DE LA RECHERCHE À L'INDUSTRIE

CATALYTIC STRATEGIES FOR THE CONVERSION OF CO_2 AND BIOMASS WASTE

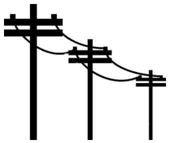
CEA / CNRS | Thibault Cantat

JOURNÉE X – ENS – ESPCI
ENS PARIS – MAY 09-2019

SCIENTIFIC ADVICE ON CCU FOR THE EC

http://www.allea.org/sapea-provides-evidence-for-the-european-commission-on-carbon-capture-and-utilisation-technologies/

Services to society



Electrical power on the grid

Power available on demand

Heat

Fuels for mobility

Industrial products (chemicals, materials, fertilizers)

Sun

Wind

Geothermy

Surfaces

Water

Ressources

Uranium

Inorganics

metals
N, Si, P

Carbon feedstocks

Services to society

Electrical power on the grid

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Industrial products (chemicals, materials, fertilizers)

Energy forms and vectors

Ressources

Sun

Wind

Geothermy

Surfaces

Water

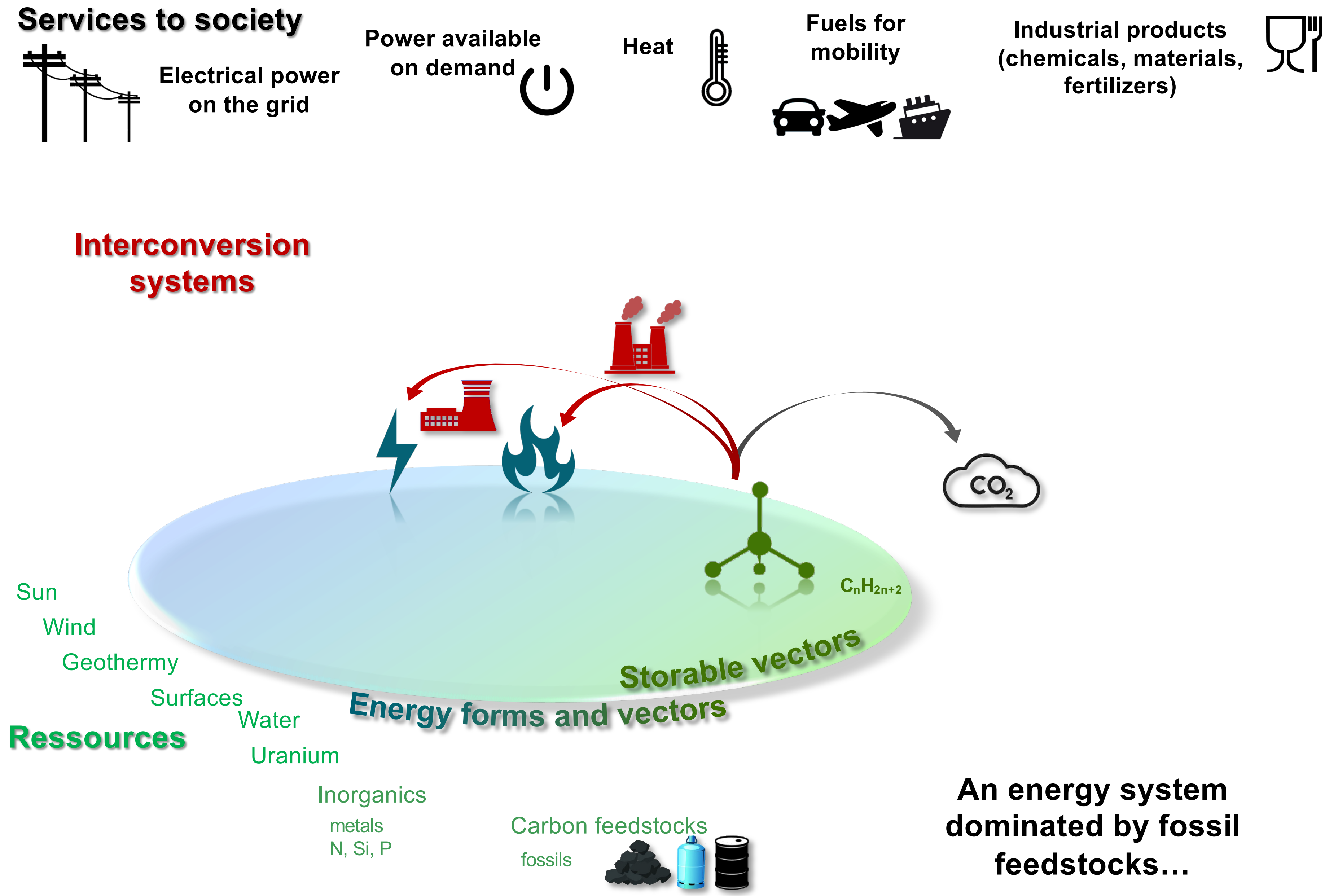
Uranium

Inorganics

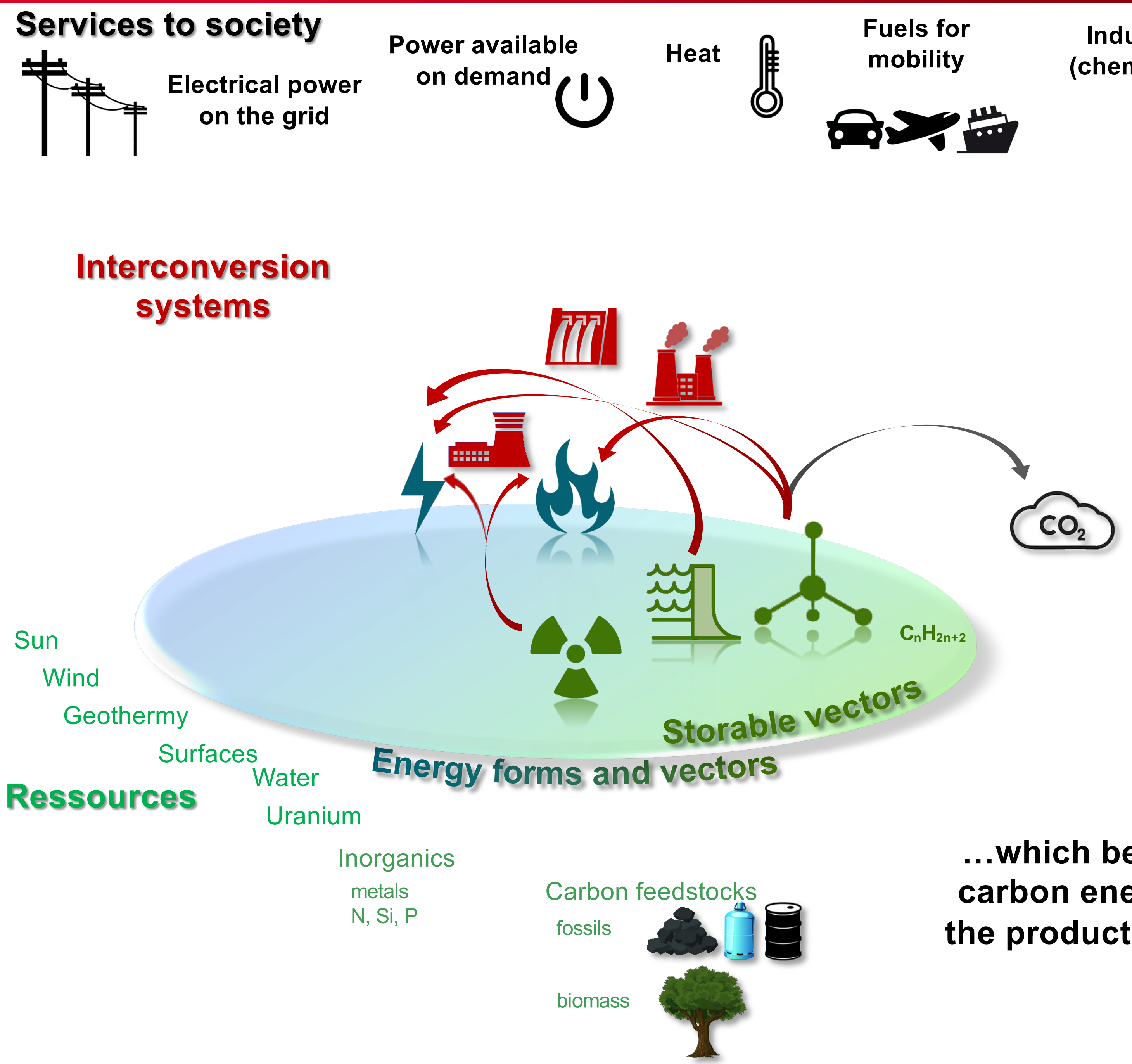
metals

N, Si, P

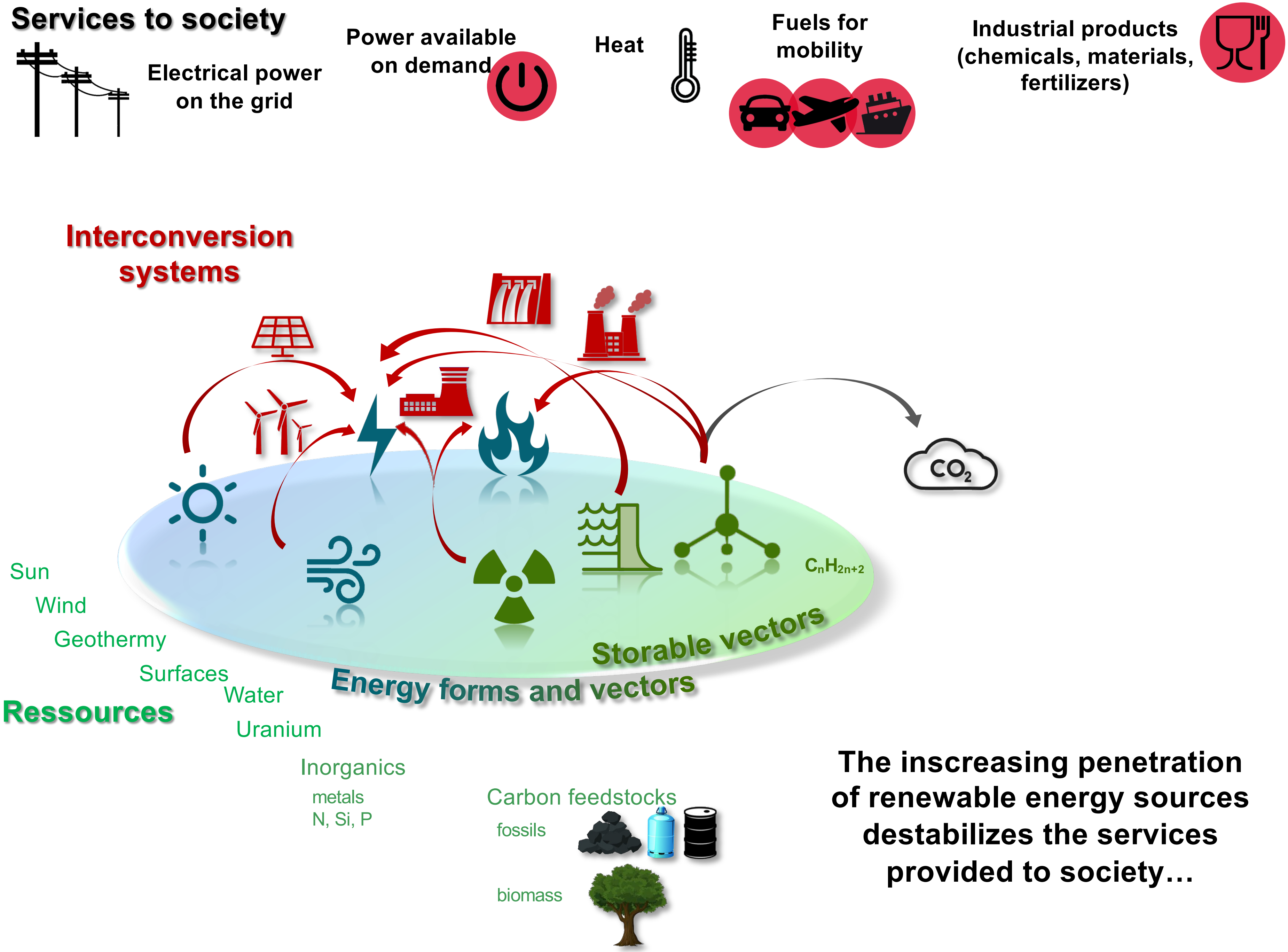
Carbon feedstocks

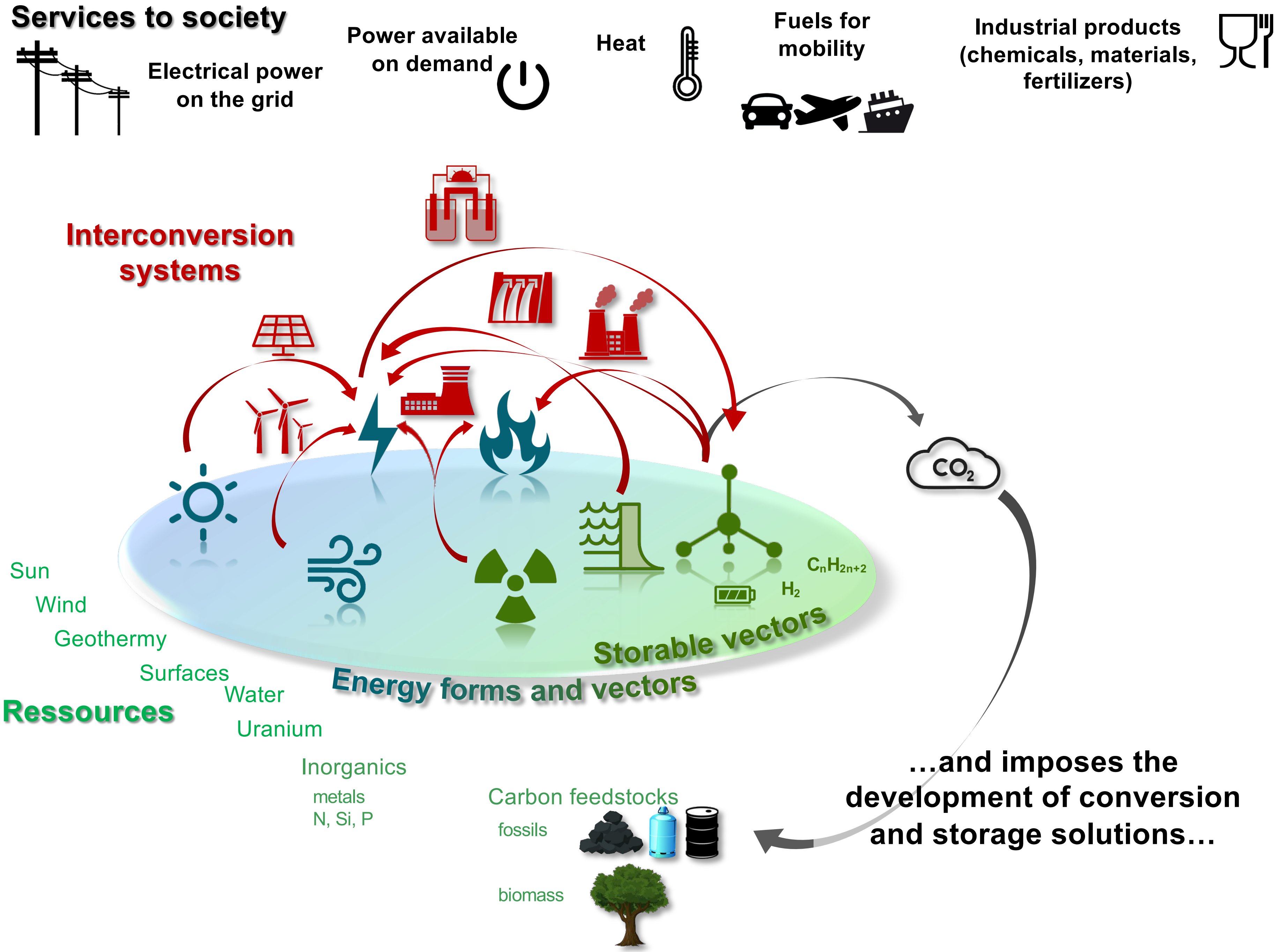


An energy system dominated by fossil feedstocks…



…which benefits from low carbon energy sources for the production of electricity.


Services to society
Electrical power on the grid
Power available on demand
Heat
Fuels for mobility
Industrial products (chemicals, materials, fertilizers)
Interconversion systems
CO_2
C_nH_{2n+2}
Storable vectors
Energy forms and vectors
Sun
Wind
Geothermy
Surfaces
Water
Uranium
Ressources
Inorganics
metals
N, Si, P
Carbon feedstocks
fossils
biomass
The inscreasing penetration of renewable energy sources destabilizes the services provided to society…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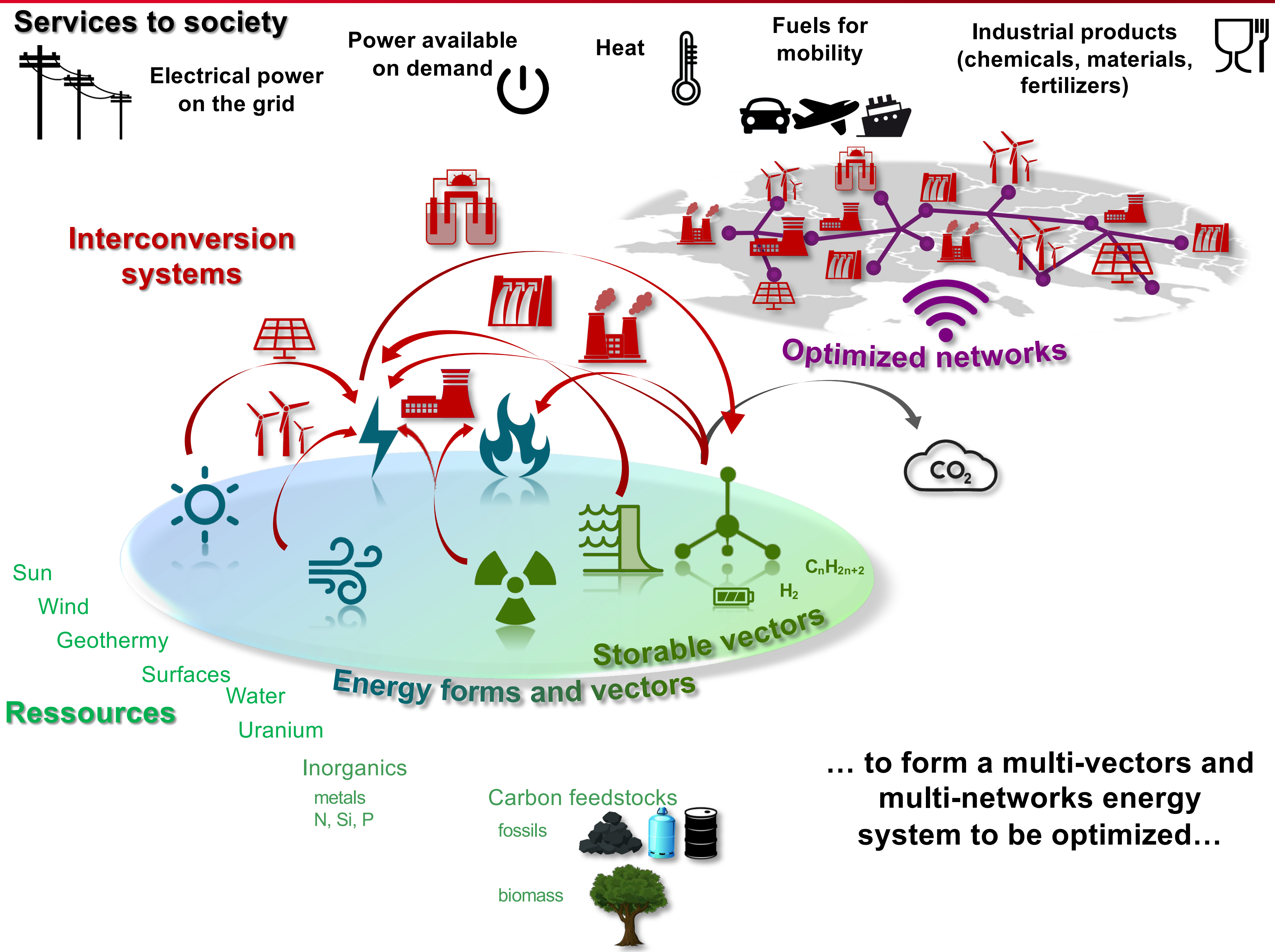
Carbon feedstocks
fossils
biomass
…and imposes the development of conversion and storage solutions…


Services to society
Electrical power on the grid
Power available on demand
Heat
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Industrial products (chemicals, materials, fertilizers)
Interconversion systems
Optimized networks
CO2
CnH2n+2
H2
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Uranium
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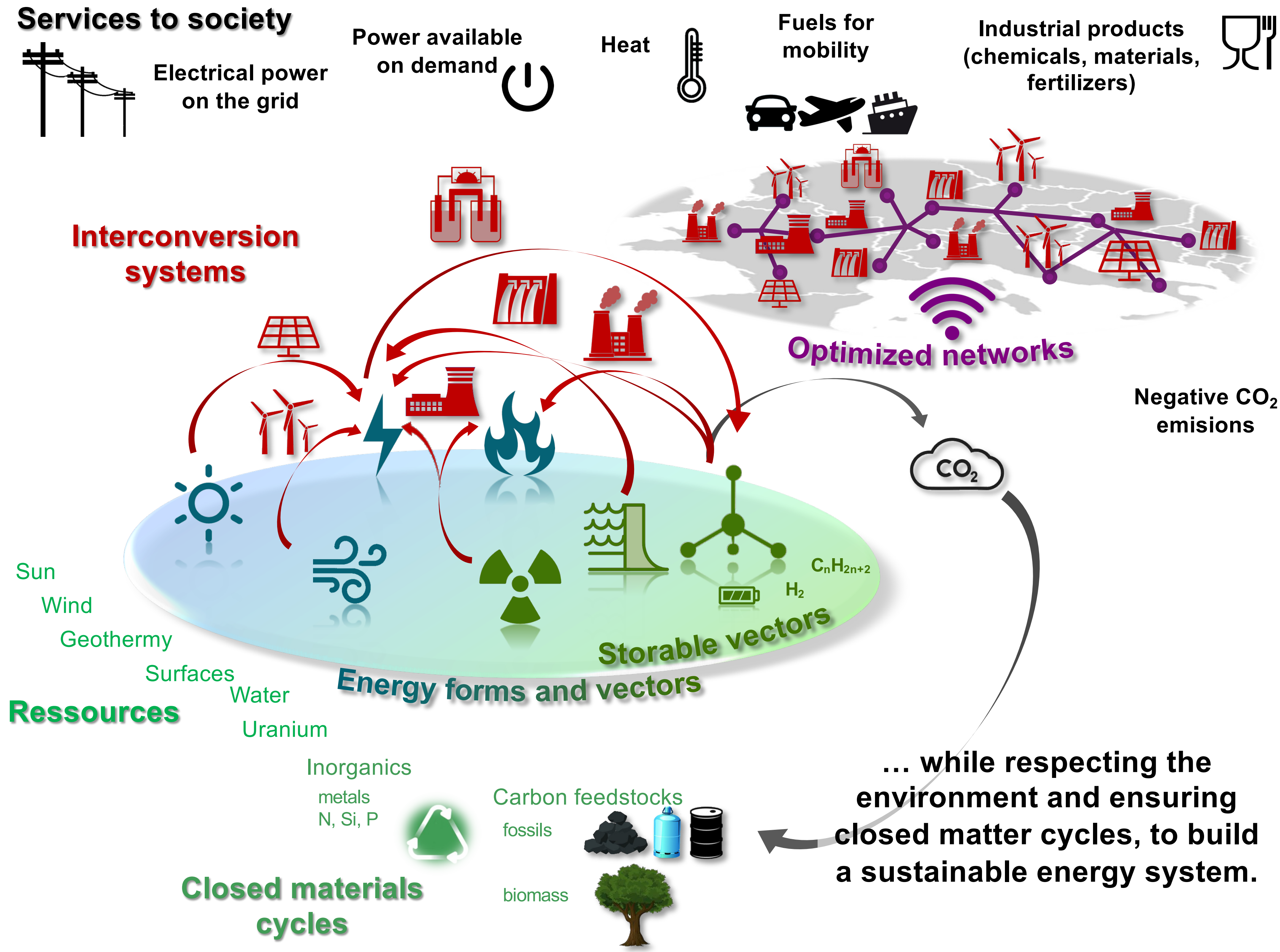
metals
N, Si, P
Carbon feedstocks
fossils
biomass
… to form a multi-vectors and multi-networks energy system to be optimized…


Services to society
Electrical power on the grid
Power available on demand
Heat
Fuels for mobility
Industrial products (chemicals, materials, fertilizers)
Interconversion systems
Optimized networks
Negative CO_2 emisions
CO_2
C_nH_{2n+2}
H_2
Storable vectors
Energy forms and vectors
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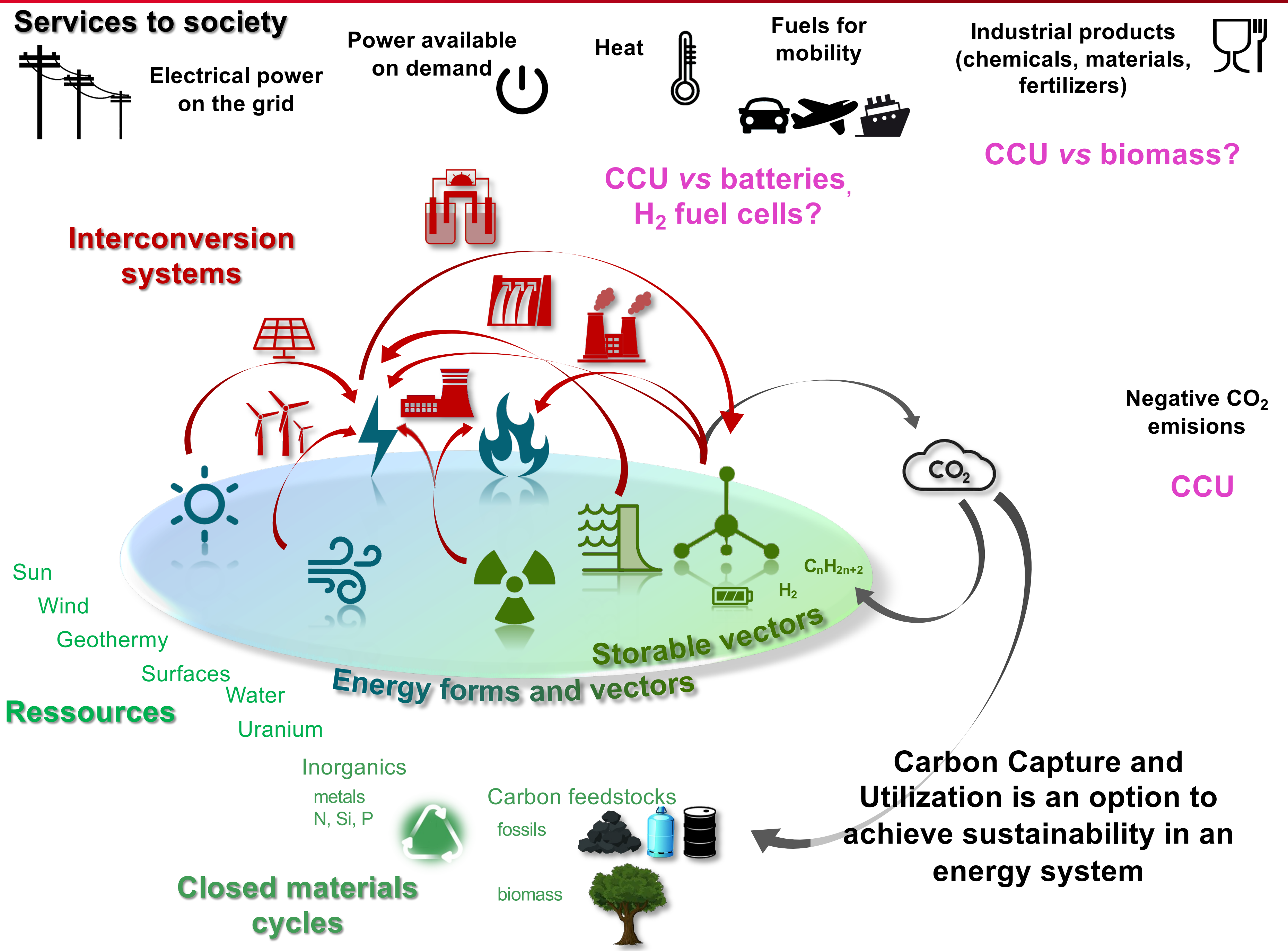
Ressources
Inorganics
metals
N, Si, P
Carbon feedstocks
fossils
biomass
Closed materials cycles
… while respecting the environment and ensuring closed matter cycles, to build a sustainable energy system.



Services to society
Electrical power on the grid
Power available on demand
Heat
Fuels for mobility
Industrial products (chemicals, materials, fertilizers)
CCU vs biomass?
CCU vs batteries, H_2 fuel cells?
Interconversion systems
Negative CO_2 emisions
CO_2
CCU
C_nH_{2n+2}
H_2
Storable vectors
Energy forms and vectors
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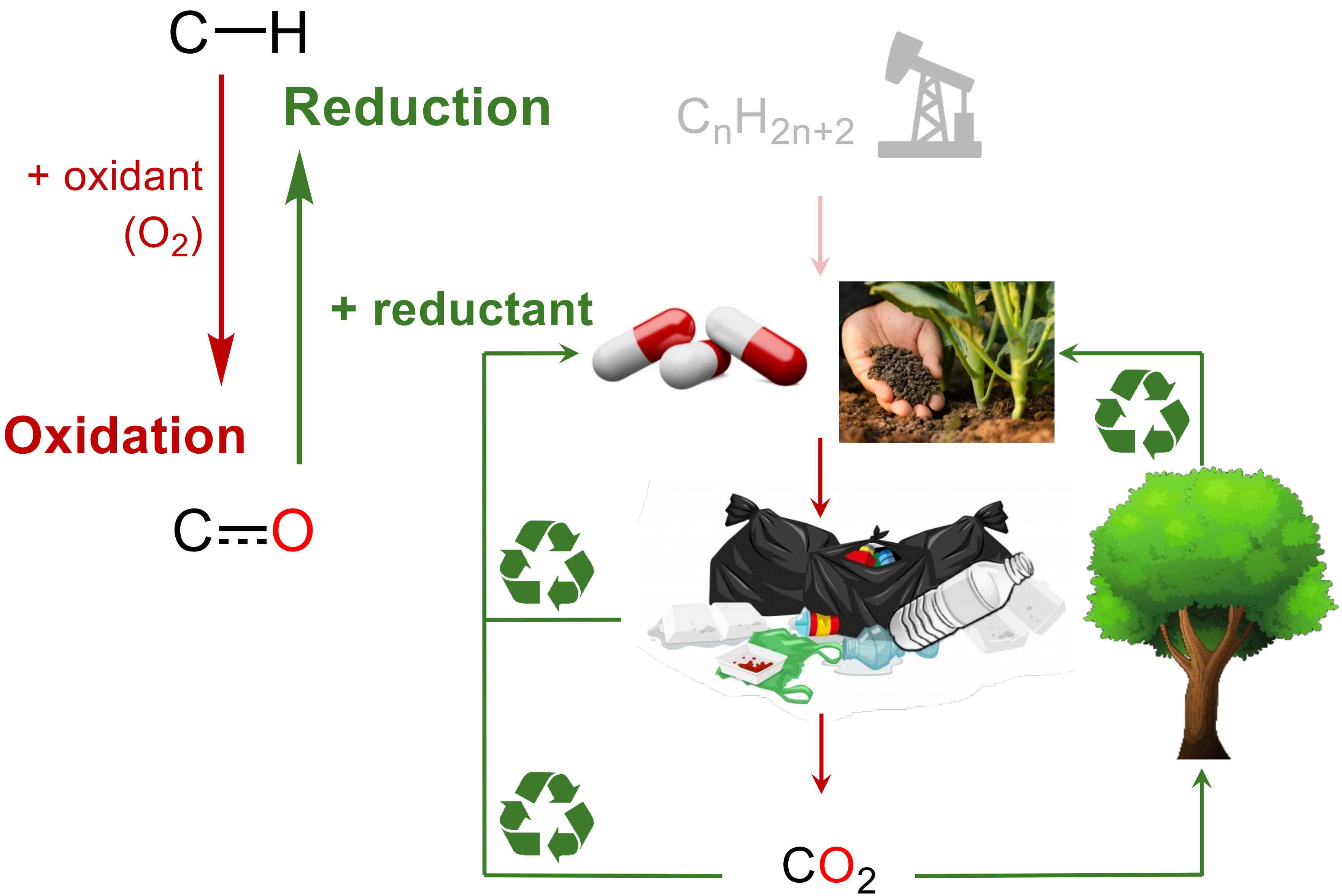
Carbon feedstocks
fossils
biomass
Closed materials cycles
Carbon Capture and Utilization is an option to achieve sustainability in an energy system

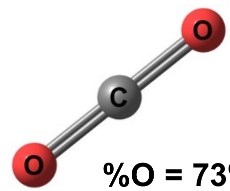
A CHANGE OF PARADIGM



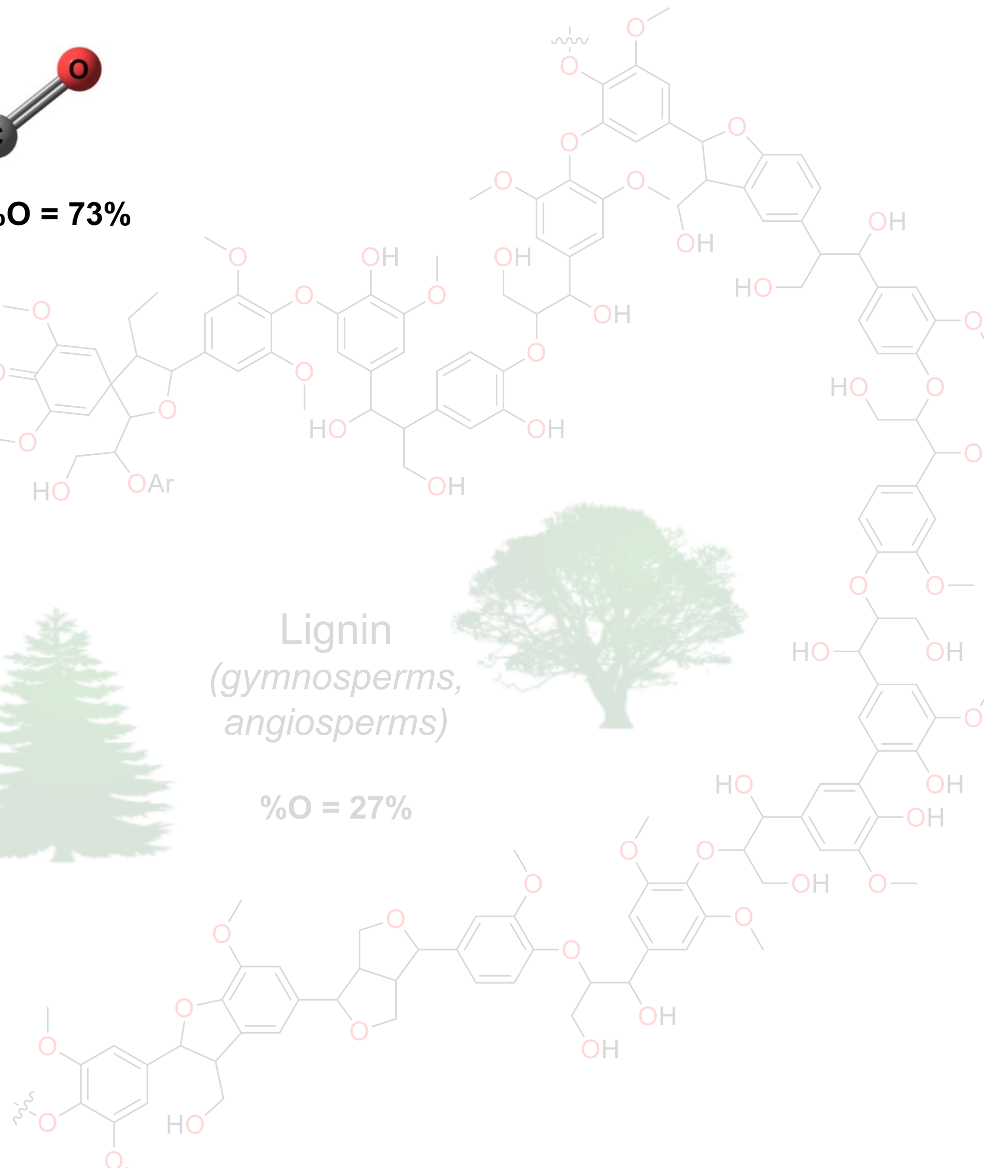
RENEWABLE CARBON FEEDSTOCKS

Saccharose
(beetroot)

%O = 27%



%O = 73%



Lignin
(gymnosperms, angiosperms)

%O = 27%

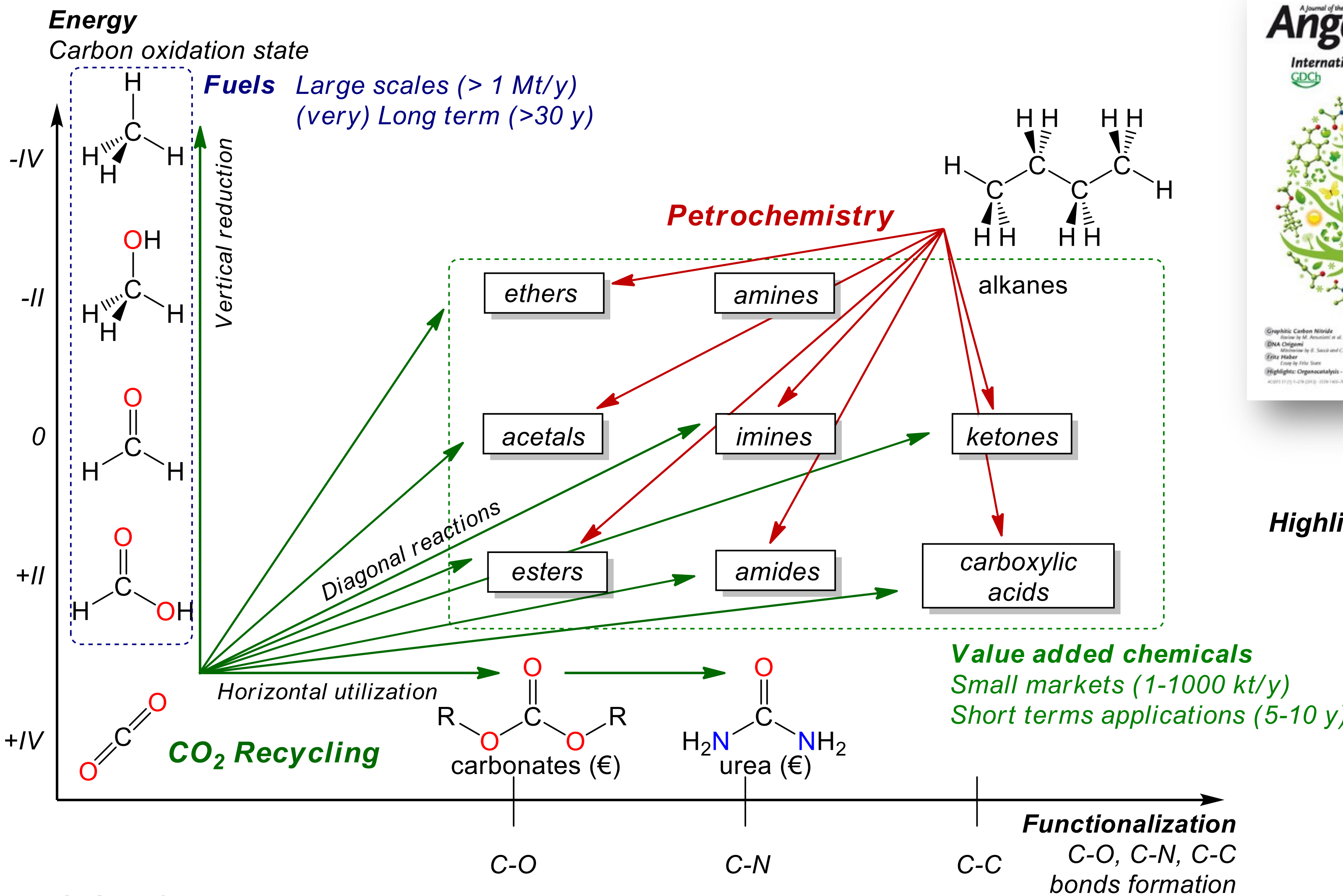
D-catechin
(Senegalia catechu)

%O = 33%

E. Adler, *Wood Sci. Technol.* **1977**, *11*, 169

DE LA RECHERCHE À L'INDUSTRIE

VARIOUS OPPORTUNITIES TO CO_2 RECYCLING…

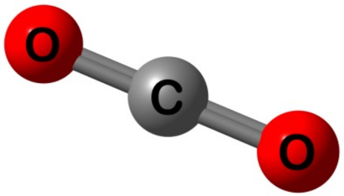


COVER
VIP Paper
Highlighted in Nature

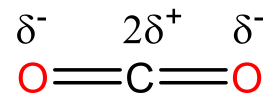
CO_2 functionalization and reduction steps coupled in a single process

Cantat *et al.*, *Angew. Chem. Int. Ed.* **2012**, *51*, 187.

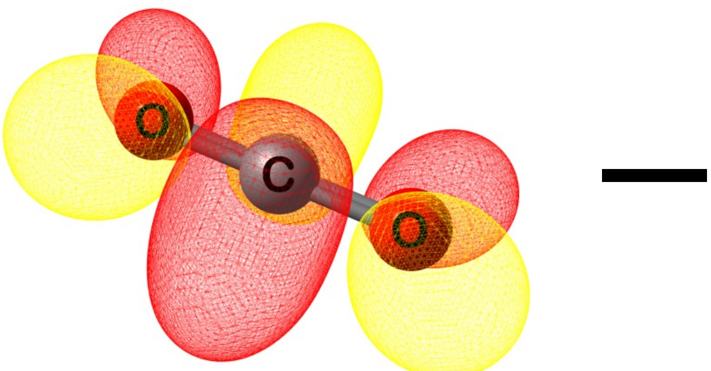
CO_2 STABILITY



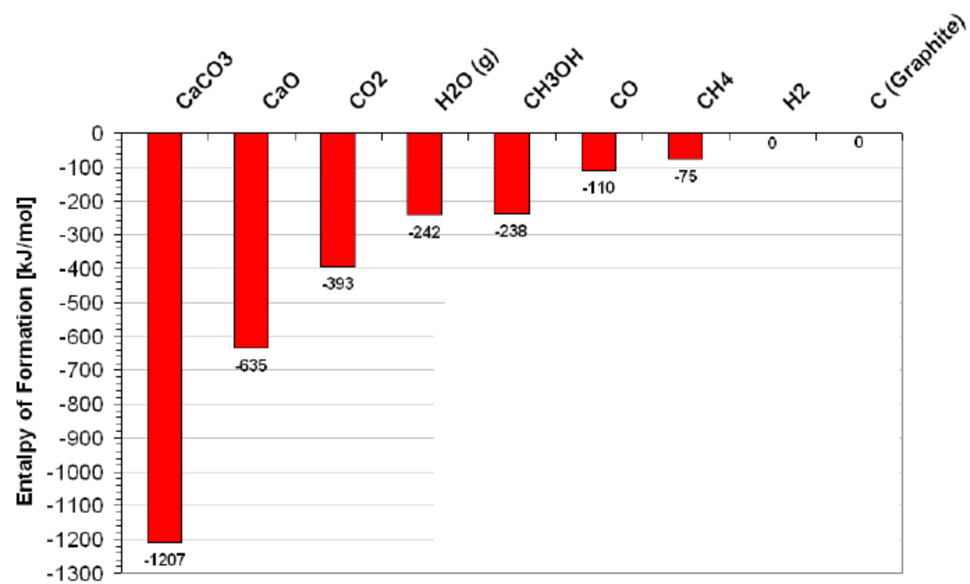
C-O: 1.16 Å

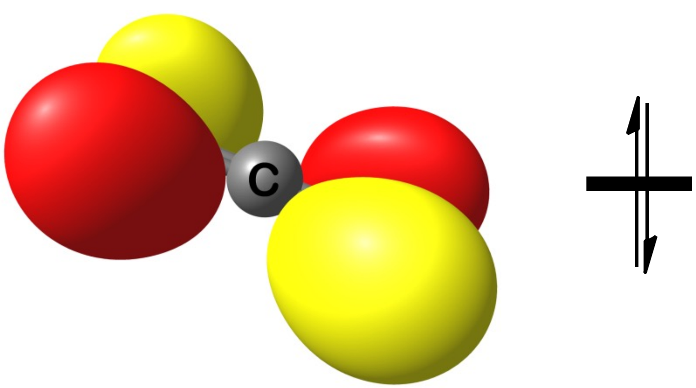


- Non-polar
- Electrophilic at C (Lewis acid)
- Nucleophilic at O (Lewis base)



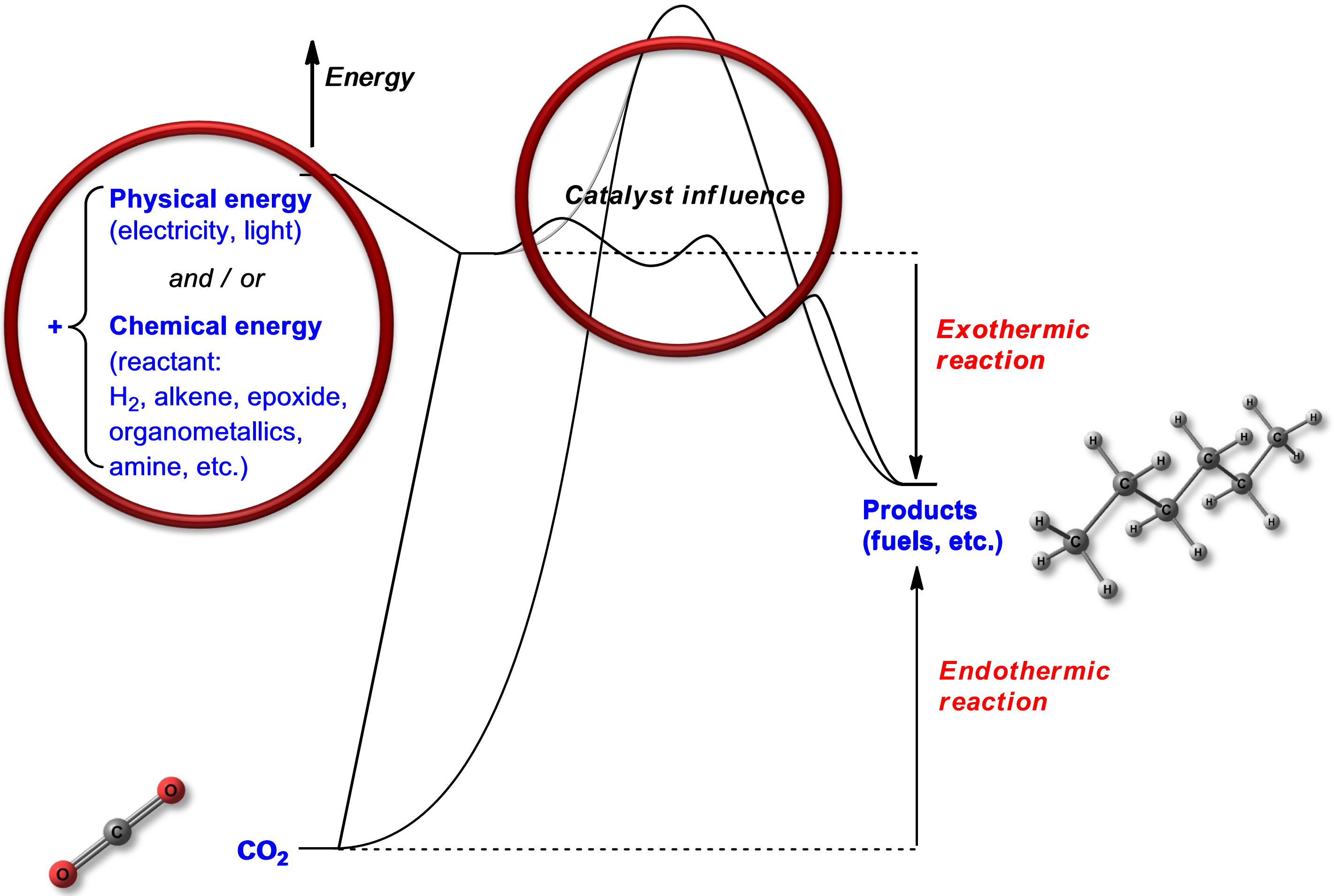
LUMO
$2\pi_u$





HOMO
$1\pi_g$

CHEMICAL TRANSFORMATION OF CO_2

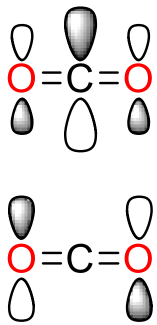


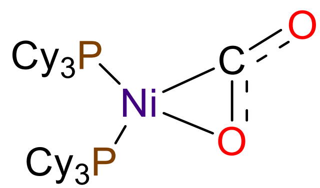
Two energetic challenges: thermodynamic **and** kinetic

CO_2 ACTIVATION BY TRANSITION METALS

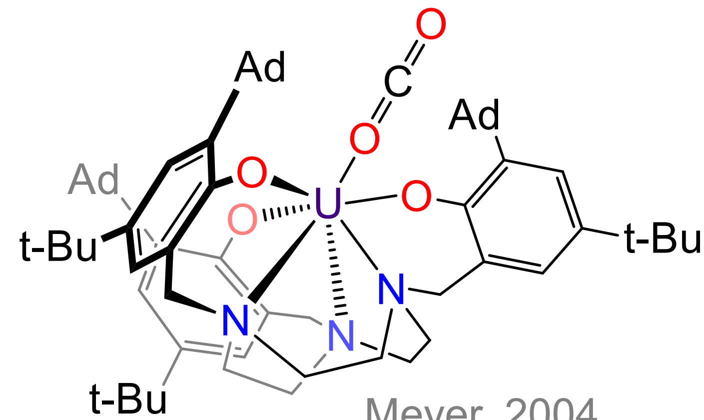
LUMO → Lewis acid (at C)

HOMO → Lewis base (at O)

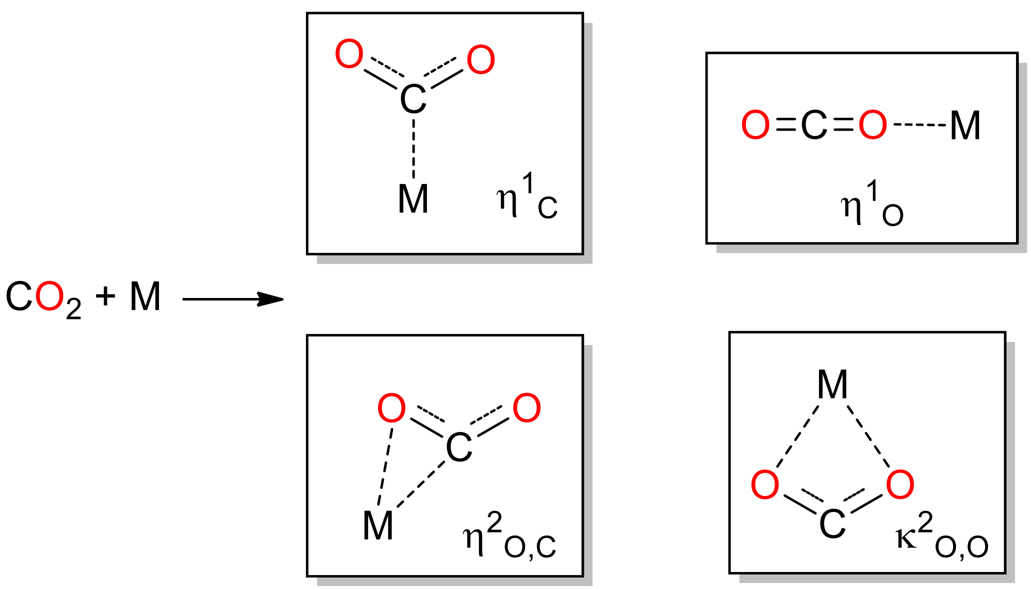




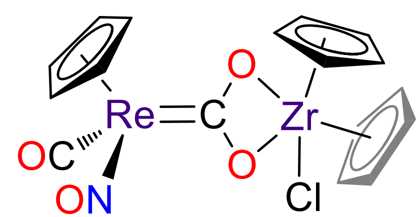
Aresta, 1975



Meyer, 2004



Bimetallic activation

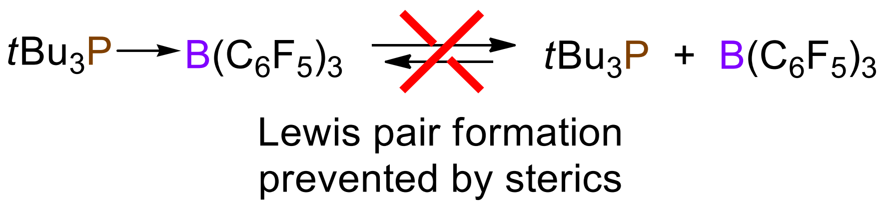


μ^2-η^3

Cutler, 1986

CO_2 ACTIVATION BY ORGANIC COMPOUNDS

- Activation by Frustrated Lewis Pairs (FLPs)

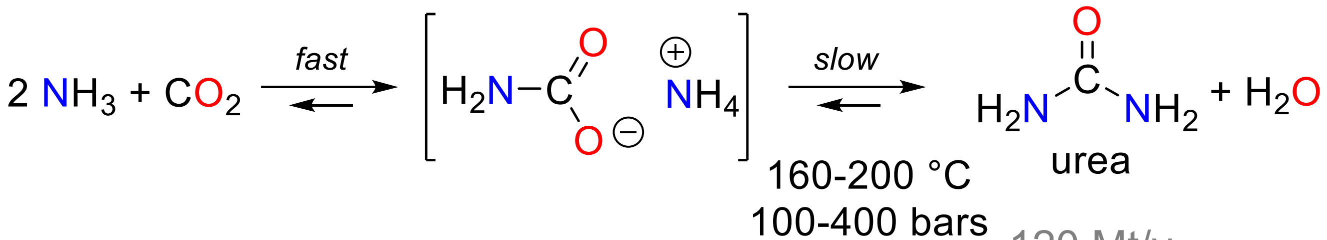


CO_2 CONVERSION IN THE INDUSTRY

INDUSTRIAL PROCESSES UTILIZING CO_2

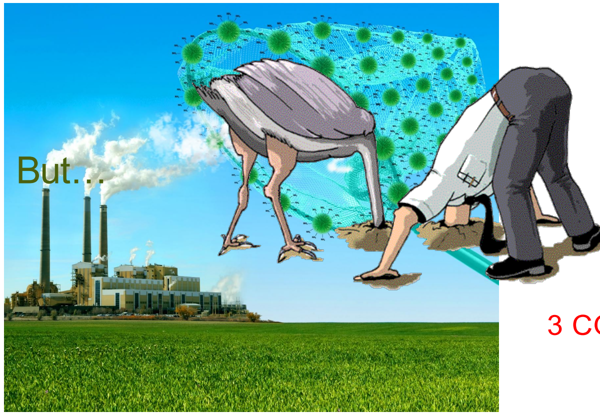
Industrial routes from CO_2

- Bosch-Meiser process for urea production



120 Mt/y

CO_2 CAPTURE AND MINERALIZATION

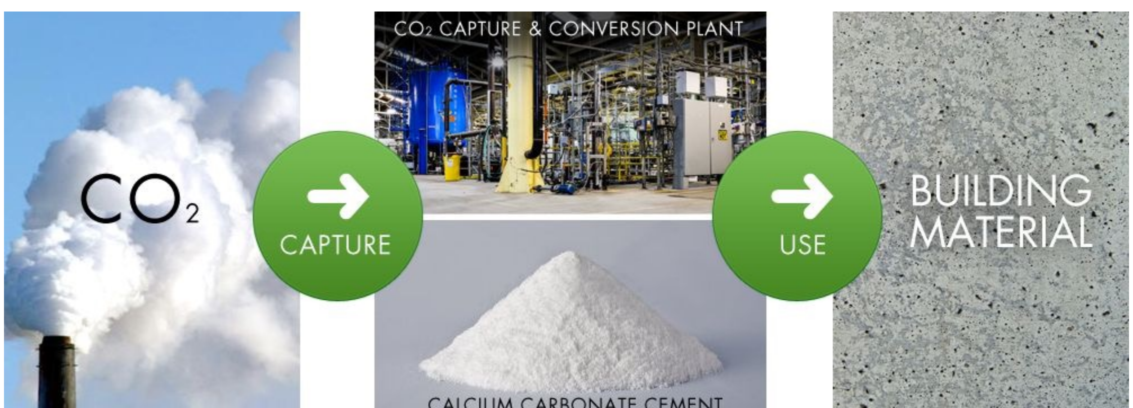


Strategy

$$CO_2\,(g) + CaSiO_3\,(s) \longrightarrow CaCO_3\,(s) + SiO_2\,(s)$$

$$3\,CO_2\,(g) + Mg_3Si_2O_5(OH)_4\,(s) \longrightarrow 3\,MgCO_3\,(s) + 2\,SiO_2\,(s) + 2\,H_2O$$

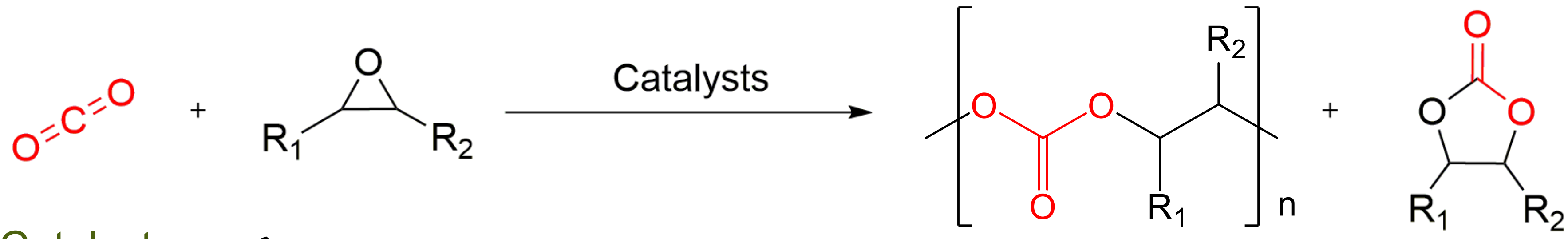
Brick and ciment made from CO_2



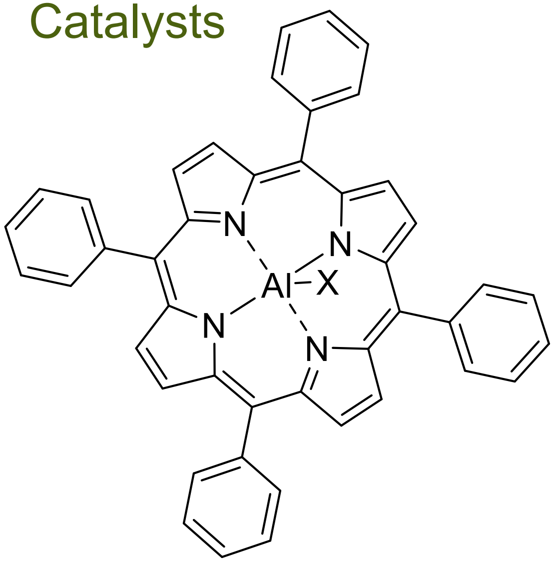
Calera

FROM CO_2 TO POLYMERS

Strategy



Catalysts



1st generation: Inoue et al (1983)

X = -Cl, $-(-O-CHR-CH_2-)_n-Cl$

$R-O^{\ominus}\ K^{\oplus}$

+

BEt_3

Metal free catalyst

$Zn_3[Co(CN)_6]_2 \cdot aZnCl_2$

Industrial catalyst

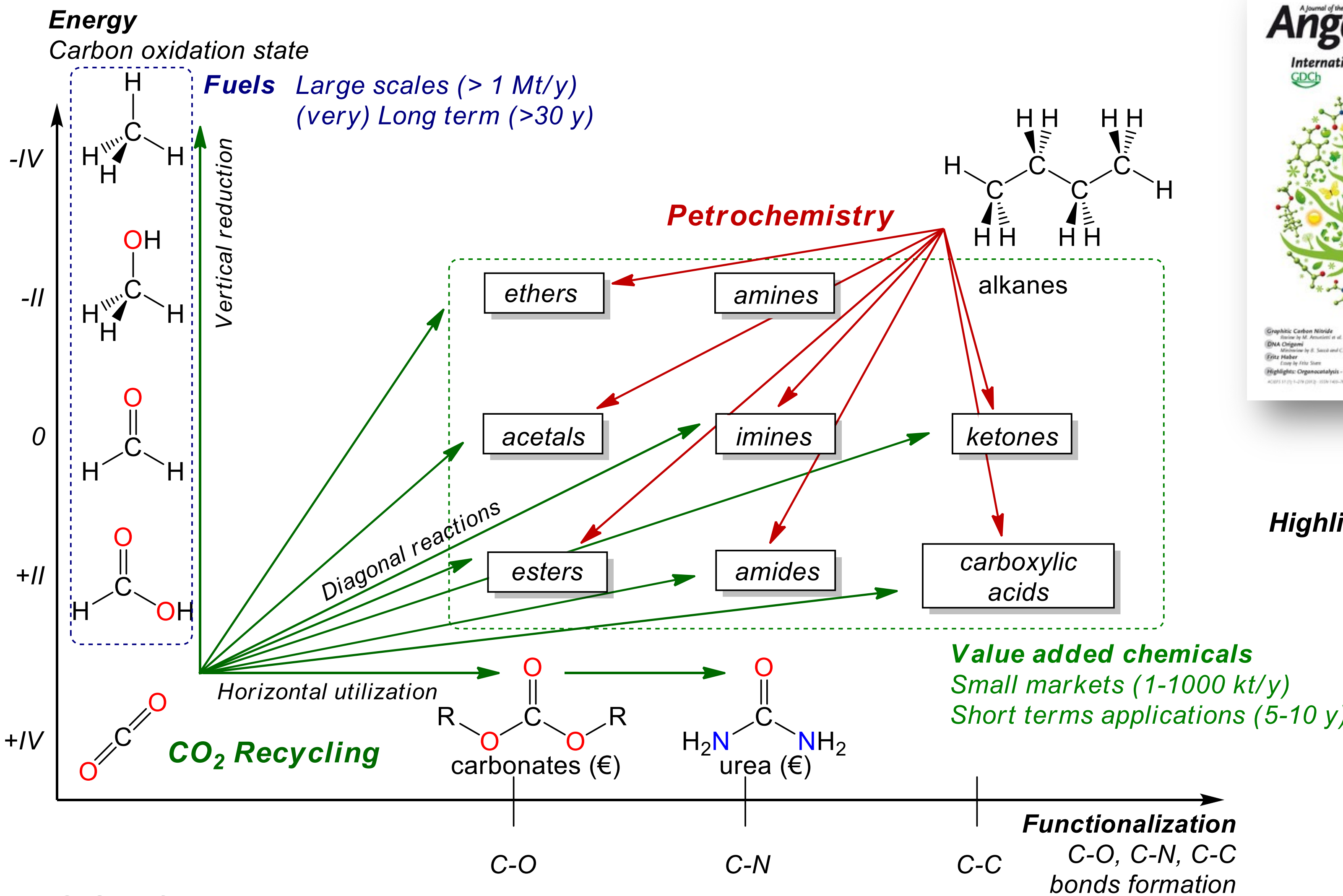
Double metal cyanide

covestro

J. Am. Chem. Soc., Vol. 105, No. 5, 1983

J. Am. Chem. Soc., 2016, 138, 11117

VARIOUS OPPORTUNITIES TO CO_2 RECYCLING…



COVER
VIP Paper
Highlighted in Nature

CO_2 functionalization and reduction steps coupled in a single process

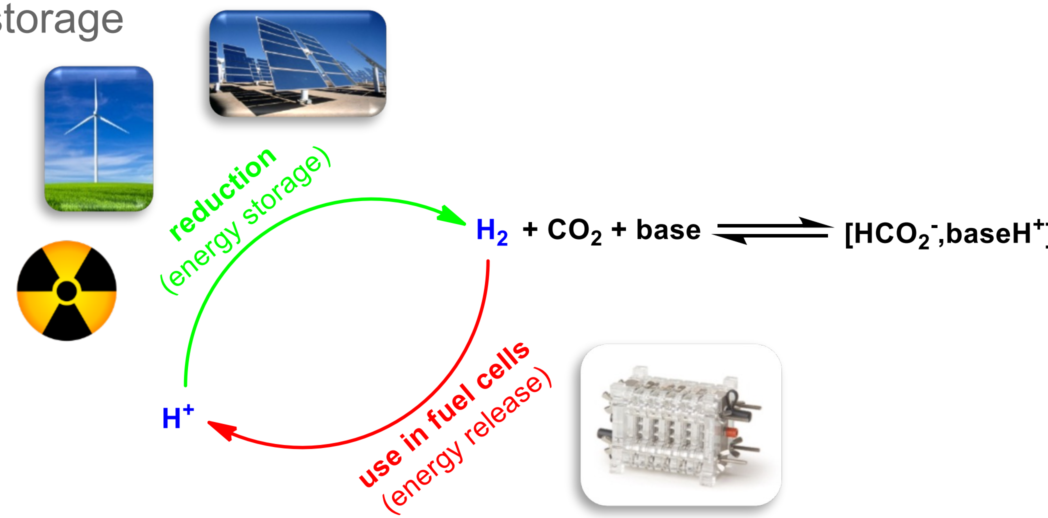
Cantat *et al.*, *Angew. Chem. Int. Ed.* **2012**, *51*, 187.

CO_2 REDUCTION TO FUELS

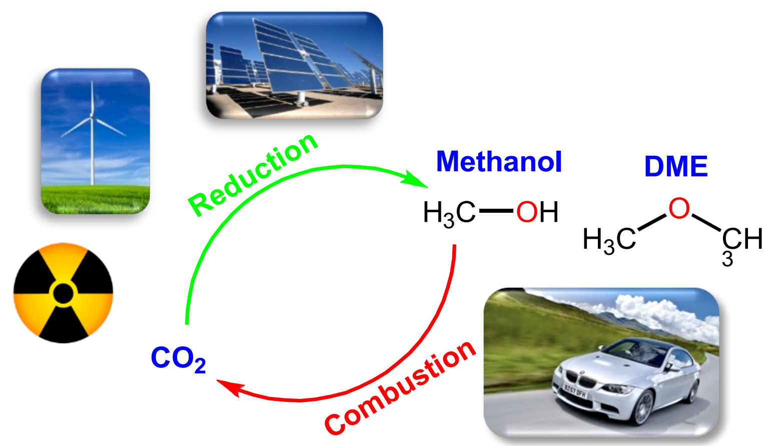
CO_2 FOR ENERGY STORAGE

CO_2 reduction: recycling to fuels

- CO_2 hydrogenation for hydrogen storage
  - CO_2 to formic acid
  - CO_2 to methanol

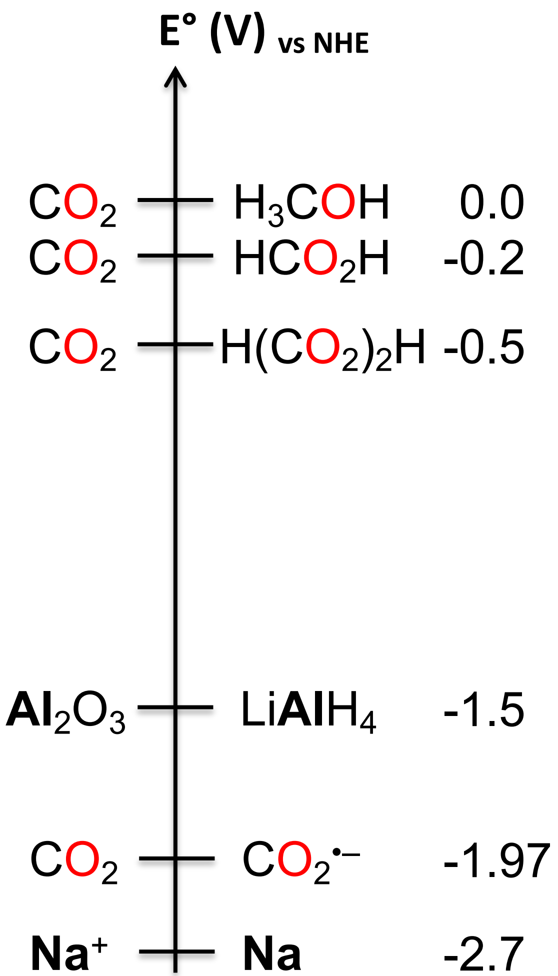


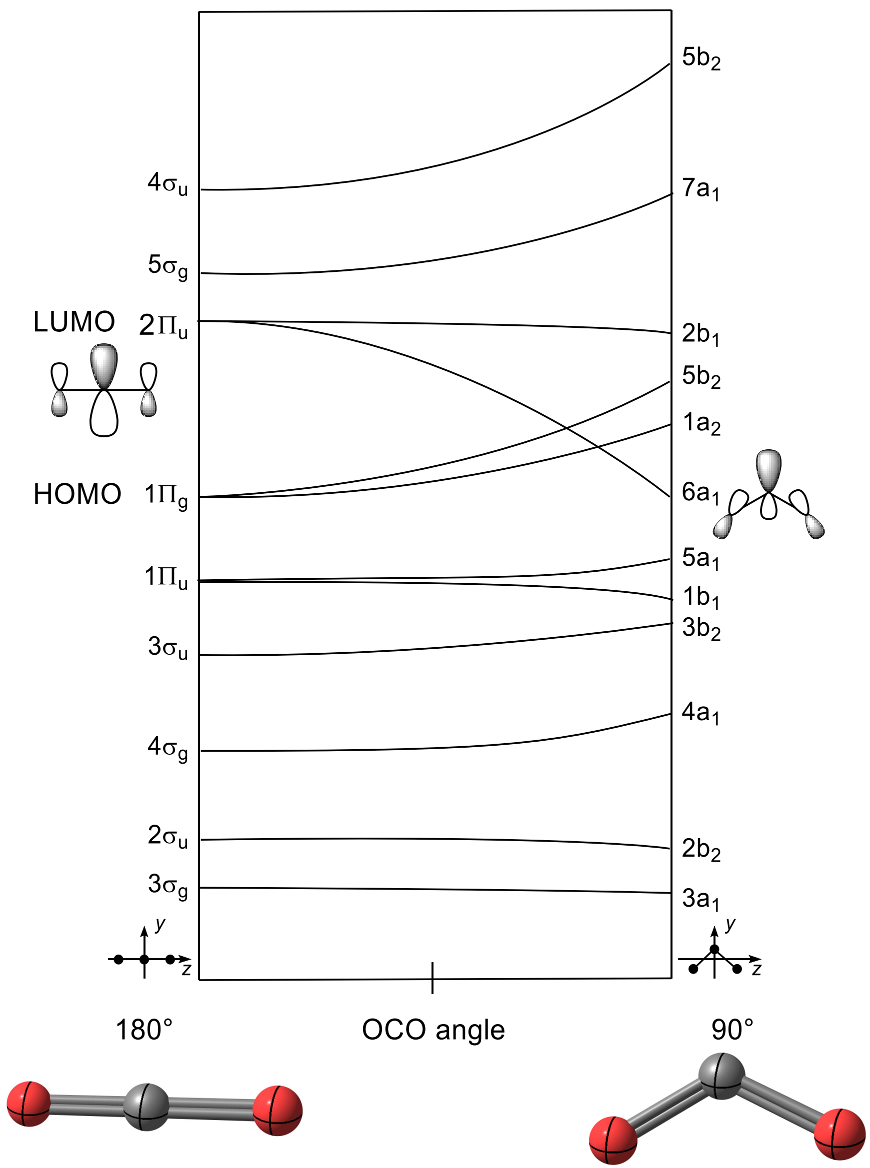
- CO_2 electro- and photoelectro-catalytic reduction to CO, formic acid, methanol, etc.



CO_2 REDUCTION: THERMODYNAMICS

Thermodynamics

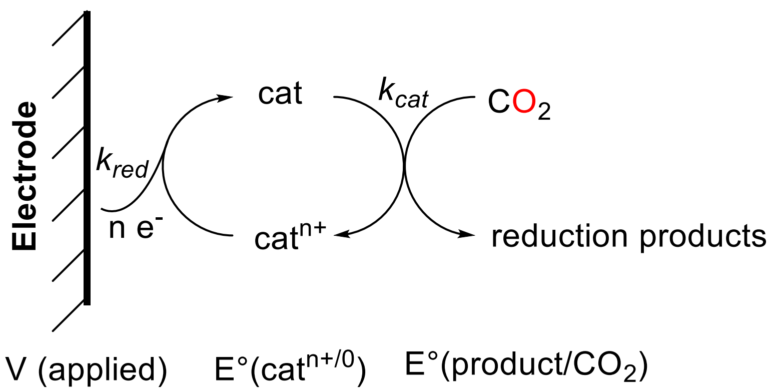




Cantat *et al.*, *ACS Catal.* **2017**, *7*, 2107
Savéant *et al.*, *Chem. Soc. Rev.* **2013**, *42*, 2423

CO_2 ELECTROREDUCTION

Principle of CO_2 electroreduction



Multi-electron reduction of CO_2 in water (pH=7) vs. SCE

$CO_2 + e^- \longrightarrow CO_2^{\bullet -}$ E° = -1.90 V

$CO_2 + 2\,H^+ + 2\,e^- \longrightarrow CO + H_2O$ E° = -0.76 V

$CO_2 + 2\,H^+ + 2\,e^- \longrightarrow HCOOH$ E° = -0.85 V

$CO_2 + 4\,H^+ + 4\,e^- \longrightarrow HCOH + H_2O$ E° = -0.72 V

$CO_2 + 6\,H^+ + 6\,e^- \longrightarrow CH_3OH + H_2O$ E° = -0.62V

$CO_2 + 8\,H^+ + 8\,e^- \longrightarrow CH_4 + 2\,H_2O$ E° = -0.48 V

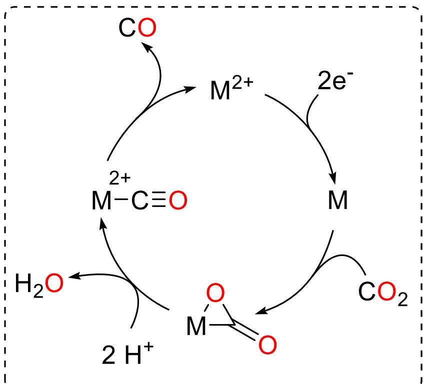
$2\,H^+ + 2\,e^- \longrightarrow H_2$ E° = -0.41 V

Review: Kubiak et al., *Chem. Soc. Rev.* **2009**, *38*, 89

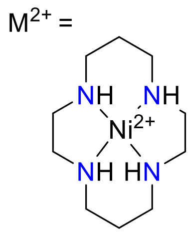
CO_2 ELECTROREDUCTION TO CO

$$CO_2 + 2\,H^+ + 2\,e^- \longrightarrow CO + H_2O \qquad E° = -0.76\ V$$

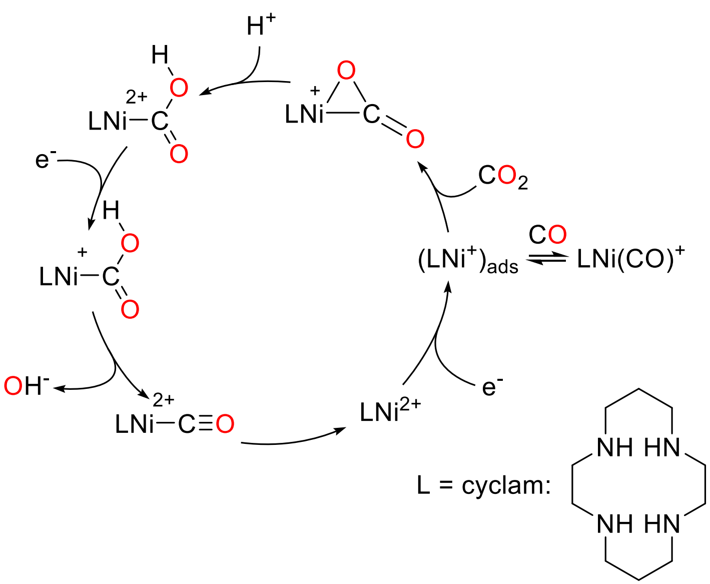
Mechanistic scheme

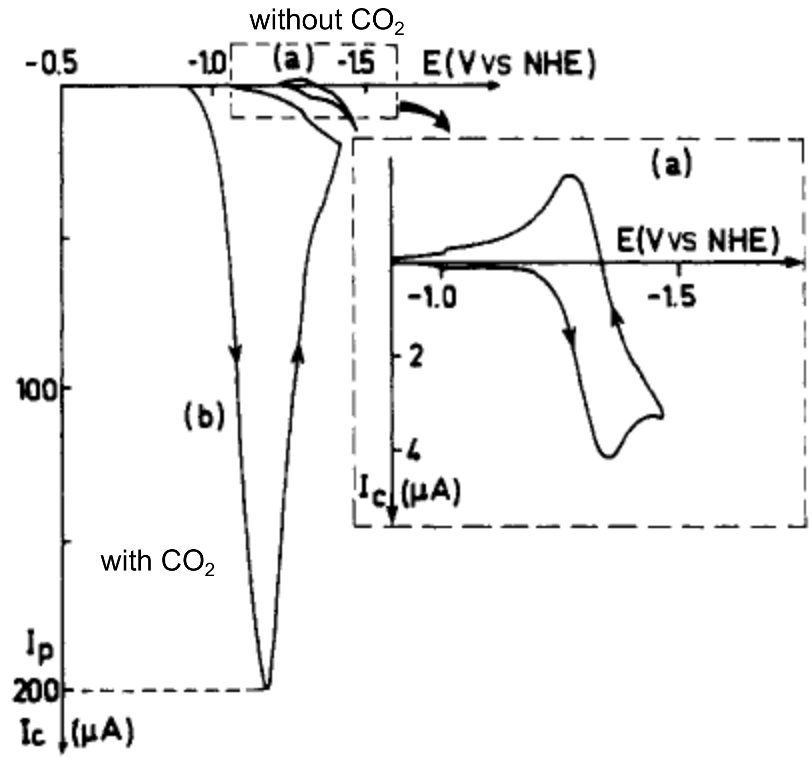


Example:



Sauvage, 1984





Voltammogram for the electroreduction of CO_2 catalyzed by $Ni(cyclam)^{2+}$

Overpotential: $\eta = 0.55$ V (V = -1.31 V)

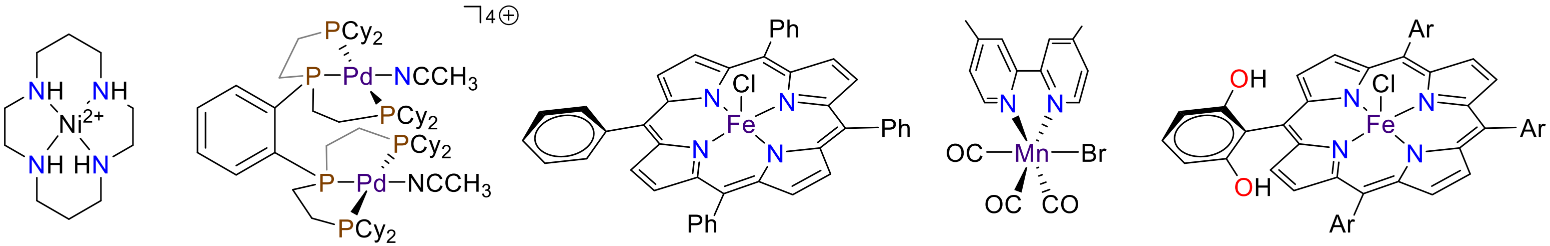
TurnOver Frequency: TOF = 1250 s^{-1}

Sauvage et al. *JACS*, **1986**, *108*, 7460

CO_2 ELECTROREDUCTION TO CO

Improved catalysts and performances

$CO_2 + 2\,H^+ + 2\,e^- \longrightarrow CO + H_2O \qquad E° = -0.76\ V$



	Sauvage, 1984	Dubois, 1990	Savéant, 1994	Deronzier, 2011	Savéant, 2012
η (V)	0.6	0.8	0.9	0.5	0.5
log*TOF* (s^{-1})	2.2	0.7	2	-0.1	3
logTOF_0 (s^{-1}) at η = 0 V	-7.1	-7.5	-14	-8.4	-4.6

- Concomittant H_2 evolution is observed for all the catalysts
- Fine management of the local concentration of H^+ is crucial

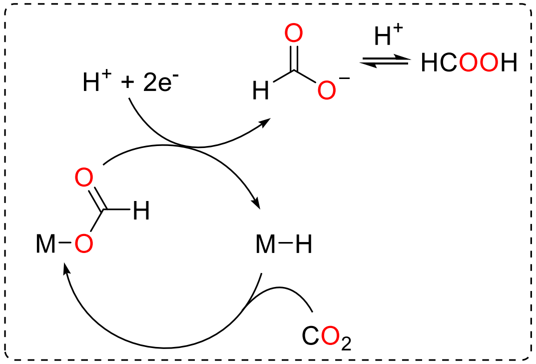
Savéant et al., *Science* **2012**, *338*, 90

CO_2 ELECTROREDUCTION TO FORMIC ACID

$CO_2 + 2\,H^+ + 2\,e^- \longrightarrow HCOOH$ $E° = -0.85\ V$

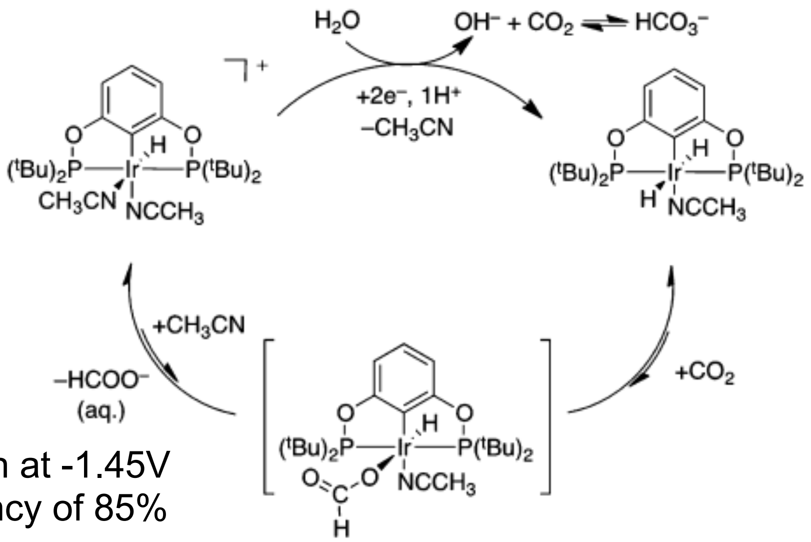
- Molecular catalysts:

Mechanistic scheme



Copper, rhodium and iridium complexes are good catalysts

Example with iridium:



Formic acid production at -1.45V with a Faraday efficiency of 85% and a TOF of 20 s^{-1}

High selectivity: Low contamination of the products with H_2 and CO

Brookhart, JACS **2012**, *134*, 5500

- Formate dehydrogenase (FDH) selectively reduces CO_2 to formate at the thermodynamic potential with a TOF of ca. 280 s^{-1}
- Industrial developments are underway, using modified copper(0) metal electrodes (Farady efficiencies >90%, overpotential ~1V)

CO_2 ELECTROREDUCTION TO METHANOL

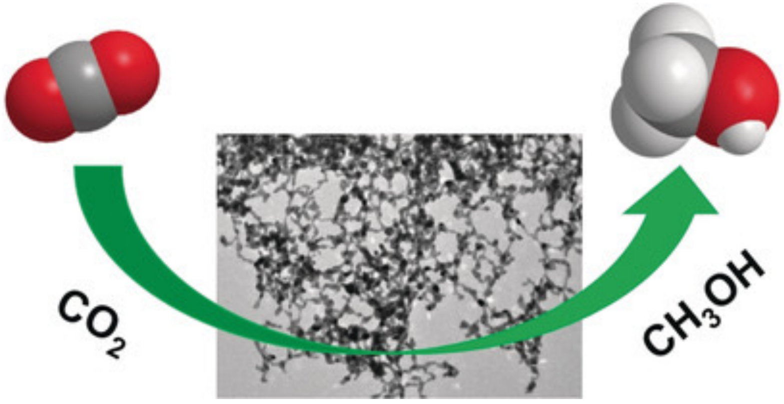
A completely different story !

$$CO_2 + 6\,H^+ + 6\,e^- \longrightarrow CH_3OH + H_2O \quad E° = -0.62V$$

- Much more difficult because of multiple H^+ and e^- transfers to synchronize

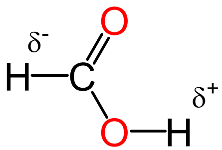
- Few successes:

Faradaic efficiency of CH_3OH production can reach 80.0% with a current density of 31.8 $mA.cm^{-2}$



Sun, Han, et al. *Angew. Chem. Int. Ed.* **2018**, *57*, 14149

CO_2 ELECTROREDUCTION TO CH_3OH VIA HCOOH

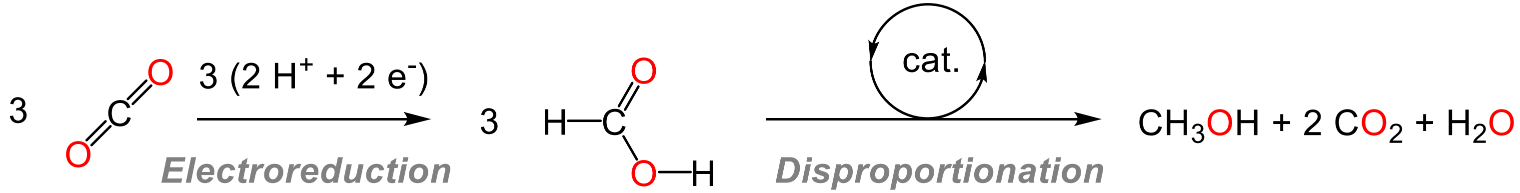


$E°(CO_2/HCOOH) = -0.61$ V

BDE(C-H) = 91 kcal/mol

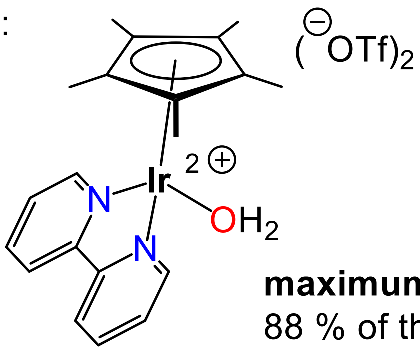
Renewable through CO_2 electrolysis

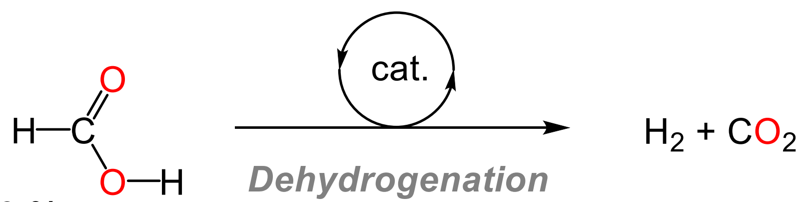
Thermodynamic
***and* kinetic advantage**



rG°(298 K) = -25.8 kcal/mol

cat.:





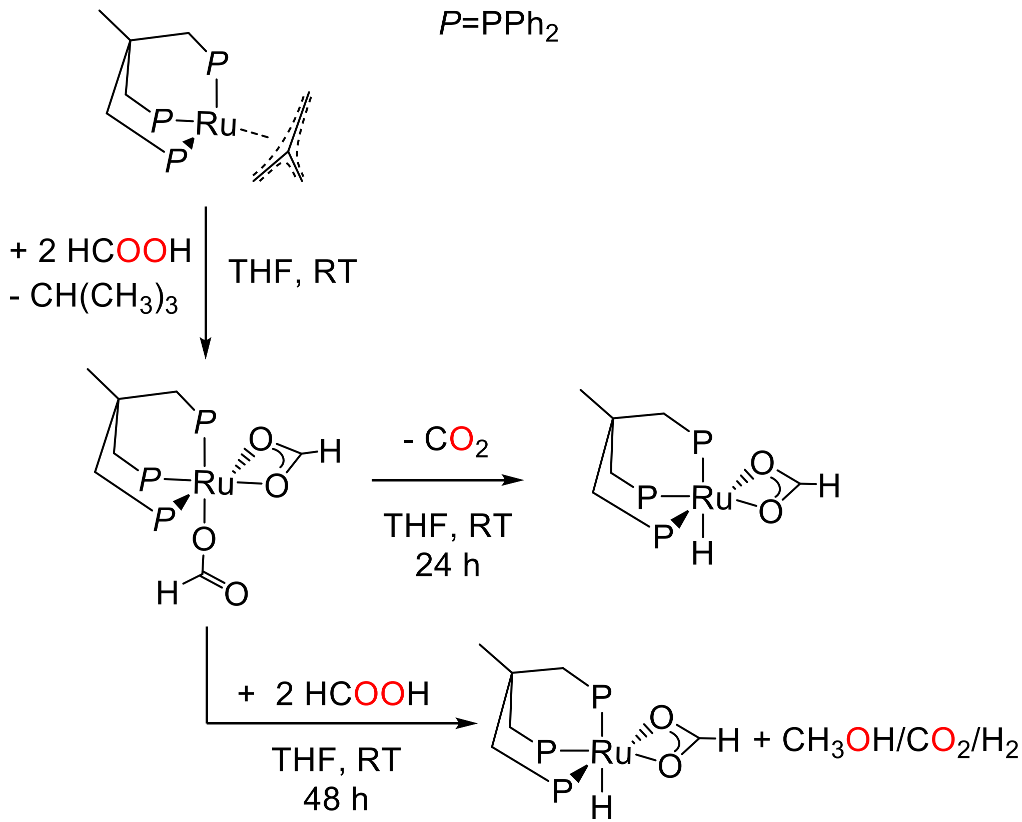
maximum CH_3OH yield = 1.9 %
88 % of the C-H bonds yield H_2

rG°(298 K) = -3.2 kcal/mol

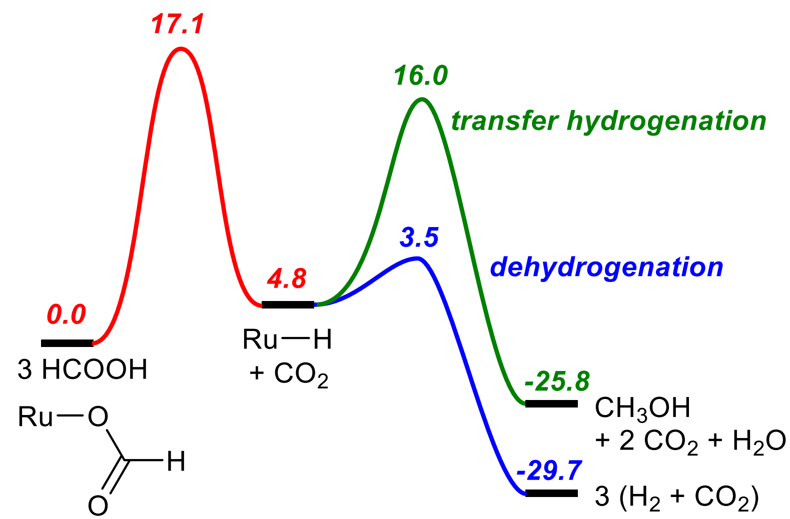
Goldberg, Miller et al., *Angew. Chem. Int. Ed.* ***2013***, *3981*

Cantat et al. *Angew. Chem. Int. Ed.* **2014**, *53*, 10466

CO_2 ELECTROREDUCTION TO CH_3OH VIA HCOOH



M06-2X/6-31+G*(H,C,O,P)+SDD(Ru) PCM(THF)

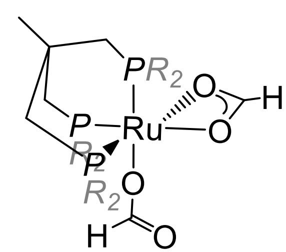


Selectivity is under thermodynamic control

$3\ HCO_2H \xrightarrow[\text{THF, 150°C, 1 h}]{\text{0.6 mol\% cat., 1.5 mol\% }CH_3SO_3H} CH_3OH + 2\ CO_2 + H_2O$

50 %

cat. =

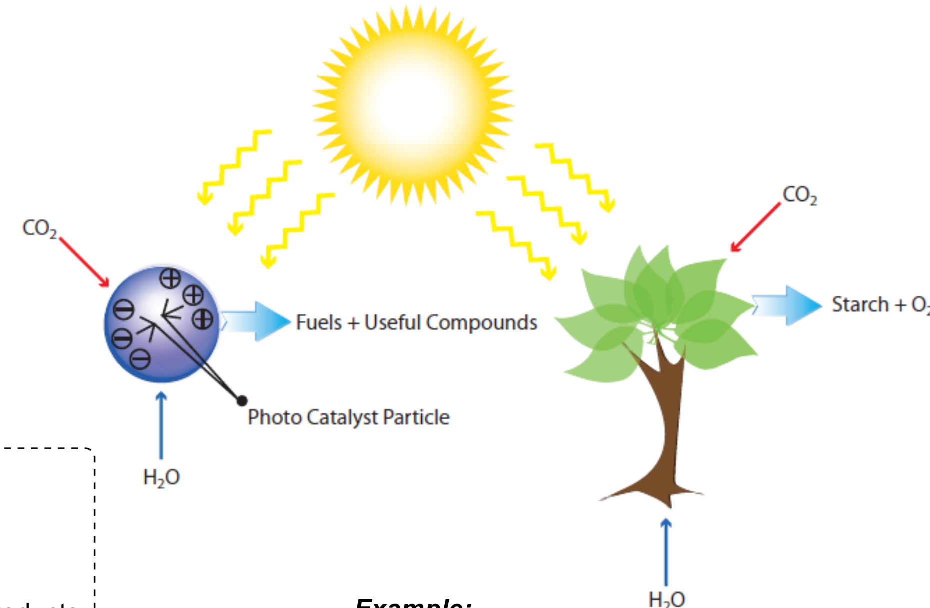


Cantat et al. *Angew. Chem. Int. Ed.* **2014**, *53*, 10466

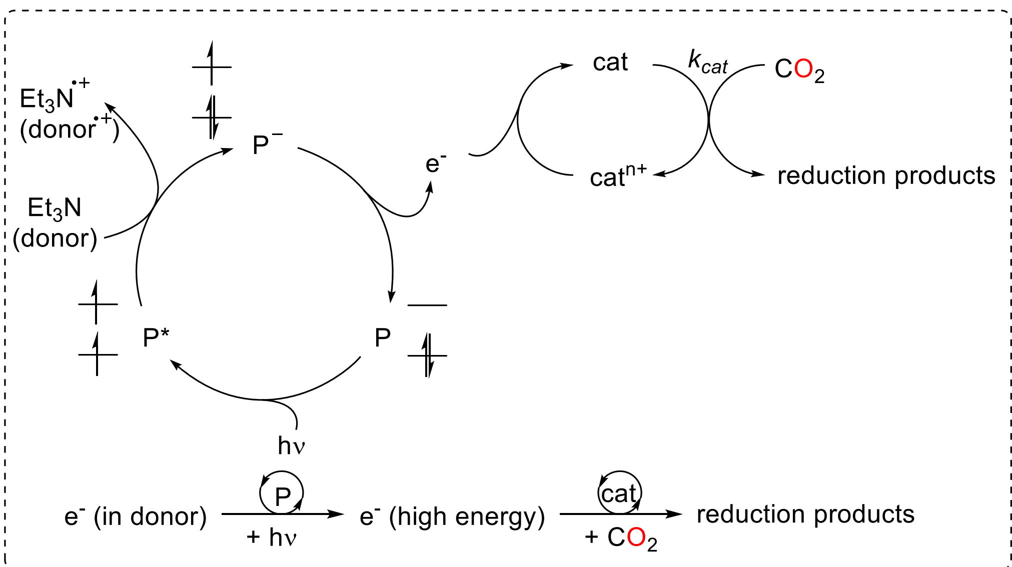
CO_2 PHOTOELECTROREDUCTION

The *dream* reaction

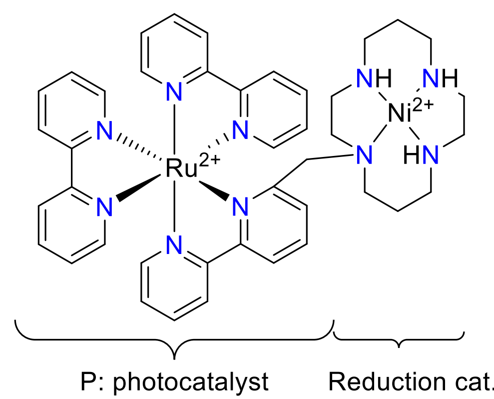
- $CO_2 + H_2O$ + light = reduction
- Artificial photosynthesis:



Mechanistic scheme



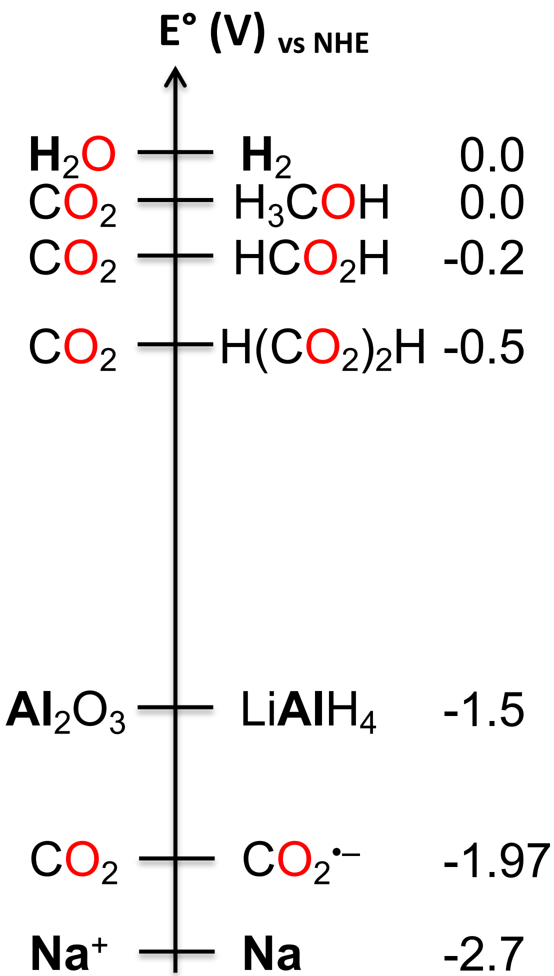
Example:



Review: Meyer, Fujita et al., *Acc. Chem. Res.* **2009**, *42, 1983*

REDUCTION OF C-O BONDS BY HYDROGENATION

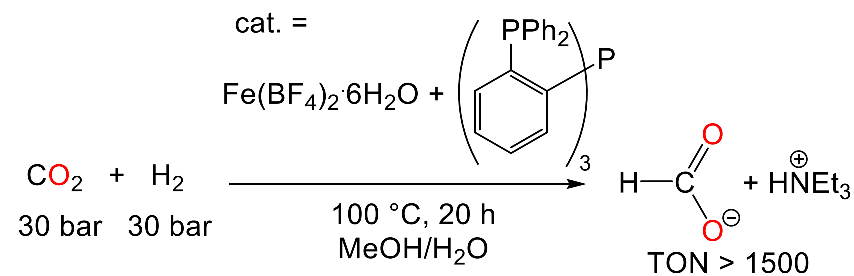
Thermodynamics



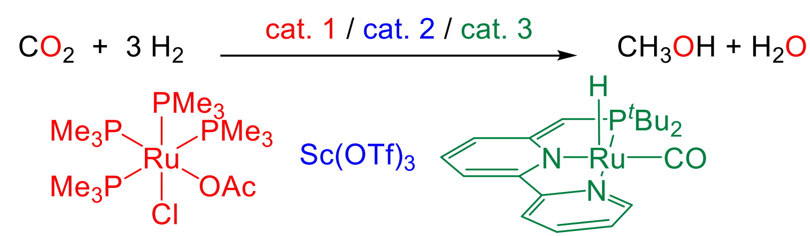
Cantat *et al.*, *ACS Catal.* **2017**, *7*, 2107
Savéant *et al.*, *Chem. Soc. Rev.* **2013**, *42*, 2423

Kinetics

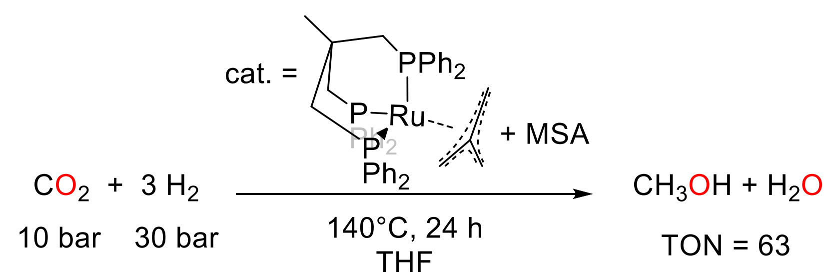
H-H Bond Dissociation Energy (BDE): 104 kcal/mol



M. Beller et al., *J. Am. Chem. Soc.* **2012**, *134*, 20701



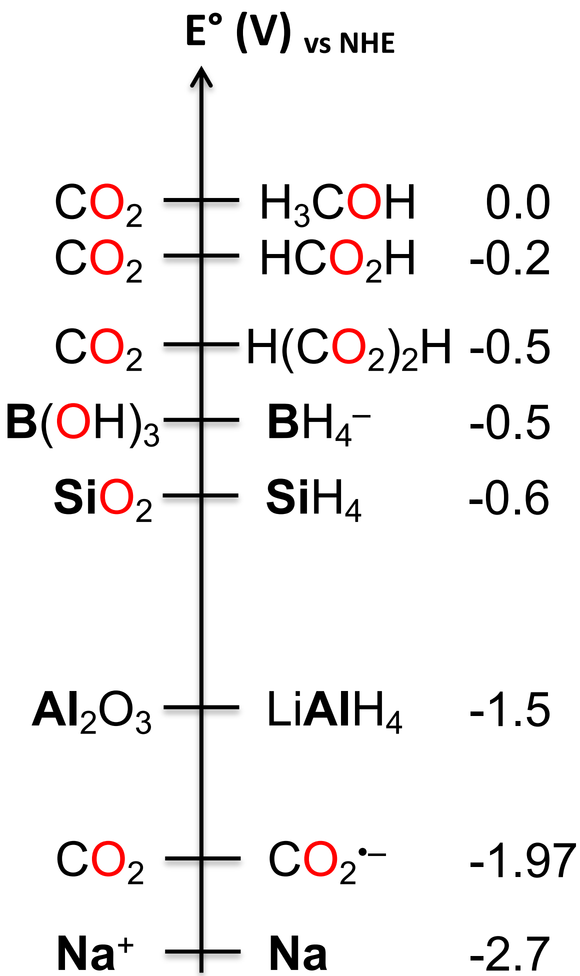
M. S. Sanford et al., *J. Am. Chem. Soc.* **2011**, *133*, 18122



W. Leitner et al., *Angew. Chem. Int. Ed.* **2012**, *51*, 7499

REDUCTION OF C-O BONDS BY HYDROSILYLATION

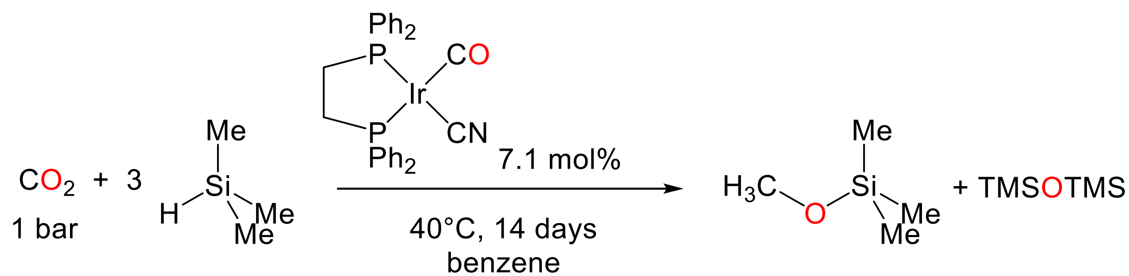
Thermodynamics



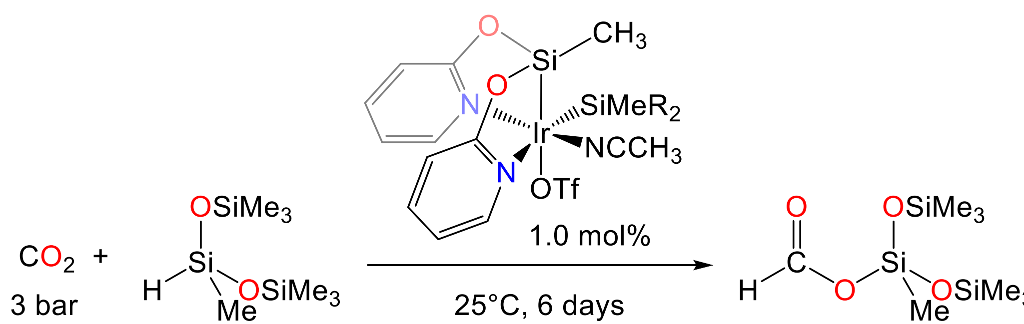
Cantat *et al.*, *ACS Catal.* **2017**, *7*, 2107
Savéant *et al.*, *Chem. Soc. Rev.* **2013**, *42*, 2423

Kinetics

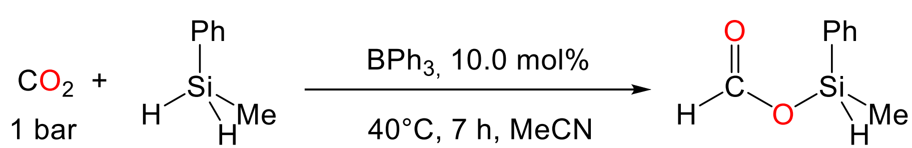
Si-H Bond Dissociation Energy (BDE): 92 kcal/mol



R. Eisenberg et al., *Organometallics* **1989**, *8*, 1822



F. J. Fernández-Alvarez, L. Oro et al., *Angew. Chem. Int. Ed.* **2012**, *51*, 12824



J. Okuda et al., *Chem. Eur. J.* **2016**, *22*, 7730

REDUCTION OF C-O BONDS BY HYDROSILYLATION

Thermodynamics

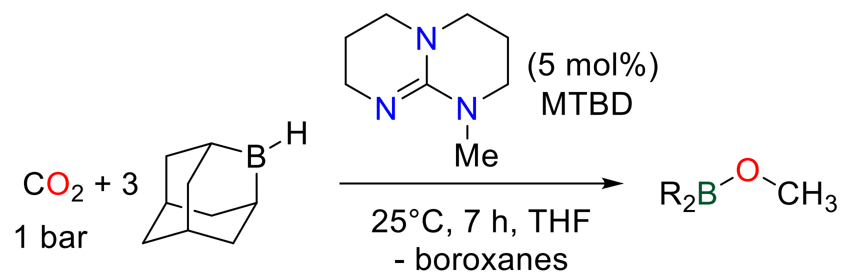
E° (V) vs NHE

		E° (V)
CO_2	H_3COH	0.0
CO_2	HCO_2H	-0.2
CO_2	$H(CO_2)_2H$	-0.5
$B(OH)_3$	**BH_3**	-0.6
SiO_2	**SiH_4**	-0.6
Al_2O_3	$LiAlH_4$	-1.5
Na^+	**Na**	-2.7

Kinetics

Si-H Bond Dissociation Energy (BDE): 92 kcal/mol

B-H Bond Dissociation Energy (BDE): 78 kcal/mol



Cantat et al., *Chem. Eur. J.* **2014**, *20*, 7098.
Patent WO2014162266 (2013/04)

REDUCTION OF C-O BONDS BY HYDROSILYLATION

Thermodynamics

E° (V) vs NHE

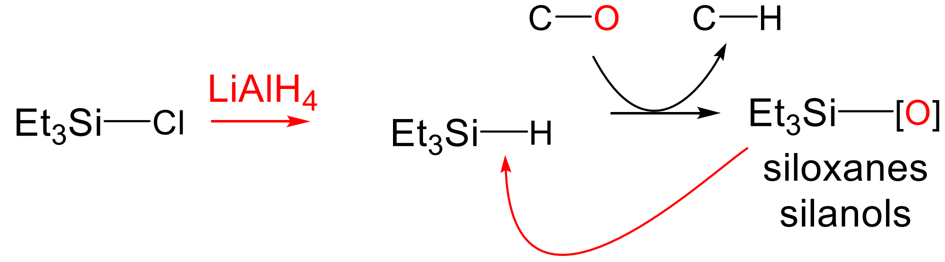
		E° (V)
CO_2	H_3COH	0.0
CO_2	HCO_2H	-0.2
CO_2	$H(CO_2)_2H$	-0.5
$B(OH)_3$	**BH_3**	-0.6
SiO_2	**SiH_4**	-0.6
Al_2O_3	$LiAlH_4$	-1.5
Na^+	**Na**	-2.7

Kinetics

Si-H Bond Dissociation Energy (BDE): 92 kcal/mol

B-H Bond Dissociation Energy (BDE): 78 kcal/mol

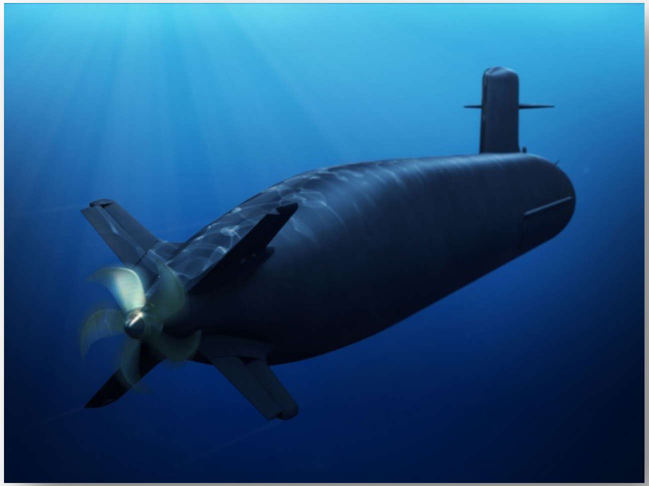
Generation and recyclability



H_2	R_3SiH, R_2BH
☑ Energy efficiency	☑ Energy efficiency
☒ Reactivity and selectivity	☑ Reactivity and selectivity
☑ Recyclability	☒ Recyclability

CO_2 TO FUELS

Limited short terms opportunities



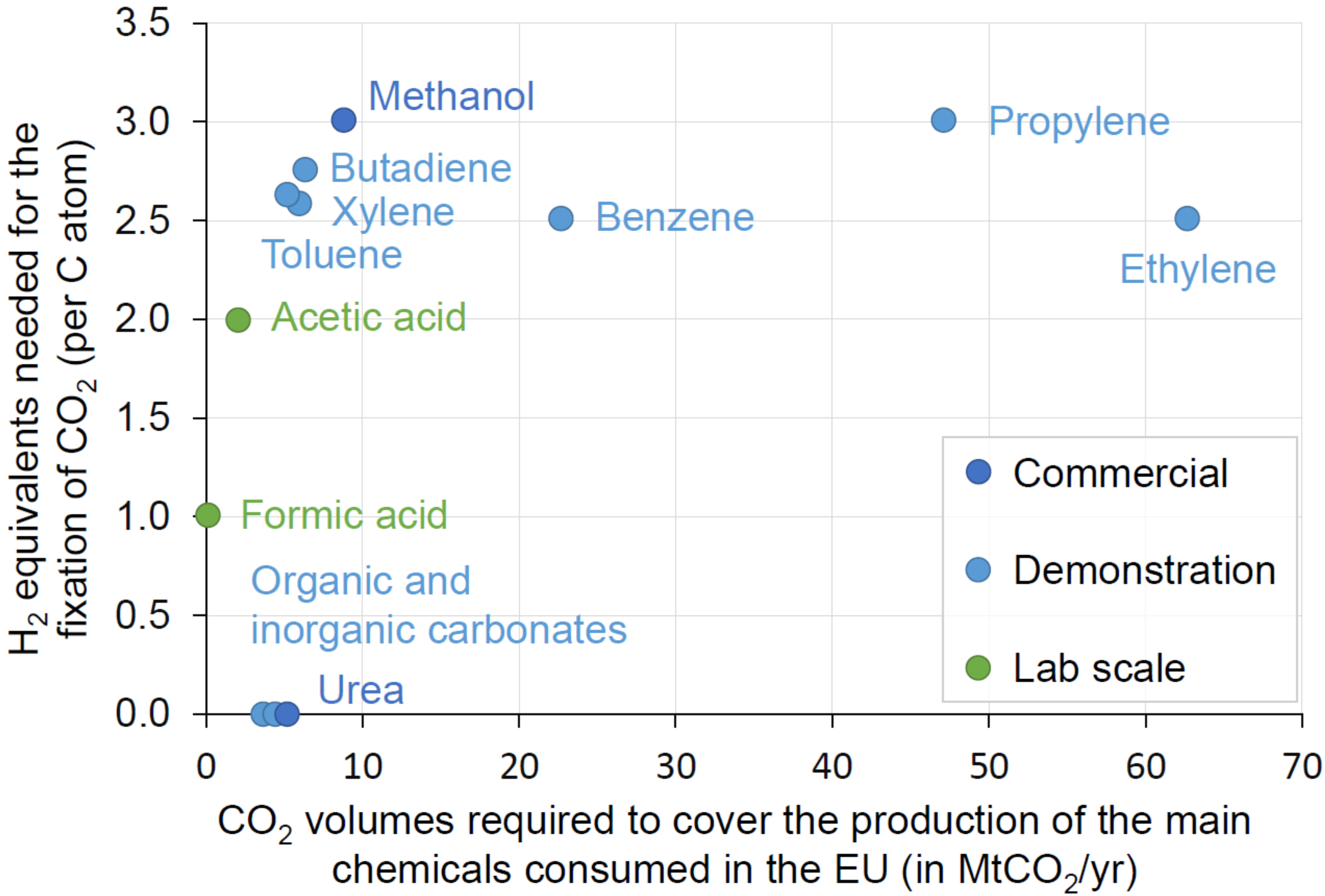
$$H_2O \longrightarrow H_2 + {}^1/_2\, O_2$$

$$H_2 \xrightarrow{+\ CO_2} CH_3OH + H_2O$$

methanol

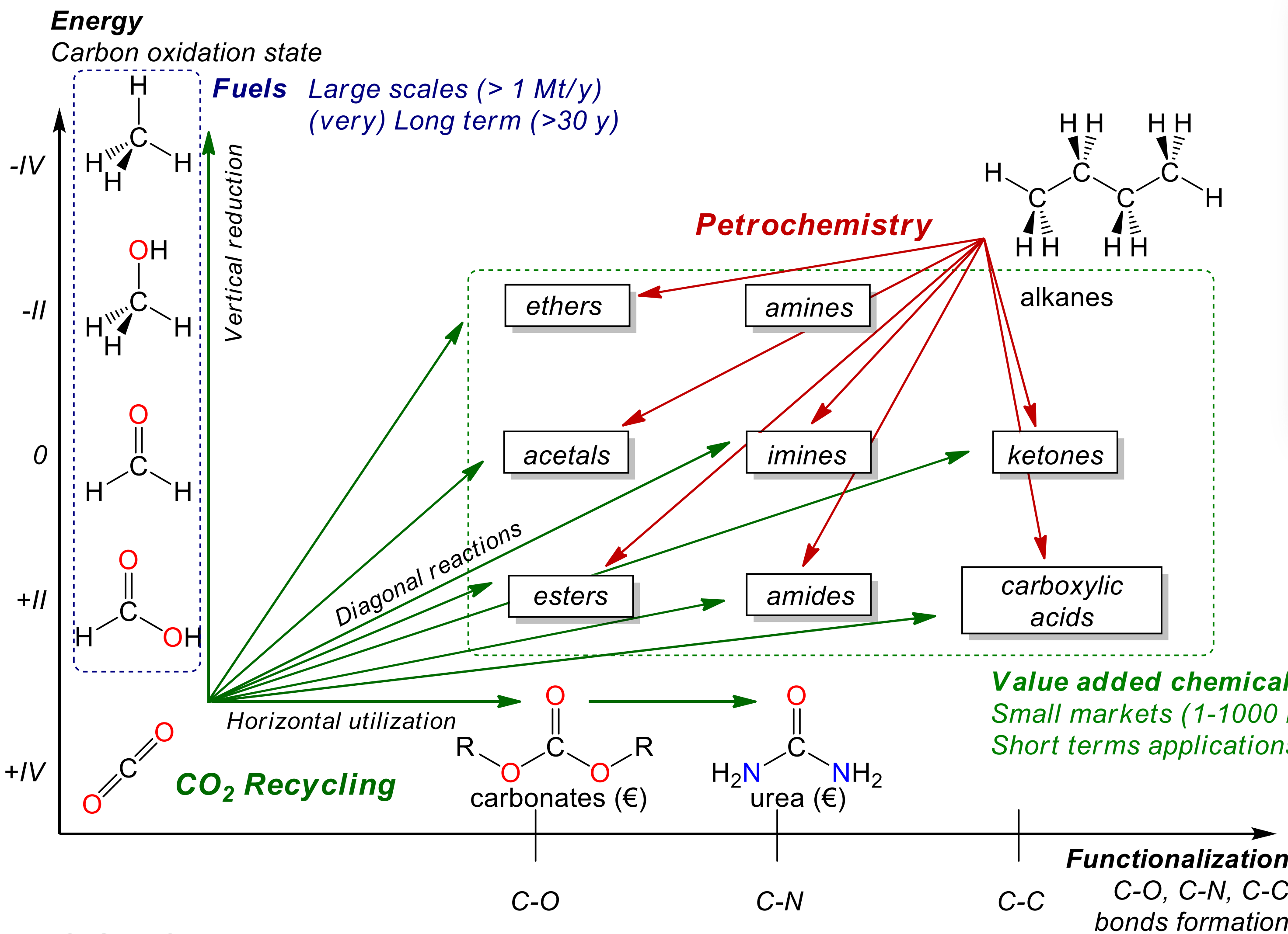
CO_2 CONVERSION TO VALUE-ADDED CHEMICALS

CARBON BASED PRODUCTS IN AN ENERGY SYSTEM



Abanades, Aresta, Blekkan, Cantat, Centi, El Khamlichi, Mazzotti, Schlögl, *et al.*,
Report on CCU for the Science Advice for Policy by European Academies, Feb. 2018

VARIOUS OPPORTUNITIES TO CO_2 RECYCLING…



COVER
VIP Paper
Highlighted in Nature

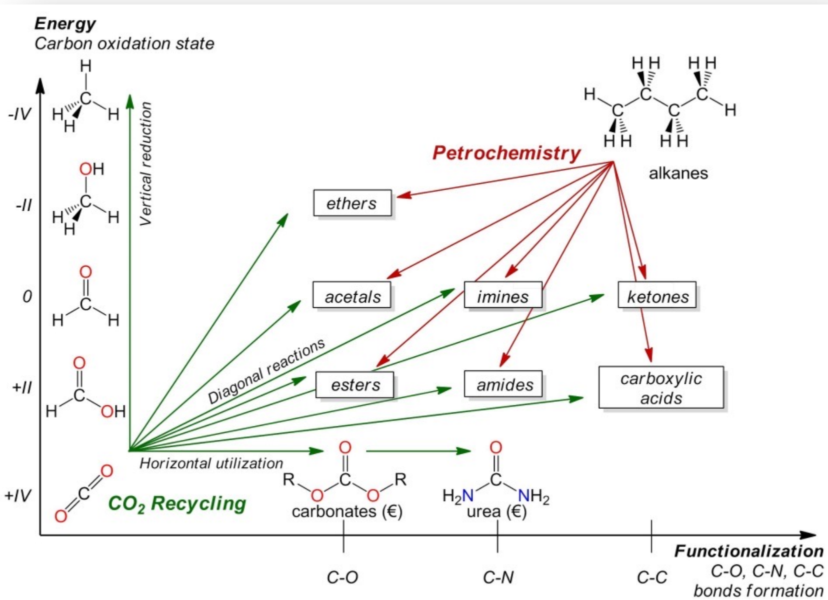
CO_2 functionalization and reduction steps coupled in a single process

Cantat *et al.*, *Angew. Chem. Int. Ed.* **2012**, *51*, 187.

DE LA RECHERCHE À L'INDUSTRIE

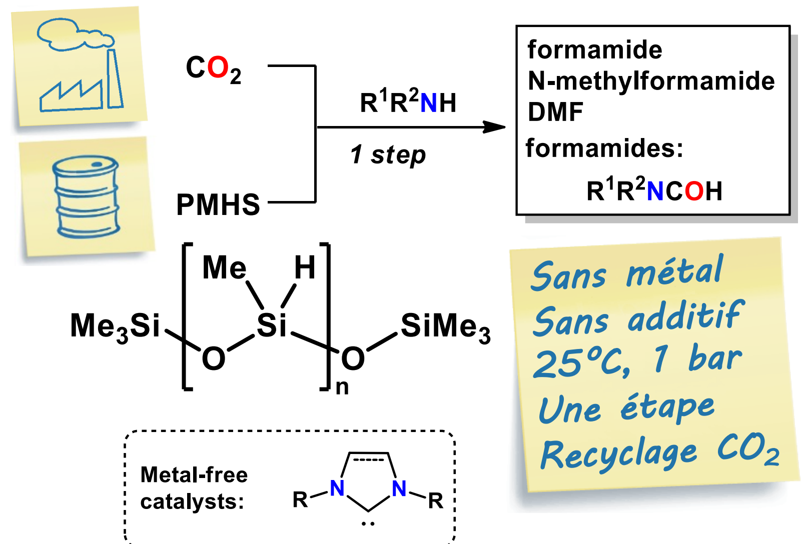
PROOF-OF-CONCEPT: NEW CATALYTIC PROCESS

Proof-of-concept for the diagonal approach



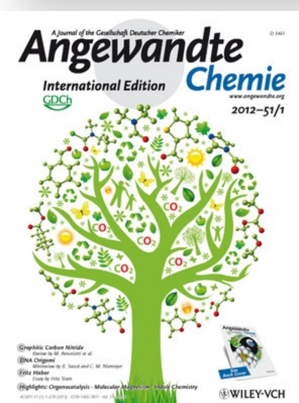
Co-recycling CO_2/PMHS (CEA/DSM technology)

Metal-free catalysts, room temperature, single step



formamide
N-methylformamide
DMF
formamides:
R[1]R[2]NCOH

World production: 500 kt/y from oil
Utilization as solvents and reactants



- Cover picture in **Angewandte Chemie**
- **Very Important Paper** (top 5%)
- Highlighted in **Nature**

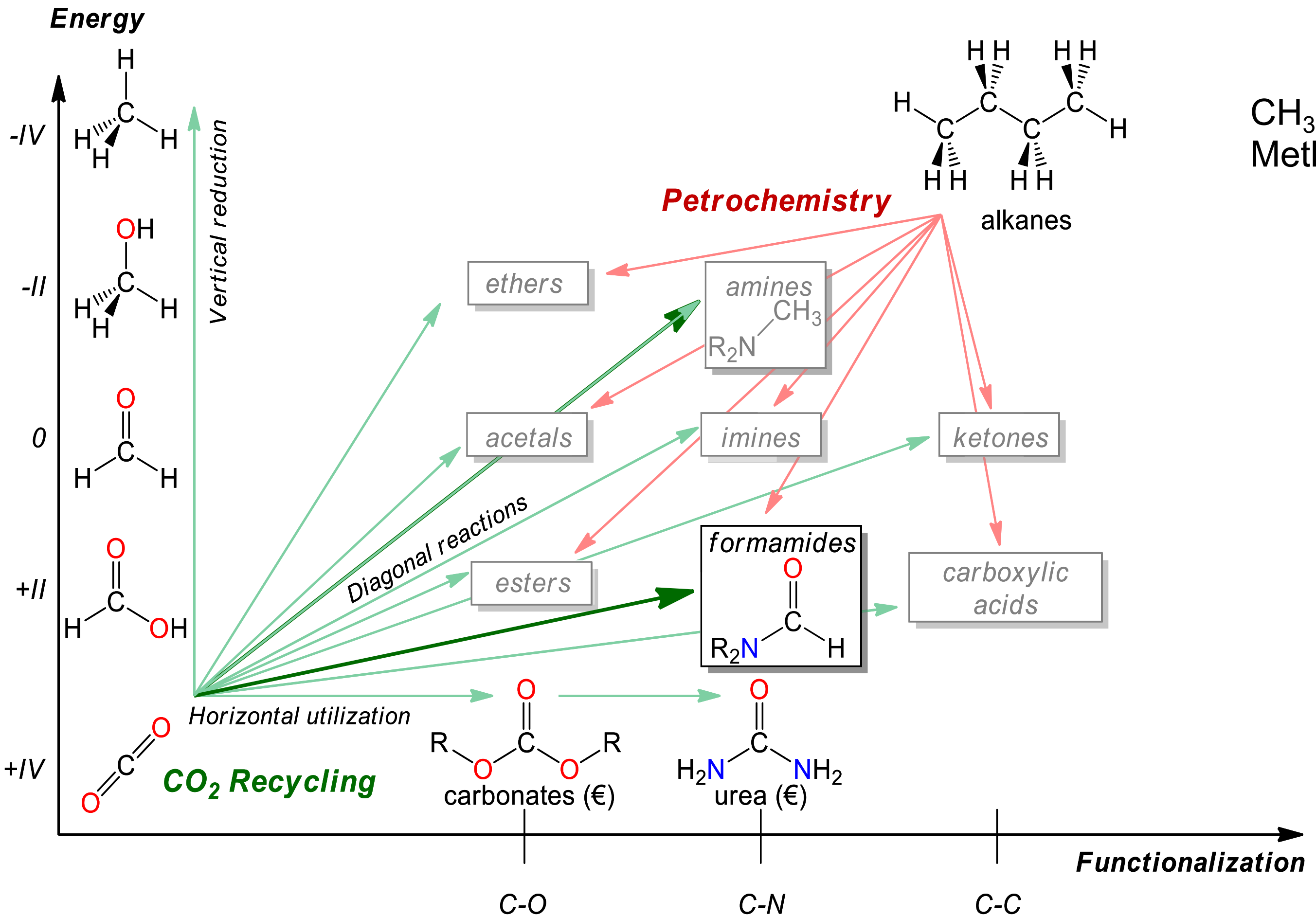
- CO_2 as an alternative to petrochemistry
  Utilization of an energy vector (H, Si) coupled with a functionalizing reactant

Cantat et al., *Angewandte Chemie* **2012**, *JACS* **2012**, WO2012137152

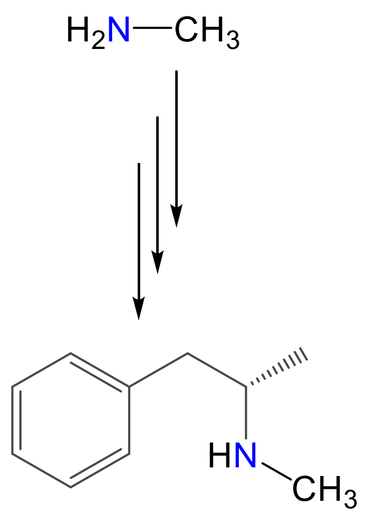
SECOND CHALLENGE: METHYLATION USING CO_2

CO_2 as a methylating reagent

- Goal: diagonal reactions with large slope (access to highly reduced compounds)



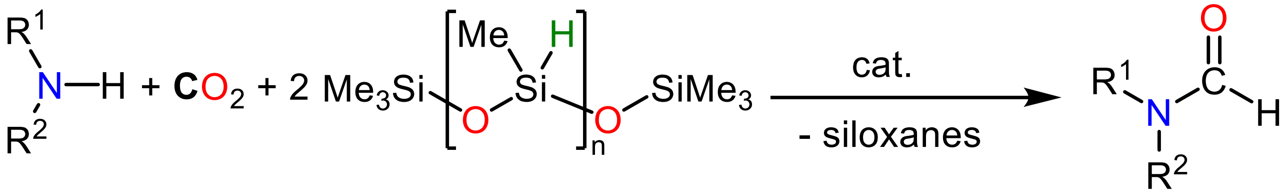
CH_3OH: 400 €/ton
Methylamines: > 4,000 €/ton



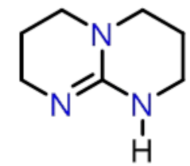
methanphetamine

NEW REACTIONS INVOLVING CO_2

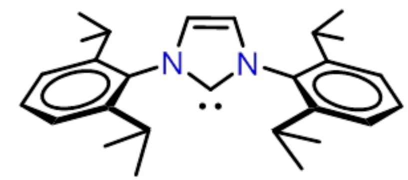
Catalysts:



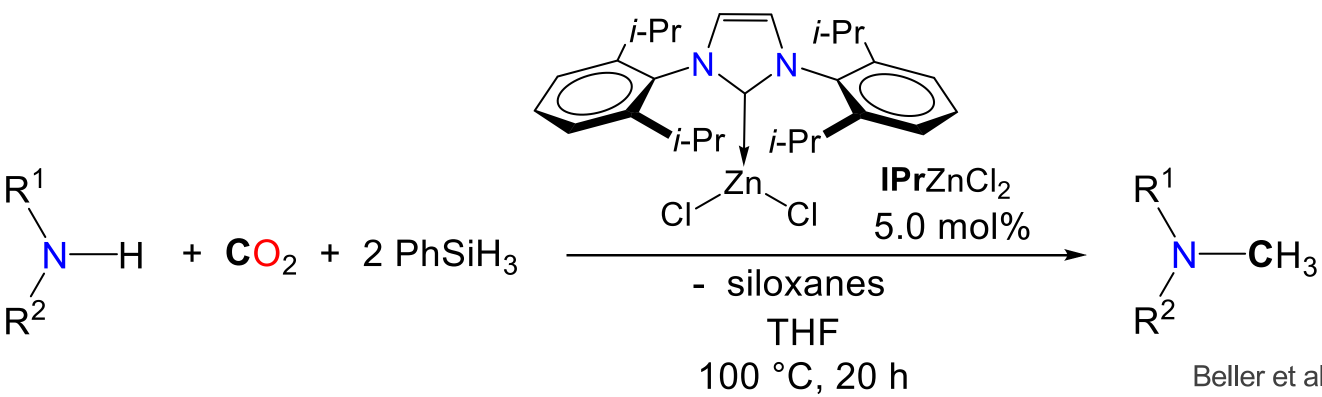
PMHS (3€/kg)



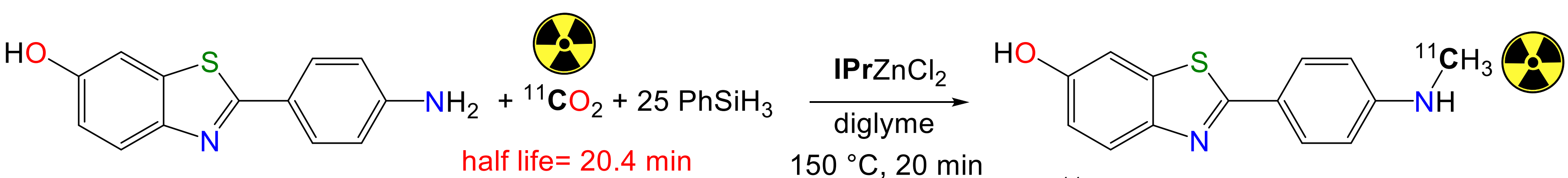
TBD



IPr



For a Ru cat., see:
Beller et al. *Angew. Chem. Int. Ed.* **2013**, *52*, 9568



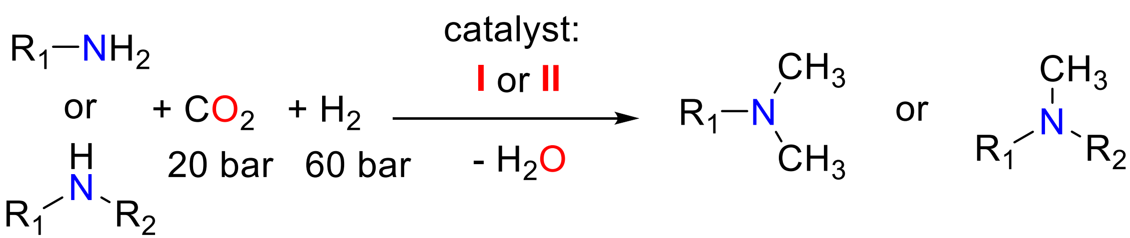
[^{11}C] **PIB,** β-amyloid radiotracer
RCY=38%, overall time: 50 min

Angew. Chem. Int. Ed. **2012**, *51*, 187
J. Am. Chem. Soc. **2012**, *134*, 2934
Chem. Sci. **2013**, *4*, 2127
ChemCatChem **2013**, *5*, 117

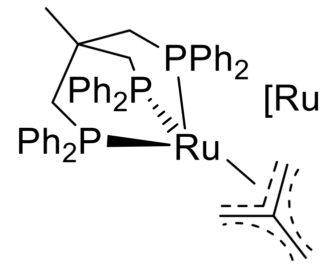
Liger et al., *EurJOC*, **2015**, 6434
Cantat *et al.*, *Patent PCT/IB2013/054599*

METHYLATION OF AMINES USING HCOOH

- H_2 as a reductant



I, *Klankermayer et al.*

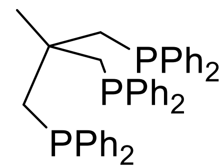


[Ru(triphos)(tmm)]
2.5 mol%

$HNTf_2$ 5 mol%
THF, 150 °C

II, *Beller et al.*

[Ru-(acac)$_3$] 1-5 mol%

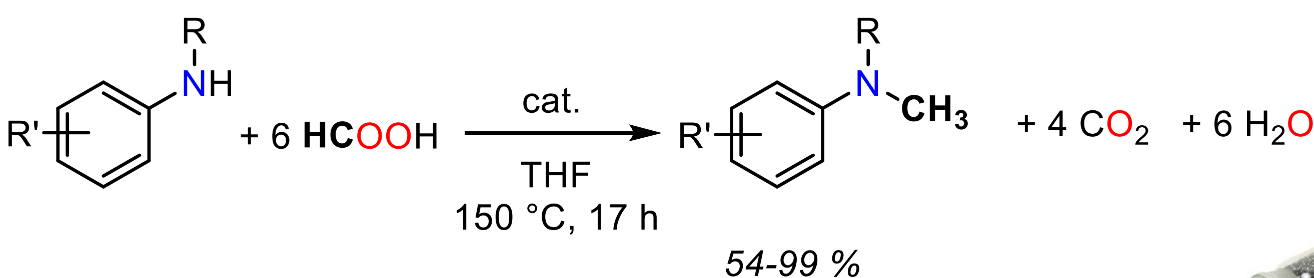


triphos
2-7.5 mol%

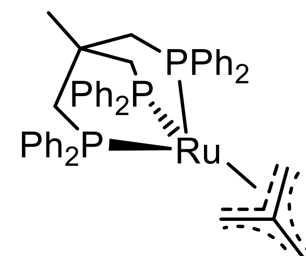
MSA 1.5 mol%
THF, 140 °C

Klankermayer *et al.*, *Angew. Chem. Int. Ed.* **2013**, *52*, 9554.
Beller *et al.*, *Angew. Chem. Int. Ed.* **2013**, *52*, 12156.
Cantat *et al.*,, *Angew. Chem. Int. Ed.* **2014**, *53*, 2543 [*Highlight*]

- HCO_2H as a carbon and hydrogen source



cat. =



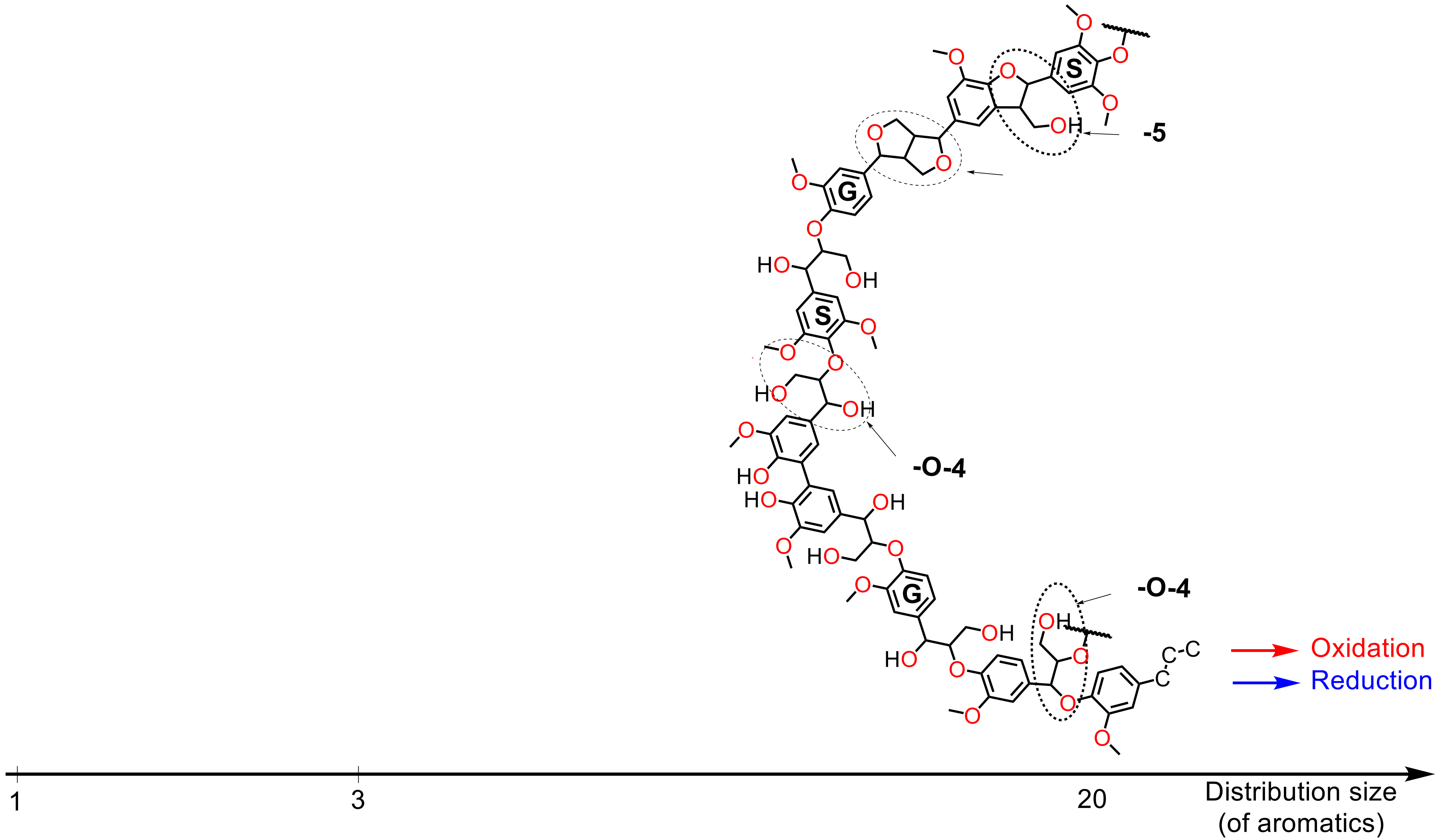
[Ru(triphos)(tmm)]
1.0 mol%
$HNTf_2$ 1.5 mol%

or Pd/In_2O_3

Cantat *et al.*, *Chem. Commun.* **2014**, *50*, 14033

BEYOND CO_2 REDUCTION: DEPOLYMERIZATION OF WASTE PLASTICS AND LIGNIN

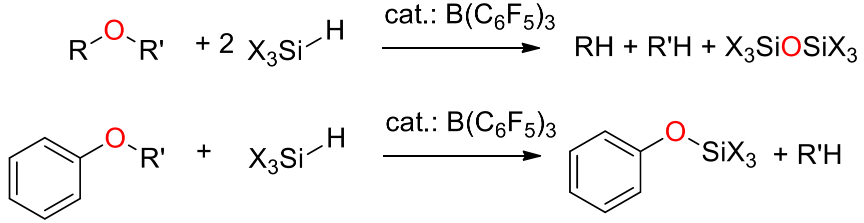
CONVERGENT REDUCTIVE DEPOLYMERIZATION



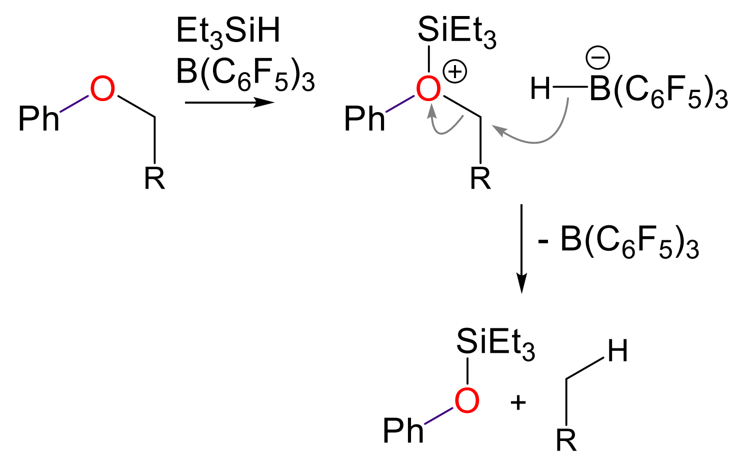
Cantat et al., *Energy Environ. Science,* **2015**, 8, 2734
For lignin oxidation see: Weckhuysen et al. *Chem. Rev.*, **2010**, *110*, 3552
Stahl et al. *Nature* **2014**, 515, *J. Am. Chem. Soc.* **2013**, 135, 6415
Zhang et al. *Chem. Rev.*, **2015**, *115*, 11559

CATALYTIC HYDROSILYLATION OF ETHERS

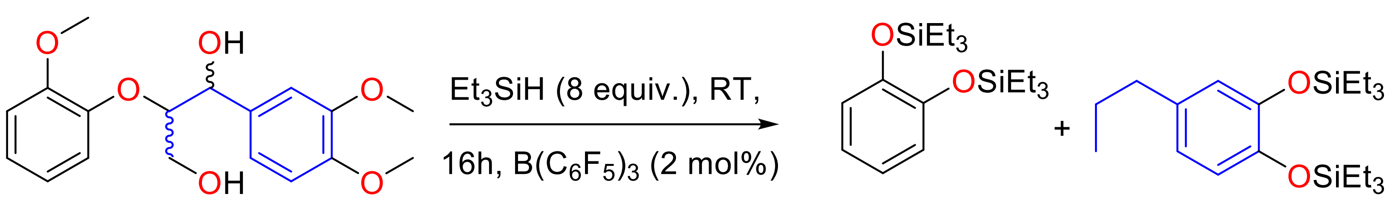
Catalytic hydrosilylation of ethers (Piers and Gevorgyan)



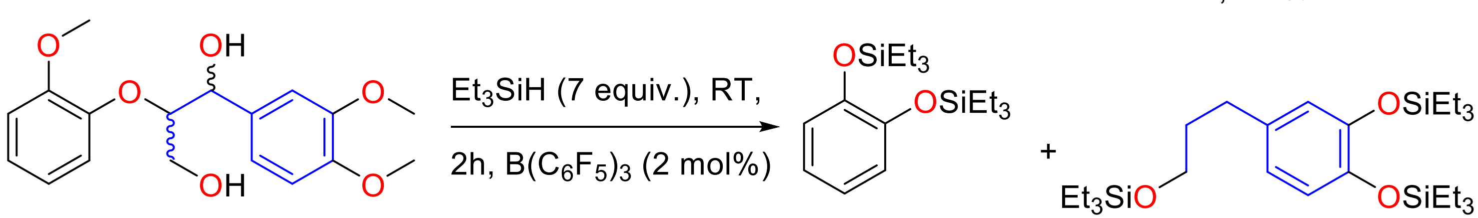
Utilized in organic chemistry only
Never applied to biomass molecules



V. Gevorgyan, et al. *J. Org. Chem.* **2000**, *65*, 6179
Piers et al, *J. Org. Chem.* **2000**, *65*, 3090



99 % **3G**, 84 %

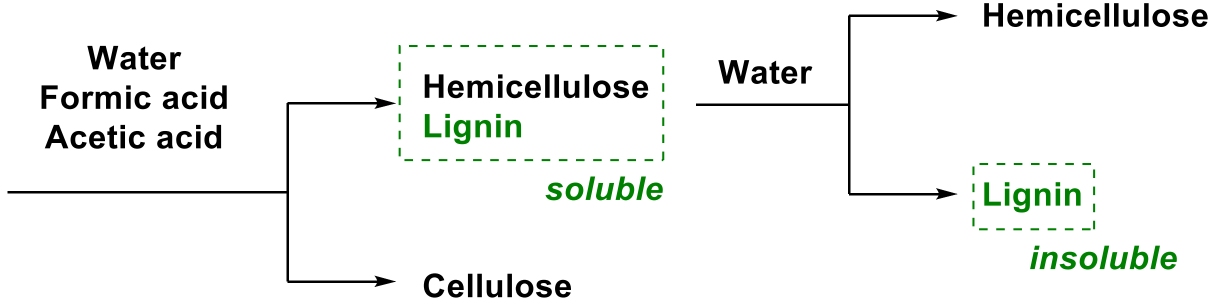


99 % **4G**, 83 %

Chem. Commun. **2014**, *50*, 862

REDUCTIVE DEPOLYMERIZATION OF LIGNIN

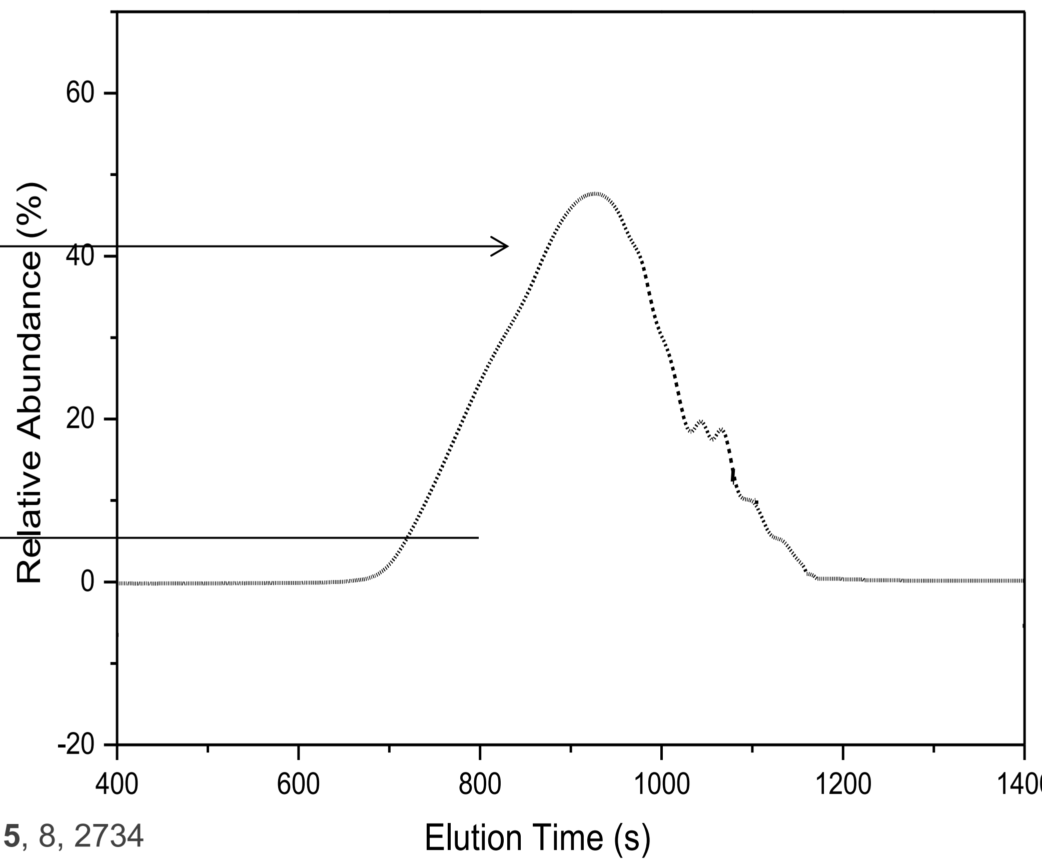
Formacell process:



SEC chromatograms

Black poplar lignin

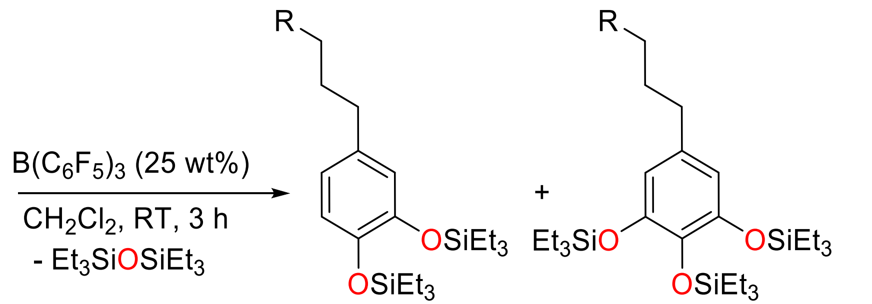
Black poplar lignin
+ 276 wt% Et_3SiH
+ 25 wt% $B(C_6F_5)_3$
After 20 h at RT in CH_2Cl_2



Feghali, Cantat et al., *Energy Environ. Science*, **2015**, 8, 2734

REDUCTIVE DEPOLYMERIZATION OF LIGNIN

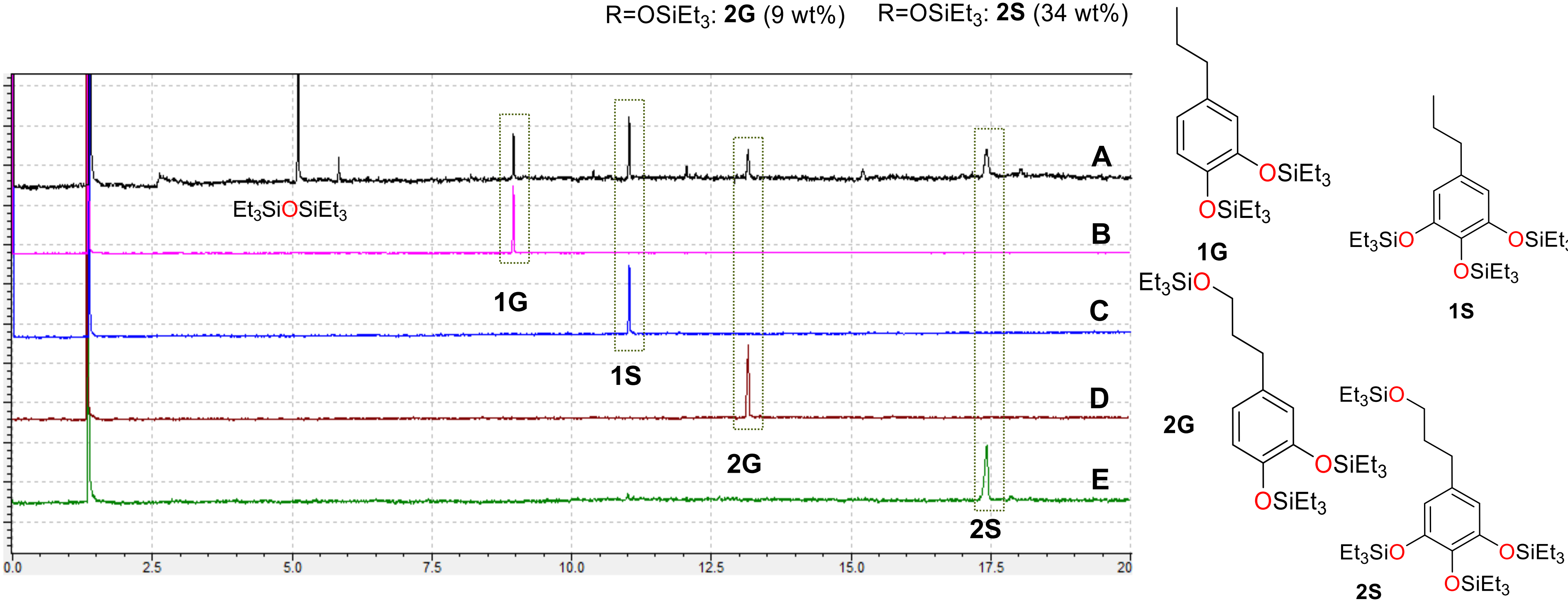
Black poplar (*Formacell*) + 276 wt% Et_3SiH



R=H: **1G** (9 wt%)
R=$OSiEt_3$: **2G** (9 wt%)

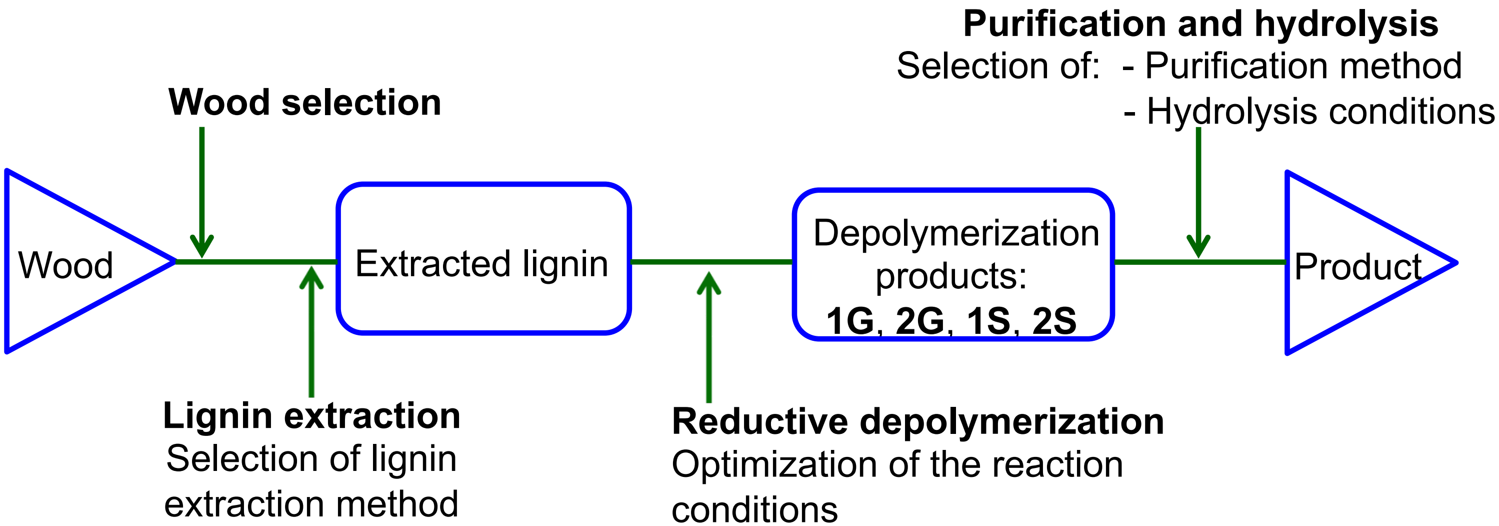
R=H: **1S** (21 wt%)
R=$OSiEt_3$: **2S** (34 wt%)

Conditions correspond to:
10 mol% catalysts
5 equiv. Si-H per aromatic unit



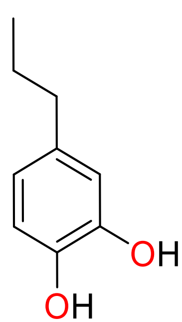
Feghali, Cantat et al., *Energy Environ. Science*, **2015**, 8, 2734

AN INTEGRATIVE APPROACH

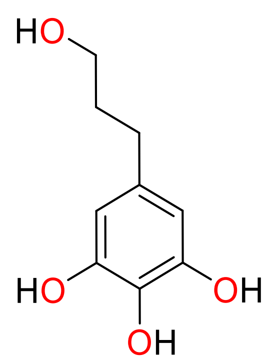


~40% efficiency **30-80% efficiency** **>80% efficiency**

Global efficiency = 5-25%



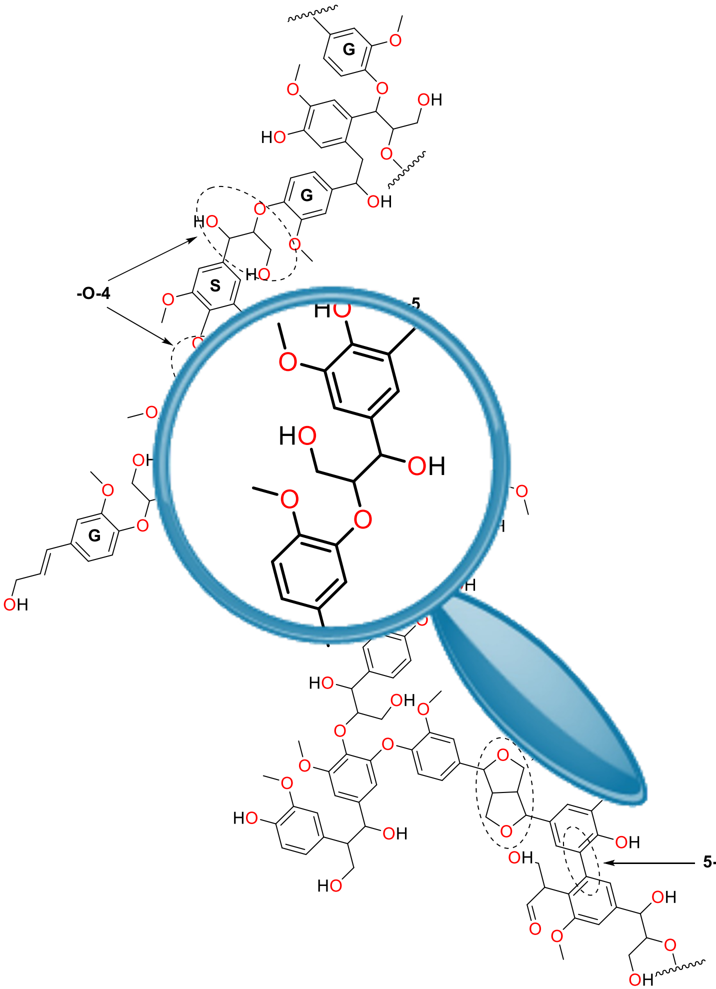
0.5 wt% from wood!
7.0 wt% from lignin



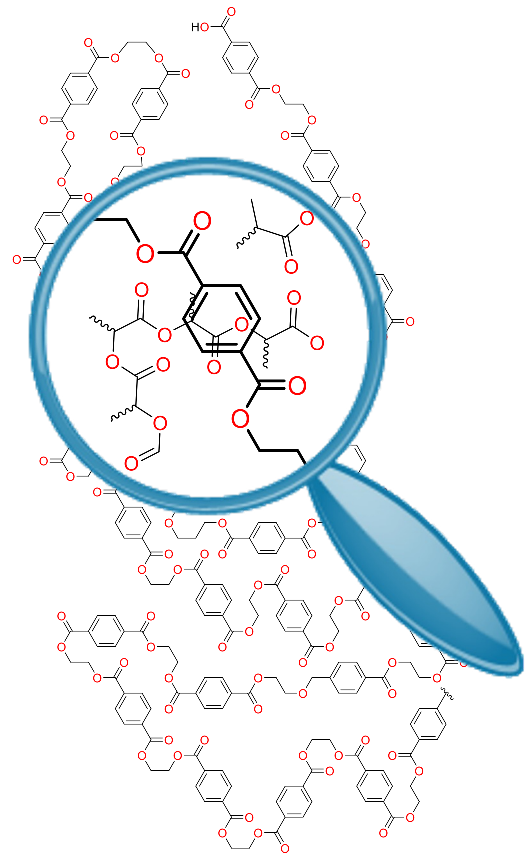
2.4 wt% from wood!
24.0 wt% from lignin

Feghali, Cantat et al., *Energy Environ. Science*, **2015**, 8, 2734

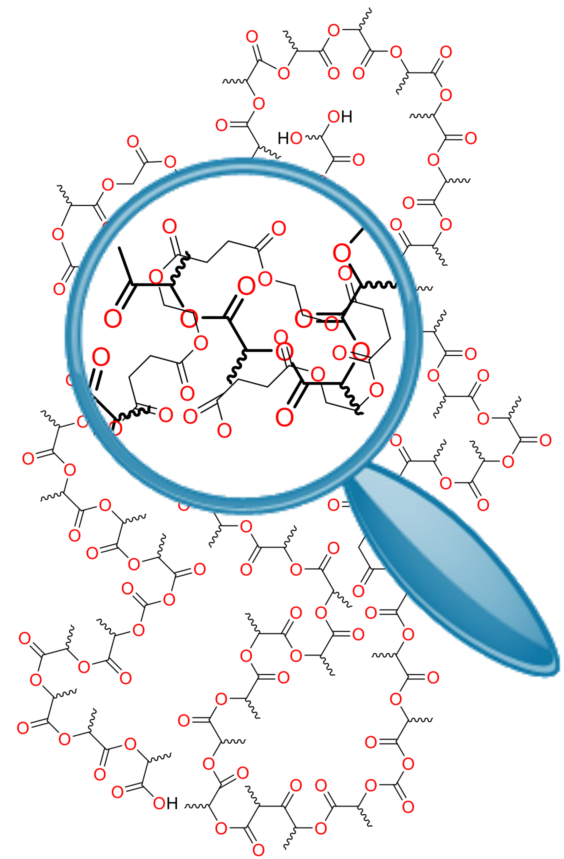
BIOMASS/PLASTIC DEPOLYMERIZATION, SAME CHALLENGE ?



Lignin

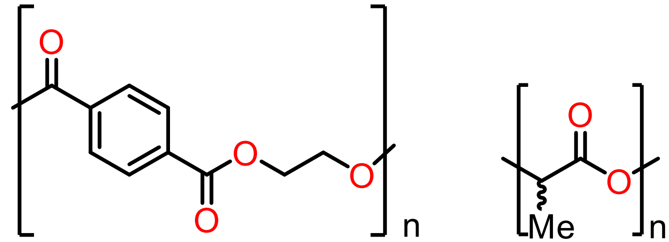


Poly(Ethylene Terephtalate)

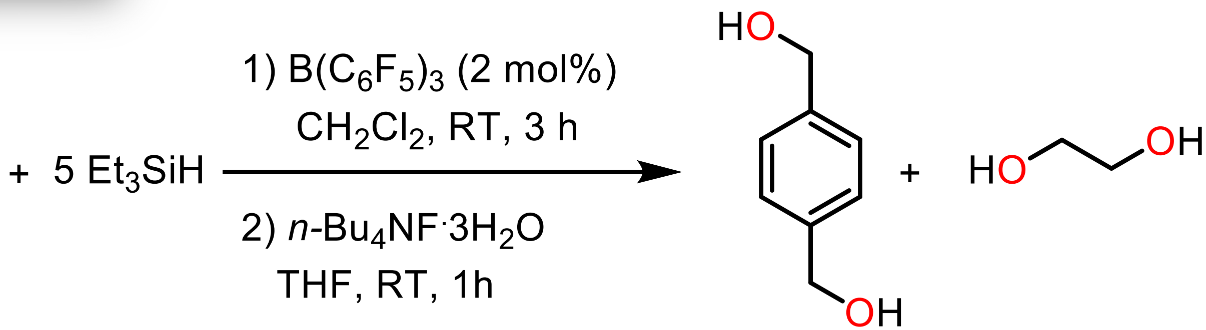


Poly(Lactic Acid)

DEPOLYMERIZATION OF WASTE PLASTICS

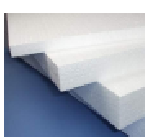


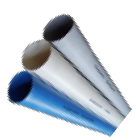
PET **PLA**



PET

65 % 65 %





PS **PVC**

PLA

ChemSusChem, **2015**, *8*, 980; *ACS Sust. Chem. Eng.* **2018**, *6*, 10481
Patent app. PCT/IB2016/059684
For the hydrogenation of pure PET, see: Robertson *et al.*, *Chem. Commun.* **2014**, *50*, 4884

RECYCLING STRATEGIES

REWEAR
CLOTHING THAT CAN BE WORN AGAIN IS MARKETED WORLDWIDE AS SECOND-HAND GOODS.

ENERGY
WHEN REWEAR, REUSE AND RECYCLE ARE NOT OPTIONS, TEXTILES ARE USED TO PRODUCE ENERGY.

REUSE
TEXTILES THAT ARE NO LONGER SUITABLE TO WEAR ARE CONVERTED INTO OTHER PRODUCTS, SUCH AS CLEANING CLOTHS.

RECYCLE
TEXTILES THAT CAN'T BE REUSED GET A NEW CHANCE AS TEXTILE FIBRES, OR ARE USED TO MANUFACTURE PRODUCTS SUCH AS DAMPING AND INSULATING MATERIALS FOR THE AUTO INDUSTRY.

StG 2013-2018
CoG 2019-2024

ACKNOWLEDGMENTS

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