY



global warming impact reduction: ↓ 11-19 %

fossil resource depletion reduction: ↓ 13-16 %

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

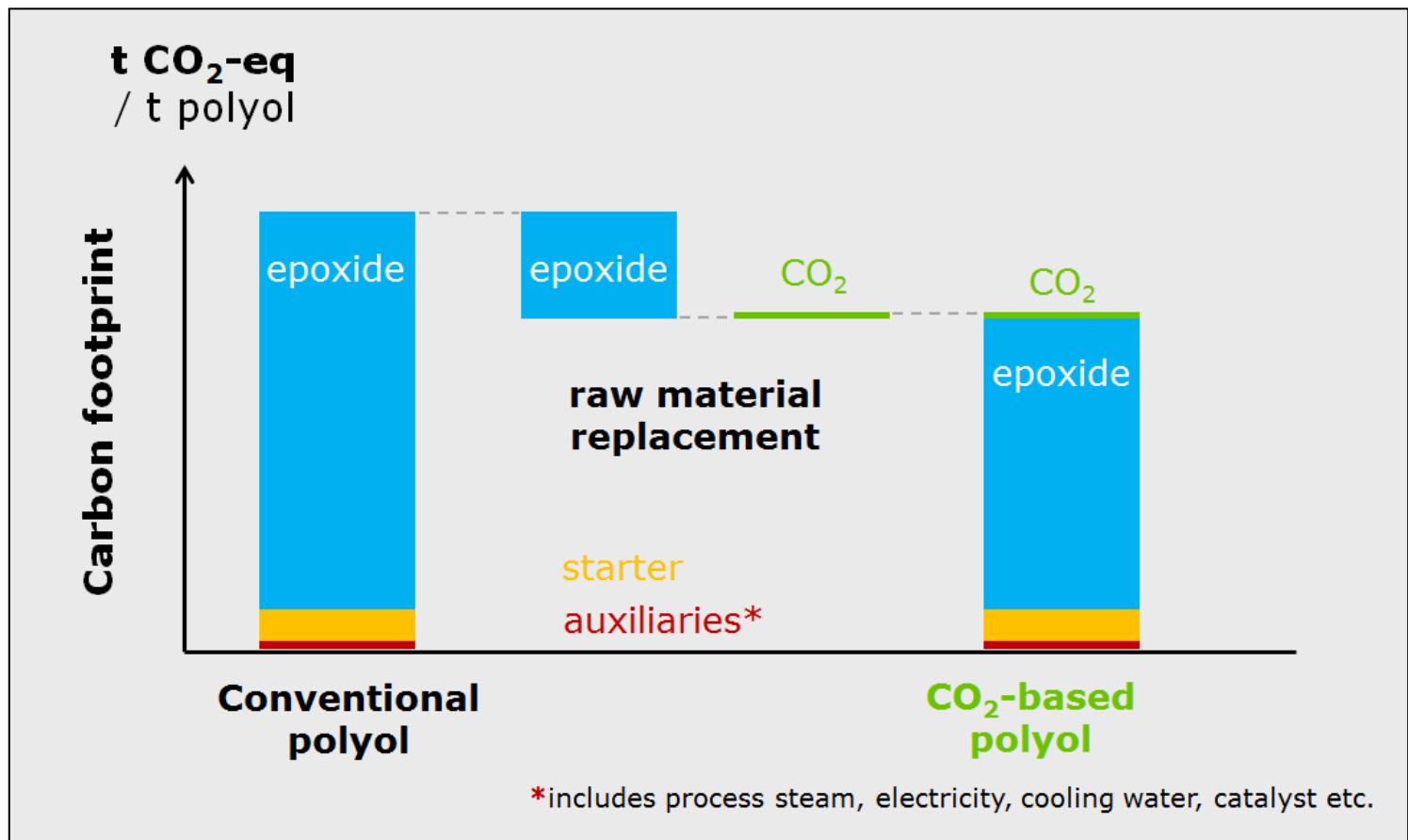


- New production plant to be built at Bayer site Dormagen, Germany
- Investment of 15 million Euros

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



Photographs courtesy of Bayer MaterialsSciences



global warming
impact reduction:

↓ 11-19 %



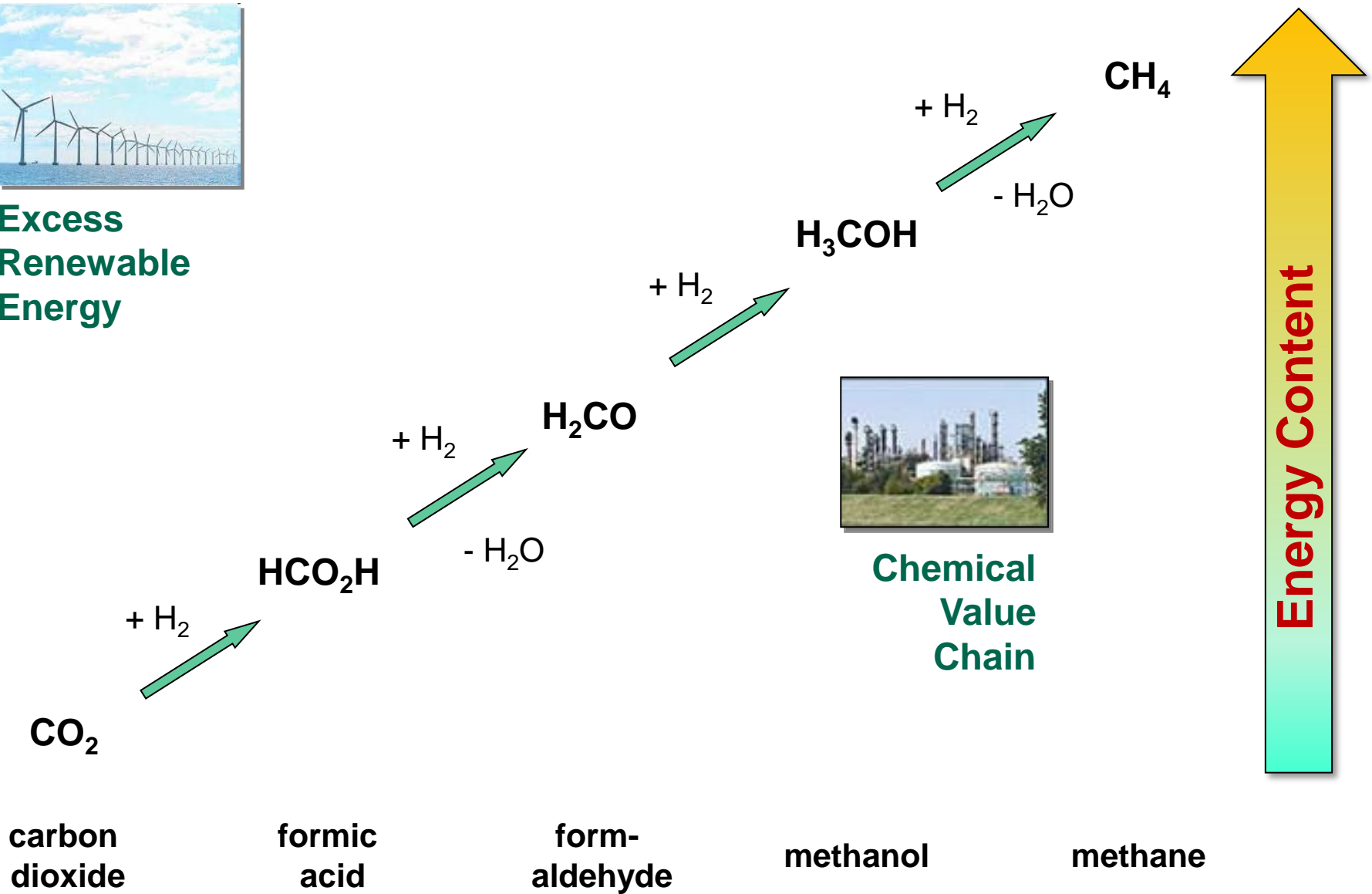
fossil resource
depletion reduction:

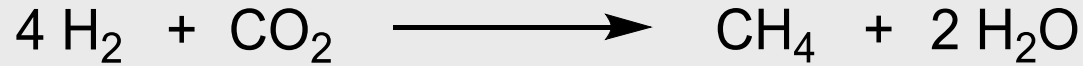
↓ 13-16 %

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



**Excess
Renewable
Energy**

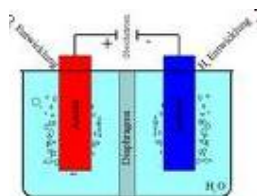




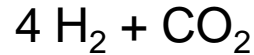
Methane for energy storage



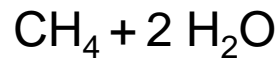
<http://merkur-online.de>



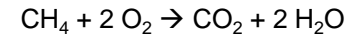
<http://membres.multimania.fr>



Sabatier, P.



<http://www.wintershall.com>



<http://rwe.com>

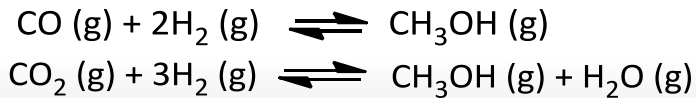
H₂ from renewable energy
via electrolysis of water

Catalytic conversion
of CO₂ to methane

Natural gas infrastructure
and power plants

CH₃OH

Fossil fuel based MeOH



Cu/ZnO/Al₂O₃
50 – 100 bar, 200 – 300 °C
50 Mt/a

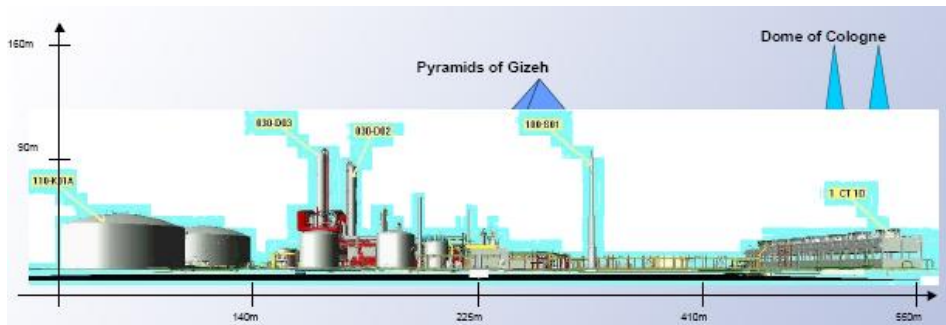
CO₂ based MeOH



New catalysts and process concepts needed

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

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

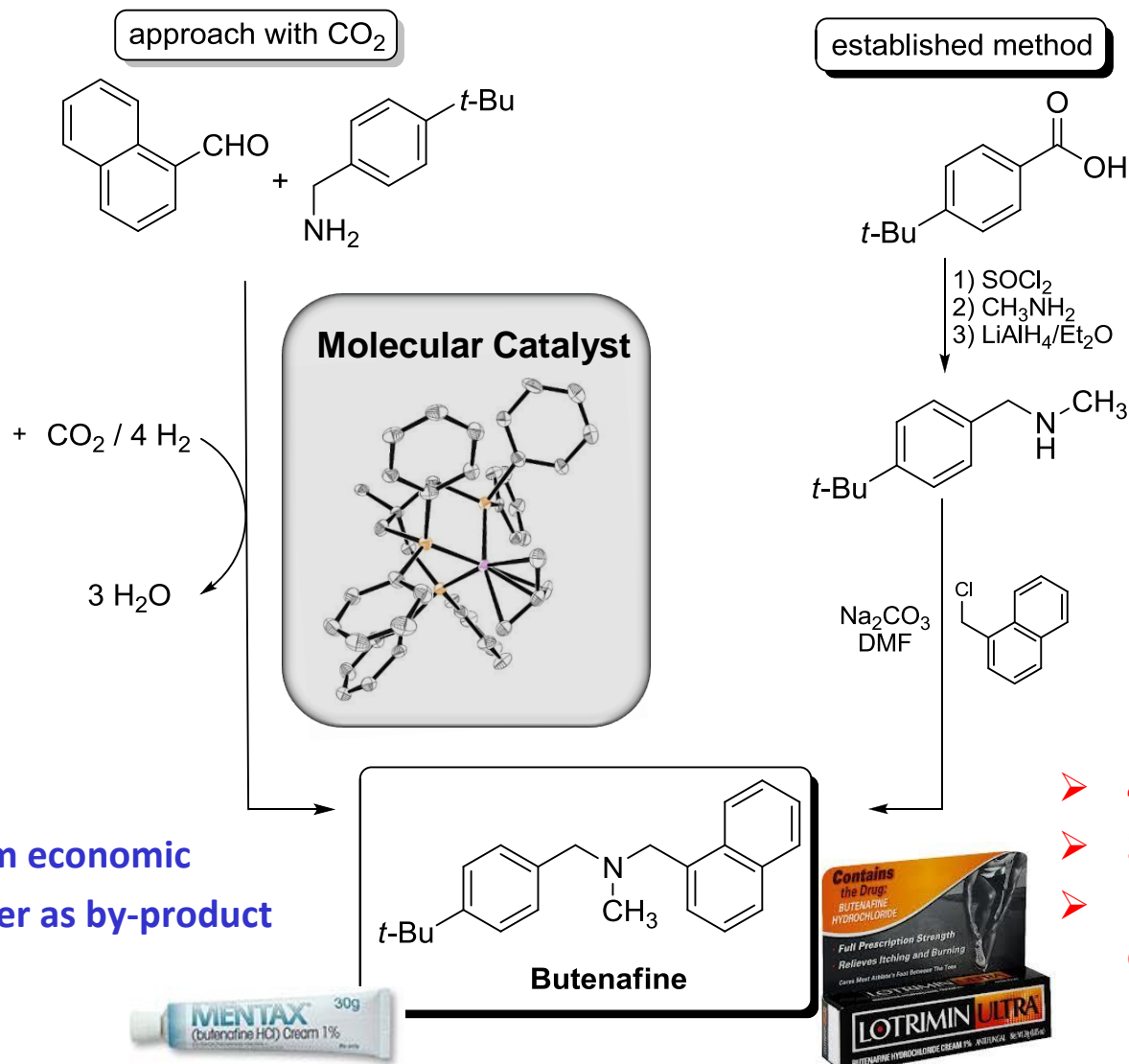


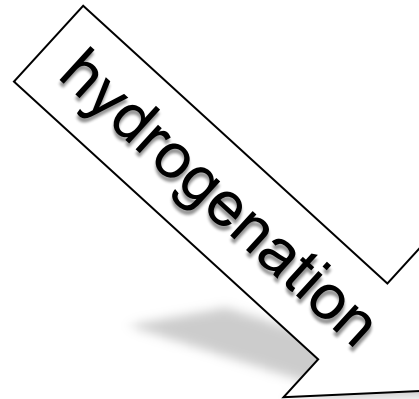
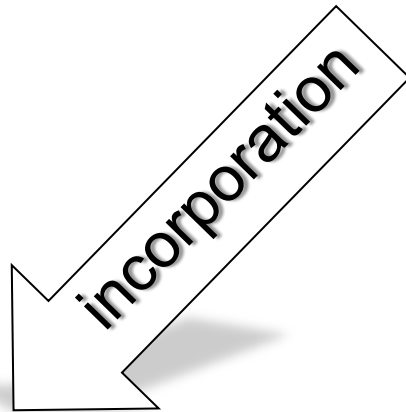
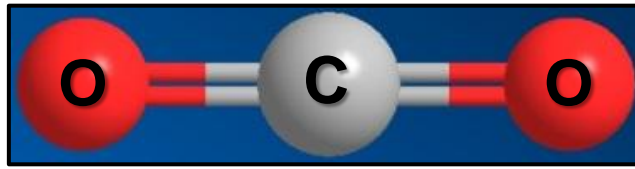
Courtesy of L. Plass (Lurgi)



www.carbonrecycling.is

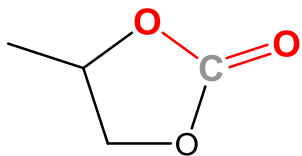
“Green Chemisty” using CO₂/H₂



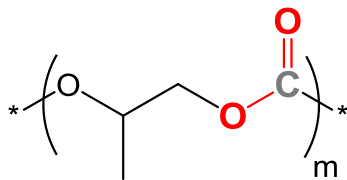


**carbon
source**

**energy
storage**

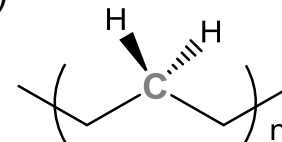


cyclic carbonate
(solvent)

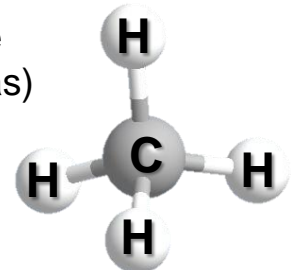


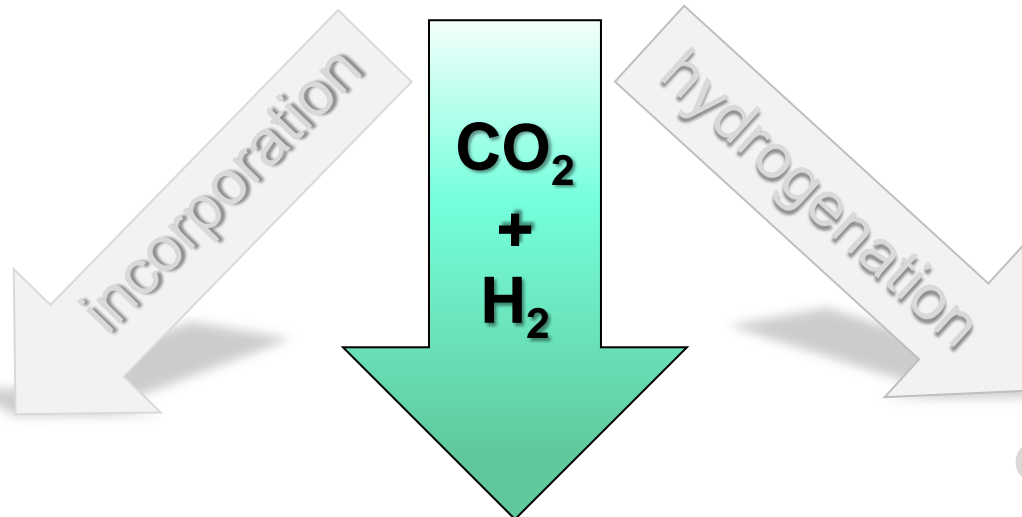
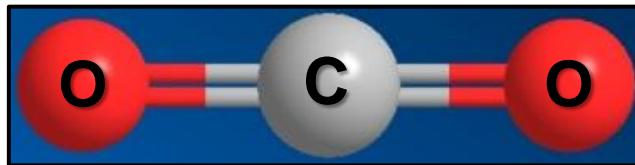
poly-carbonate
(plastic)

hydrocarbon
(fuel)



methane
(natural gas)

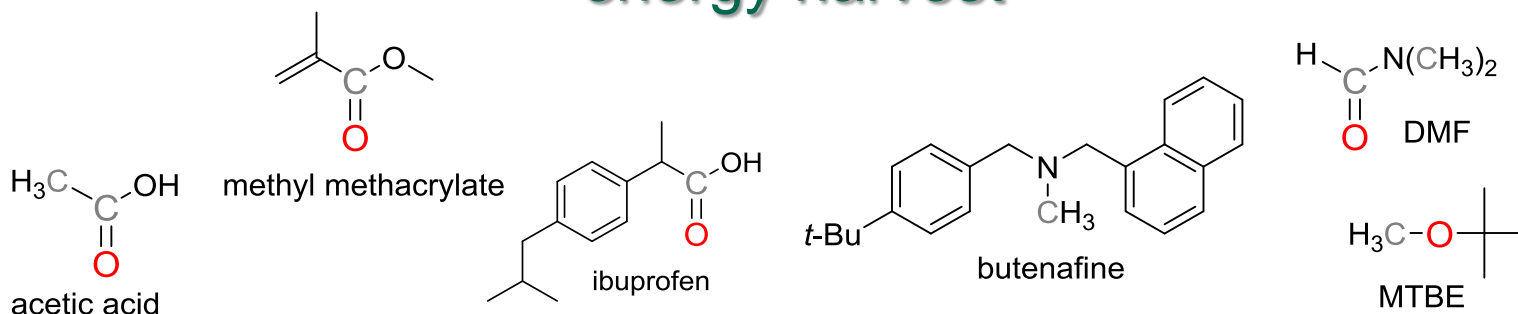




carbon source

energy storage

energy harvest



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

Use of CO₂ 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



Development time

Use of CO₂ as feedstock **requires...**

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

