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Membrane-assisted Ethylene Synthesis over Nanostructured Tandem Catalysts

CO_2 conversion to green ethylene: a tandem CZA-zeolite catalyst approach

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Catalytic CO_2 Conversions

August 27th, 2026
Copenhagen, Denmark

*Research Enginner at
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

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Catalytic CO_2 Conversions

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Catalytic CO_2 Conversions

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Where Transport Meets Reaction

- Heterogeneous catalysis
- Electrolysis
- Coatings

Catalytic CO_2 Conversions

MemCat Project

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Membrane-assisted Ethylene Synthesis over Nanostructured Tandem Catalysts

Why Ethylene?

1.2 tons

of CO_2

per ton of produced ethylene!

Mackenzie, 09 April 2024.

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Catalytic CO_2 Conversions

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Current production & utilization of ethylene

Diverse Applications of Ethylene

Healthcare Applications: Ethylene derivatives are essential in manufacturing medical devices, sterilization agents, and pharmaceuticals

Renewable Energy Materials: Ethylene-based materials contribute to solar panel production and wind turbine components

Advanced Industrial Materials: Ethylene is vital in developing advanced materials for construction, automotive, and electronics industries

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Catalytic CO_2 Conversions

MemCat Project

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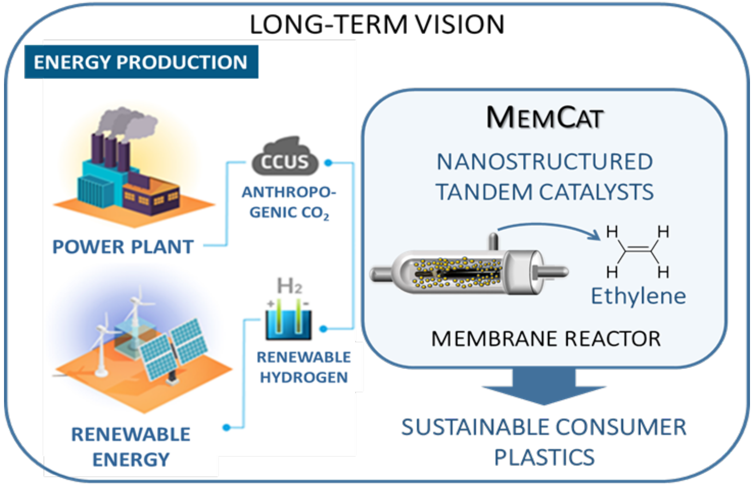
Membrane-assisted Ethylene Synthesis over Nanostructured Tandem Catalysts

The goal of MemCat:

Deliver a proof-of-concept for carbon dioxide (CO_2) direct conversion to ethylene (ET)

using tandem catalysts within a membrane reactor



- CO_2 hydrogenation to Ethylene with $X \geq 80\%$ and $S \geq 95\%$

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Catalytic CO_2 Conversions

MemCat Project

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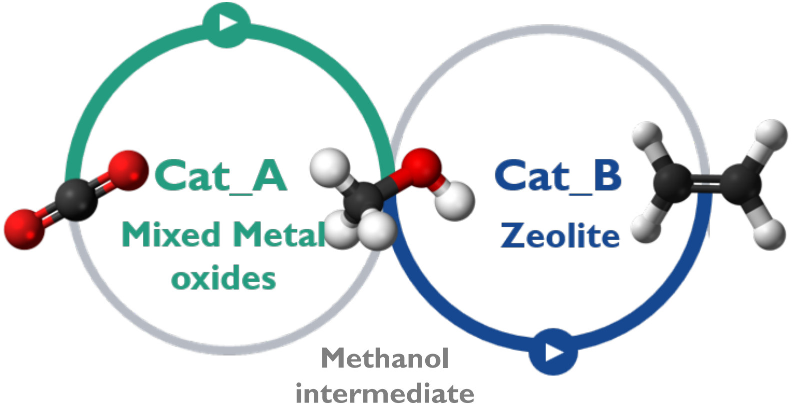
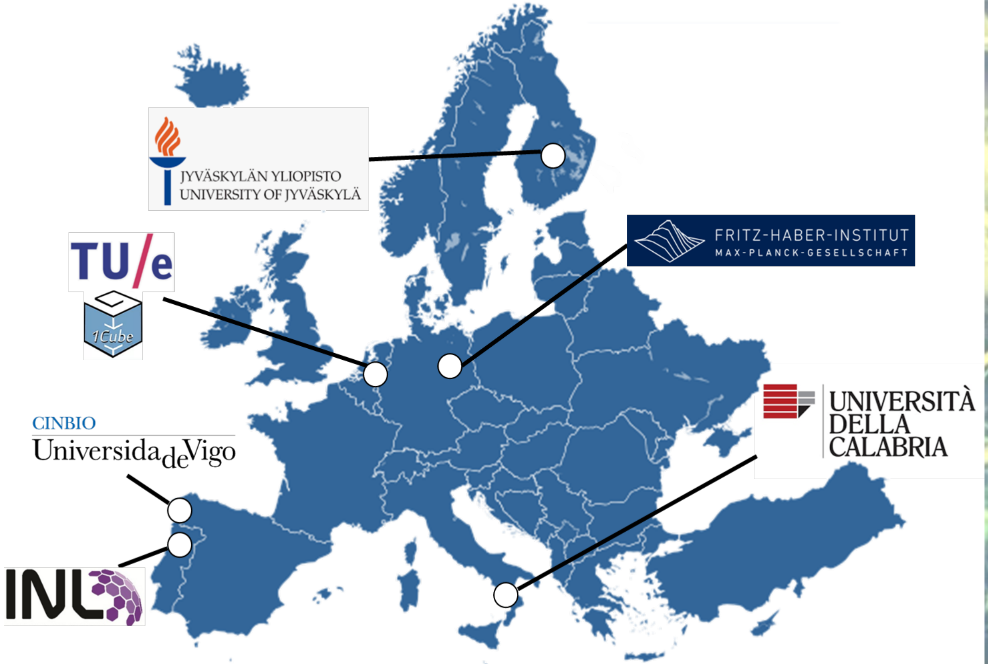
Our role





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CO_2 to light olefins

Four matching rules for constructing high-performance bifunctional MCs-zeolites-based catalysts

Catalysis Reviews, 2024, 1-76

1. **Methanol catalyst:**
High CO_2-to-methanol selectivity under high temperatures

2. **Zeolite:**
Appropriated topology, moderate acidity, and pore-structure to high selectivity

3. **Efficient matching in conversion rate:**
MeOH formation higher than its conversion rate: unconverted MeOH can be decomposed to CO;
MeOH formation lower: zeolite-efficiency cannot be fully utilized, and the over-hydrogenation will form paraffin

4. **Unique spatial distributions:**
Too far, diffusion distance of MeOH prolonged: concentration gradient and decreases the catalytic activity;
Too close, active sites can poison each other: loss of catalytic activity.

Catalytic CO_2 Conversions

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Catalytic CO_2 Conversions

Catalyst synthesis

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Tandem Catalyst

Materials selection

Cat_A$_{MeOH}$: Metal oxides

Co-precipitation procedure

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MAX-PLANCK-GESELLSCHAFT

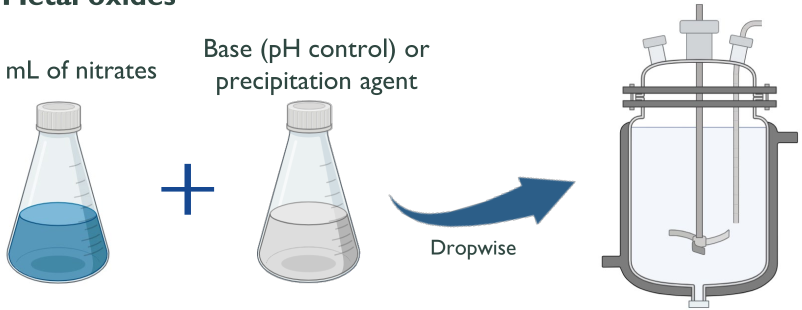
CZA

$CuZnO/Al_2O_3$

Mixed Metal oxides

500 mL of nitrates

Base (pH control) or precipitation agent



MQ water

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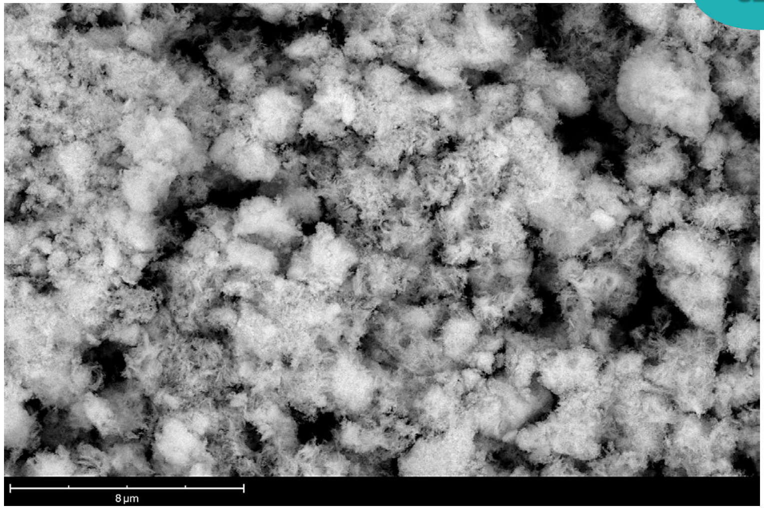
Catalyst characterization

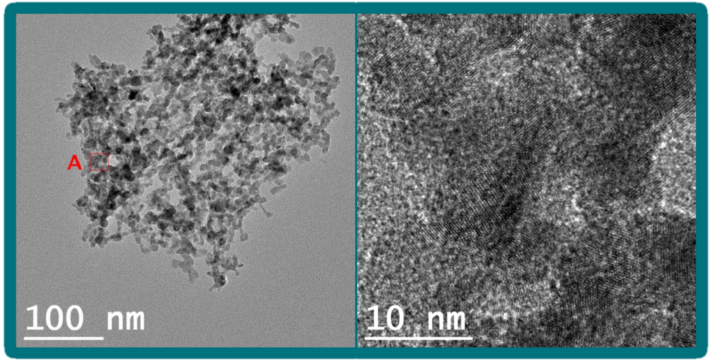
Tandem Catalyst Materials selection

Morphology

CZA



S_{BET} = 90.93 m^2/g
V_{pore} = 0.524 cm^3/g
D_p = 8.1 nm



Crystallite size: 9 nm ± 1 nm

	Cu (%)	Zn (%)	Al (%)	O (%)	Cu	Zn	Al
XRF data	31.7	12.5	0.8	55.0	42.5	16.8	1.0

Preliminary results

Tandem Catalyst   Materials selection

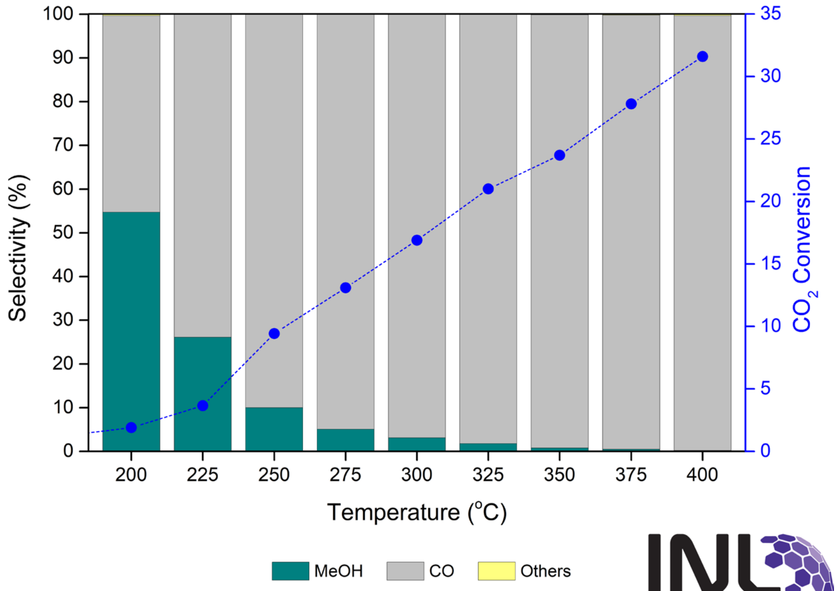
Catalytic activity

K. Kappis, M. Borrelli, A. Trunschke

WHSV: 16800 ml/g/h

$CO_2 : H_2 \rightarrow 1:3$

CZA



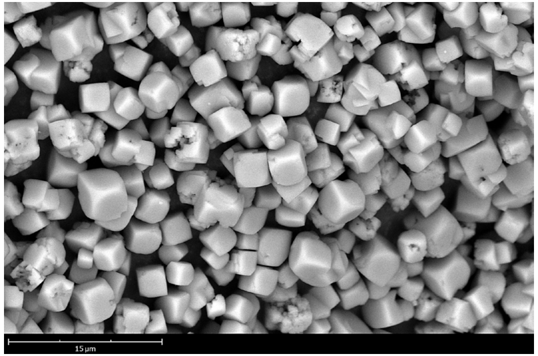
Catalyst synthesis

Tandem Catalyst   Materials selection

Basic characterization

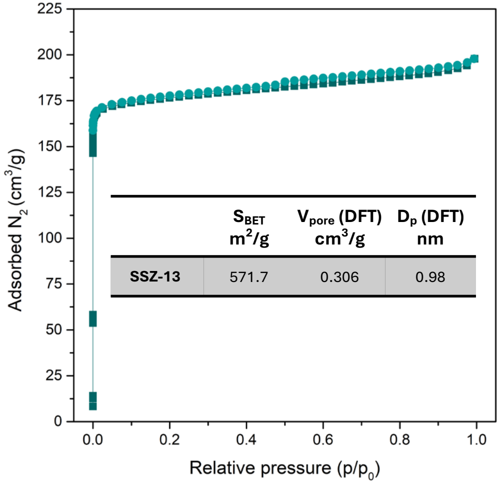
Cat_B$_{MTO}$: SSZ-13 Zeolite
Commercially available
TOSOH CORPORATION

Morphology



Particle size:
2.7 µm ± 0.4

Porosity

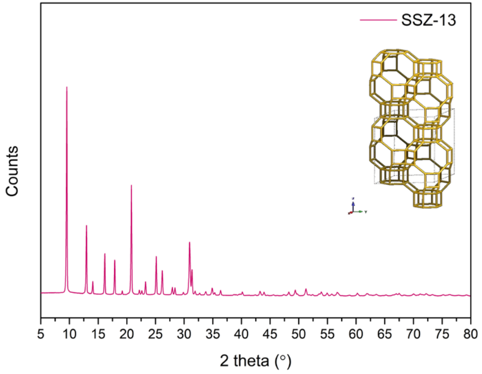


	S_{BET} m^2/g	V_{pore} (DFT) cm^3/g	D_p (DFT) nm
SSZ-13	571.7	0.306	0.98

Elemental composition

XRF data	Si (%)	Al (%)	O (%)	Si/Al ratio
SSZ-13	39.20	2.69	58.10	14.6

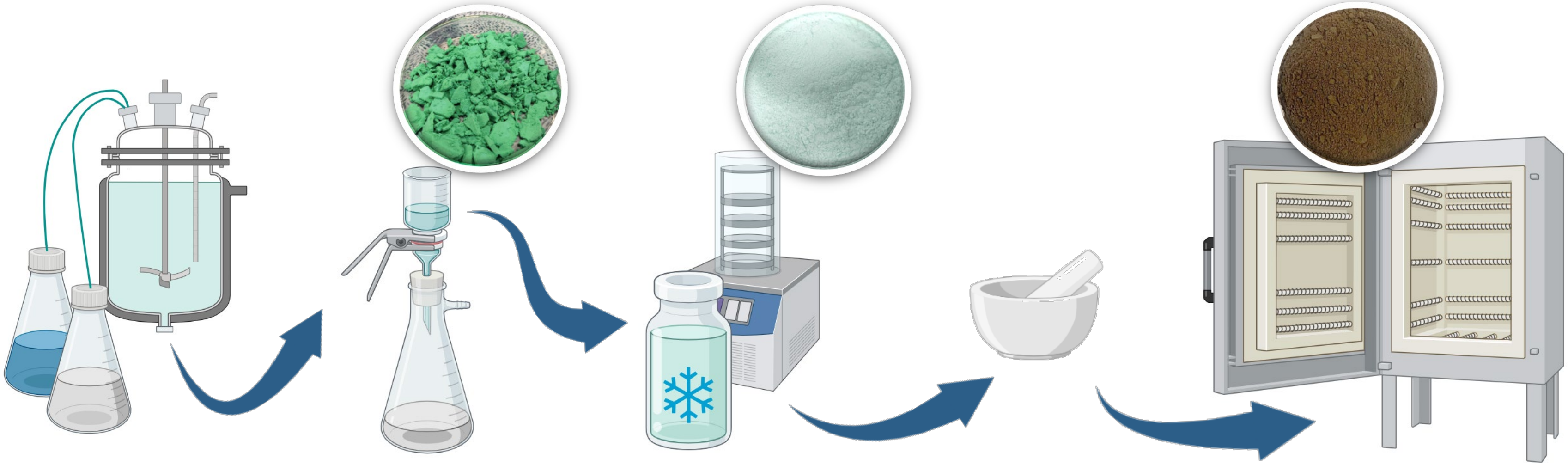
Crystallinity



Catalyst synthesis

Tandem Catalyst Synthesis

SSZ-13–CZA



Co-precipitation

+ 10 g of zeolite previously dispersed

Vacuum filtered and washed

Dispersed in MQ water

Frozen + Lyophilized

Homogenized

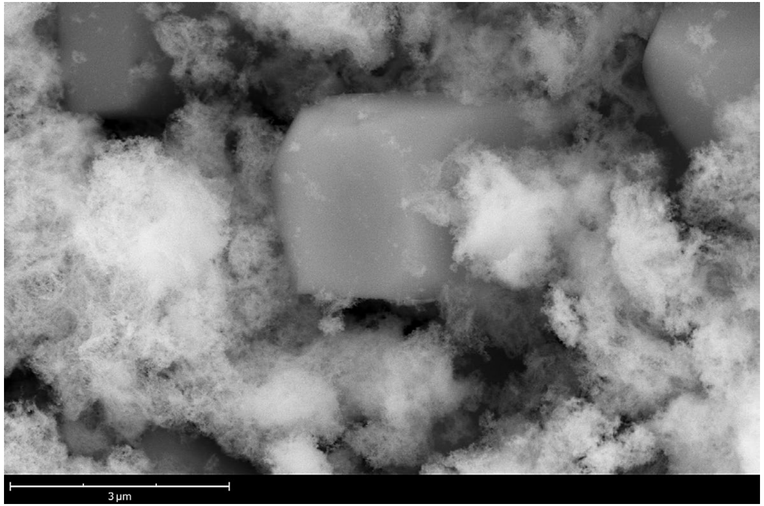
330 ºC / 2 ºC/min / 3 h

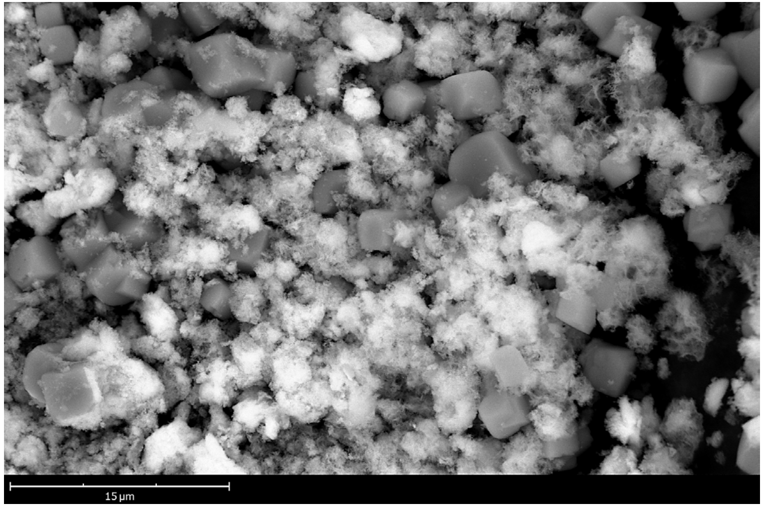
Catalyst synthesis

Tandem Catalyst Synthesis

Optimization strategy!

Morphology and elemental composition **SSZ-13_CZA**





XRF	Si (%)	Al (%)	Cu (%)	Zn (%)	O (%)	Oxide/zeolite
SSZ-13_CZA	21.80	2.12	27.20	11.20	37.70	61/39

Catalyst synthesis

Tandem Catalyst Synthesis

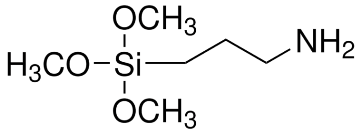
Commercial SSZ-13 zeolite

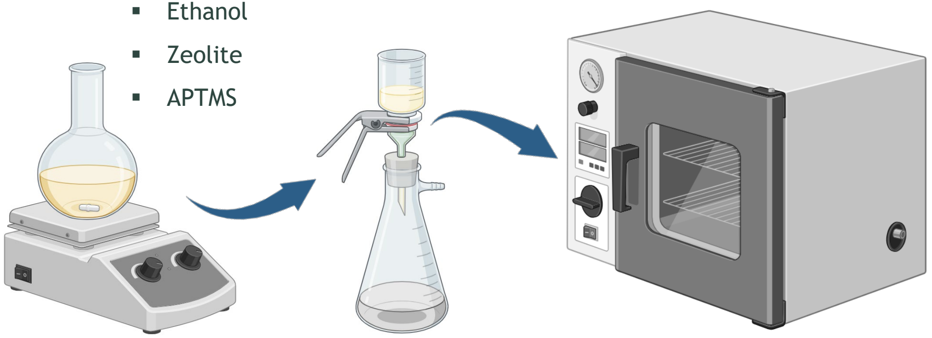
Functionalization as our optimization strategy

Can monoamine graft improve the CZA dispersion, and adhesion on the zeolite?

- Ethanol
- Zeolite
- APTMS

APTMS (3-aminopropyl)trimethoxysilane)



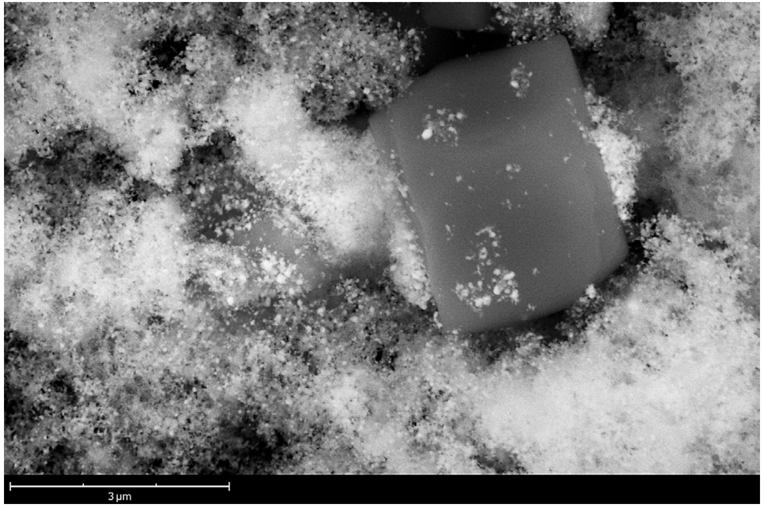


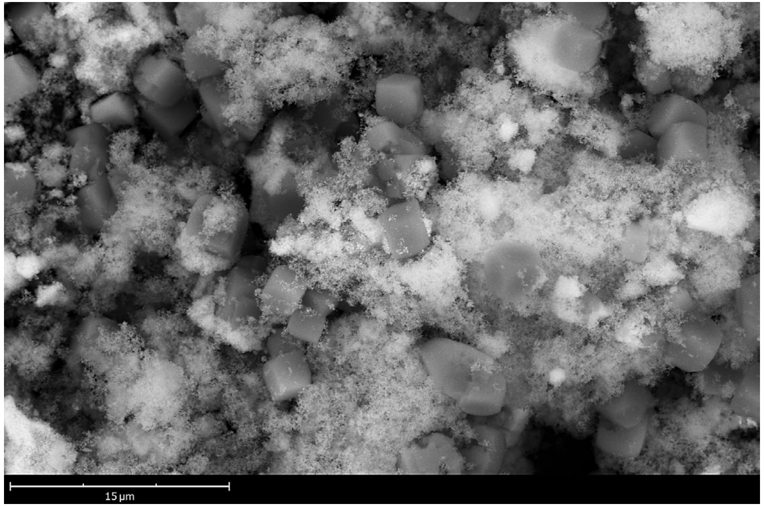
Catalyst synthesis

Tandem Catalyst Synthesis

Optimization strategy!

Morphology and elemental composition **SSZ-13-F_CZA**



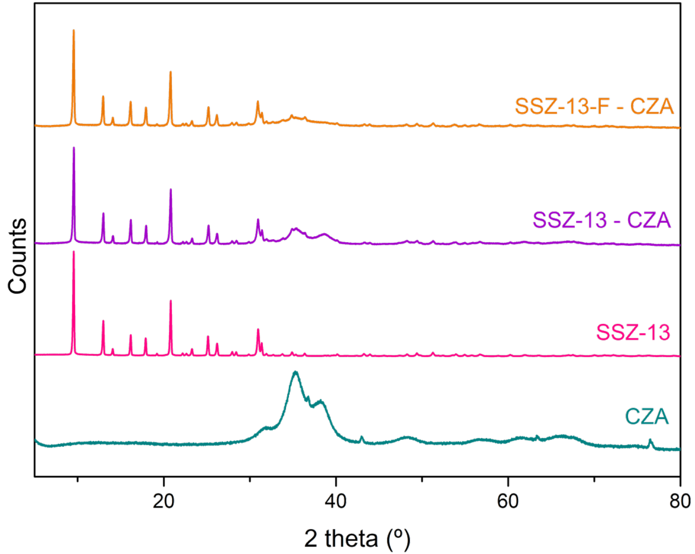


XRF	Si (%)	Al (%)	Cu (%)	Zn (%)	O (%)	Oxide/zeolite
SSZ-13_CZA-F	20.00	1.94	24.80	10.10	43.30	61/39

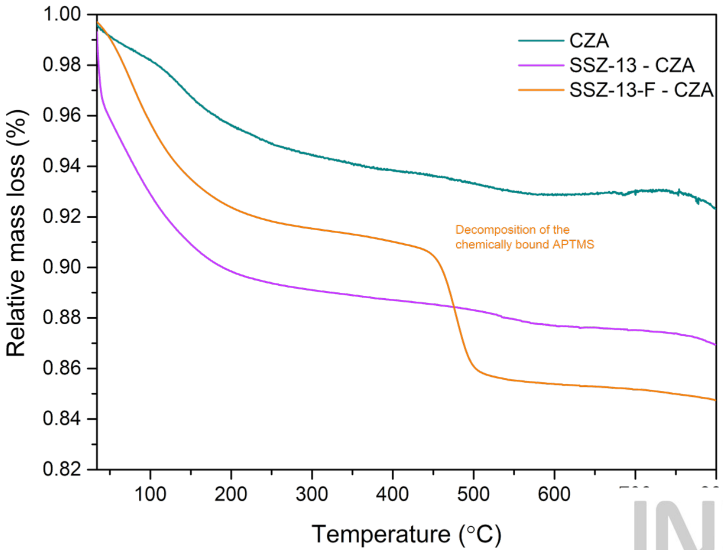
Catalyst characterization

Tandem Catalyst Characterization

Crystalline structure



Thermostability

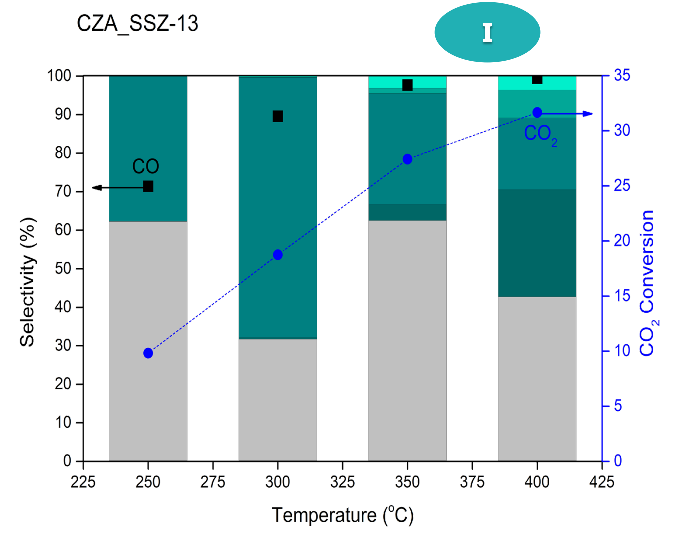


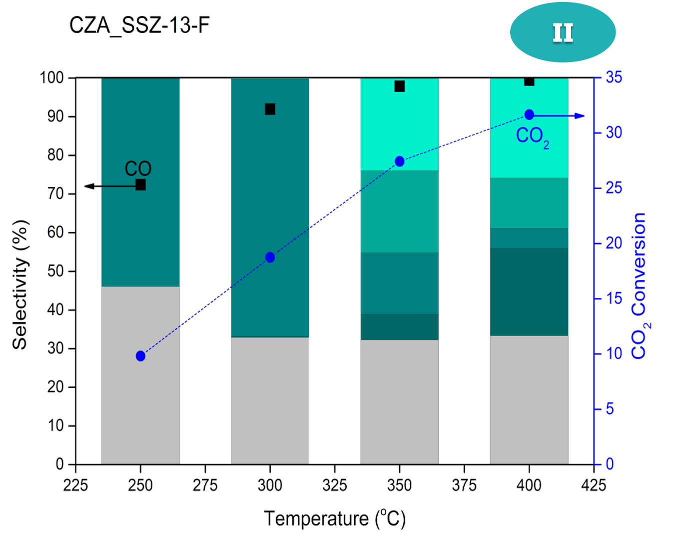
Results

Tandem Activity

Catalytic tests

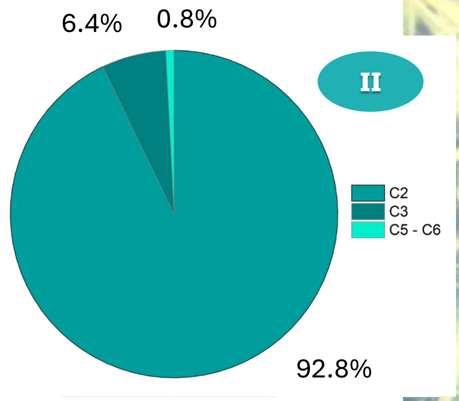
FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT





MeOH CH4 DME Paraffins Olefins Others

$S_{olefins\ @\ 350°C} = 23.9\ \%$



Catalytic CO_2 Conversions

Results

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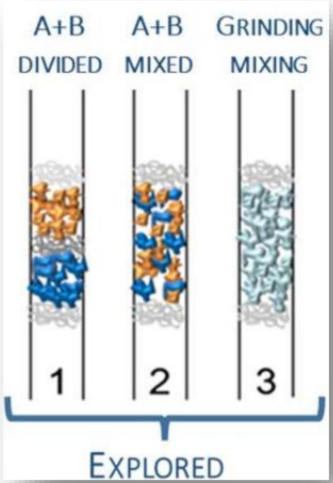
Tandem Activity

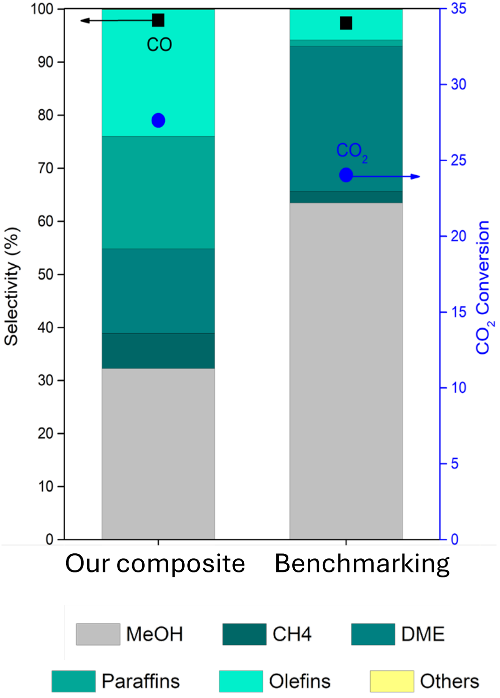
Catalytic tests

FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT

Benchmarking physical mixture



@ 350 °C



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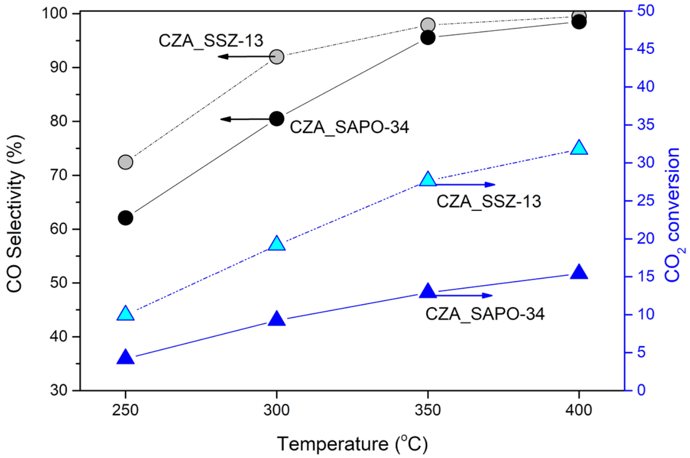
Catalyst synthesis

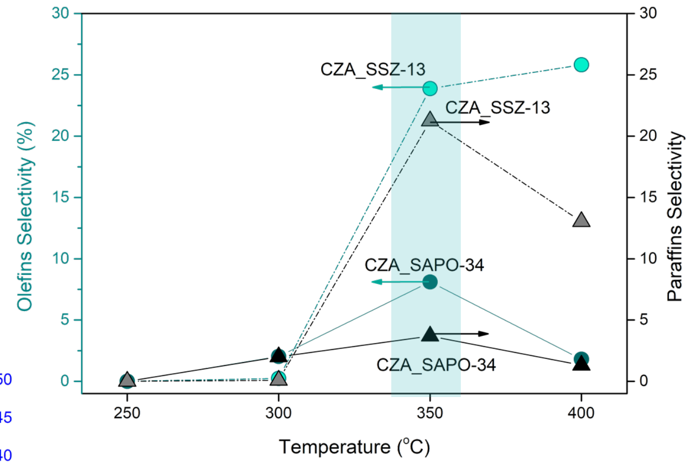
Tandem Catalyst

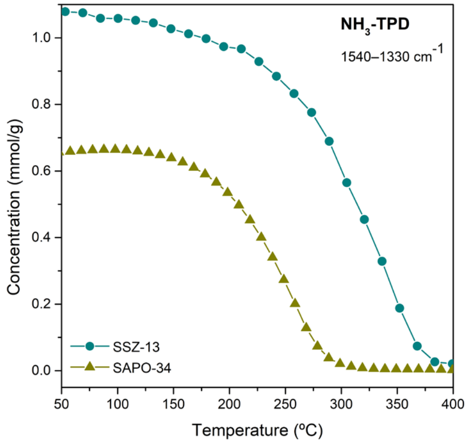
Materials selection: why not SAPO-34?

Composites:

- CZA_SSZ-13
- CZA_SAPO-34







Headroom on O/P

- Our SSZ-13 is low Si/Al
- Paraffins are tunable via Si/Al ratio
- SAPO-34 acidity is fixed

Catalytic CO_2 Conversions

Conclusions

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MCs and MTO catalysts

Operating temperature range

Materials selection for best conversion and selectivity in the lowest temperature possible

Nanostructuring

Spatial distribution rule

Functionalization of the MTO catalyst, improved olefins production

Cat_A$_{MeOH}$ / Cat_B$_{MTO}$ ratio

Efficient matching rule

Equilibrium between MeOH formation and conversion, leading an increase in $S_{olefins}$ at 350 °C!

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Catalytic CO_2 Conversions

The Future

- Tune Si/Al ratio to 50 and 100 (MTO catalyst acidity control)
- Improve spatial distribution by core-shell structuring
- Incorporation into membrane reactor ($X \geq 80\%$ and $S \geq 95\%$ goal)
- Towards green ethylene production…

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Thank you for your attention!

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https://www.memcatproject.eu/

https://nanochemgroup.org/

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Catalytic CO_2 Conversions

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Experimental details

Catalytic activity

- Catalytic tests

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MAX-PLANCK-GESELLSCHAFT

✓ Activation: 250 °C (5 °C/min) for 2h with 10% H_2/Ar, total flow rate: 1460 NmL/min (~209 NmL/min per reactor)

✓ Reaction stream, CO_2 : H_2 → 1:3 (22.5 vol.% CO_2 / 67.5 vol.% H_2 / 10% Ar as internal standard)

✓ Analysis via GC/MS

✓ T = 150-400 °C, p = 30.0 bar

✓ Weight of catalyst: 0.5 g

✓ Total flow rate: 140 NmL/min per reactor - dwell: 12h in each temperature

✓ Weight Hourly Space Velocity (WHSV): 16800 ml g^{-1} h^{-1}

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