Warsaw University of Technology

Advanced Materials for Chemical and Electrochemical Energy Conversion and Storage

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Professor

International Energy and Environment Conference 2026 (IEEC)

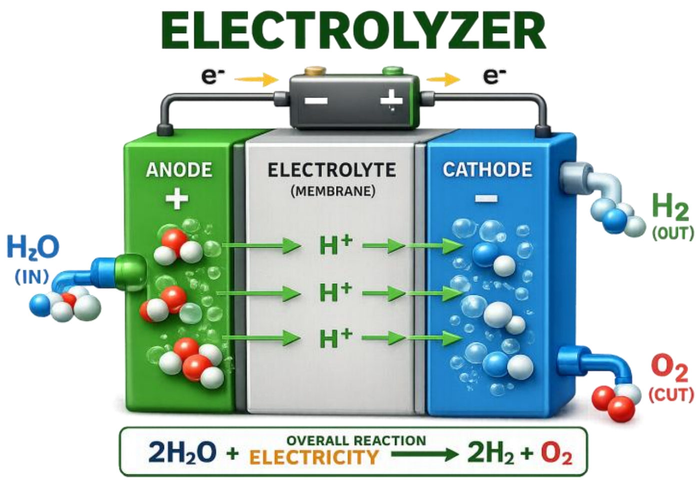
7-9 September 2026, Ostrava

Faculty of Materials Science and Engineering

SCOPE

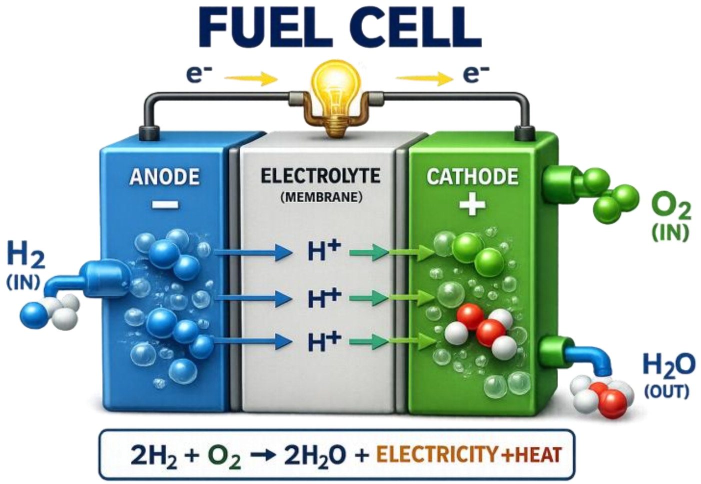
Energy conversion

H_2O →



→ H_2

H_2 →

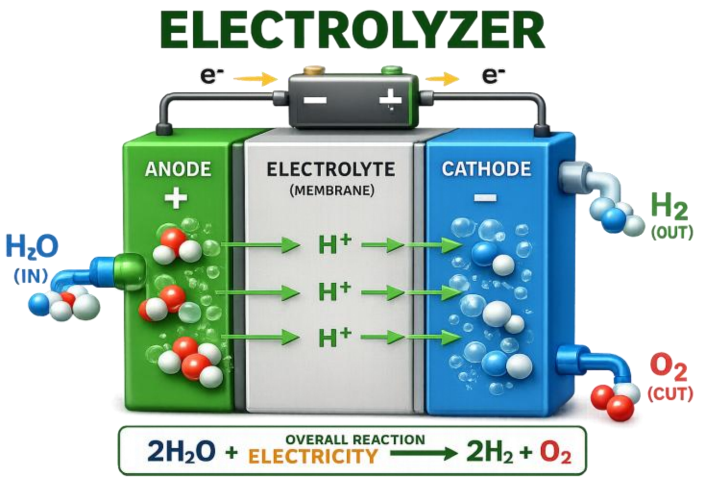


→

H_2O

SCOPE

Energy storage

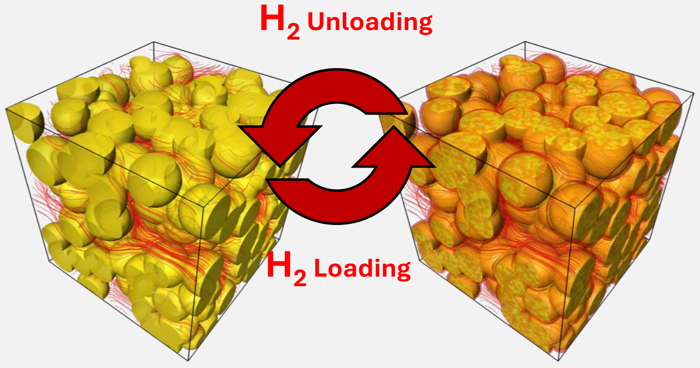


H_2

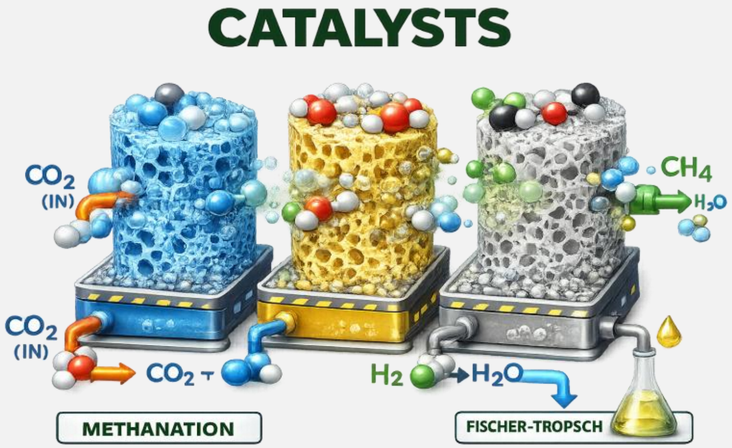
CO_2

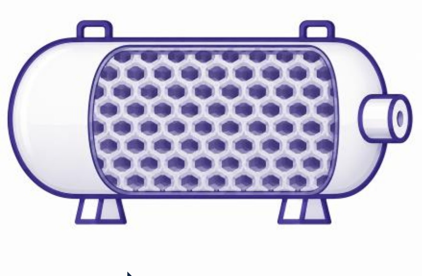
Materials

- Hydrogen storage



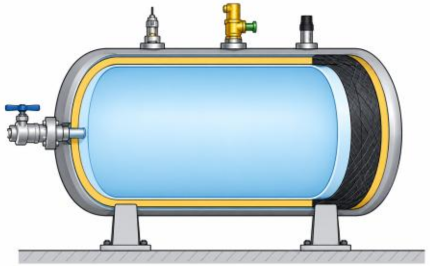
- Synthetic fuels / Catalysts



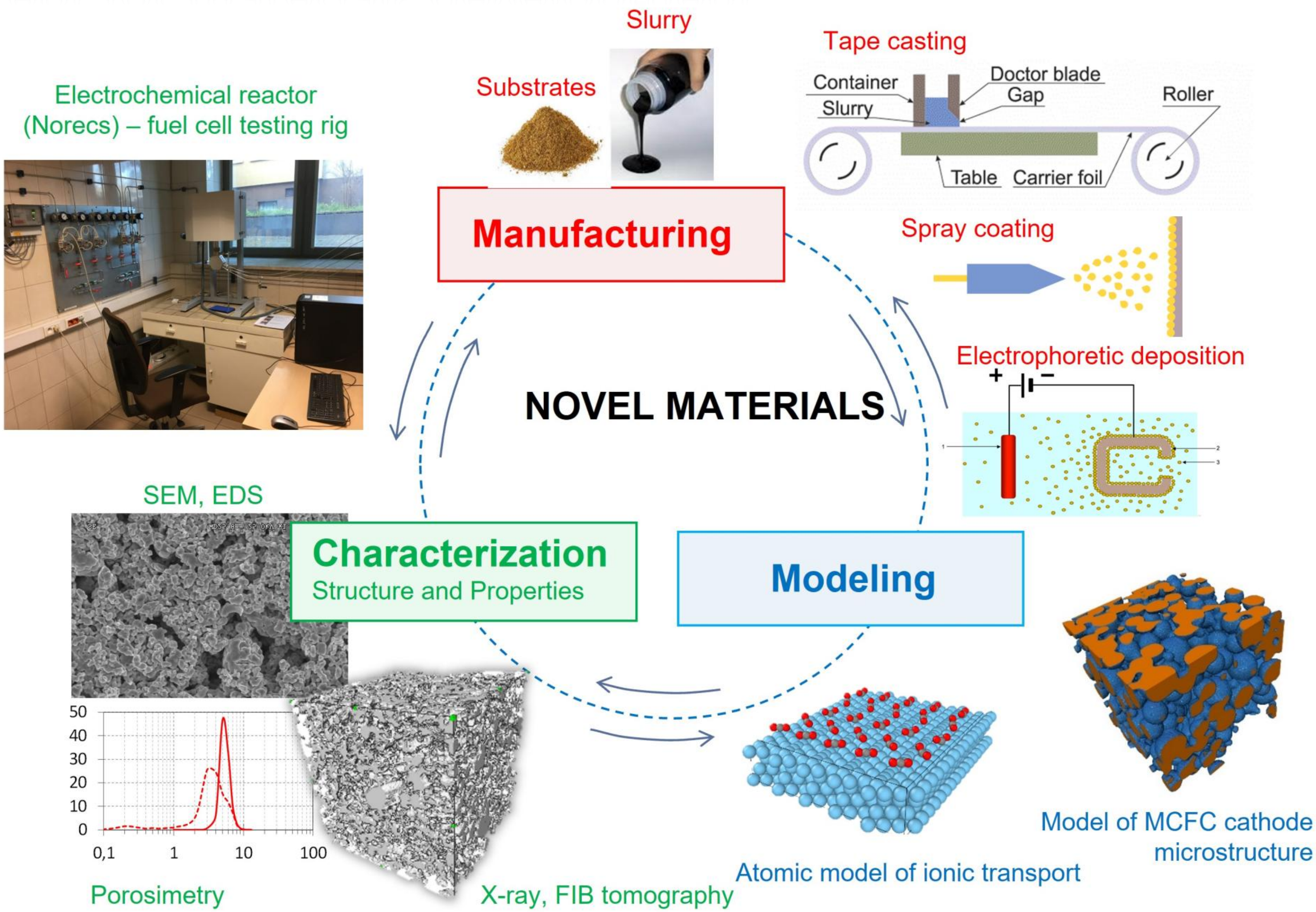


H_2

CH_4

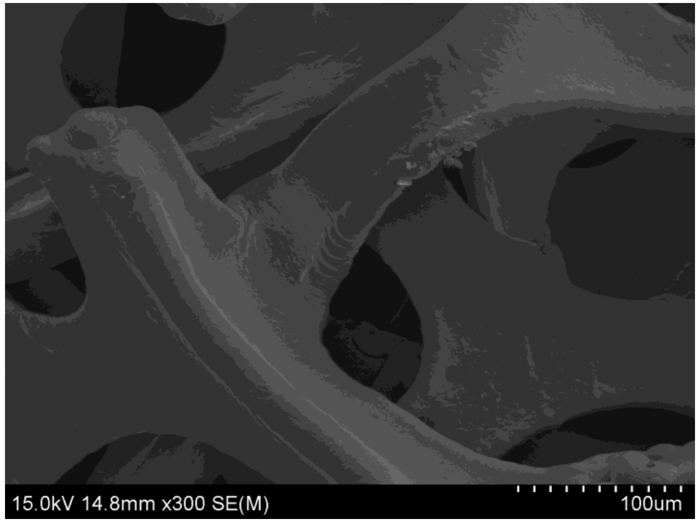


Concept for materials development



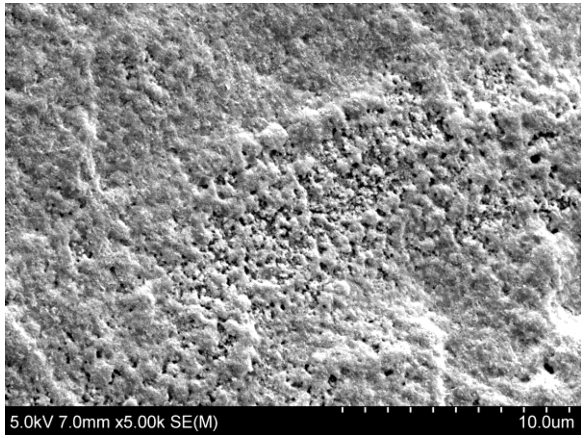
Materials for electrolyzers

Investigation of transition-metal-based catalysts for alkaline water splitting

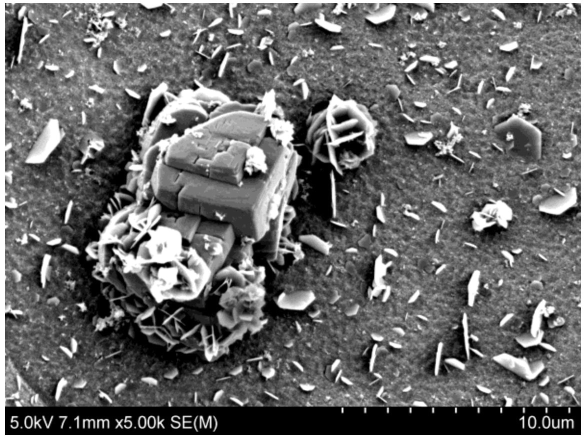


Nickel foam
(bare)

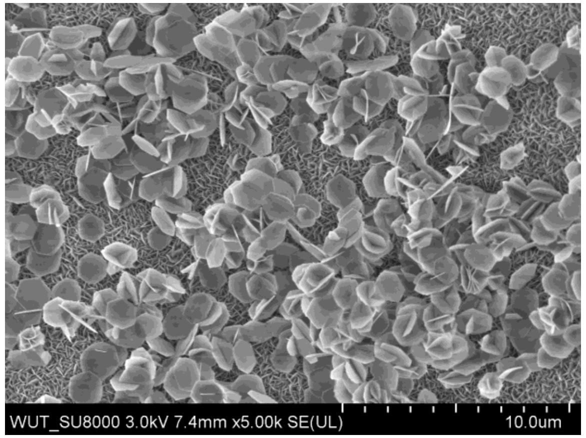
@



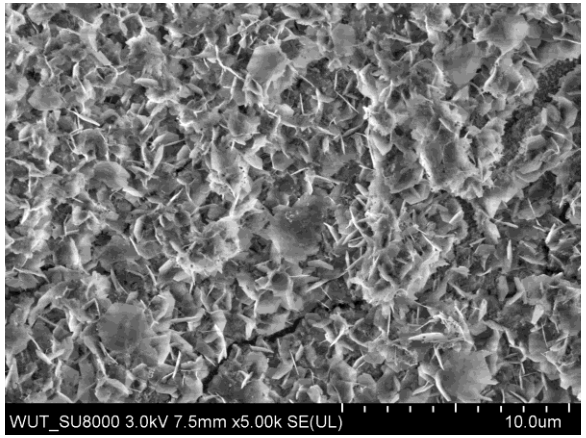
Fe oxide



Mn carbonate



Ni hydroxide

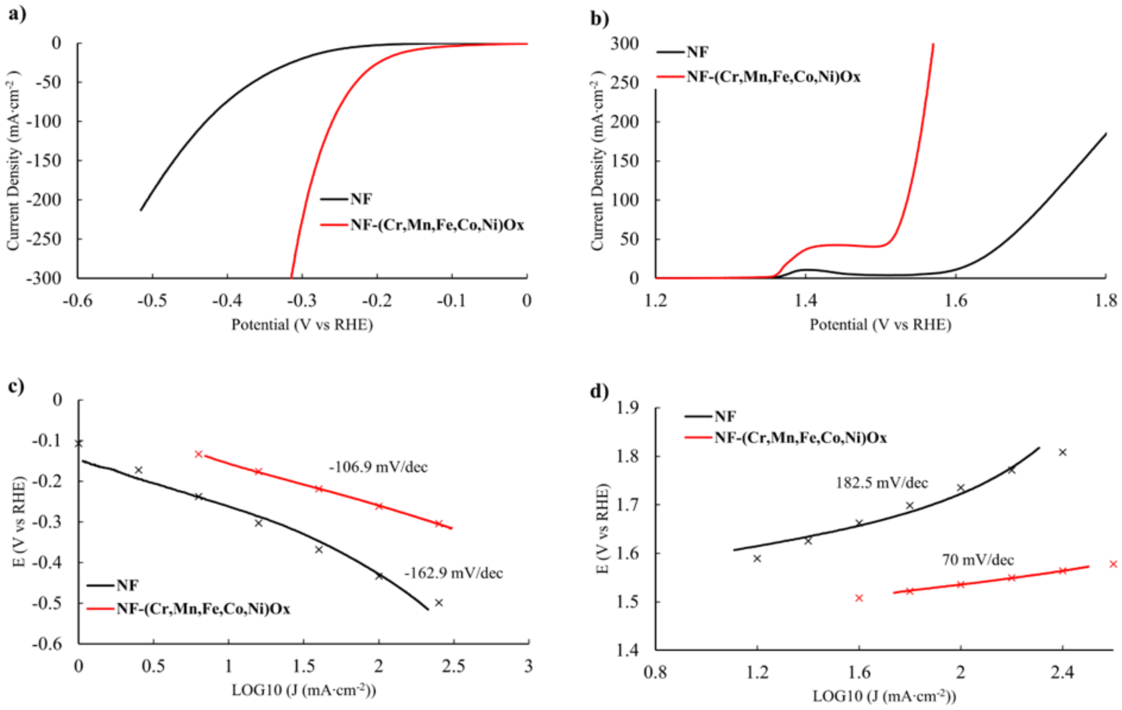


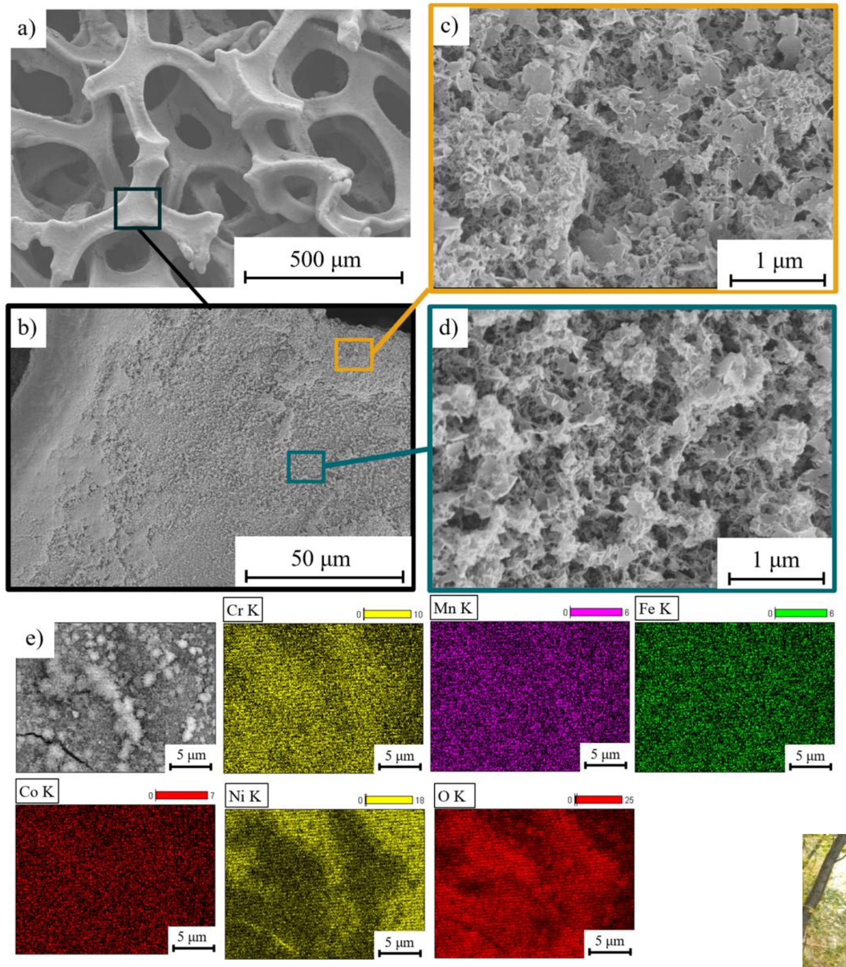
Co hydroxide

Materials for electrolyzers

mixed (Cr,Mn,Fe,Co,Ni) oxide

A multielement approach can enhance catalytic performance through synergistic effects



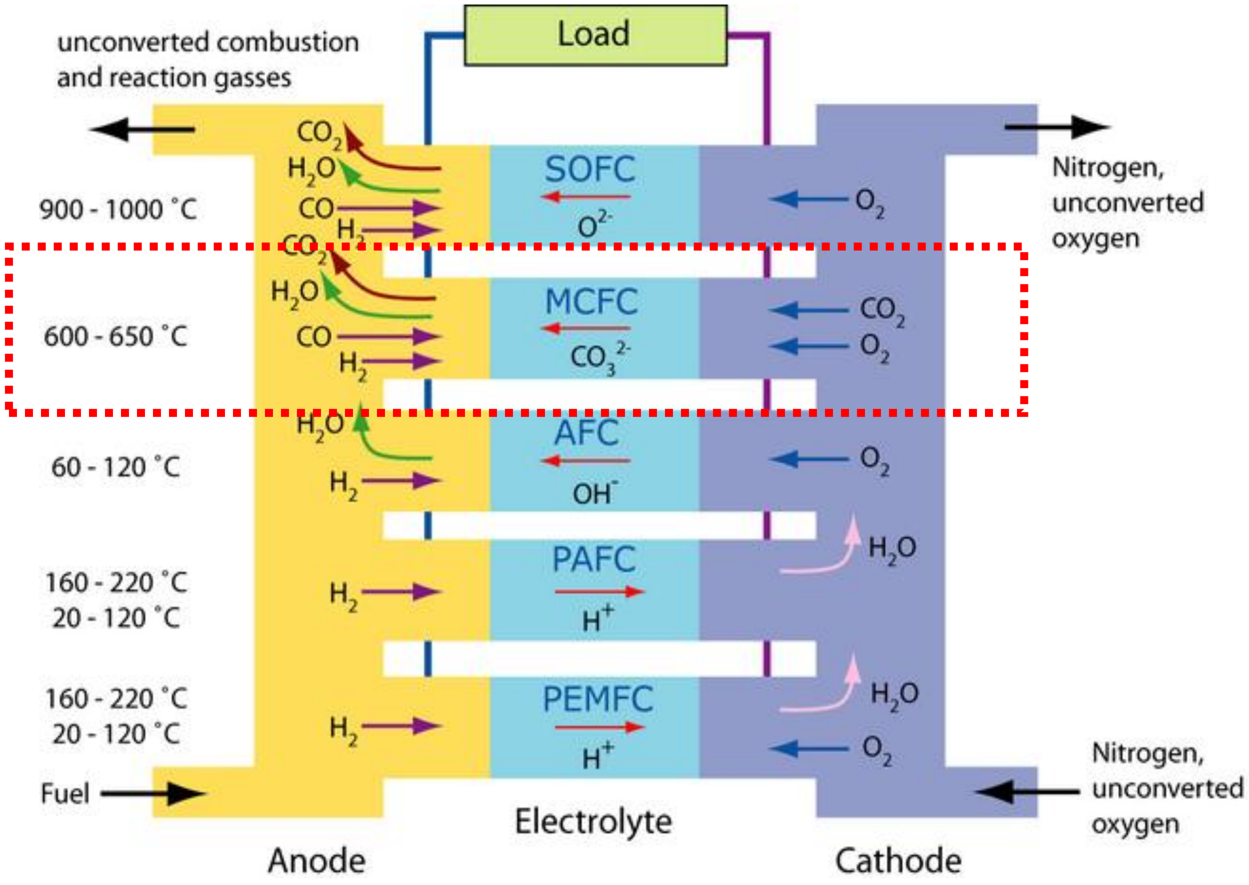


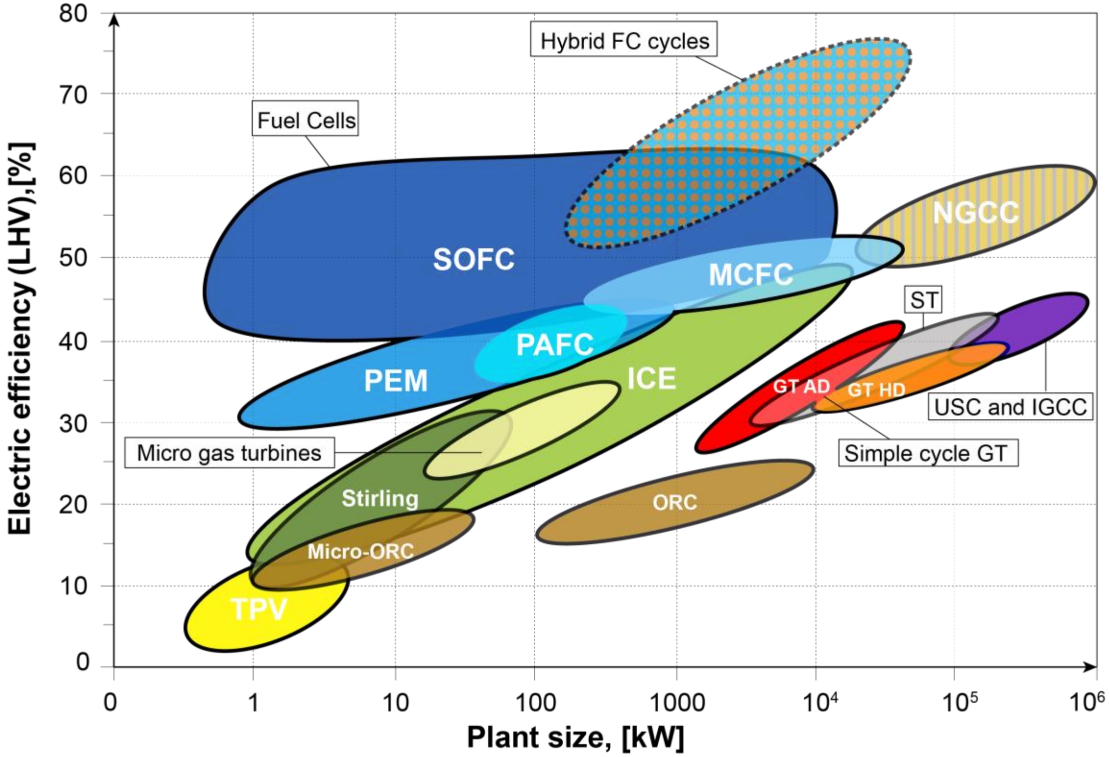
W. Kuklewski, M.-S. Akhtar, G. Komorowska, G. Cieślak, T. Wejrzanowski, Multi-component Cr-Mn-Fe-Co-Ni oxide as bifunctional electrode for alkaline water splitting, Mater Lett X, 27 (2026), Article 100274, doi

Hydrogen Technologies, Poster

Tuesday 8th September

Fuel Cells - principles





https://www.gecos.polimi.it/research-areas/hydrogen-fuel-cells-and-electrochemical-energy-systems/

Fuel cells are classified primarily by the kind of electrolyte

Fuel cell overall efficiency

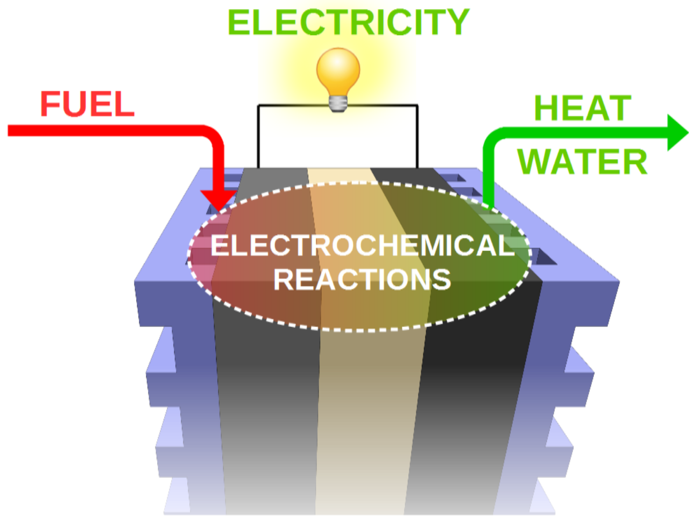
Fuel Cells - principles

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Electrical Efficiency (LHV)	Applications	Advantages	Challenges
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	<120°C	<1 kW - 100 kW	60% direct H_2;[i] 40% reformed fuel[ii]	• Backup power • Portable power • Distributed generation • Transportation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up and load following	• Expensive catalysts • Sensitive to fuel impurities
Alkaline (AFC)	Aqueous potassium hydroxide soaked in a porous matrix, or alkaline polymer membrane	<100°C	1 - 100 kW	60%[iii]	• Military • Space • Backup power • Transportation	• Wider range of stable materials allows lower cost components • Low temperature • Quick start-up	• Sensitive to CO_2 in fuel and air • Electrolyte management (aqueous) • Electrolyte conductivity (polymer)
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a porous matrix or imbibed in a polymer membrane	150 - 200°C	5 - 400 kW, 100 kW module (liquid PAFC); <10 kW (polymer membrane)	40%[iv]	• Distributed generation	• Suitable for CHP • Increased tolerance to fuel impurities	• Expensive catalysts • Long start-up time • Sulfur sensitivity
Molten Carbonate (MCFC)	Molten lithium, sodium, and/ or potassium carbonates, soaked in a porous matrix	600 - 700°C	300 kW - 3 MW, 300 kW module	50%[v]	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	500 - 1000°C	1 kW - 2 MW	60%[vi]	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Solid electrolyte • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Limited number of shutdowns

Source: US DOE (2010). *Fuel Cell Factsheet*

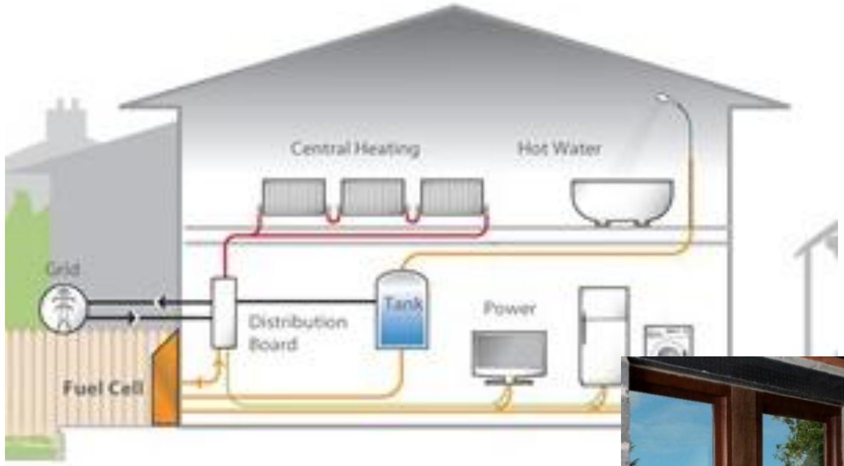
High-temperature fuel cells

Molten carbonate fuel cells (MCFCs) are the one of the most promising high efficiency and sustainable power generation technologies. MCFCs convert chemical energy of **fuel (hydrogen)** into **electricity, heat and water** through electrochemical reactions.



Main features:

- 300 kW–2.8 MW units, commercially available,
- combination of heat and power with gas expansion turbine delivers up to 65% efficiency,
- fuels: natural gas, anaerobic digester gas with internal reforming, sewage gas, natural gas and biogas compatible,
- average 10 000h lifetime,
- possible to employ in electrical utilities, industrial, and military applications.



◄▼ **Residential**

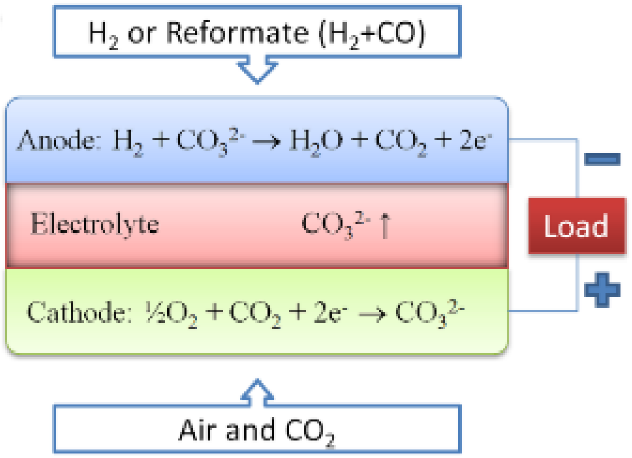
▼ **Commercial**

The world's largest operating fuel cell power plant (59 MW), located in Hwaseong, South Korea

Source:E4Tech http://www.fuelcelltoday.com

Materials for molten carbonate fuel cells (MCFCs)

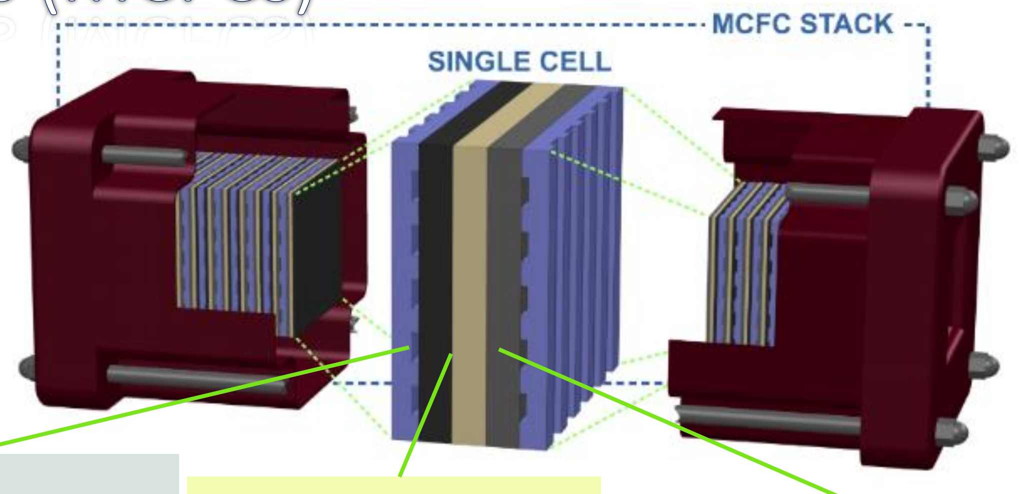
Molten carbonate fuel cells are highly efficient **chemical to electrical energy converters** and emerges as the one of the **most promising sustainable power generation technologies**.

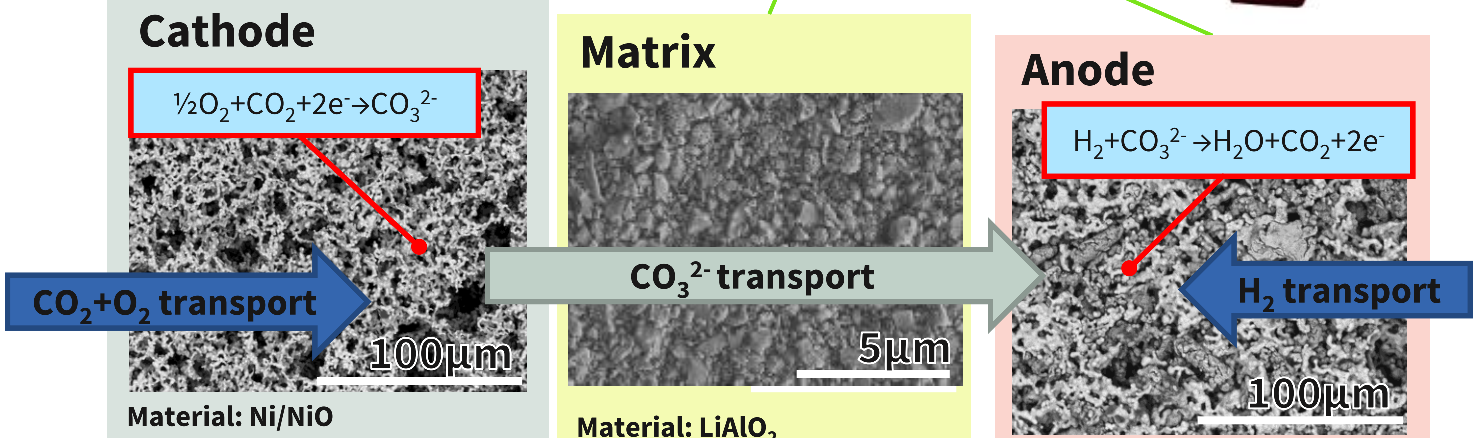


MCFC stacks are assemblies of **single cells**, where each single cell comprises of **porous** components:

- **cathode,**
- **anode,**
- **electrolyte matrix.**

The **electrolyte** – mixture of $(Li/K)_2CO_3$ or $(Li/Na)_2CO_3$ – is kept in molten state in MCFC operating conditions (600-700 °C).





Cathode

Material: Ni/NiO

- **catalyses O_2 reduction reaction**
- **high open porosity (70-80%)**
- **mean pore size 7-15µm**
- **thickness: 0.70-0.80mm**

Matrix

Material: $LiAlO_2$

- **holds molten carbonate electrolyte**
- **high open porosity (~50%)**
- **mean pore size ~0.3µm**
- **thickness: ~1.00mm**

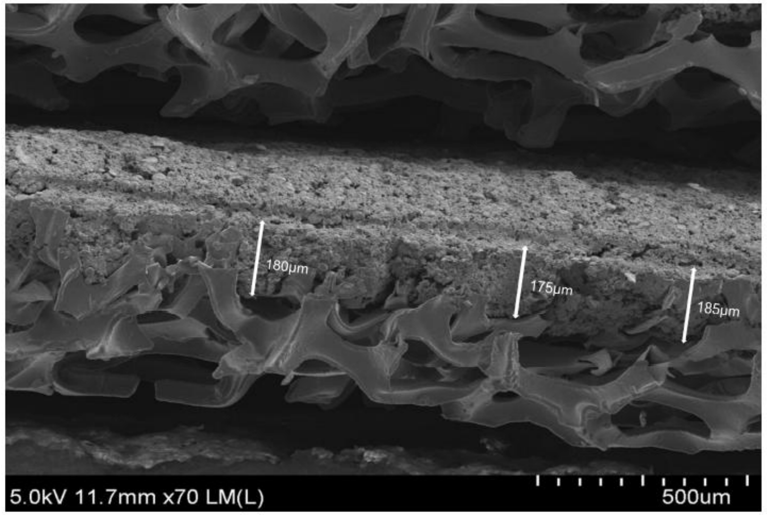
Anode

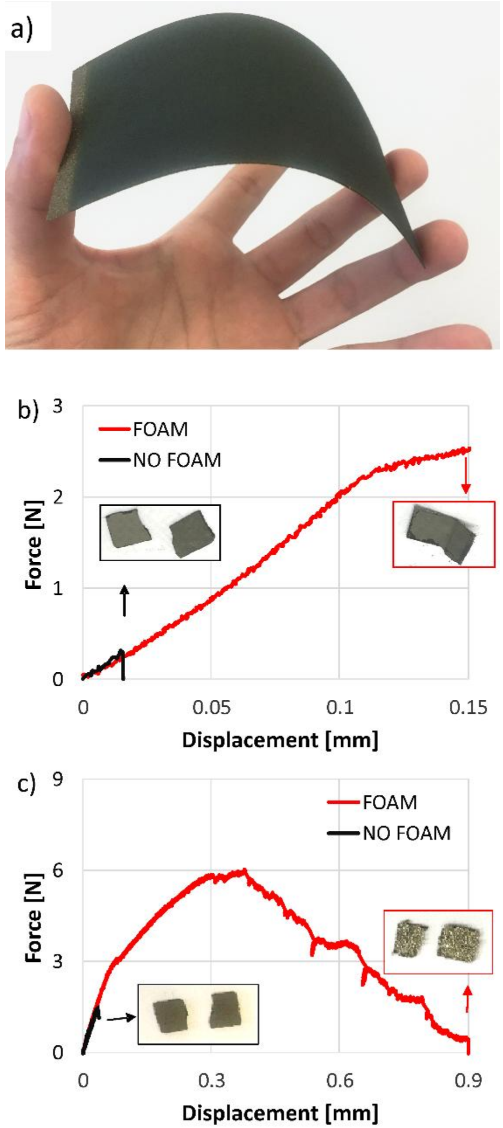
Material: Ni, Ni-Cr/Al.

- **catalyses H_2 oxidation reaction**
- **high open porosity (60-70%)**
- **mean pore size 5-7µm**
- **thickness: 0.60-0.80mm**

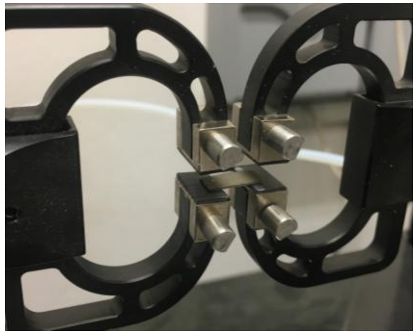
Milestone 2

Application of nickel foam support





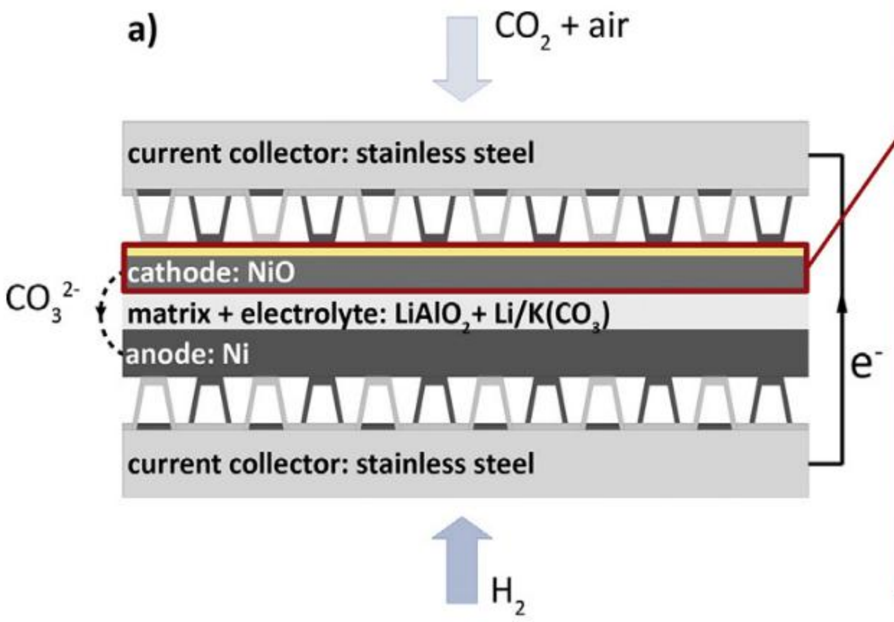
Mechanical testing

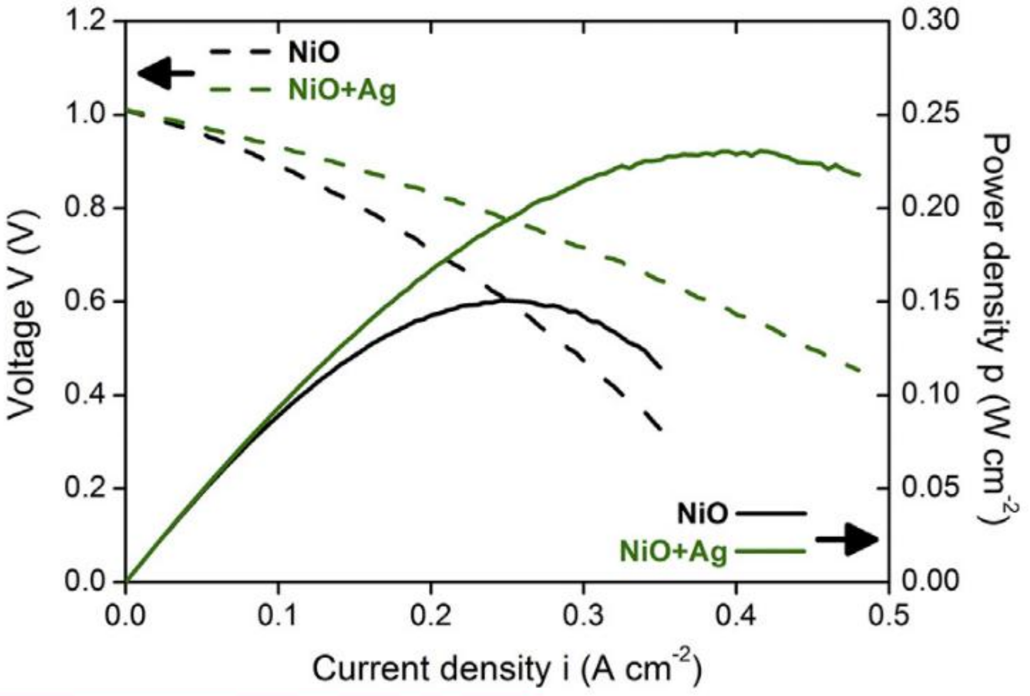


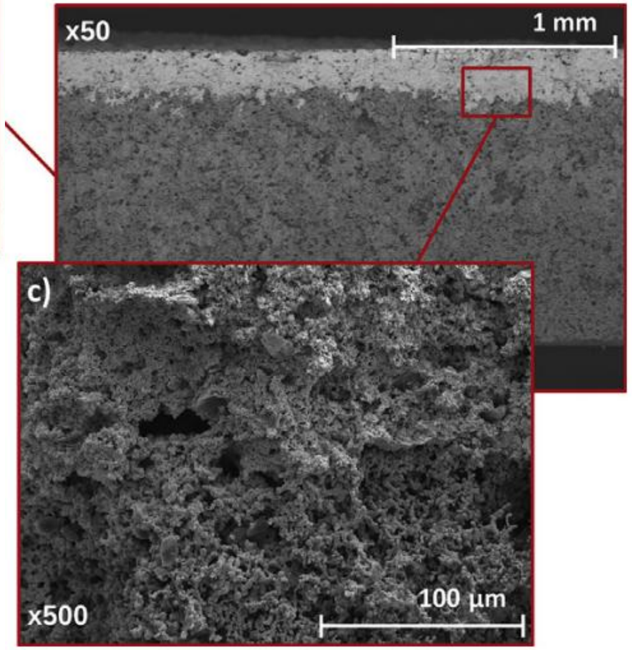
T. Wejrzanowski, K. Cwieka, J. Skibinski, T. Brynk, S. Haj Ibrahim, J. Milewski, W. Xing,
Metallic foam supported electrodes for molten carbonate fuel cells, Materials & Design 2020

Patent: Pat.241140 „Elektroda węglanowego ogniwa paliwowego o zwiększonej wytrzymałości mechanicznej”

Milestone 3
Application of silver coating







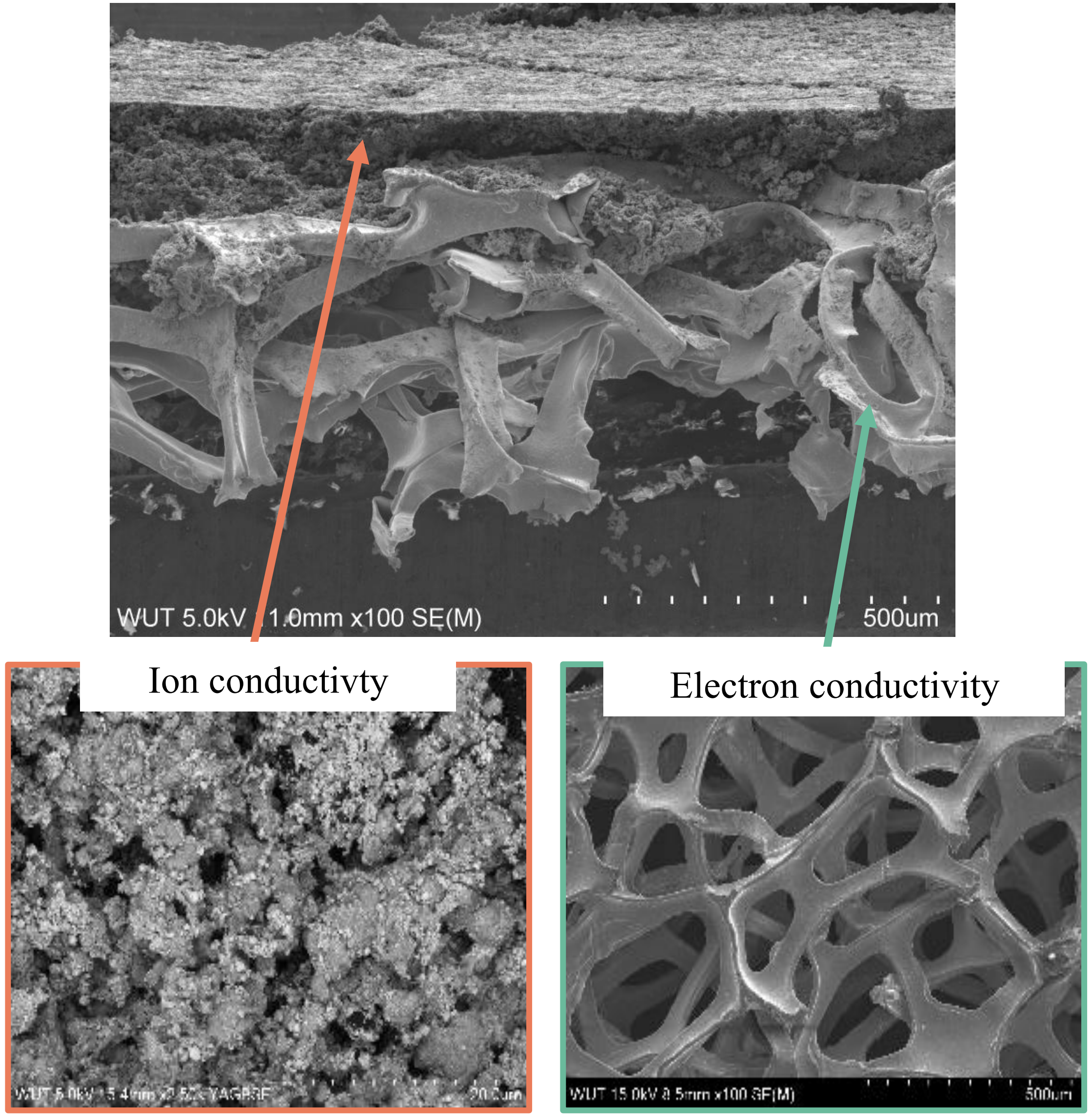
Aleksandra Lysik, Karol Cwieka, Tomasz Wejrzanowski, Jakub Skibinski, Jaroslaw Milewski, Fernando M. B. Marques, Truls Norby, Wen Xing, Silver coated cathode for molten carbonate fuel cells, June 2020, International Journal of Hydrogen Energy 45(38)

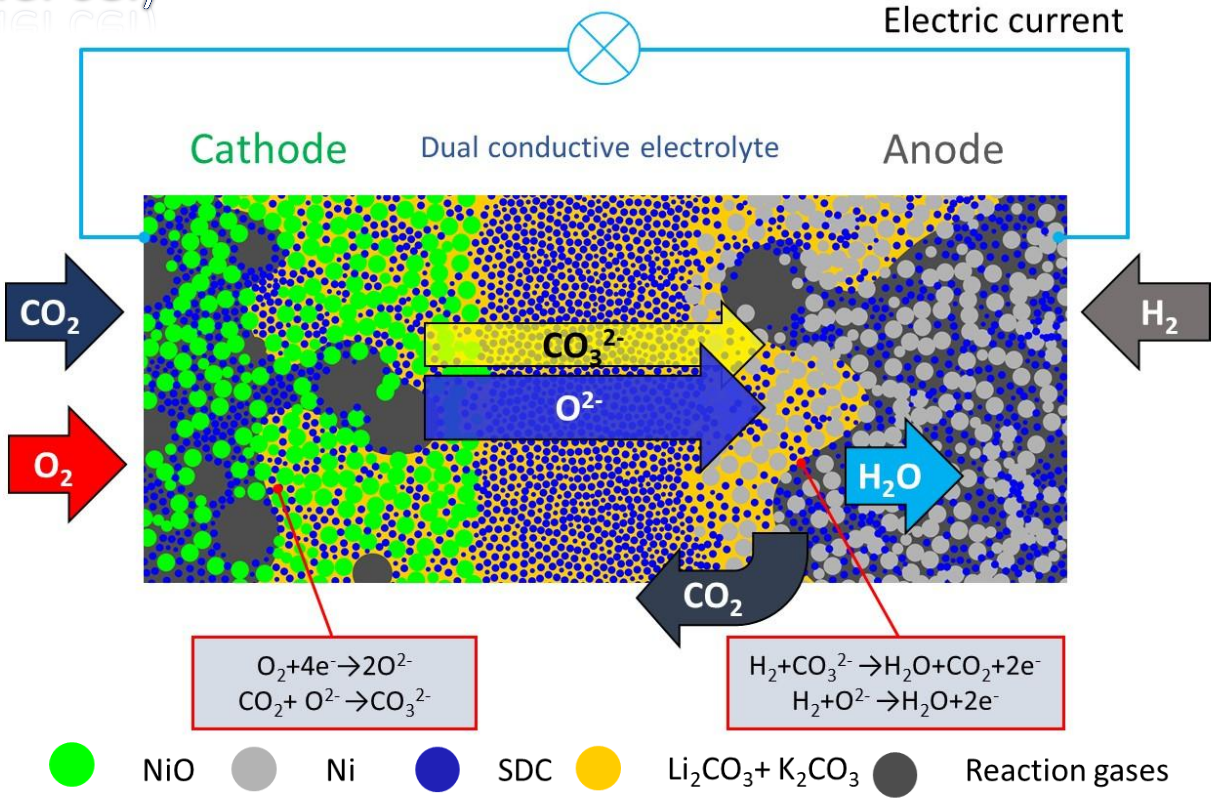
Karol Ćwieka, A Lysik, Tomasz Wejrzanowski, Truls Norby, Wen Xing, Microstructure and electrochemical behavior of layered cathodes for molten carbonate fuel cell, Journal of Power Sources 500 (2021) 229949

Patent: P.430869 Katoda węglanowego ogniwa paliwowego z warstwą spieku srebra

Milestone 4

Hybrid MCFC/SOFC = COFC (Carbonate oxide fuel cel)

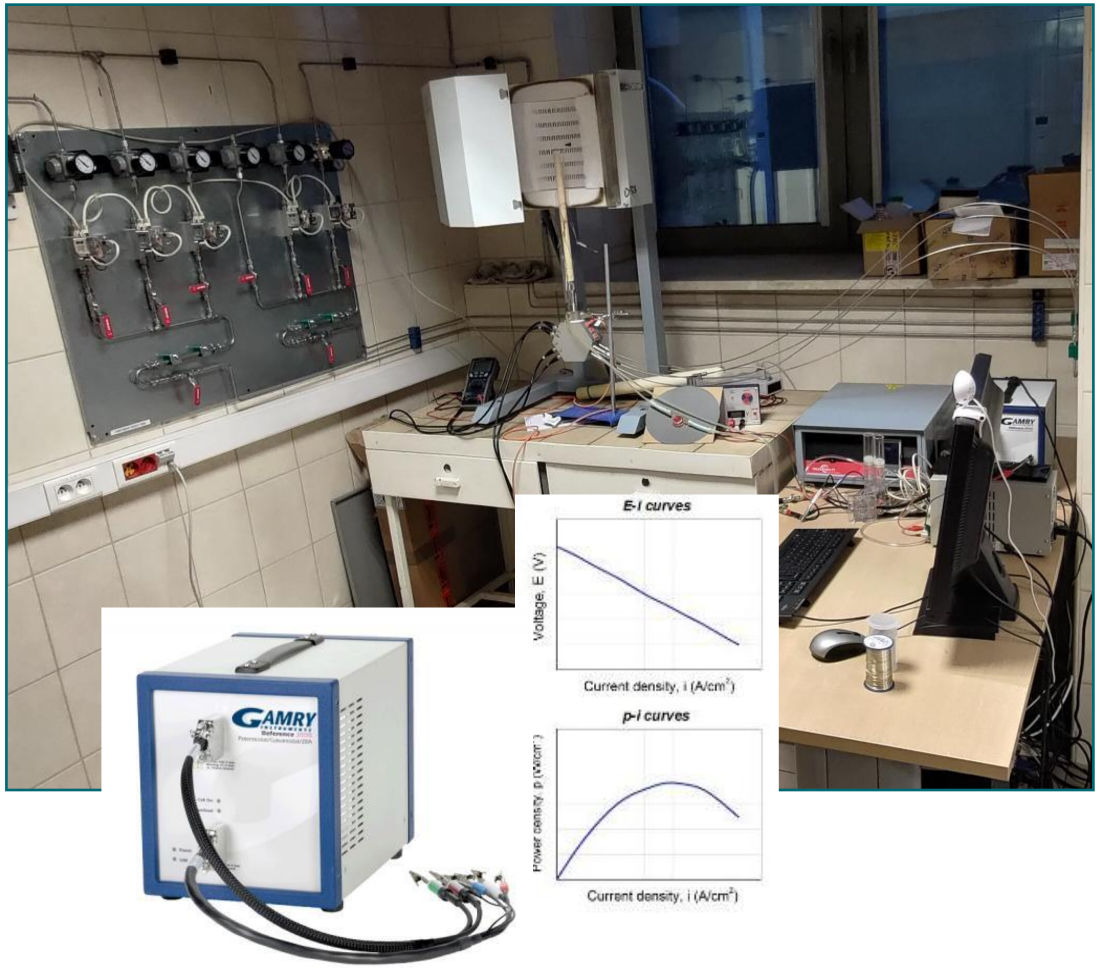


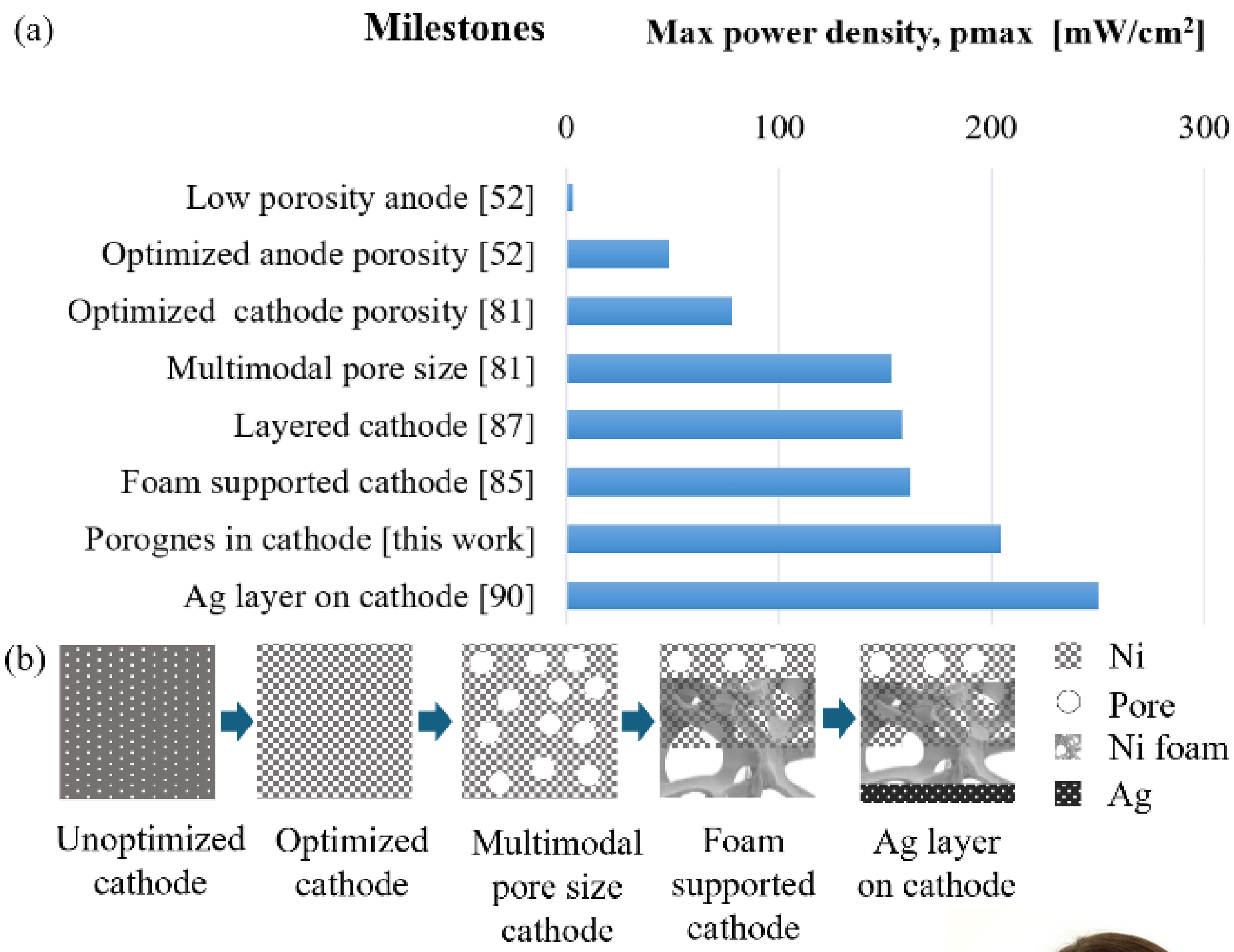


Komorowska, G.; Wejrzanowski, T.; Jamroz, J.; Jastrzębska, A.; Wróbel, W.; Tsai, S.-Y.; Fung, K.-Z. Fabrication and Characterization of a Composite Ni-SDC Fuel Cell Cathode Reinforced by Ni Foam. Materials 2022, 15, 4891. https://doi.org/10.3390/ ma15144891

Gabriela Komorowska, Jan Jamroz, Tomasz Wejrzanowski, Kamil Dydek, Rafał Molak, Wojciech Wróbel, Shu-Yi Tsai, Kuan-Zong Fung, Thermal treatment and properties of Ni-SDC cathode for high temperature fuel cells, Materials Science for Energy Technologies 6 (2023) 105-113

Fuel cell performance





Gabriela Komorowska, Samih Haj Ibrahim, Tomasz Wejrzanowski, Microstructural and chemical design of materials for molten carbonate fuel cells: recent progress and challenges, Bulletin of the Chemical Society of Japan, 2026, 99, https://doi.org/10.1093/bulcsj/uoag093

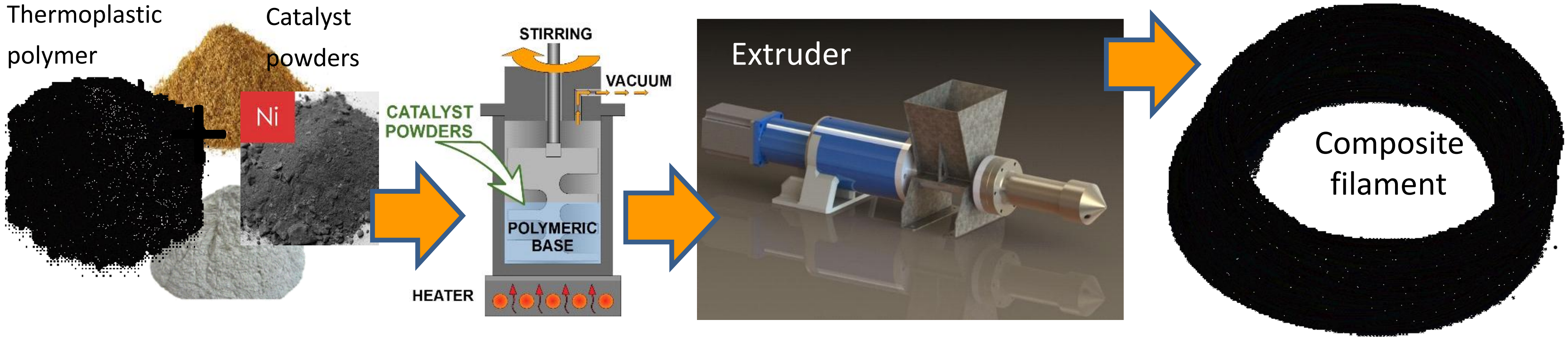
14:15-14:30, Room 2

Manufacturing Strategies for Functional Layers in Carbonate-Oxide Fuel Cells

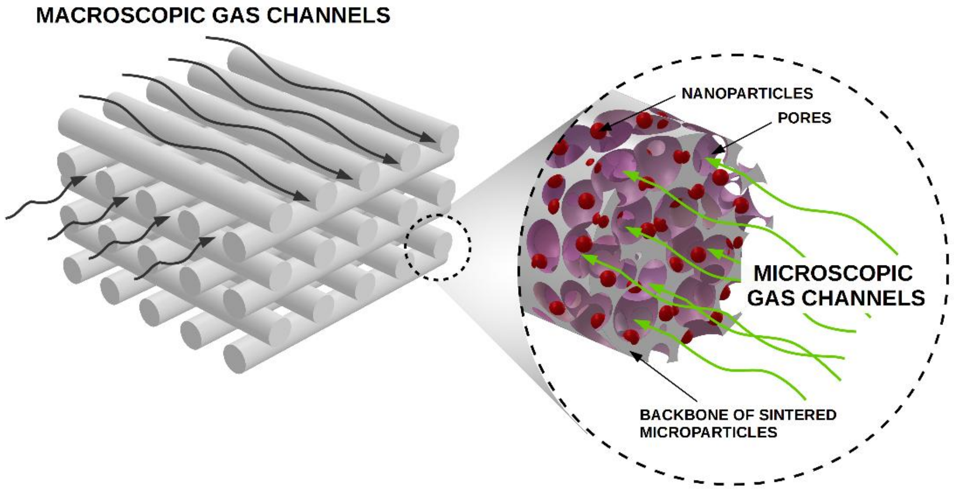
Hierarchical porous materials – 3D printing

The concept

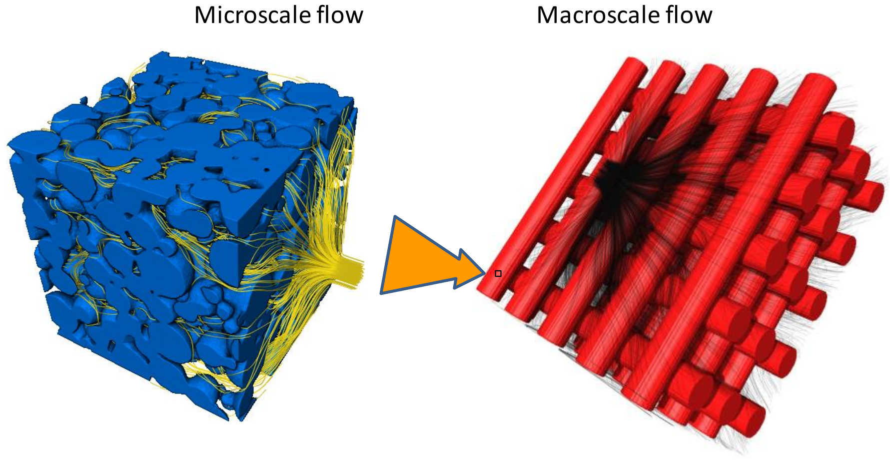
Methanation CO_2+H_2



Fabrication of hierarchical open porous materials by application of 3D printing

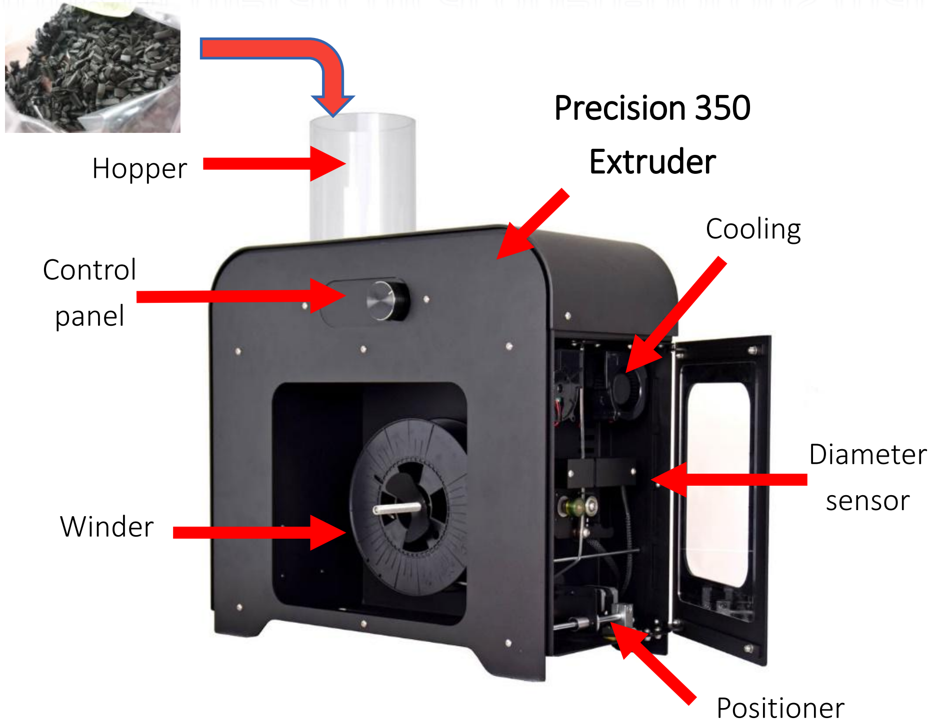


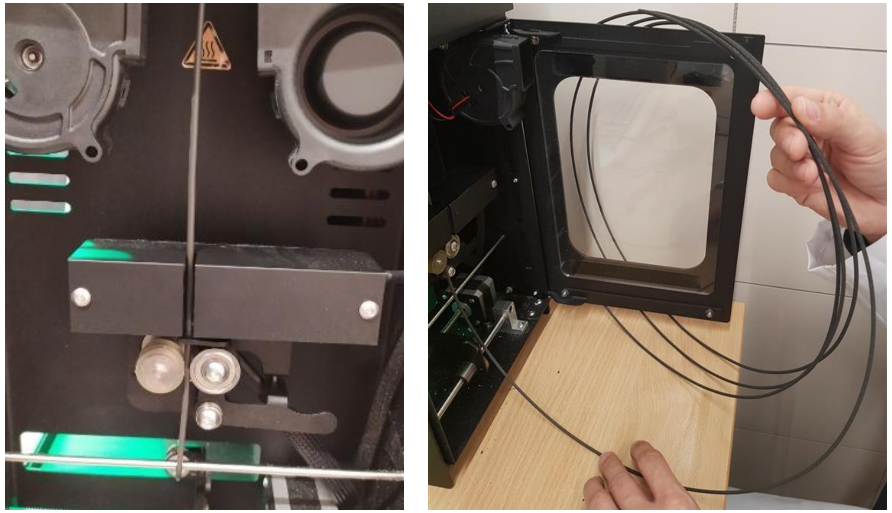
Schematic illustration of hierarchical open-porous microstructure of catalytic materials fabricated via 3D printing



Multiscale modeling of reactive flow in hierarchical microstructure.

3D printing of hierarchical open-porous materials by FDM (Fused Deposition Modeling)

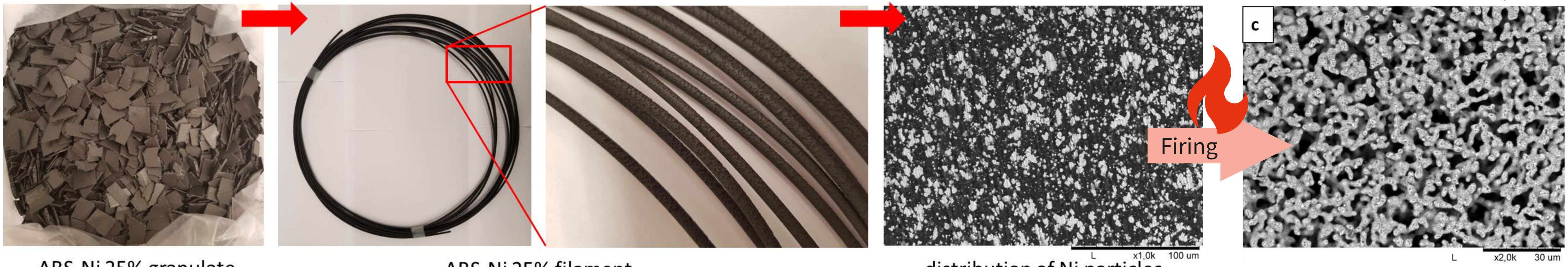




Filament diamater – 2,85 µm

Filament extrusion

SEM analysis



ABS-Ni 25% granulate

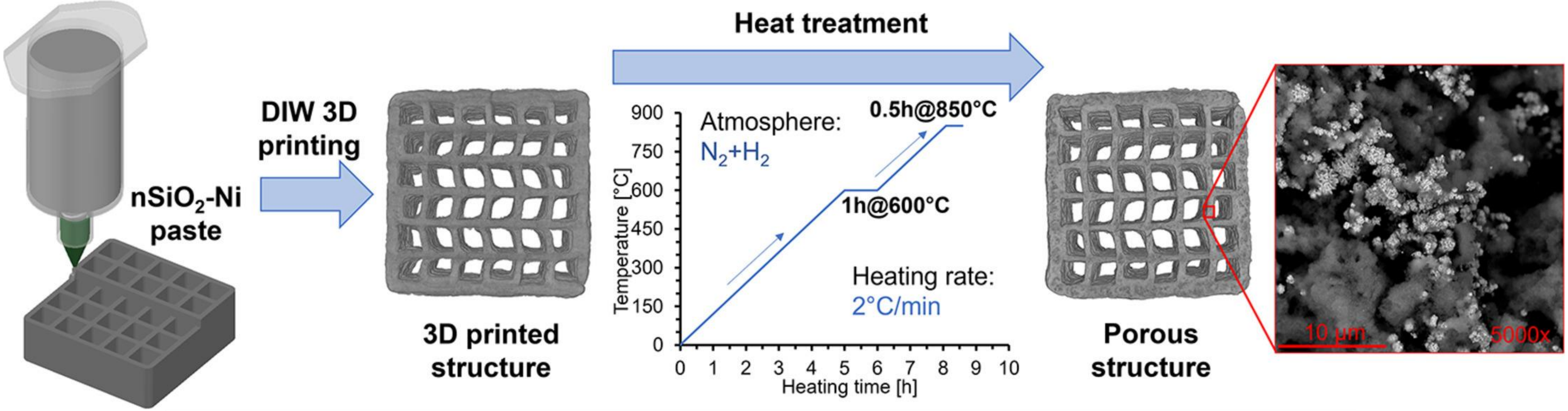
ABS-Ni 25% filament

distribution of Ni particles

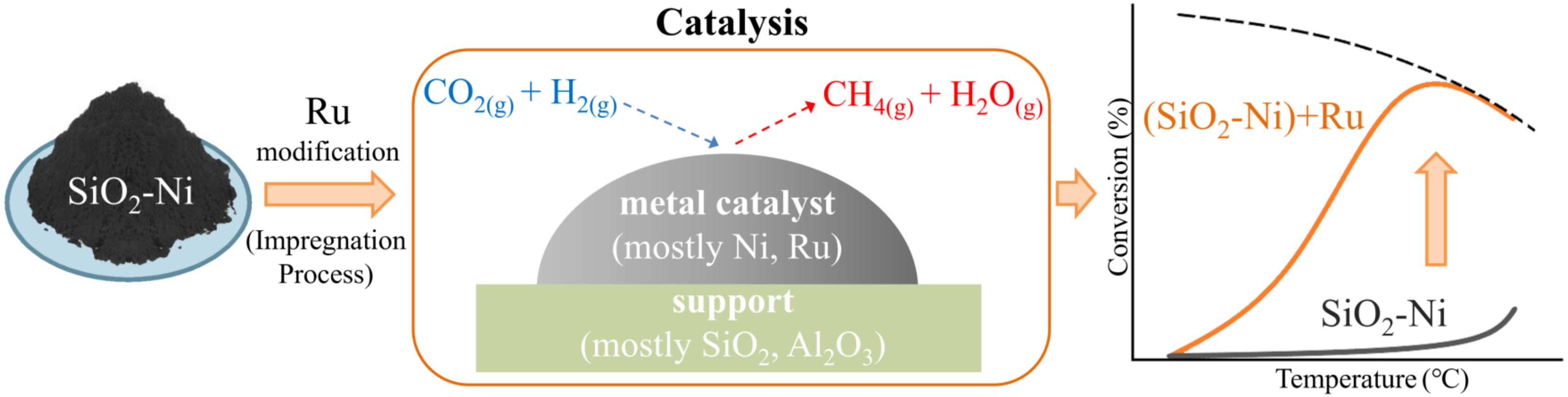
E. Mackiewicz, T. Wejrzanowski, B. Adamczyk-Cieślak, G.J. Oliver *„Polymer–Nickel Composite Filaments for 3D Printing of Open Porous Materials”*, Materials 2022, 15, 1360

Porous 3D printed materials – Direct Ink Writing (DIW)

Preparation of silica-nickel 3D structures using Direct Ink Writing technique



Catalysis



Mackiewicz, E., Wejrzanowski, T., Nowacki, R., Jaroszewicz, J., Marchewka, J., Wilk, Ł., Bezkosty, P., & Sitarz, M. (2023). 3D hierarchical porous structures printed from a silica-nickel composite paste. *Applied Materials Today*. https://doi.org/10.1016/j.apmt.2023.101859

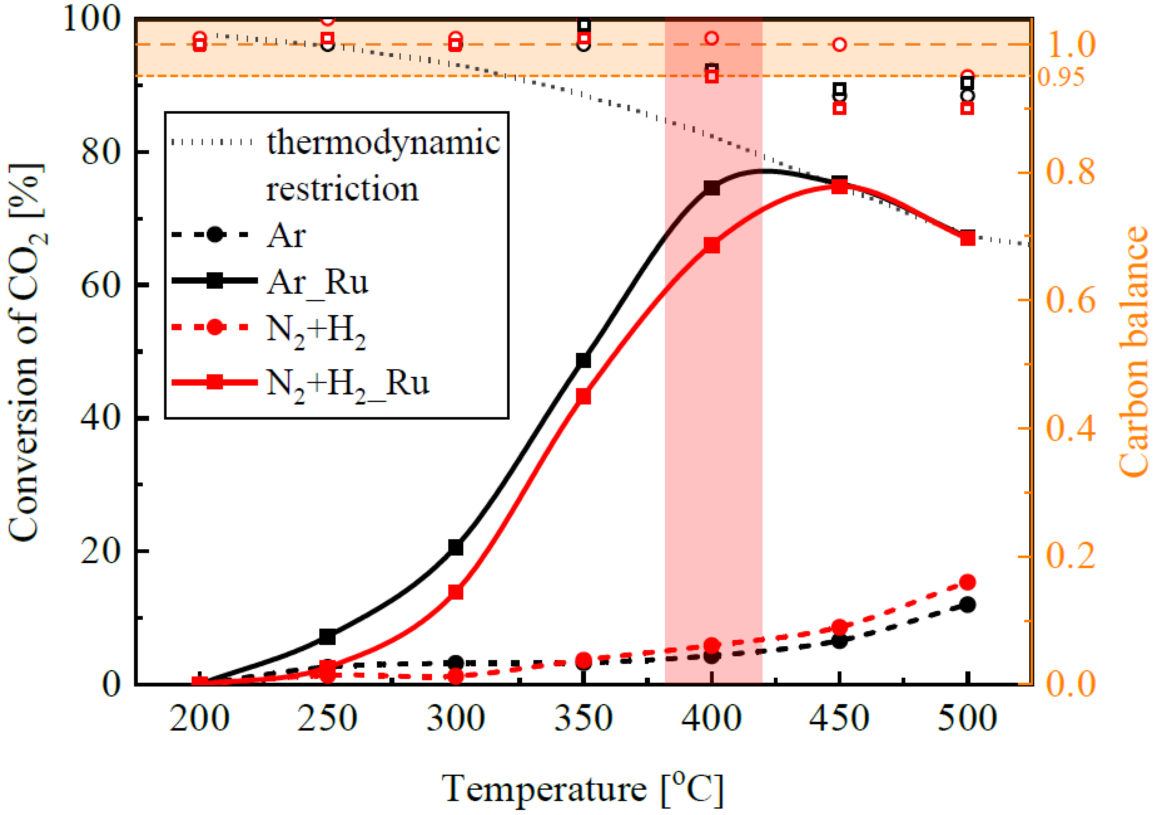
Ewelina Mackiewicz, Remigiusz Nowacki, Gabriela Komorowska, Tomasz Wejrzanowski, Impregnation of Composite 3D Prints for Enhanced Structural Stability, International Journal of Precision Engineering and Manufacturing-Green Technology (2025) 1-14.

Porous 3D printed materials – Direct Ink Writing (DIW)

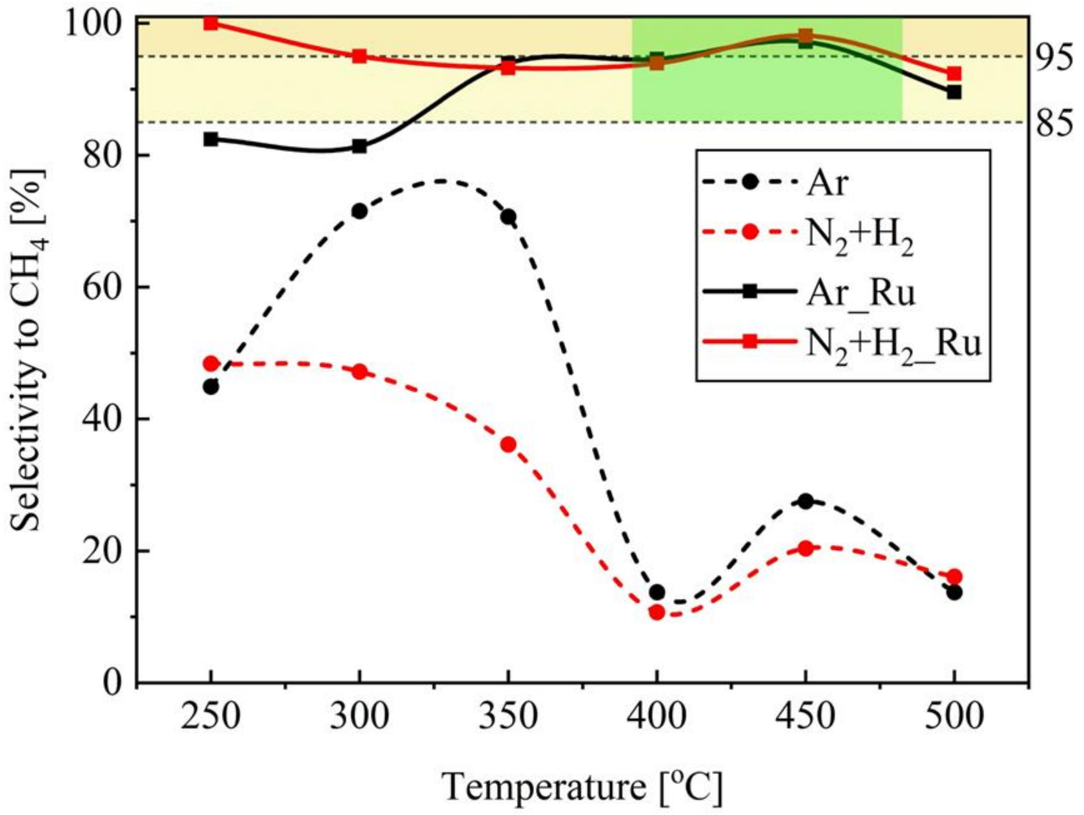
Methanation CO_2+H_2

The catalytic activity tests for the Ni catalysts and Ru-promoted catalysts :

CO_2 conversion and carbon balance



selectivity to CH_4



At 400 °C CO_2 conversion reached almost 75% and 66% for Ar_Ru and H_2+N_2_Ru, respectively

Monolithic catalysts - tests

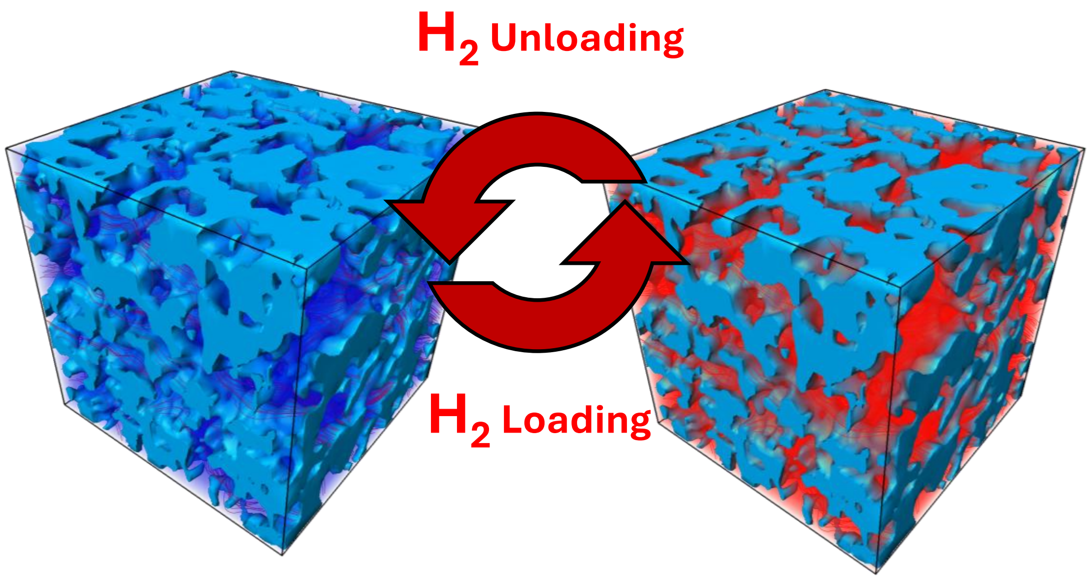
R. Nowacki, E. Mackiewicz, G. Komorowska, T. Wejrzanowski, J. Marchewka, Ł. Wilk, M. Sitarz, M. Pietrowski, Ruthenium-impregnated three-dimensional printed composites for catalytic applications, MRS Bulletin 51, 2 (2026) 105

Hydrogen storage

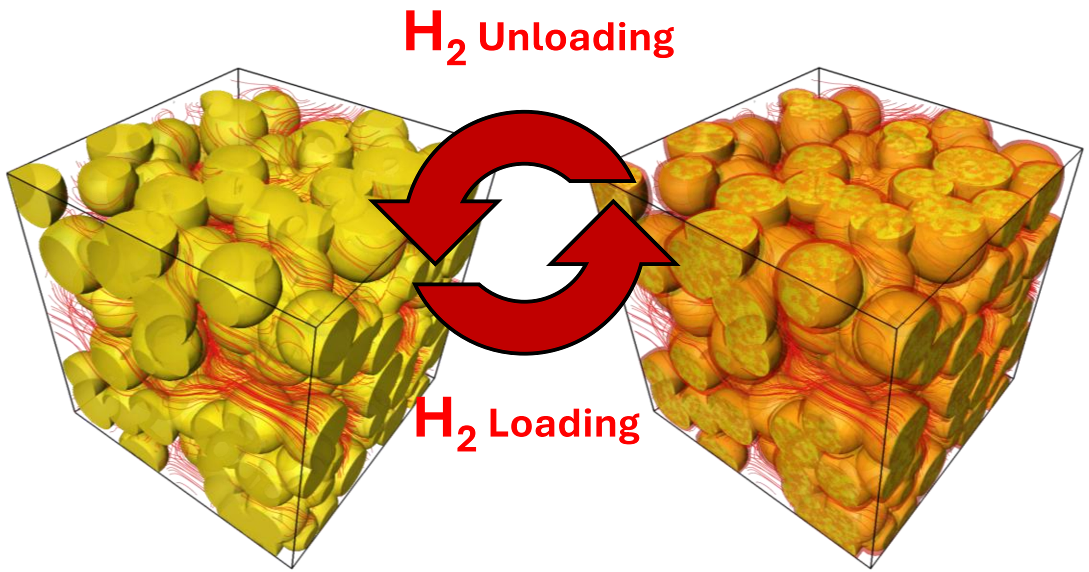
PROJECT:
Cost- and resource-efficient storage of hydrogen at ambient temperature and at a maximum pressure of 3.5 MPa, NCDR, European, 2024-2027

Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT | Germany
AMAZEMET | Poland
JA-Gastechnology GmbH | Germany
VSB-Technical University of Ostrava, CEET; Energy Research center | Czech Republic
Faculty of Sciences of Monastir, University of Monastir | Tunisia
Warsaw University of Technology | Poland
Institut für Nichtklassische Chemie e.V. | Germany
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. | Germany

Aerogel H_2 storage

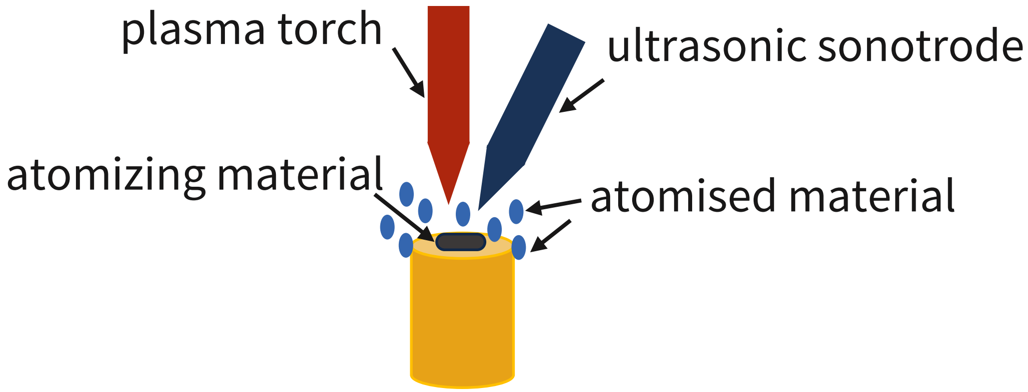


HEA H_2 storage

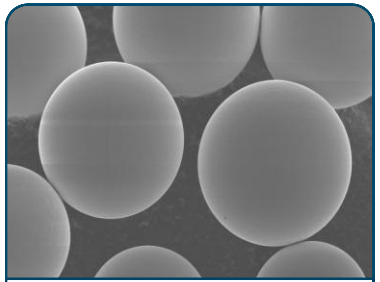


HEA H_2 storage

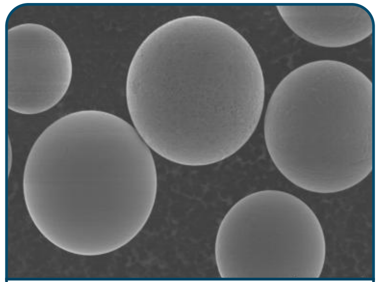
High entropy alloys produced by ultrasonic atomization



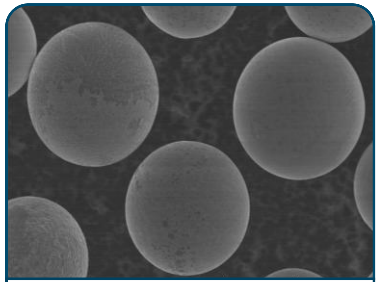
Żrodowski, Ł., Wróblewski, R., Choma, T., Morończyk, B., Ostrysz, M., Leonowicz, M., Łacisz, W., Błyskun, P., Wróbel, J. S., Cieślak, G., Wysocki, B., Żrodowski, C., & Pomian, K. (2021). Novel Cold Crucible Ultrasonic Atomization Powder Production Method for 3D Printing. *Materials*, *14*(10), 2541. https://doi.org/10.3390/ma14102541



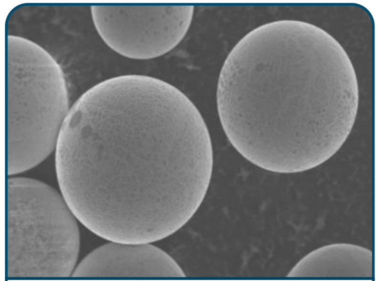
TiTaNbZr



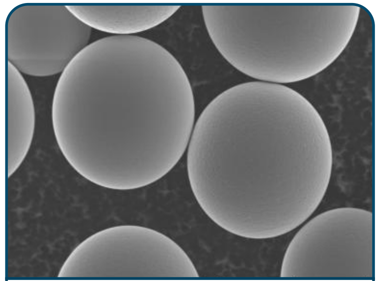
$(TiTaNbZr)_{99}Y_1$



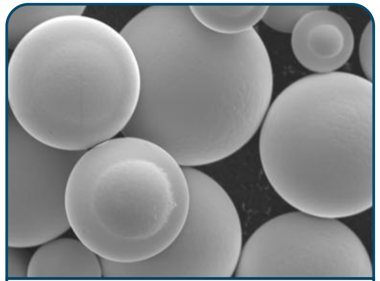
$(TiTaNbZr)_{95}Y_5$



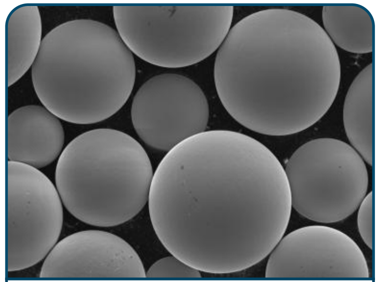
$(TiTaNbZr)_{90}Y_{10}$



$(TiVNb)_{85}Cr_{15}$



$Ti_{18,0}Zr_{28,7}Nb_{29,2}Mo_{24,1}$



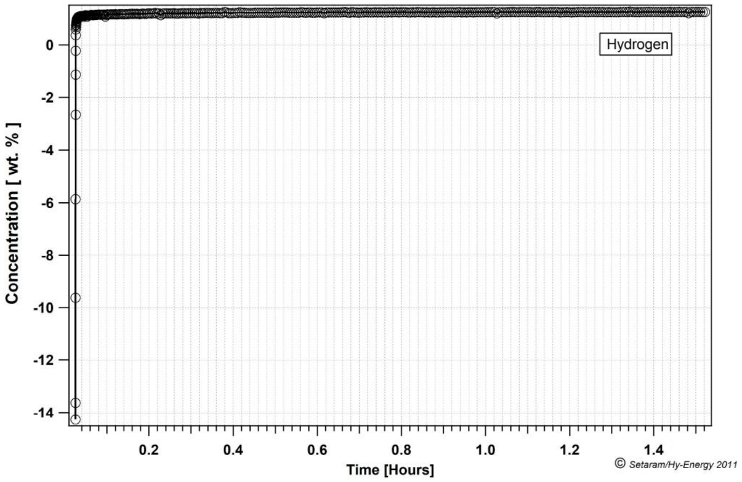
$Ti_{18,5}Zr_{29,4}Nb_{24,0}Mo_{24,8}V_{3,3}$

https://www.amazemet.com/pl/repowder/

AMAZEMET

HEA H_2 storage

TiTaNbZr adsorption kinetics



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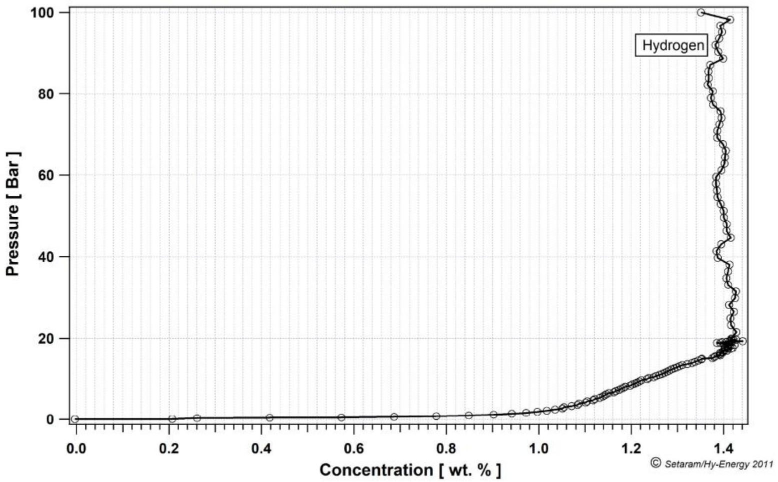
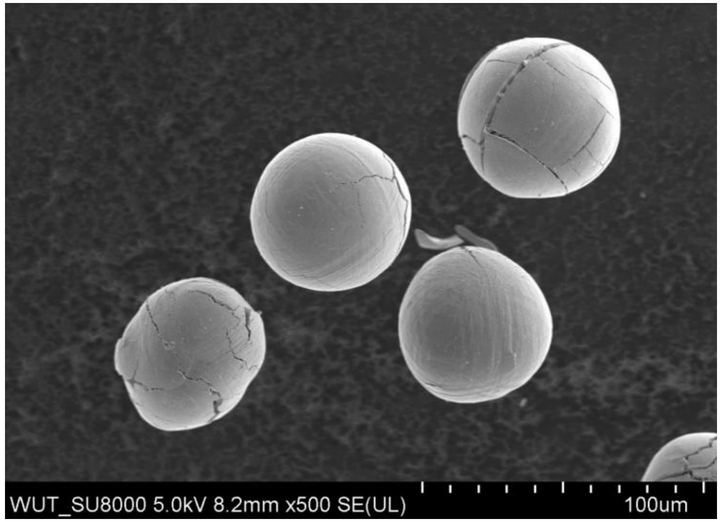
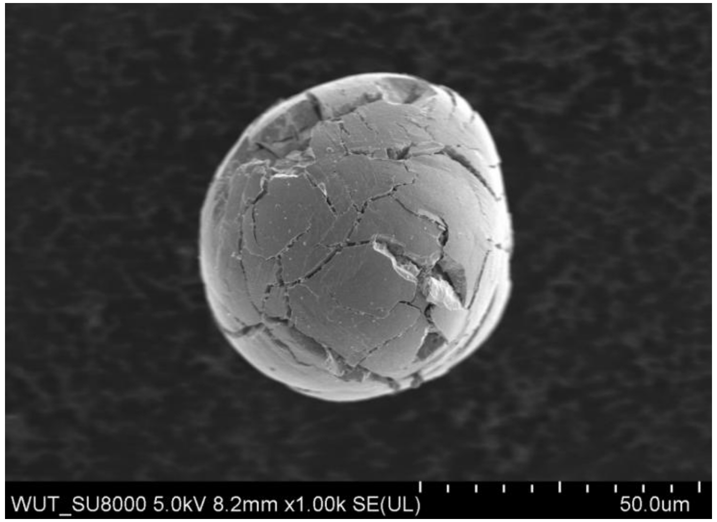
Hydrogen sorption testing

TiTaNbZr PCT Curve



TiTaNbZr after hydrogen tests





11:30-11:45, Room 2
Characterization of Ti-containing HEA as Emerging Materials for Solid-State Hydrogen Storage

Faculty of Materials Science and Engineering
Warsaw University of Technology

Recent projects

NCBR
National Centre for Research and Development

1. High-performance molten carbonate fuel cells (MCFC), 2015-2018, PBS, NCRD
2. Innovative matrix materials for molten carbonate fuel cells (MATRIX), 2016-2019, Poland-Taiwan bilateral project, NCRD
3. Improved fabrication of fuel cells for extended durability, improvement of working parameters, in particular power per volume/mass unit of the fuel cell and reduction of investment and exploitation costs by application of alternative catalytic systems in printing technology (AUGUSTINE), 2016-2019, POIR.01.02.00-00-0045/16, NCRD
4. Development of technology for noble metals and rare earth elements recycling for fabrication of molten carbonate fuel cell elements (RECREATE), 2017-2020, POIR. 01.02.00-00-0086/17-00, NCRD
5. Novel molten carbonate/ceramic composite materials for sustainable energy technologies with CO_2 capture and utilization (MOCO3), M-ERA_NET2/2016/04/2017, 2017-2020, NCRD
6. Development of the industrial scale of molten carbonate fuel cells and solid oxide electrolysers for integration into power-to-gas installations (TENNESSEE), 2018-2020, POIR, NCRD
7. Cost- and resource-efficient storage of hydrogen at ambient temperature and at a maximum pressure of 3.5 MPa, NCDR, European, 2024-2027

National Science Centre Poland

UCZELNIA BADAWCZA
INICJATYWA DOSKONAŁOŚCI

1. Study of the influence of microstructure and chemical composition on catalytic properties of open-porous components of molten carbonate fuel cells, 2018-2021, OPUS, NSC
2. Study of the influence of microstructure on reactive flow process in open-porous components for high-temperature fuel cells, 2018-2021, PRELUDIUM, NSC
3. POB Technologie Materiałowe of Warsaw University of Technology within the Excellence Initiative: Research University (IDUB) program
4. Hierarchical porous structures fabricated by 3D printing technology 2019-2024, OPUS, NSC
5. Carbonate-oxide fuel cell, 2023-2026, OPUS, NSC

Thank you !

tomasz.wejrzanowski@pw.edu.pl