CAPTURE

CAPTURE days
Centre for Advanced Process Technology for Urban Resource recovery

CO_2 utilisation for dimethyl ether production via 3D printed reactor- and solid oxide cell technologies

CO2FOKUS
ADVANCING CO_2 CONVERSION

Vesna Middelkoop
VITO, CO_2Fokus coordinator

CO_2 utilisation focused on market relevant dimethyl ether production, via 3D printed reactor and solid oxide cell based technologies

vito
tecnalia Inspiring Business
Consiglio Nazionale delle Ricerche
ATAE
Hybrid Catalysis
FeyeCon
HTF HIGH TECHNOLOGY FILTERS SA
ECODESIGN company
LCE
LGi sustainable innovation
SOLID POWER
ICI CALDAIE
Petkim
SOCAR

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n. 838061

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Outline

Introduction, background to 3D printed chemical reactors for direct CO_2 conversion

- Why do 3D printing of catalytic systems?
- Examples of VITO's studies

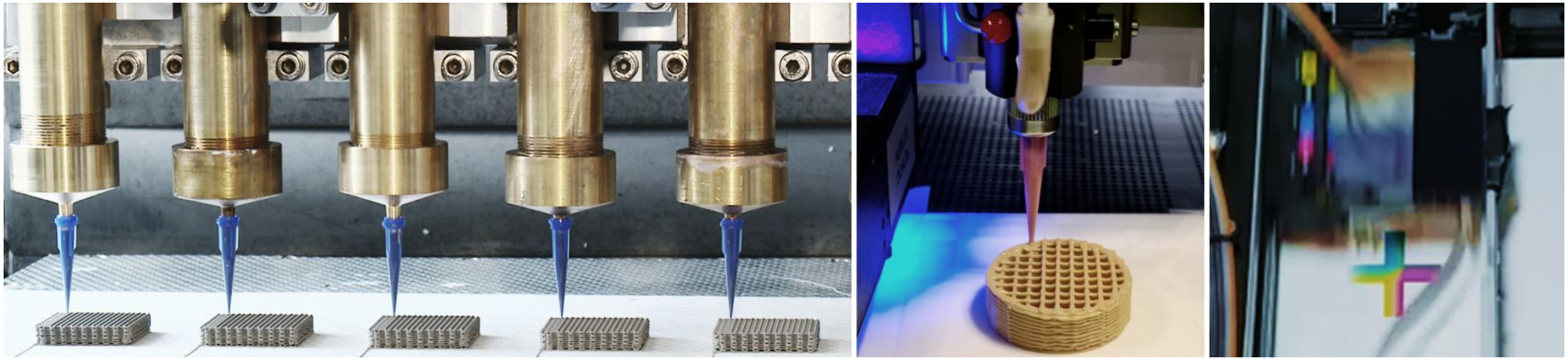
CO2Fokus project

- CO_2 conversion to dimethyl ether production
- 3D printed catalysts for DME conversion

Conclusions

Introduction and Background: 3D printing for direct conversion of CO_2

Why do 3D printing of catalytic systems and chemical reactors?



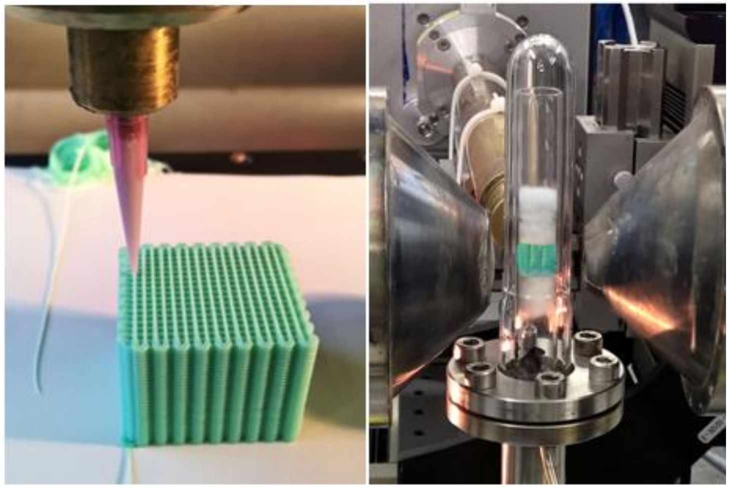
Major advantages of ‘direct write’ is to tailor multi-channel, multi-layer structures into multi-modal reactors that allow for:

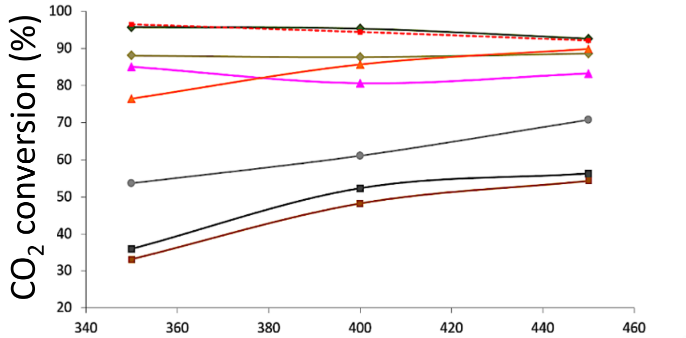
- **precise and uniform distribution of active material over a high surface area**
- **highly adaptable and well-controlled design for optimal flow pathways**
- **low pressure drop**
- **improved mass- and heat-transfer**
- **easy (in-situ) regeneration and cost-effective product removal**
- **overall greatly improved productivity per cubic meter of reactor volume**

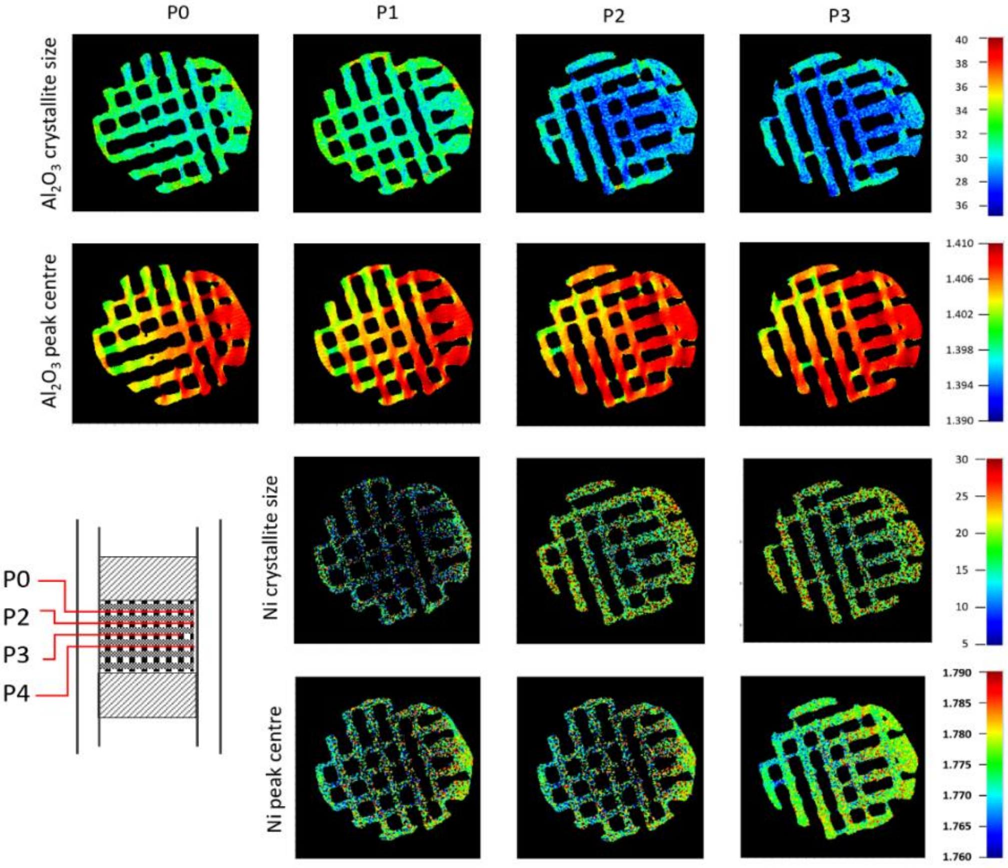
Introduction and Background:
3D printed Ni catalysts for direct conversion of CO_2

$CO_2 + 4 H_2 \rightarrow CH_4 + H_2O$

3D printed Ni/Al_2O_3 based catalysts for CO_2 methanation







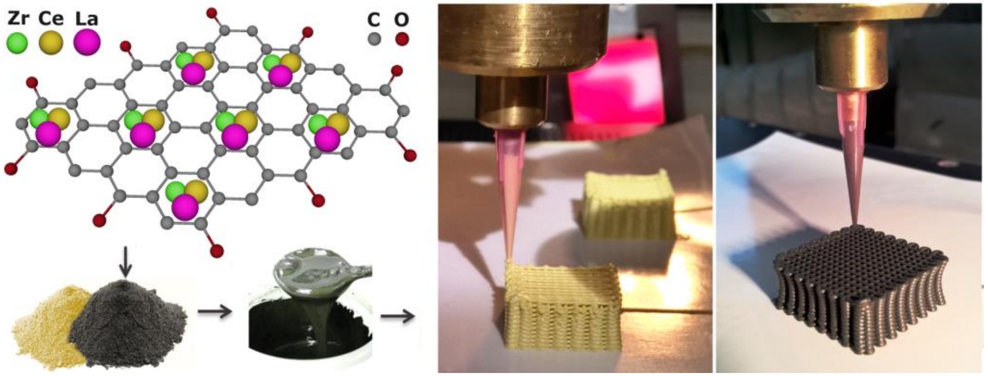
400°C under methanation operating conditions

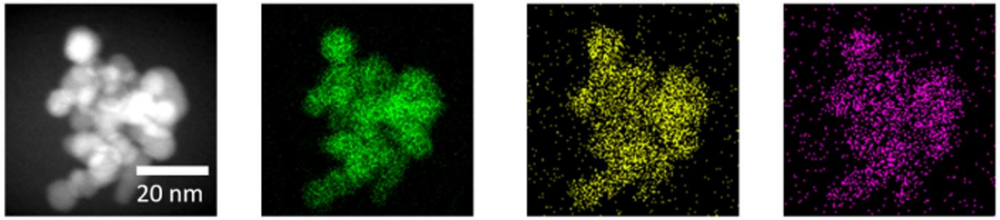
XRD-CT scans, 78.5 keV focused to a spot size of 30 µm x 30 µm, 10 ms per step covering 0 to 180 ° in steps of 1 ° translated over 11 mm in steps of 50 µm (220 steps). Each scan comprised 39 600 diffraction patterns.

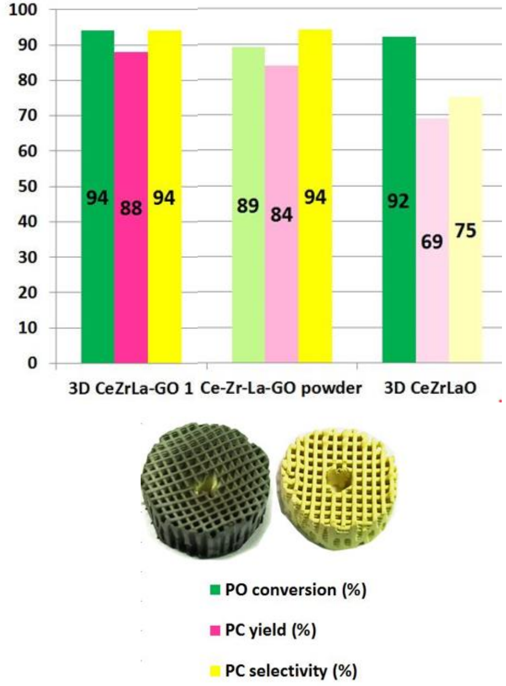
V. Middelkoop, A. Vamvakeros, D. de Wit, S.D.M, Jacques, S. Danaci, C. Jacquot, Y. de Vos, D. Matras, D., S.W.T. Price, S. W. A. Beale, 2019, *Journal of CO2 Utilization*, 33, 478–487 vito

Introduction and Background:
3D printed graphene oxide nano-composite catalyst for direct CO_2 conversion

CeZrLa-graphene oxide nano-catalyst for conversion of CO_2 and propylene oxide to propylene carbonate







V. Middelkoop, T. Slater, M. Florea, F. Neațu, S. Danaci, V. Onyenkeadi, K. Boonen, B. Saha, I-A. Baragau, S. Kellici, Next frontiers in cleaner synthesis: 3D printed graphene-supported CeZrLa mixed-oxide nanocatalyst for CO2 utilisation and direct propylene carbonate production, *Journal of Cleaner Production*, 2019, 214, 606-614

MANCHESTER
1824
The University of Manchester

CO$_2$Fokus facts and figures

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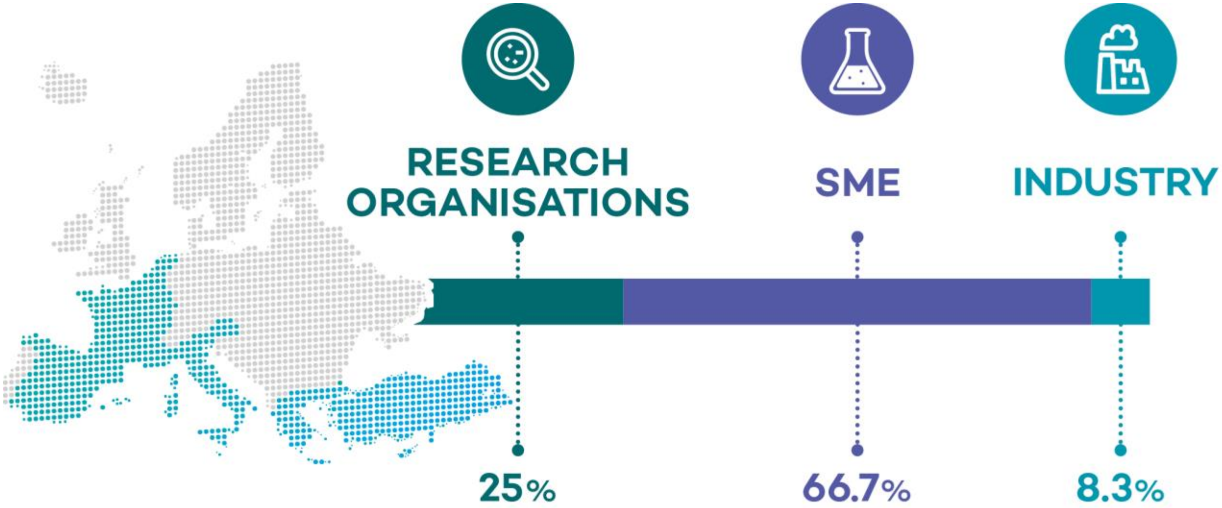
12
PARTNERS



42
MONTHS

2019/07/01
STARTING DATE

8
COUNTRIES

COORDINATED by
vito

CO_2Fokus at a glance

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The project is developing a cutting-edge technology to directly convert industrial CO_2 into DME (Dimethyl Ether), by:

- employing innovative 3D printed multichannel catalytic reactors and solid oxide electrolyser cells
- integrating and testing them in industrial environment with CO_2 point source at end-user facilities

CO_2Fokus concept

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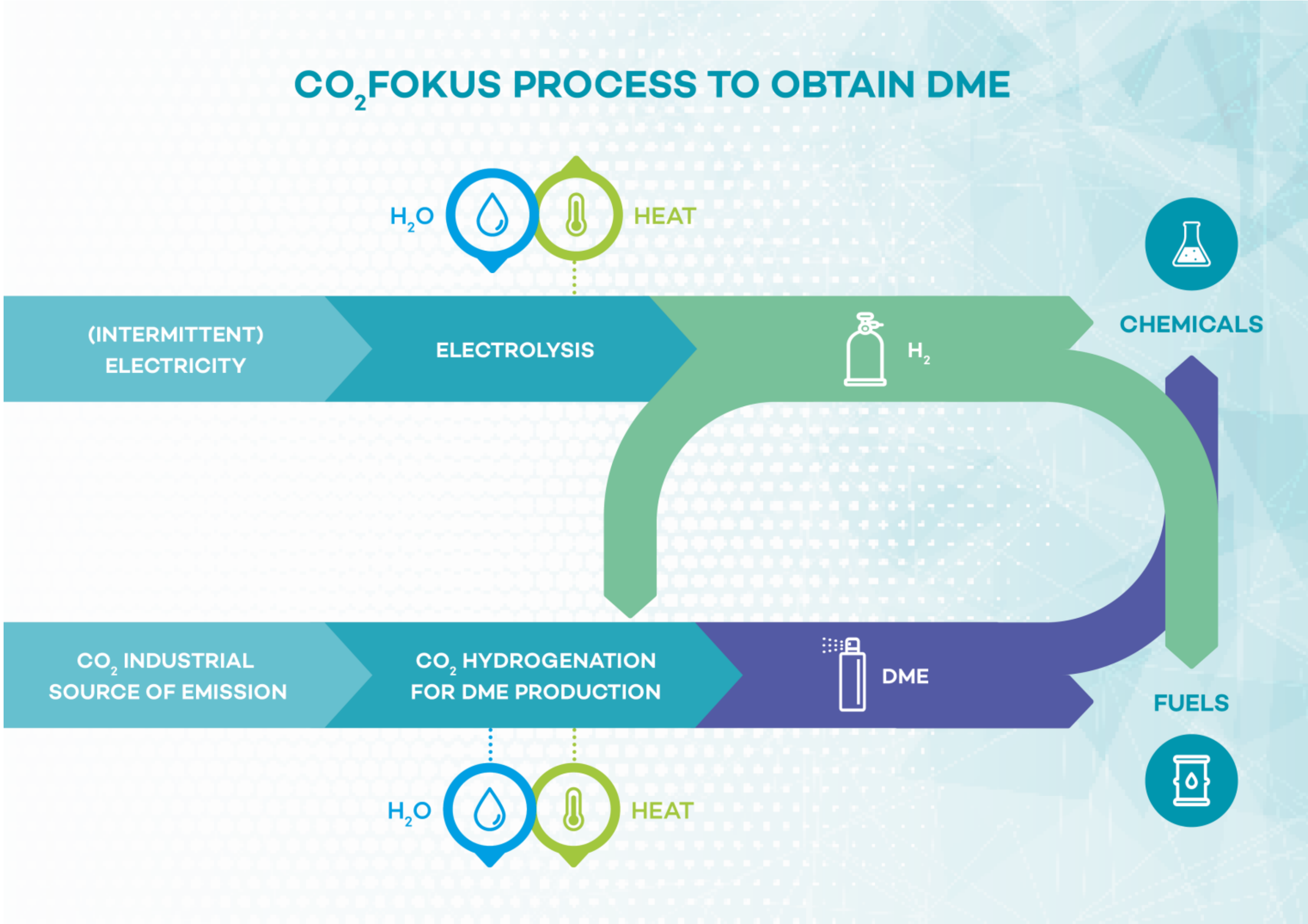

3D printed catalysts for direct CO$_2$-to-DME

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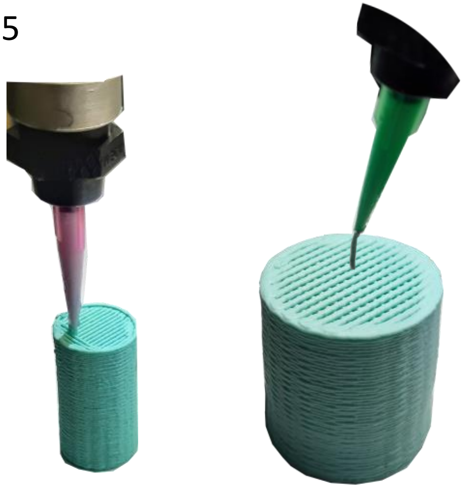
Cu-ZnO-Al_2O_3 or ZrO2-based formulations mixed with H-ZSM-5

as-prepared

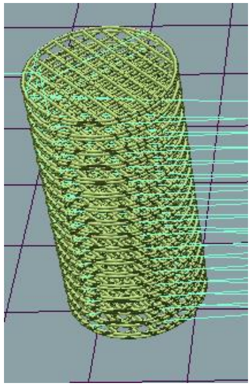
mixing



printing

calcination

calcined



**optimising
the printing model**

varying design and size

**integration
into the reactor**

3D printed multi-tubular millireactors

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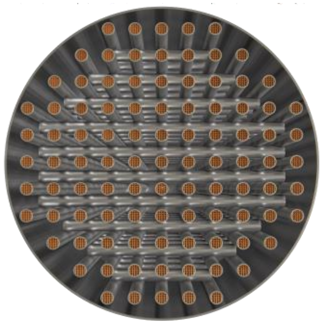
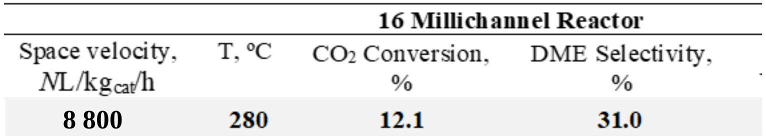


PROCESS INTENSIFICATION
↑↑↑ A/V

Characteristics required of the reactor:

- Improve the mass transference
- Optimisation of heat dissipation
- Dimensional uniformity of the tubes
- Thermal and mechanical stability
- Ease of handling

while tuning the operating parameters



		16 Millichannel Reactor	
Space velocity, $NL/kg_{cat}/h$	T, °C	CO_2 Conversion, %	DME Selectivity, %
8 800	**280**	**12.1**	**31.0**

TRL4-TRL6

Solid oxide electrolyser cell and design, development and build up for H_2 production

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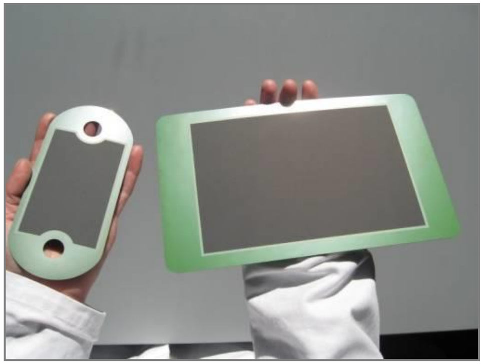
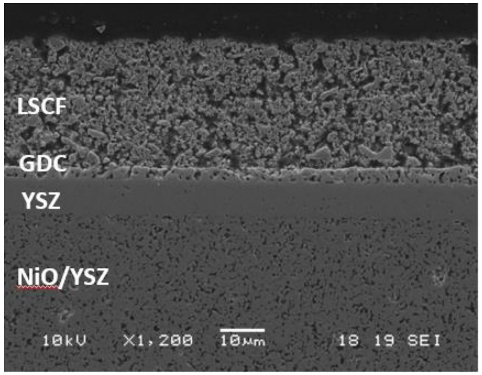
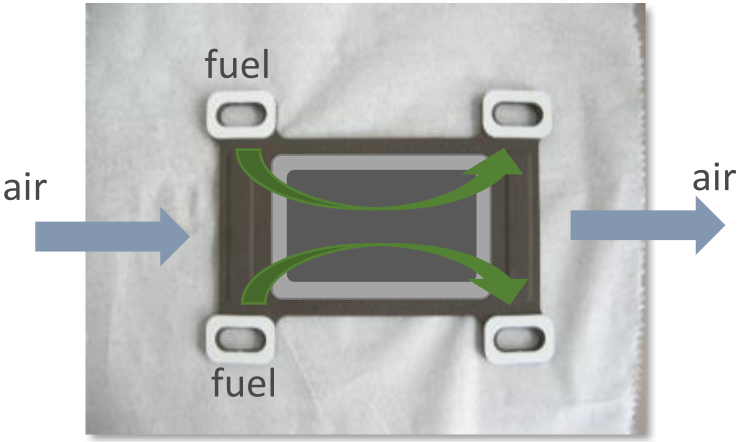
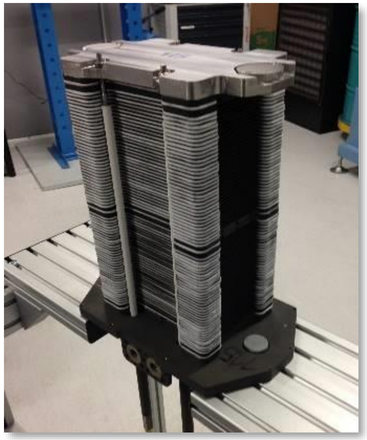
cell design









- Thin (ca. 250 µm) anode support with GDC/LSCF cathode
- Low cost state-of-the-art materials
- High mechanical strength and reliability

performances	unit	nominal
Conversion	%	60
H_2 Production	Nl	0.30-0.32
Stack power DC	kW	4.5
Thermal cycling	-	100-200

Prototype demonstration and on site integration

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Reactor and SOE units will be integrated into existing carbon-intensive industrial facilities for on-site recycling of CO_2

Key Performance Indicators (KPI)	State-of-the-art	CO2Fokus
Energy efficiency (MJ/ton) DME	$2300^{\#}$	20-30% reduction
Catalyst & reactor design	TRL 3-4	TRL 6
Catalyst durability (hrs)	10^2	10^3
Pressure (bar)	30-70	30
Temperature (°C)	280	250
CO_2/H_2 feed (N L/h)	33/100	500/1500 or larger by numbering tubes
DME yield (%)	20-25	>30 (multichannel reactor)
CO_2 conversion (%)	30	>30
Overall H_2 conversion (%)	50	50

Conclusions

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Advance beyond the state-of-the-art

- Tuning of catalyst composition and morphology (shape/geometry/porosity)
- Multi-tubular reactors scale-up/increasing throughput: stacking up monoliths and numbering-up tubes
- Reactor design: controlled shape, geometry and macrostructure: large surface to volume ratio, enhanced mass and heat transfer and 10-20% increase in reaction performance
- SOEC Electrolysis for in situ H_2 production
- Integration and operation at industrial CO_2 point source to demonstrate direct conversion of CO_2 and H_2 to DME

Thank you for watching!

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