European Innovation Council

Funded by the European Union

MEMCAT

Membrane-assisted Ethylene Synthesis over Nanostructured Tandem Catalysts

Shaping SSZ-13 zeolite–metal oxide architectures for efficient tandem CO_2 conversion to light olefins

Natalia Spera, Gaje Singh, Yury Kolen'ko

Contact: natalia.spera@inl.int

FEZA 2026

July 1st, 2026
Naples, IT

INL INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EIC and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.

FEZA 2026

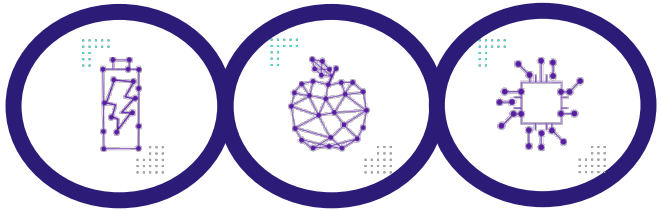
MEMCAT

INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

INTERNATIONAL IBERIAN
NANOTECHNOLOGY
LABORATORY

Grant Thematic Areas

+ 400 employees



Energy and Environment

Life Sciences

Information and Communication Technologies

FEZA 2026

MEMCAT

KOLEN'KO RESEARCH GROUP

INL INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Unconventional nanomaterials for sustainable chemistry

- Heterogeneous catalysis
- Electrolysis
- Coatings

FEZA 2026

MemCat Project

MEMCAT

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.

INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

FEZA 2026

MemCat Project

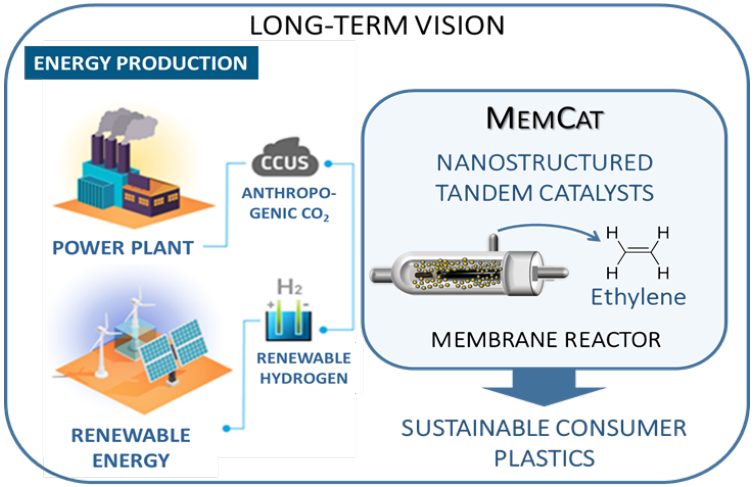
MEMCAT

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 $S \geq 95\%$

INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

FEZA 2026

MemCat Project

MEMCAT

Long-term Impact

REDUCE CARBON FOOTPRINT

Sustainable carbon negative production of ethylene using **captured CO_2** as feedstock.

Addressing the growing global demand for ethylene, expected to reach a market value of **€110 billion by 2027**, with MemCat offering a greener alternative to high CO_2-emission processes.

Supporting the **EU in green chemical production**, creating employment and contributing to a sustainable solution for plastics production.

MemCat technology could **reduce ethylene production costs** by 35%, improving yields and reducing downstream separation costs.

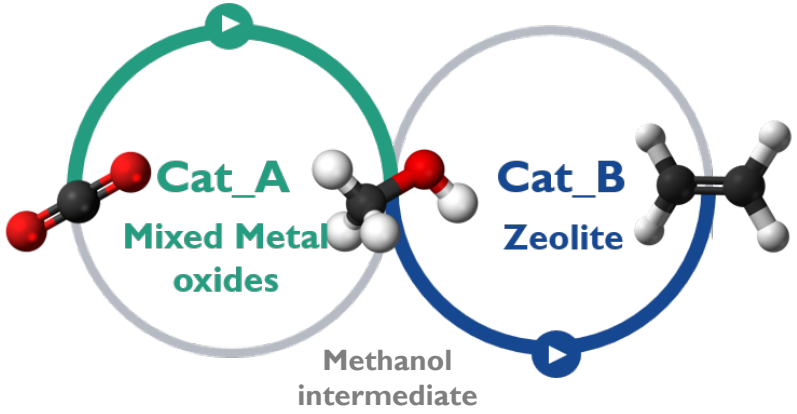
INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

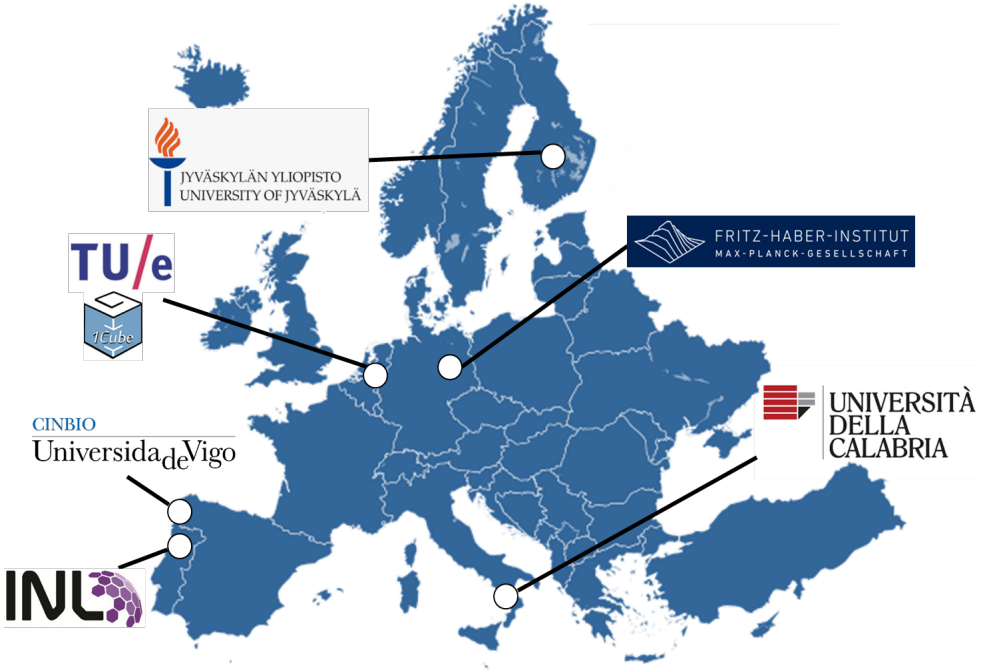
FEZA 2026

MemCat Project

MEMCAT

Our role





INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

FEZA 2026

CO_2 to light olefins

MEMCAT

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.

INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Catalyst synthesis

Tandem Catalyst Materials selection

Cat_A_{MeOH}: Metal oxides

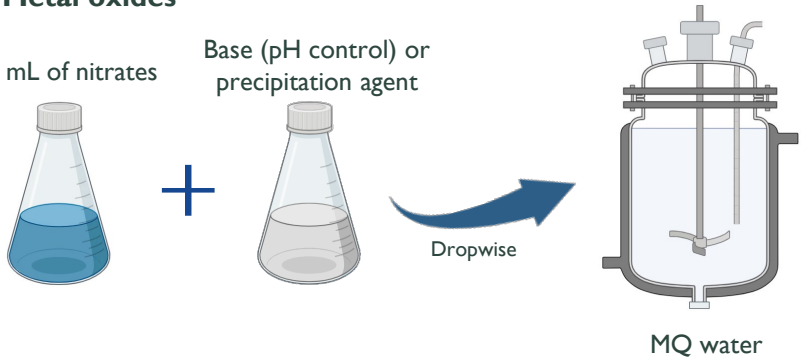
Co-precipitation procedure

FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT

CZA $CuZnO/Al_2O_3$

ZZ Zn/ZrO_2

Mixed Metal oxides



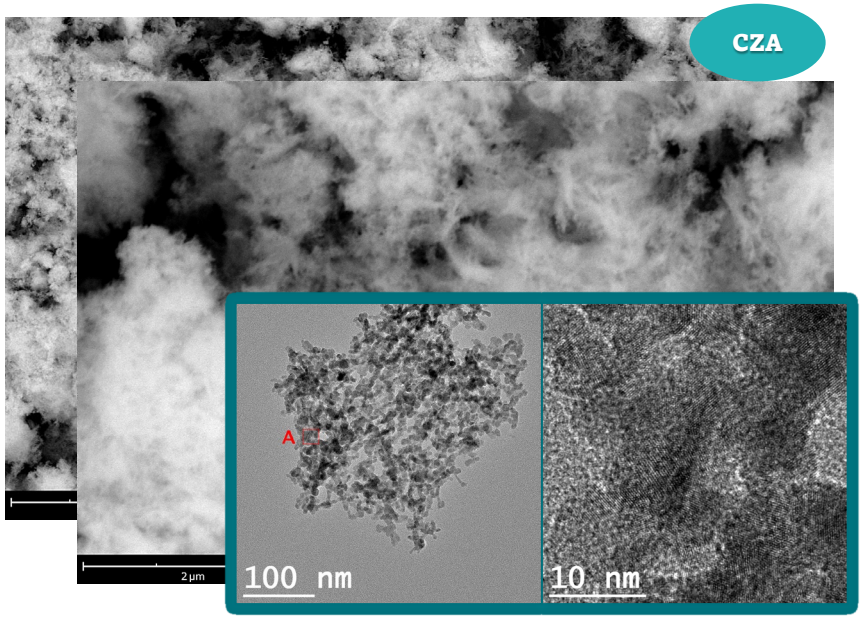
INL INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Catalyst characterization

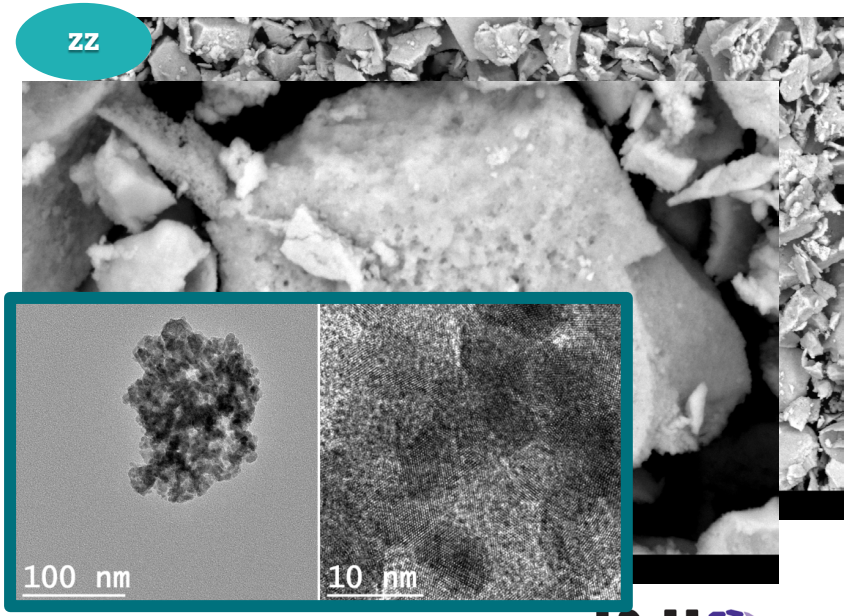
Tandem Catalyst

Materials selection

Morphology



Crystallite size: 9 nm ± 1 nm



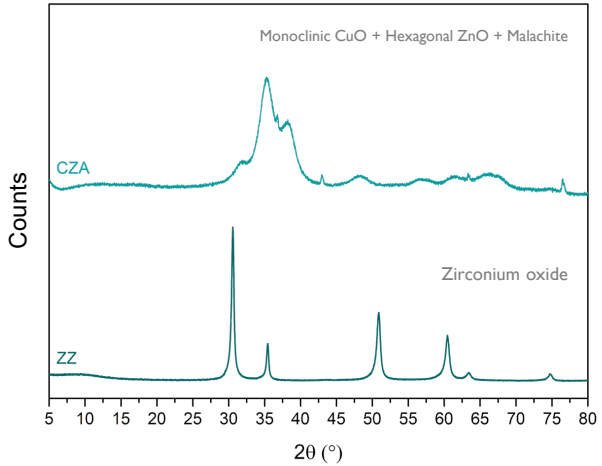
Crystallite size: 7 nm ± 1 nm

INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Catalyst characterization

Tandem Catalyst Materials selection

Crystalline structure, porosity and elemental composition



CZA

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

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

ZZ

S_{BET} = 46.51 m^2/g
V_{pore} = 0.082 cm^3/g
D_p = 4.2 nm

	Zr (%)	Zn (%)	O (%)	Zr	Zn
XRF data	14.55	1.92	83.30	7.6	1.0

FEZA 2026

Preliminary results

MEMCAT

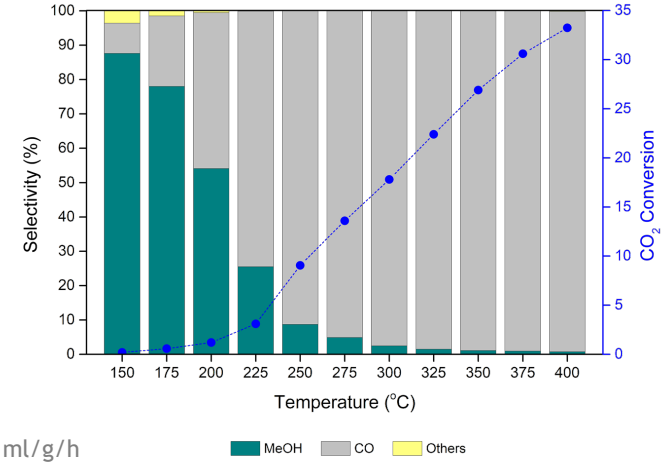
Tandem Catalyst Materials selection

Catalytic activity

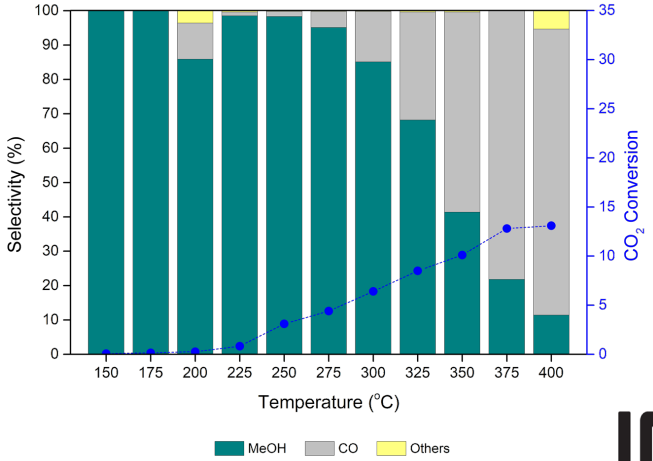
FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT
K. Kappis, M. Borrelli, A. Trunschke

Route to ethylene!

CZA



ZZ



WHSV: 16800 ml/g/h

$CO_2 : H_2 \rightarrow 1:3$

INL
INTERNATIONAL IBERIAN
NANOTECHNOLOGY
LABORATORY

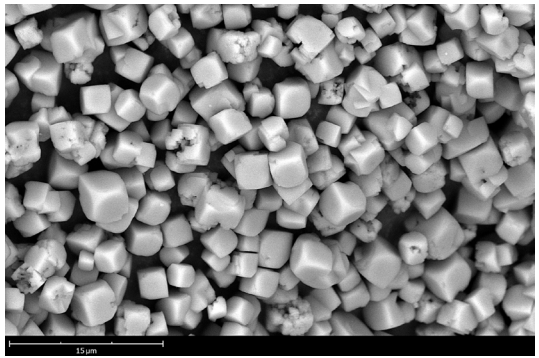
Catalyst synthesis

Tandem Catalyst Materials selection

Basic characterization

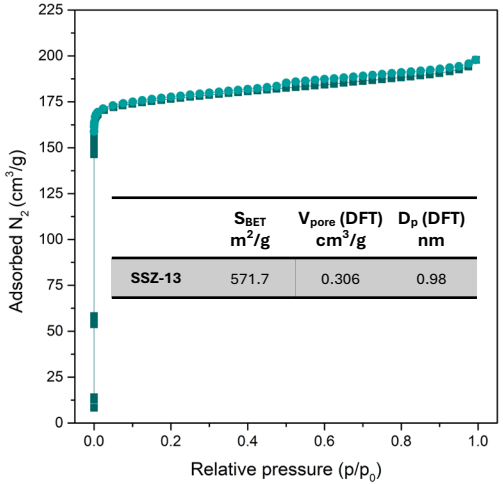
Cat_B_{MTO}: SSZ-13 Zeolite
(commercially available)

Morphology



Particle size:
2.7 µm ± 0.4

Porosity

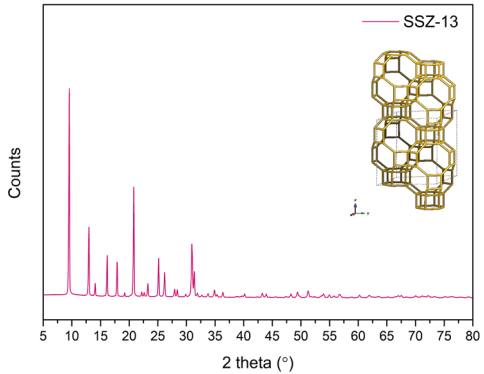


	S_{BET} m^2/g	V_{pore} (DFT) cm^3/g	D_p (DFT) nm
SSZ-13	571.7	0.306	0.98

Elemental composition

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

Crystallinity

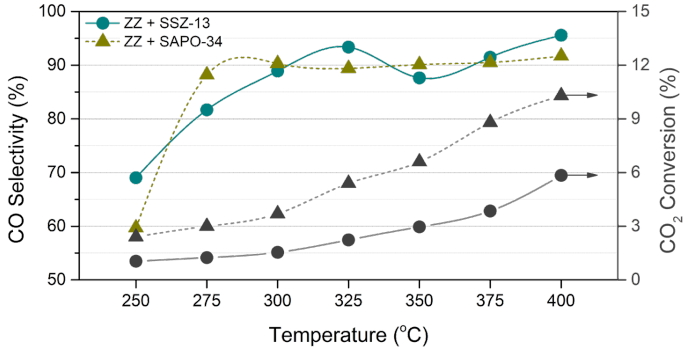


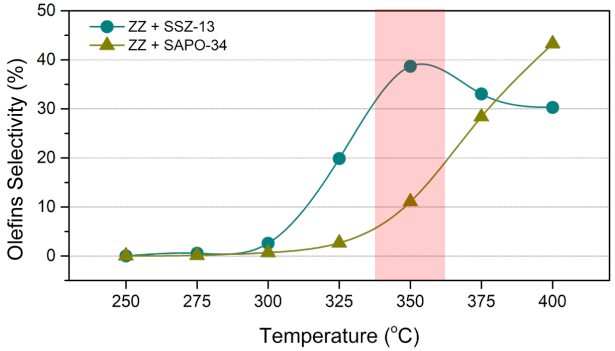
Catalyst synthesis

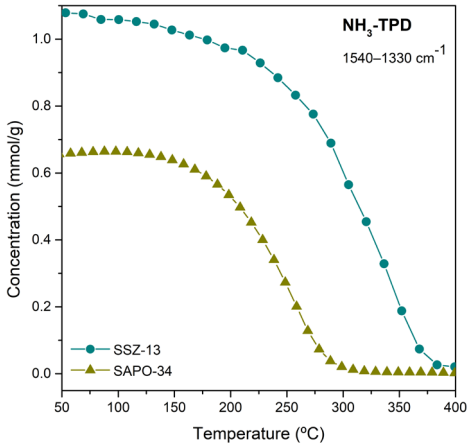
Tandem Catalyst

Materials selection: why not SAPO-34?

- Samples prepared by co-precipitation







At 400 °C, SAPO-34 wins on paper:

- X_{CO_2} is 10.3% vs 5.8%
- S_{CO} is lower
- O/P 3.3 vs 1.3

Olefins at 50 °C cooler

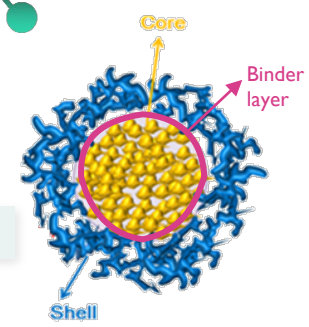
- SSZ-13 peaks ~39% at 350 °C
- SAPO-34 needs 400 °C to match

Headroom on O/P

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

Catalyst synthesis

Tandem Catalyst Synthesis



Oxide CORE@zeolite SHELL

Shaping SSZ-13 zeolite-metal oxide architectures

I Co-precipitation
Composites

500 mL of nitrates

Ammonium carbonate (prec. agent)

Dropwise

SSZ-13 dispersed in 500 mL of MQ water

Washed and filtered

Lyophilization

Calcined 500 °C / 3 h

II Physical coating
Colloidal silica assisted

ZZ pressed and sieved (180 – 250 µm)

Added to a silica sol solution

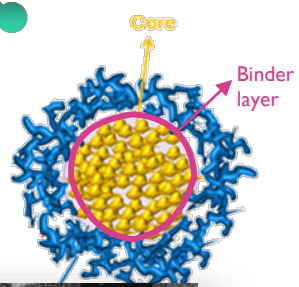
Oxide : SiO_2
1.7 : 1

Oxide : ZEO
1 : 1
1 : 1.5

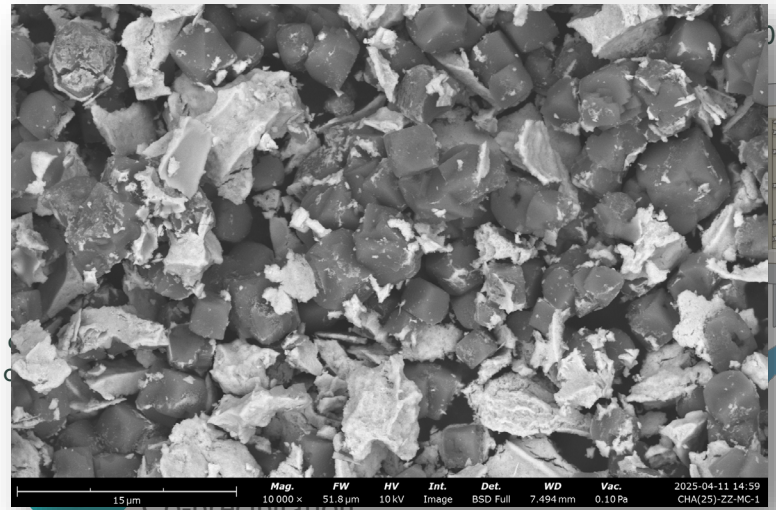
Dried overnight and homogenized

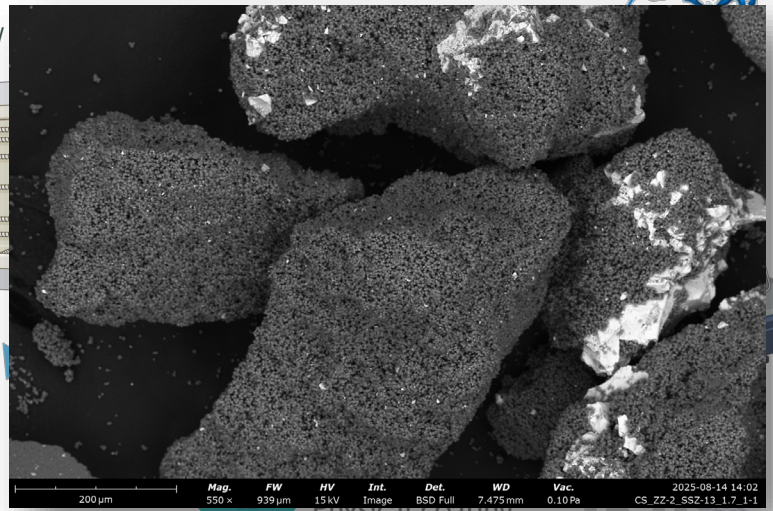
Catalyst synthesis

Tandem Catalyst Synthesis



Shaping SSZ-13 zeolite-metal oxide architectures





SSZ-13
500 mL

Co-precipitation
Composites

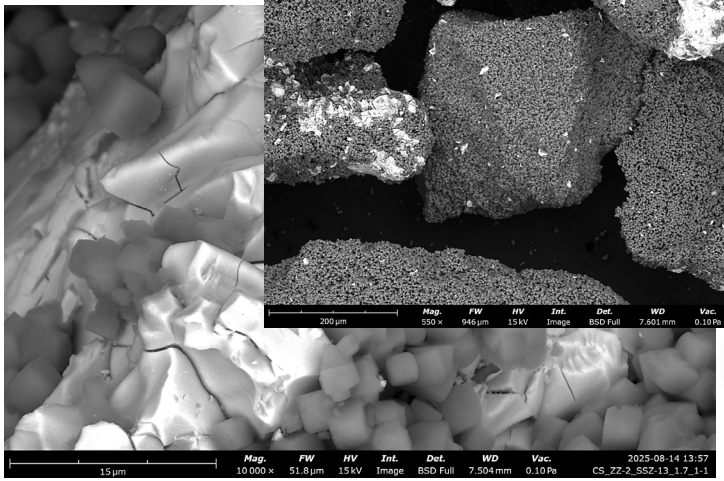
Physical coating
Colloidal silica assisted

Catalyst synthesis

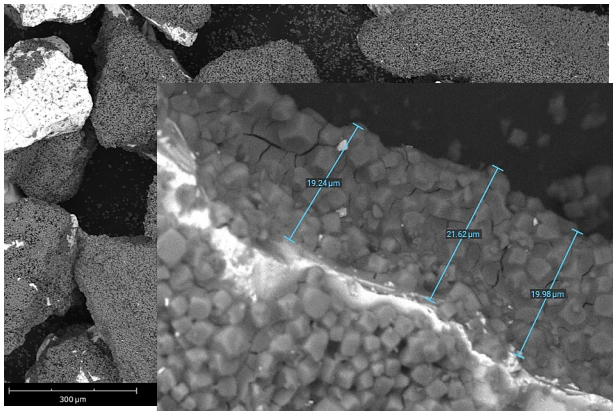
Tandem Catalyst Synthesis

Shaping SSZ-13 zeolite-metal oxide architectures

II Physical coating
Colloidal silica assisted



1 : 1



1 : 1.5

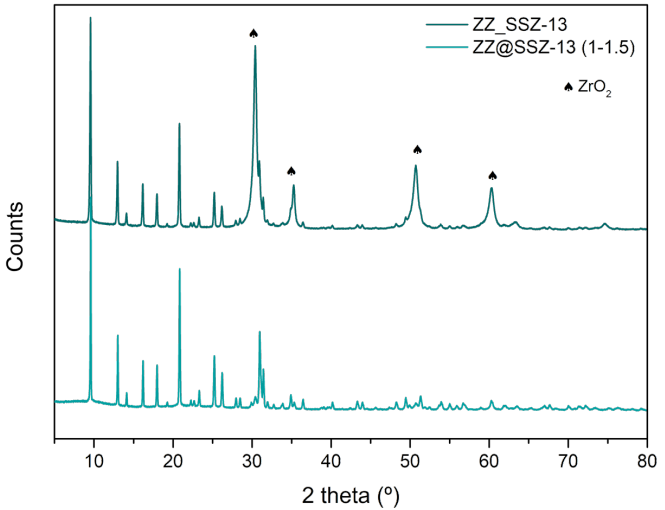
Oxide : ZEO

Catalyst characterization

Tandem Catalyst Characterization

Crystalline structure, and elemental composition

	Zr (%)	Zn (%)	Si (%)	Al (%)	O (%)	Zr	Zn	Si/Zr ratio
ZZ_SSZ-13 (I)	14.30	2.12	14.95	1.12	67.55	6.8	1.0	**1.0**
ZZ@SSZ-13_1-1 (II)	7.64	1.45	28.00	1.48	61.40	5.3	1.0	**3.7**
ZZ@SSZ-13_1-1.5 (II)	6.13	1.15	28.85	1.50	62.35	5.4	1.0	**4.7**



FEZA 2026

Results

MEMCAT

Tandem Activity

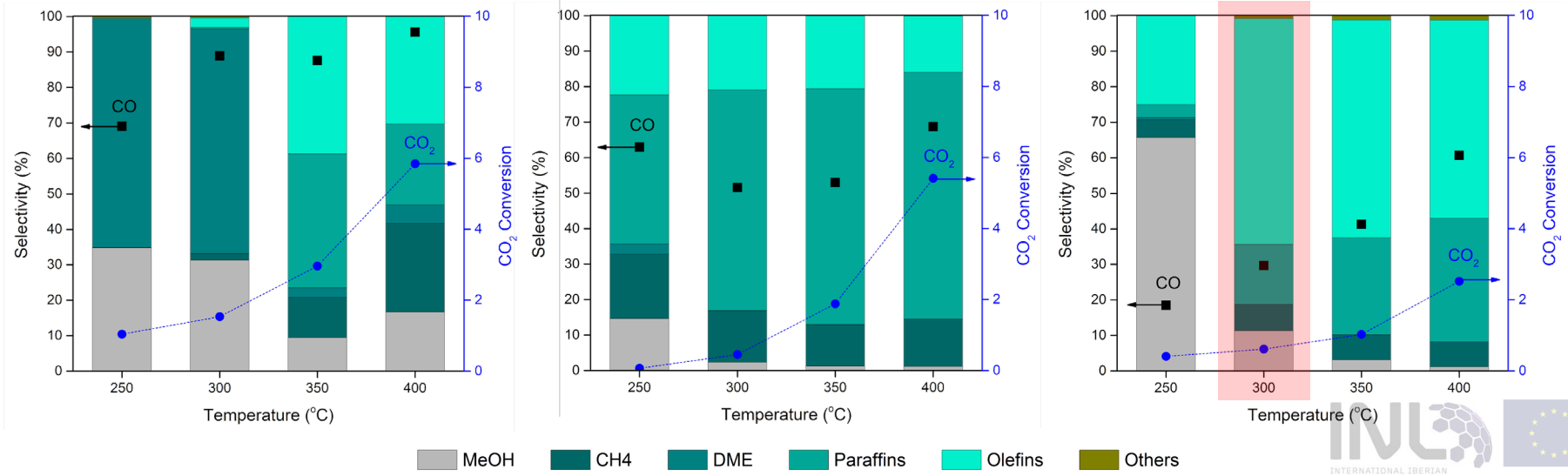
Catalytic tests

FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT

I ZZ_SSZ-13

II ZZ@SSZ-13_1-1

II ZZ@SSZ-13_1-1.5



INL INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

Funded by the European Union

Conclusions

MCs and MTO catalysts

Operating temperature range

Materials selection driven by high conversion and selectivity for both methanol and MTO conversions

Nanostructuring

Spatial distribution rule

Core-shell optimized the distance of catalytic sites to nano-level, improving olefins production

Cat_A_{MeOH} / Cat_B_{MTO} ratio

Efficient matching rule

Improved equilibrium between MeOH formation and conversion, leading to $S_{olefins}$ 63% at 350 °C!

The Future

- Tune Si/Al ratio to 50 and 100 (MTO catalyst acidity control)
- Post synthesis modification by ion-exchange (final core-shell acidity)
- Incorporation into membrane reactor ($X \geq 80\%$ and $S \geq 95\%$ goal)
- Towards green polymer production…

European Innovation Council

Funded by the European Union

MEMCAT

KOLEN'KO GROUP

https://nanochemgroup.org/

INL
INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

FEZA 2026

European Innovation Council

Funded by the European Union

MEMCAT

Membrane-assisted Ethylene Synthesis over Nanostructured Tandem Catalysts

MEMCAT

https://www.memcatproject.eu/

Thank you for your attention

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EIC and SMEs Executive Agency (EISMEA). Neither the European Union nor the granting authority can be held responsible for them.

FEZA 2026

INL INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY

MemCat Project

Experimental details

Catalytic activity

- Catalytic tests

FRITZ-HABER-INSTITUT
MAX-PLANCK-GESELLSCHAFT

- ✓ Activation: 250 ºC (5 ºC/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}

July 1st, 2026
Naples, IT

INTERNATIONAL IBERIAN NANOTECHNOLOGY LABORATORY