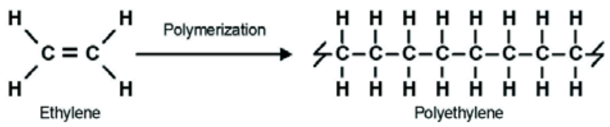
Design and Processability of Imine-based Covalent Organic Frameworks (COFs)

Félix Zamora / Química Inorgánica

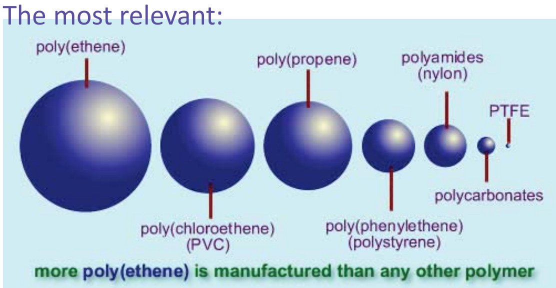
The 1st European School on Advanced Materials (ESAM2023)
Gandia, October 15-18, 2023

Félix Zamora
Dpto. Química Inorgánica
Universidad Autónoma de Madrid
E-mail: felix.zamora@uam.es
http://www.nanomater.es

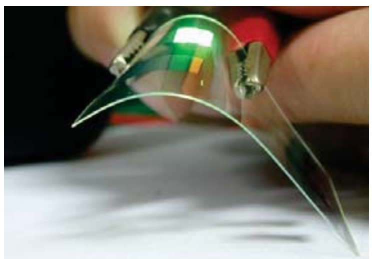
Covalent Organic Synthetic Polymers



The most relevant:

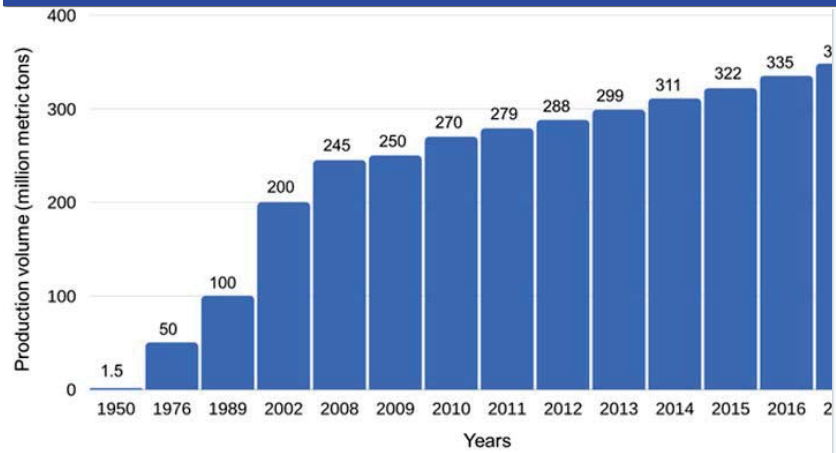


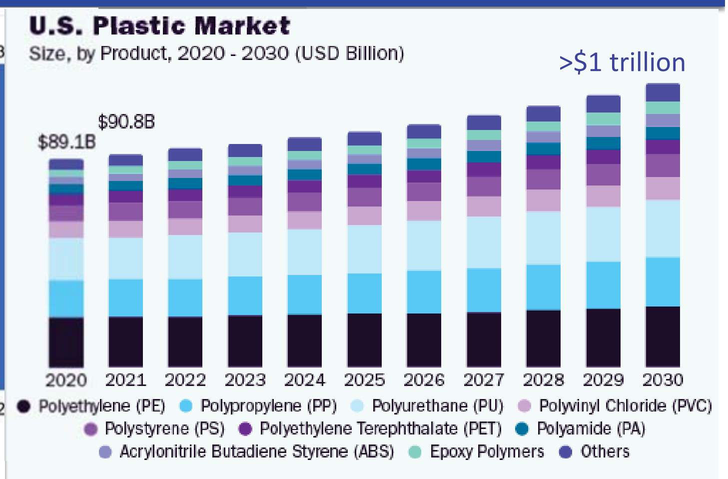
Industrial synthesis
Processability
Properties



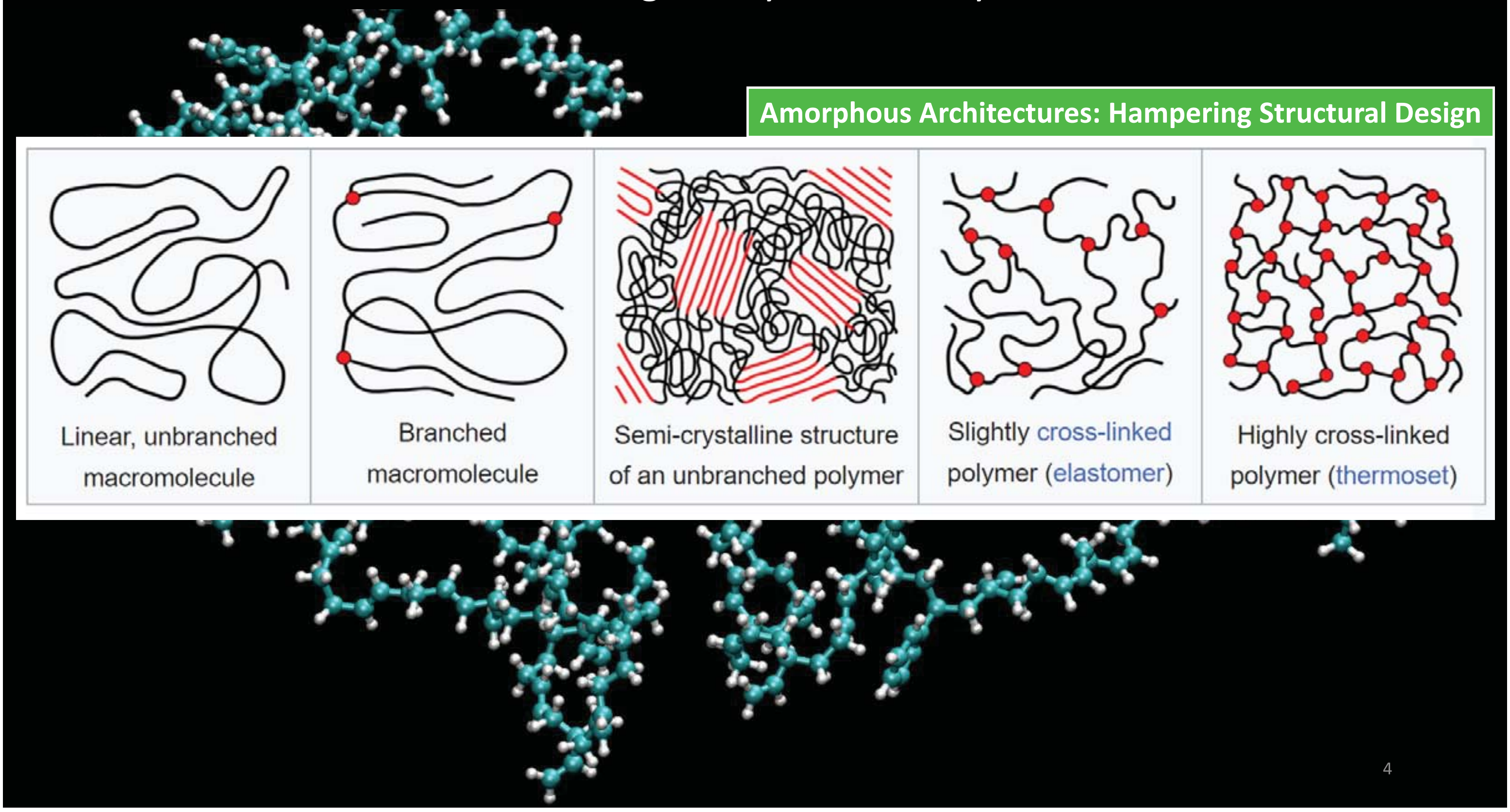
Covalent Organic Synthetic Polymers

- The most chemical products industrially fabricated > 300 mill. Tons/year // $3 trillion/year
- The most relevant 20th century materials



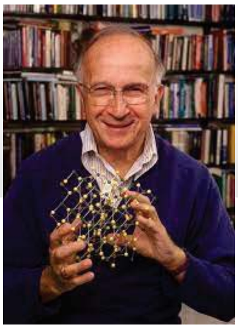


Covalent Organic Synthetic Polymers



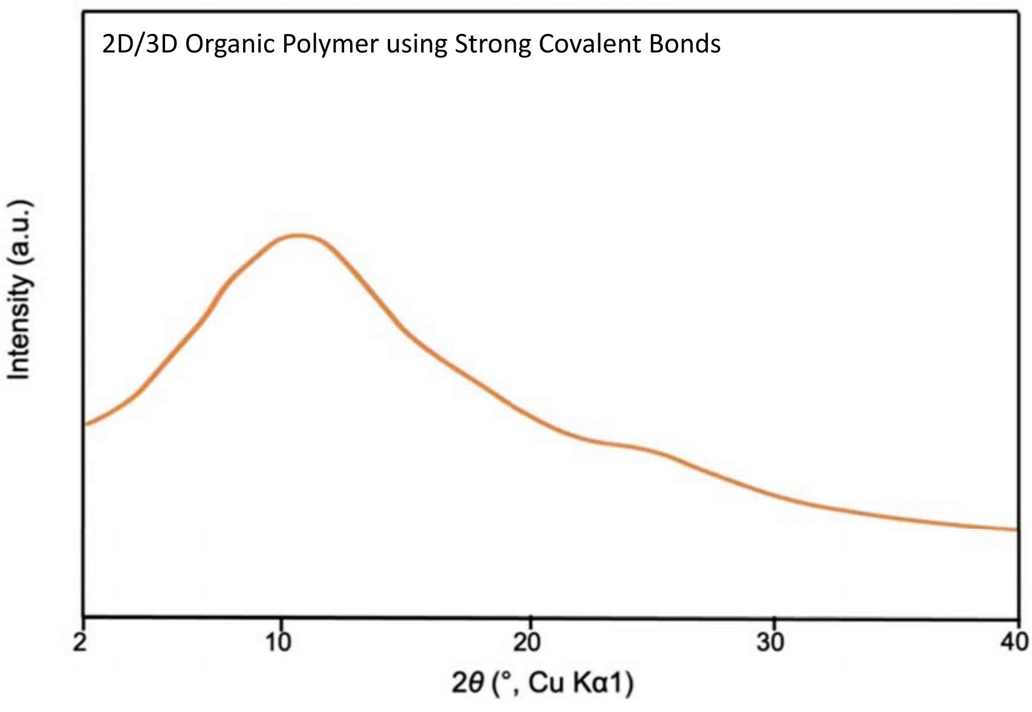
On the Possibility of Making 2D and 3D Organic Networks

*"Organic chemists are masterful at exercising control in zero dimension. One subculture of organic chemists has learned to exercise control in one dimension. These are polymer chemists, the chain builders...**But in two or three dimensions, it is a synthetic wasteland.** The methodology for exercising control so that one can make unstable but persistent extended structures on demand is nearly absent. Or to put it in a positive way—this is a certain growth point of the chemistry of the future."*



R. Hoffmann, *Scientific American*, Feb **1993**, 65–73.

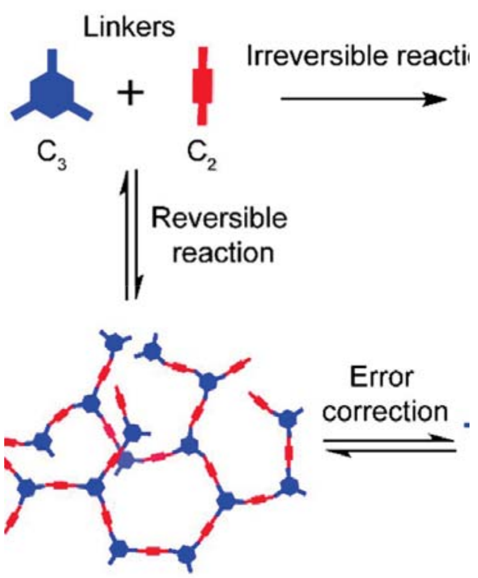
Powder X-Ray Diffraction (PXRD) of an Amorphous Solid

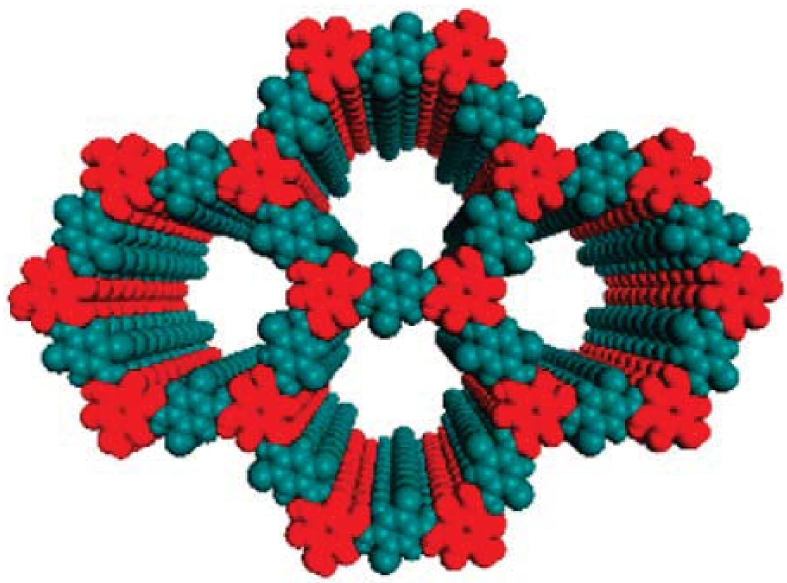


Covalent Organic Frameworks: Formation / Reversibity

Dynamic Covalent Bonds: Reversibility

Error correction: Experimental Conditions





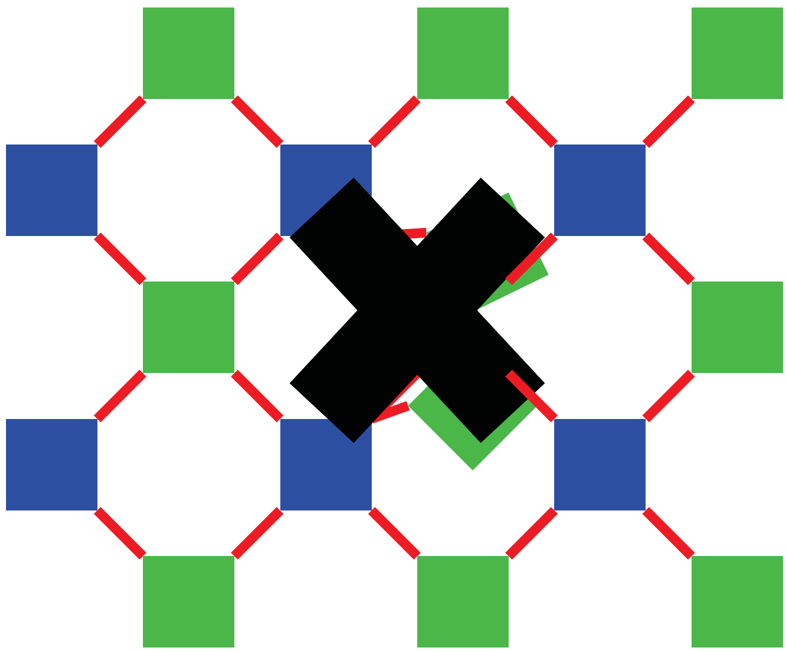
Crystalline framework

R. Banerjee et al. J. Am. Chem. Soc. 2019, 141, 1807−1822

Covalent Organic Frameworks: Formation / Reversibity

Dynamic Covalent Bonds: Reversibility

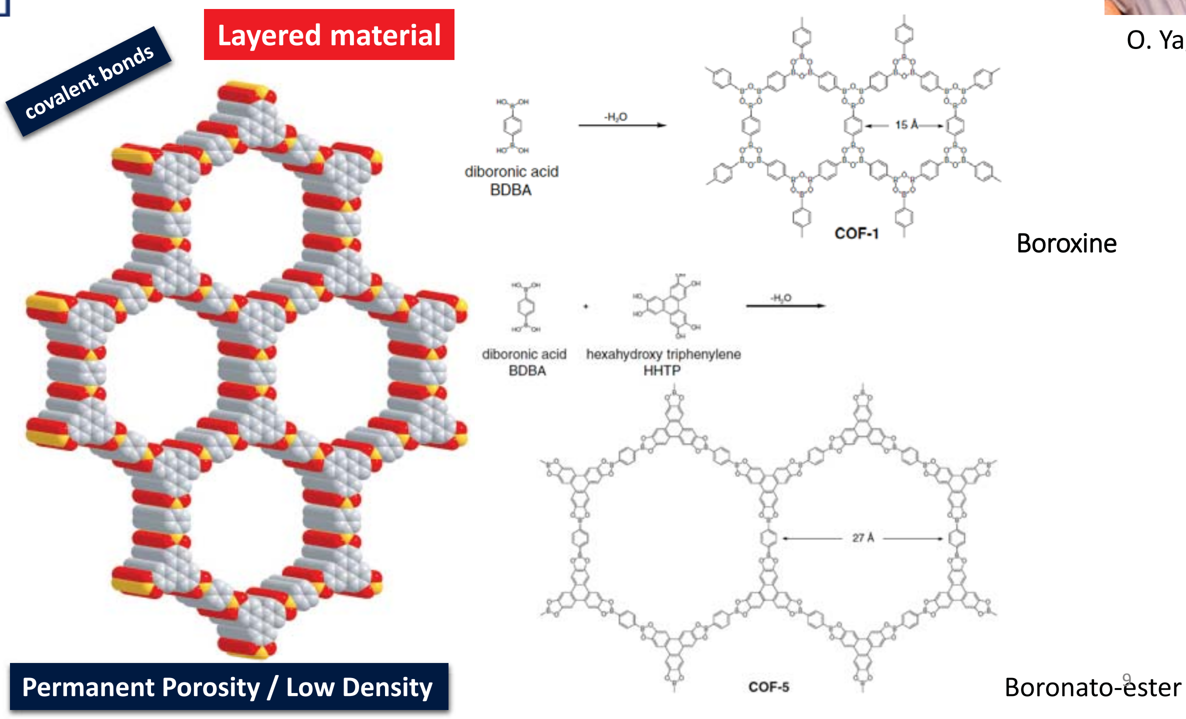
Error correction: Experimental Conditions



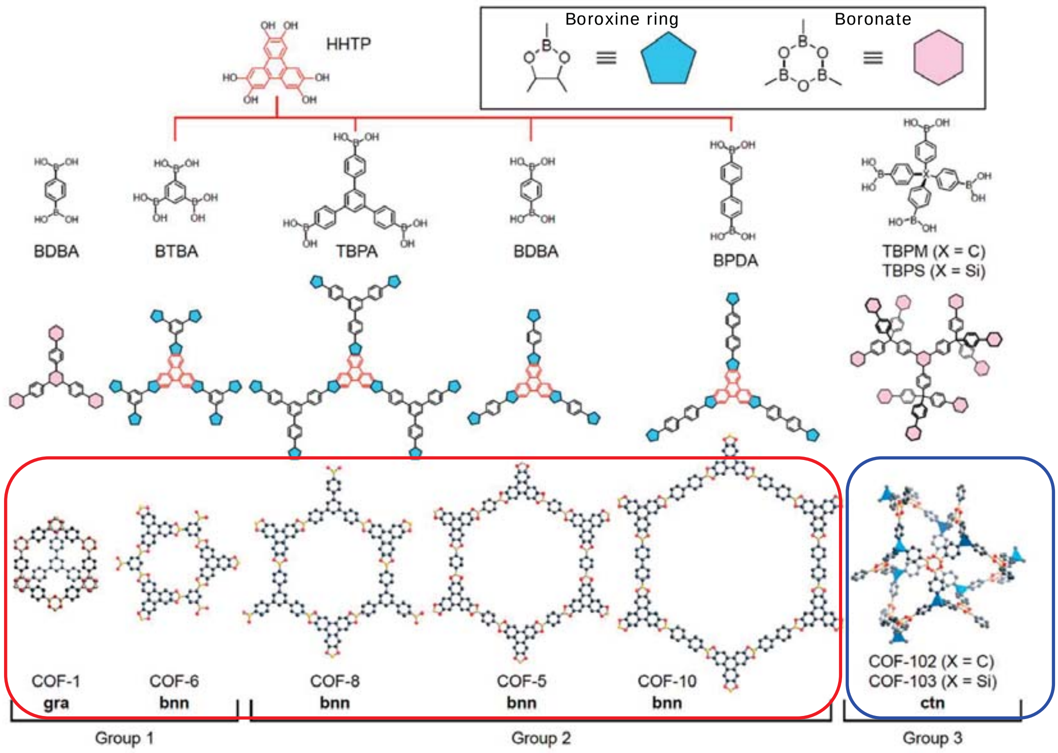
Porous, Crystalline, Covalent Organic Frameworks
Adrien P. Côté, *et al.*
Science **310**, 1166 (2005);
DOI: 10.1126/science.1120411

Solvothermal conditions

O. Yaghi

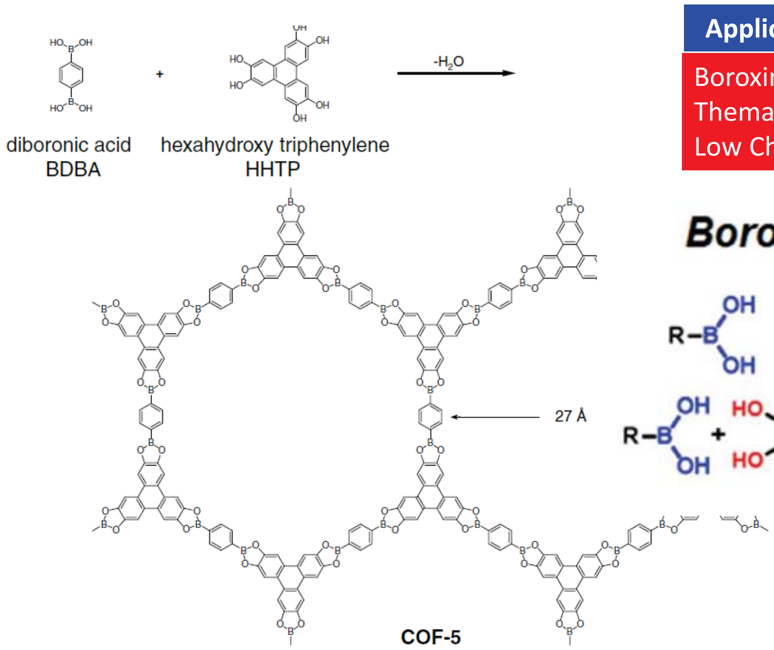


Covalent Organic Frameworks: Boron-based COFs



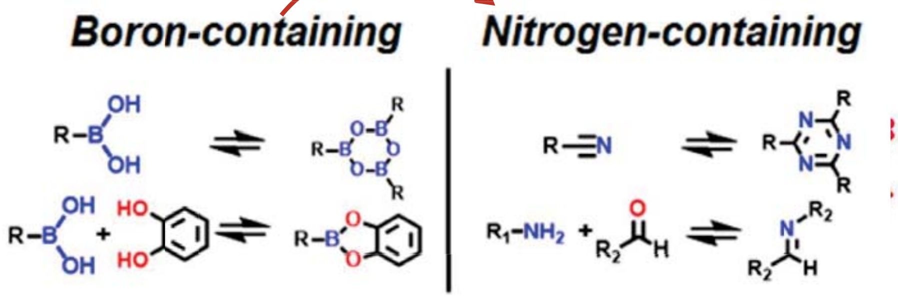
H. Furukawa, O.M. Yaghi, *J .Am. Chem. Soc.*, **2009,** *131*, 8875

Covalent Organic Frameworks: Material Design Evolution

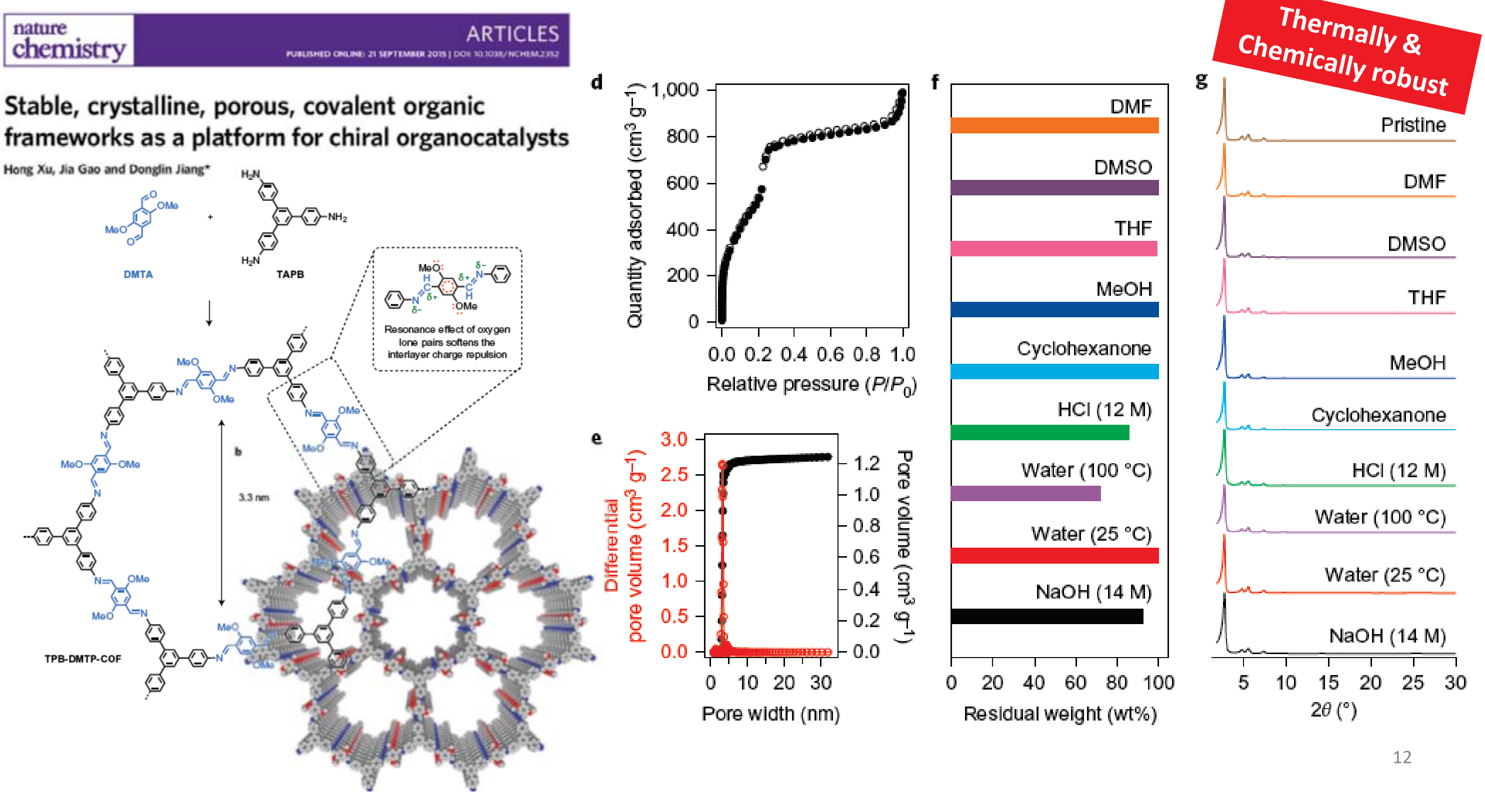


Applications: Robust Materials

Boroxine and Boronate-ester COFs
Themally robust: 400-500 ºC
Low Chemical Stability: Hydrolisis



Schiff-base chemistry or dynamic imine chemistry



Thermally & Chemically robust

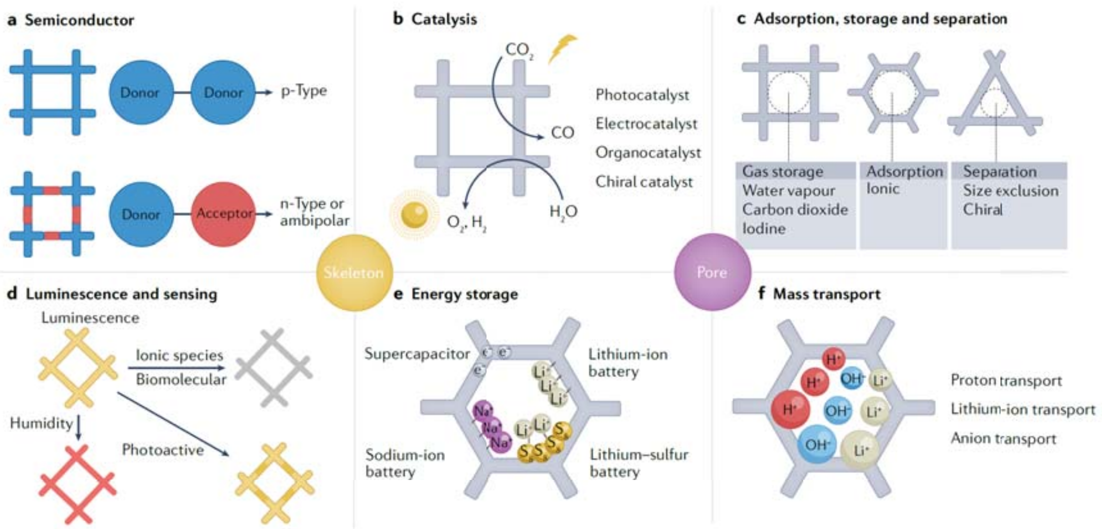
nature reviews methods primers https://doi.org/10.1038/s43586-022-00181-z

Primer Check for updates

Covalent organic frameworks

Ke Tian Tan[1], Samrat Ghosh[2,3], Zhiyong Wang[4,5], Fuxiang Wen[6], David Rodríguez-San-Miguel[7], Jie Feng[8], Ning Huang[6], Wei Wang[8], Felix Zamora[7], Xinliang Feng[4,5], Arne Thomas[3] & Donglin Jiang[1]

Aplications



Covalent Organic Frameworks: Design for Properties & Application

Structural Material Design

Molecular Library

Properties

RT-COF-1Ac

- Gas Sorption
- Charge Transport
- High Surface Area
- Ionic Conductivity
- Emission

Aplications

- Gas Storage
- Gas/molec. Separation
- Catalysis
- Sensors
- Optoelectronics
- Photovoltaics

Chemical design of COFs

Journal of Materials Chemistry A

PAPER

Cite this: *J. Mater. Chem. A*, 2017, **5**, 17973

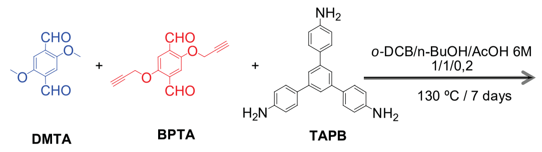
Thiol grafted imine-based covalent organic frameworks for water remediation through selective removal of Hg(II)†

Laura Merí-Bofí,[a] Sergio Royuela,[a] Félix Zamora,[b] M. Luisa Ruiz-González,[c] José L. Segura,*[a] Riansares Muñoz-Olivas*[d] and María José Mancheño*[a]

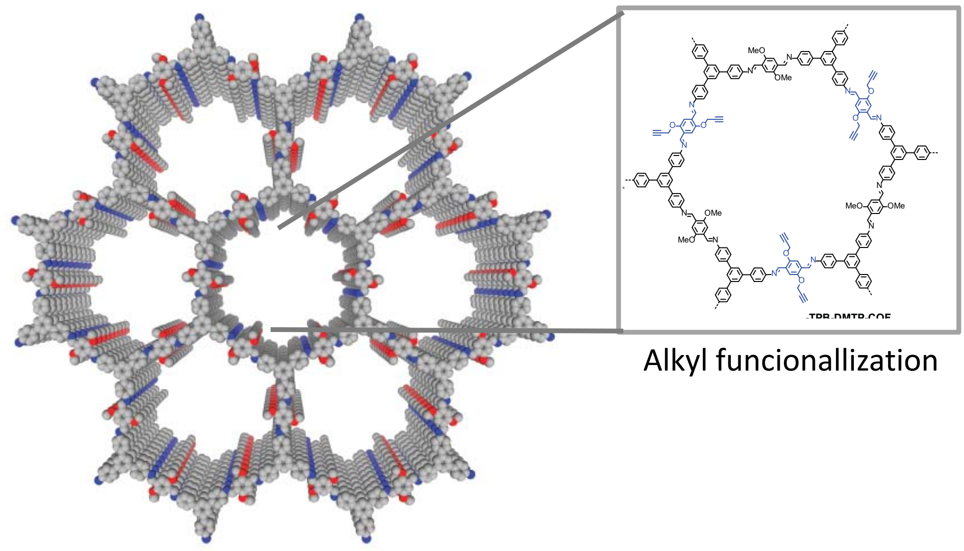
Prof. José L. Segura

Idea for COF design: Cavities decorated with tiol groups

COF Post-synthesis: Click Chemistry Azide-Alkyne



Click Chemistry Azide

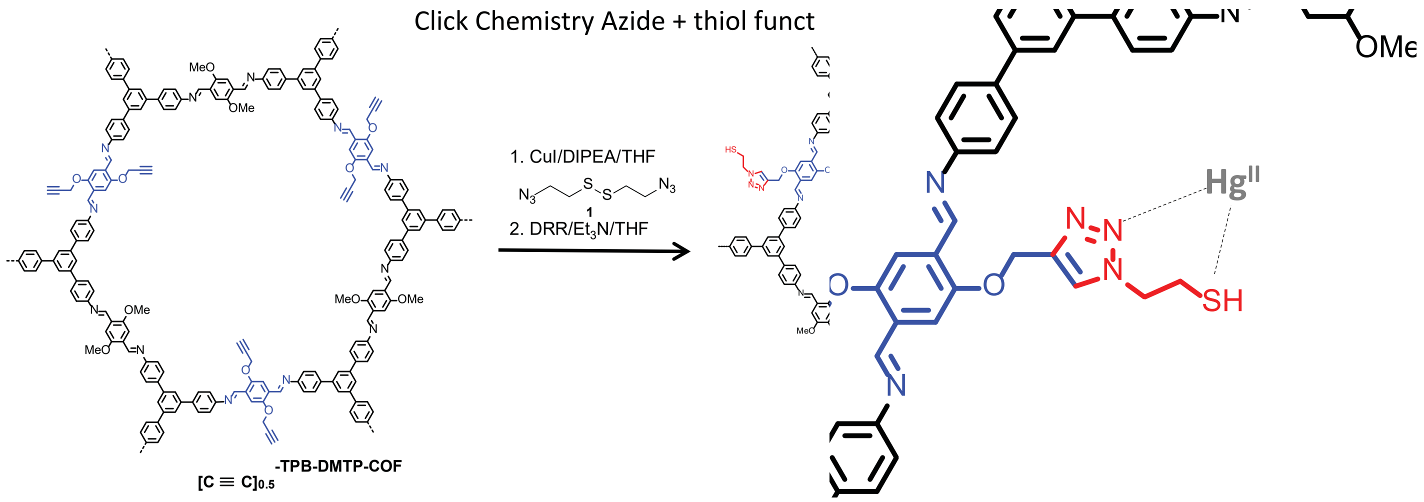


Alkyl funcionallization

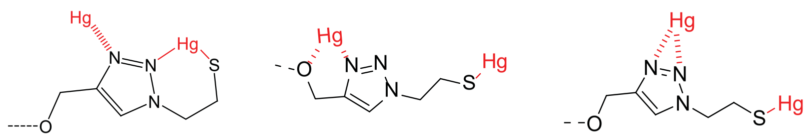
H. Xu, J. Gao, D. Jiang. *Nat. Chem.* **2015**, *7*, 905

Thiol Grafted Imine-Based Covalent Organic Framework for Water Remediation Through Selective Removal of Hg(II)

Click Chemistry Azide + thiol funct

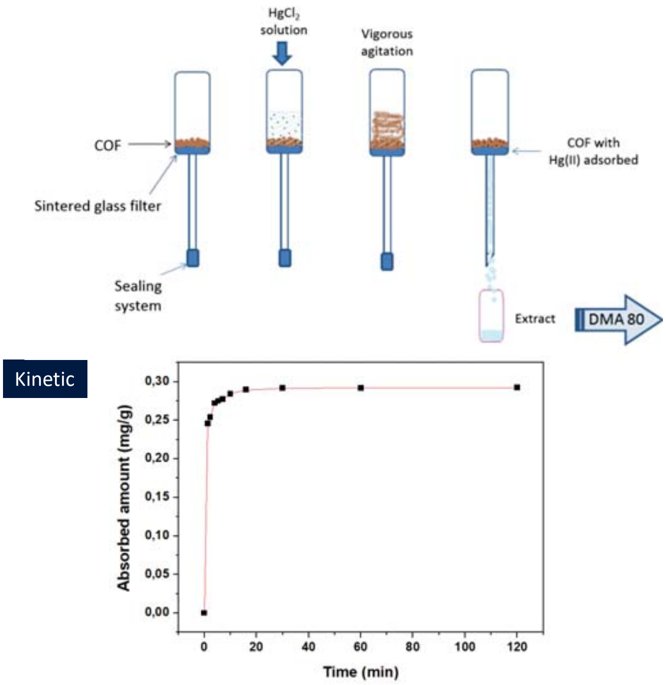


Multiple coordination sites: N (triazole) + S (thiolate) + O (ether)



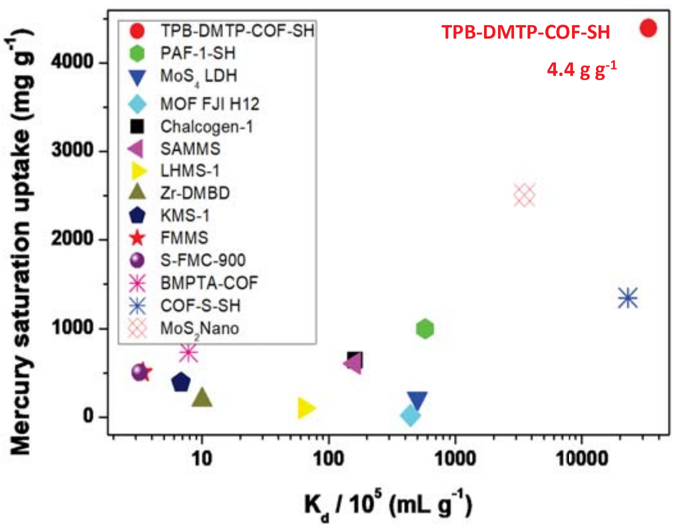
M. J. Mancheño *et al*. J. Mater. Chem. A., 5, 17973-17981 (2017)

Mercury Adsorption from water: Kinetic & Capacity



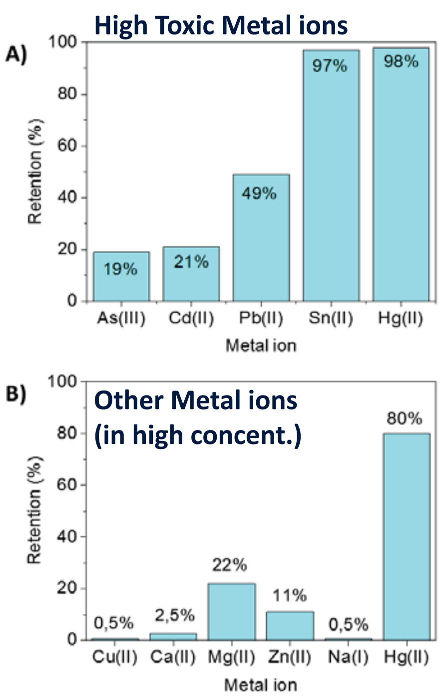
In just 10 min 99.98 % of removal efficiency (2.5 min for 2 mLg^{-1} V/m$_{COF}$)

Saturation uptake capacity of **4.4 g g^{-1}**

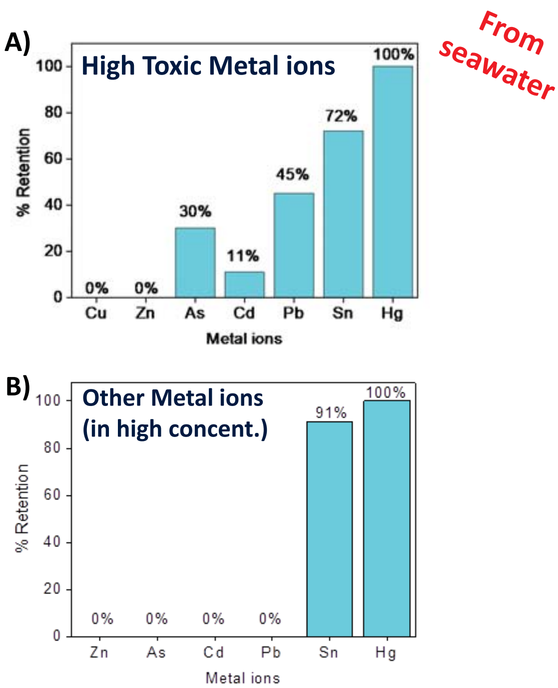


J. Mater. Chem. A., 5, 17973-17981 (2017)

Selectivity Test

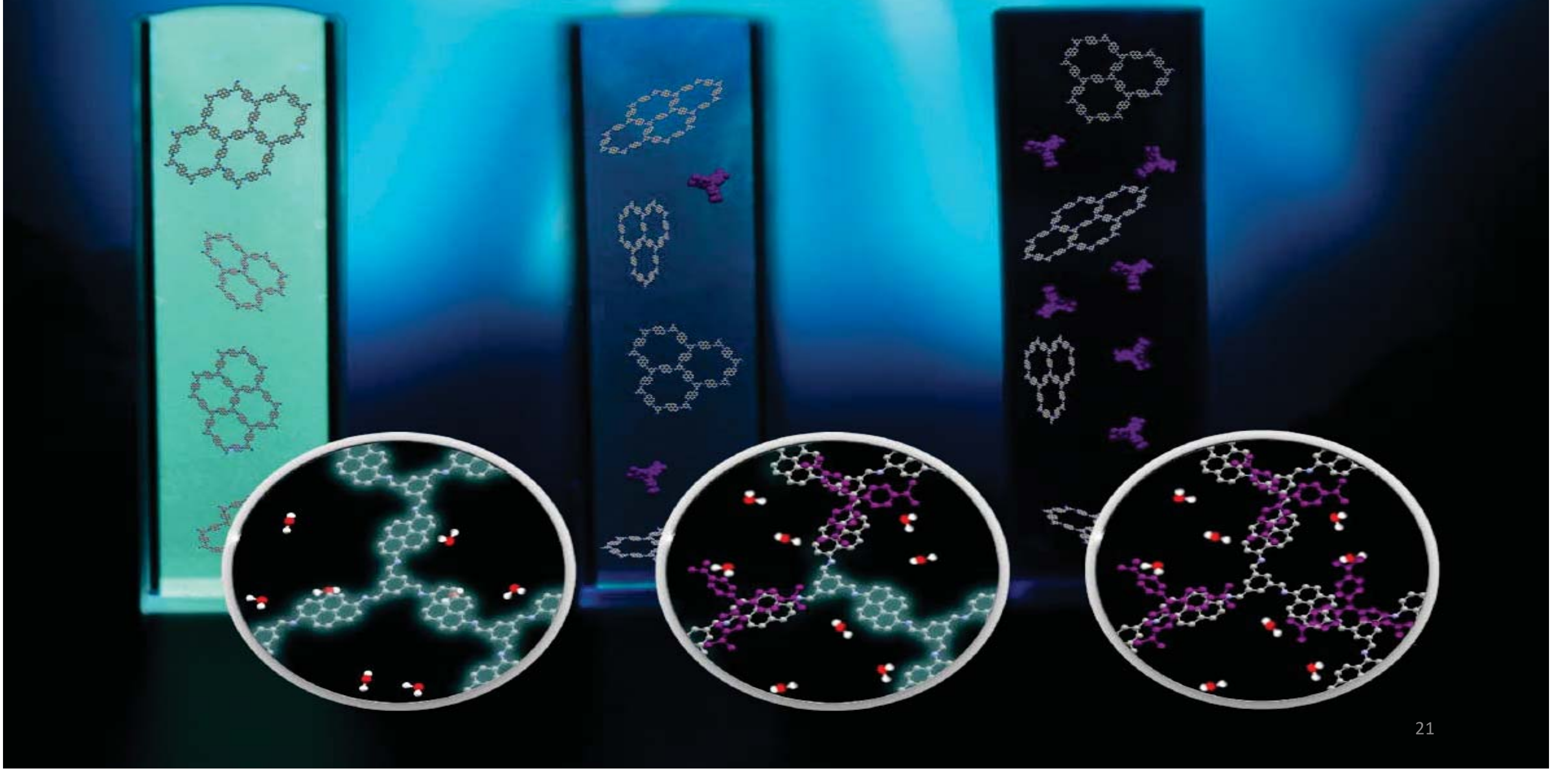


ATPB-DMTP-COF-SH in the presence of ions: A) As(III), Cd(II), Pb(II), Sn(II), Hg(II) (equimolar concentration, 1 mg L^{-1}). B) Cu(II), Ca(II), Mg(II), Zn(II), Na(I) (100 mg L^{-1}), Hg(II) (1 mg L^{-1}).



TPB-DMTP-COF-SH in seawater in the presence of ions: A) Cu(II), Zn(II), As(III), Cd(II), Pb(II), Sn(II) Hg(II) (equimolar concentration, 1 mg L^{-1}). B) Zn(II), As(III), Cd(II), Pb(II), Sn(II) (equimolar concentration, 100 mg L^{-1}) *vs* Hg(II) (1 mg L^{-1}).

Designing Fluorescence imine-COFs

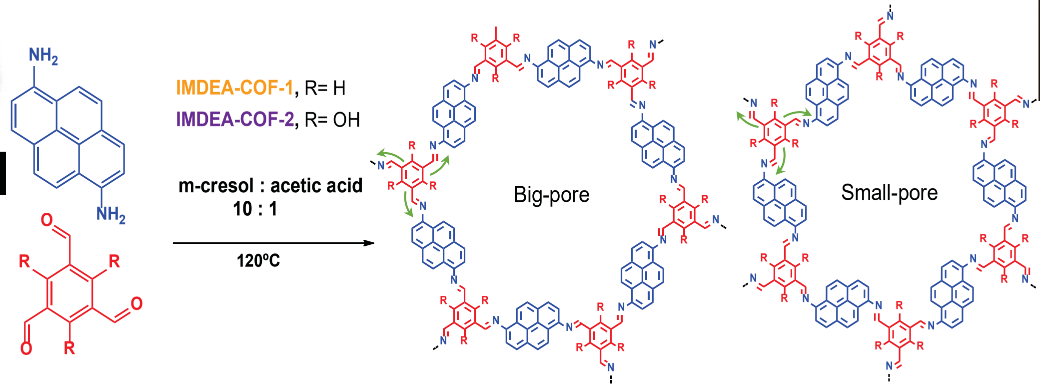


Layer-Stacking-Driven Fluorescence in a Two-Dimensional Imine-Linked COF

A. Platero

P. Albacete

blue-chromophore pyrene

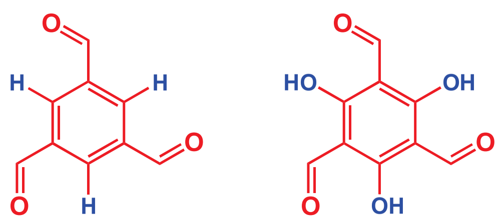


E. Pérez

*Idea for COF design: Use a **Fluorescent Building Block avoiding π-π stacking** between the layers COF structure*

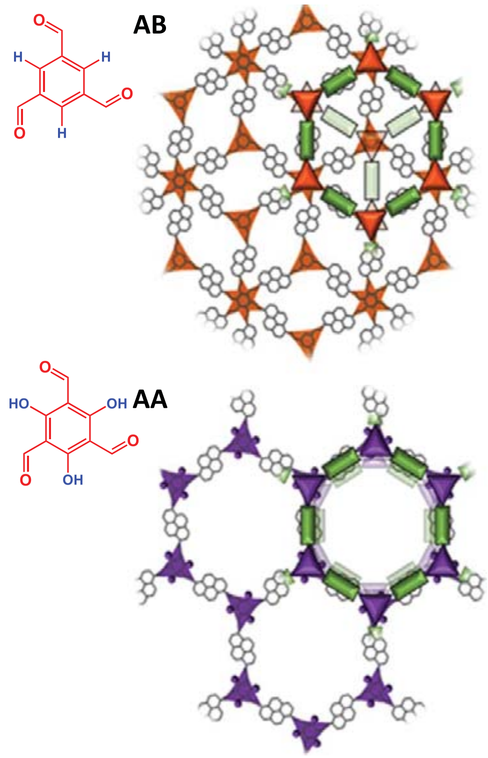
Aimed at causing a staggered stacking

R= H, OH
1,3,5-Benzenetricarbaldehyde
2,4,6-Triformylphloroglucinol



J. Am. Chem. Soc. 2018, 140, 12922

Theoretical Studies: Preferential Stacking



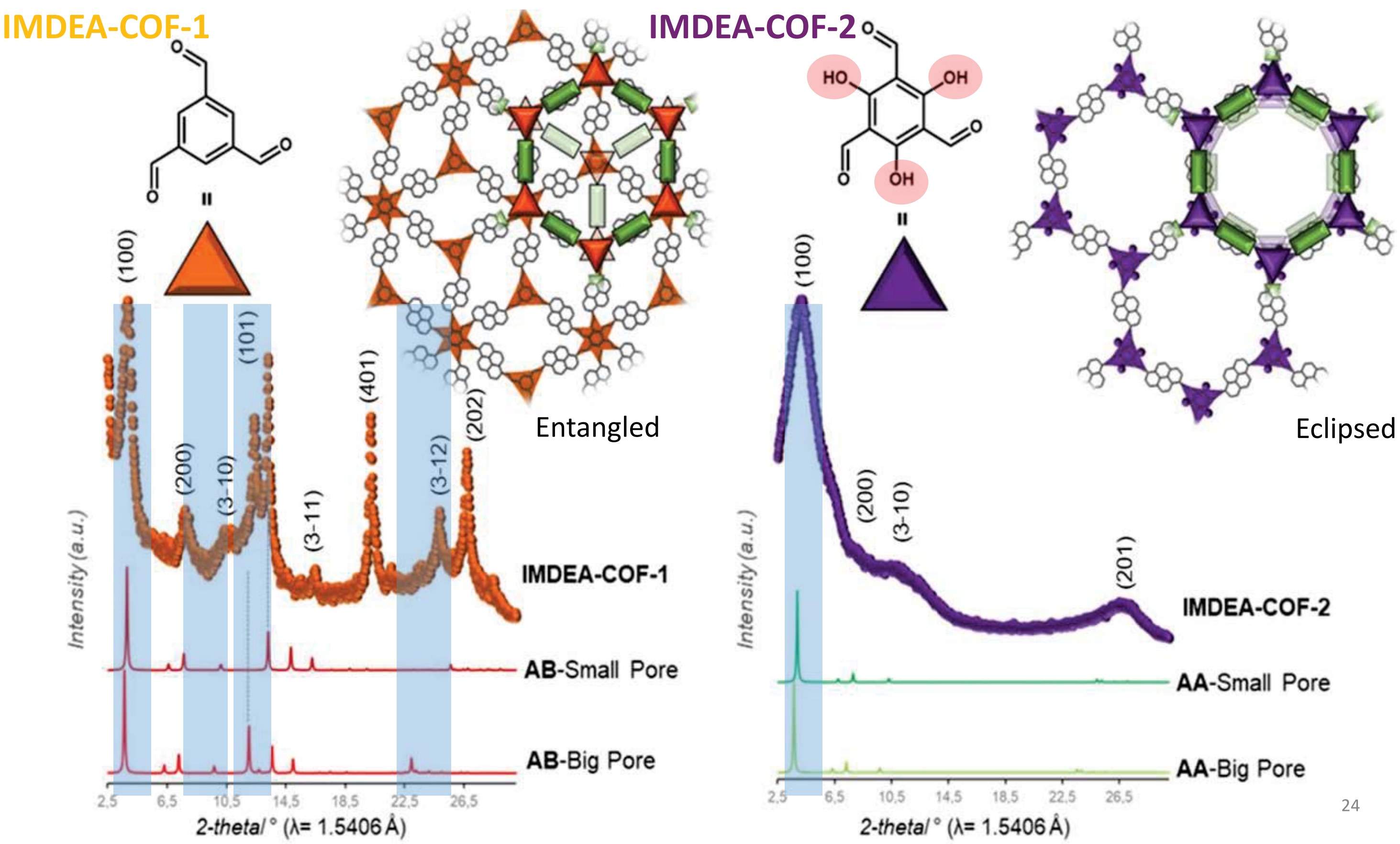
Calculated Cohesive Energy values for the two pore-isomer in either eclipsed (AA) or staggered (AB) conformations.

COF	Pore	Stacking	L, Å	E_c, kcal mol^{-1}
IMDEA-1	Small	AA	3.543	-41.05
IMDEA-1	Small	AB	3.482	-38.28
IMDEA-1	Big	AA	3.760	-42.89
IMDEA-1	Big	AB	3.749	-39.66
IMDEA-2	Small	AA	3.570	-40.36[a]/-38.742[b]
IMDEA-2	Small	AB	3.637	-14.53[a]/-16.37[b]
IMDEA-2	Big	AA	3.780	-48.20[a]/-46.81[b]
IMDEA-2	Big	AB	3.638	-20.99[a]/-19.83[b]

[a]Enol-imine form. [b]Keto-enamine form.

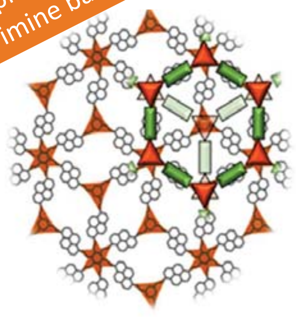
In layered systems due to aggregation-caused quenching driven by π−π interactions

J. Am. Chem. Soc. 2018, 140, 12922



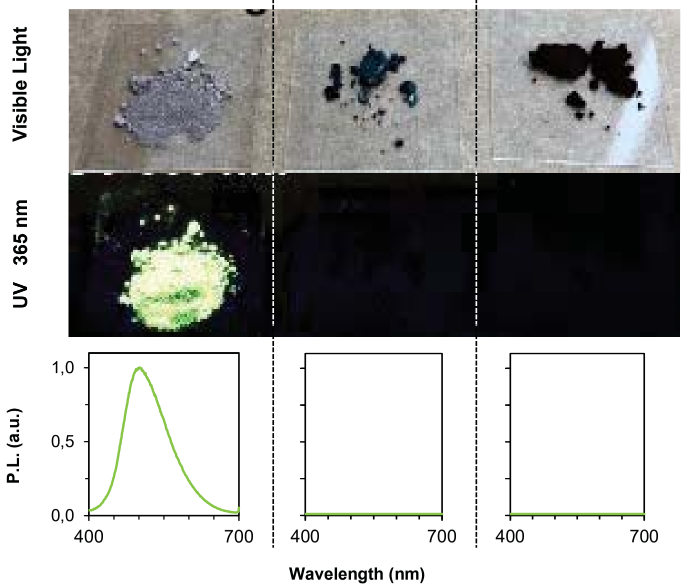
In Summary: Layer-packing-driven fluorescence in solid-state

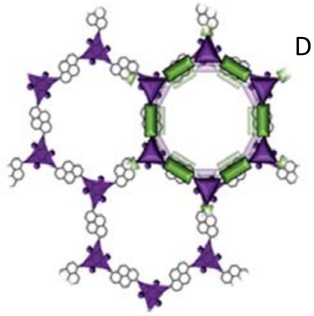
First sample of solid-state emissive imine based-COF



green color emission at 501 nm

blue-chromophore pyrene





AA Layer-packing quench fluorescence

J. Am. Chem. Soc. 2018, 140, 12922

Covalent Organic Frameworks

Structural Material Design

Robust Materials

Properties

- Gas Sorption
- Charge Transport
- High Surface Area
- Ionic Conductivity

RT-COF-1Ac

Processability

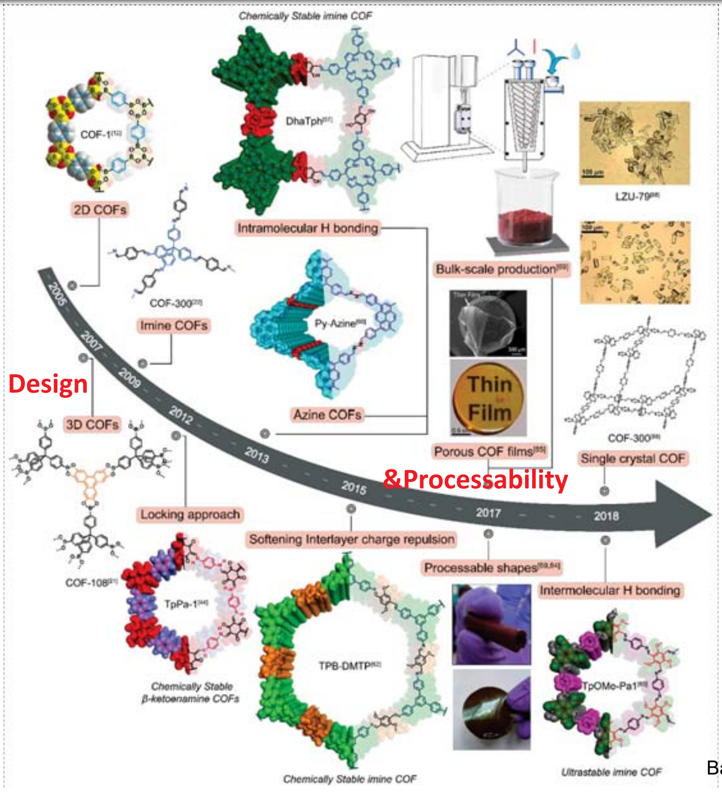
Aplications

- Gas Storage
- Gas/molec. Separation
- Catalysis
- Sensors
- Optoelectronics
- Photovoltaics

Production methods

controlling the shaping and sizing of COFs

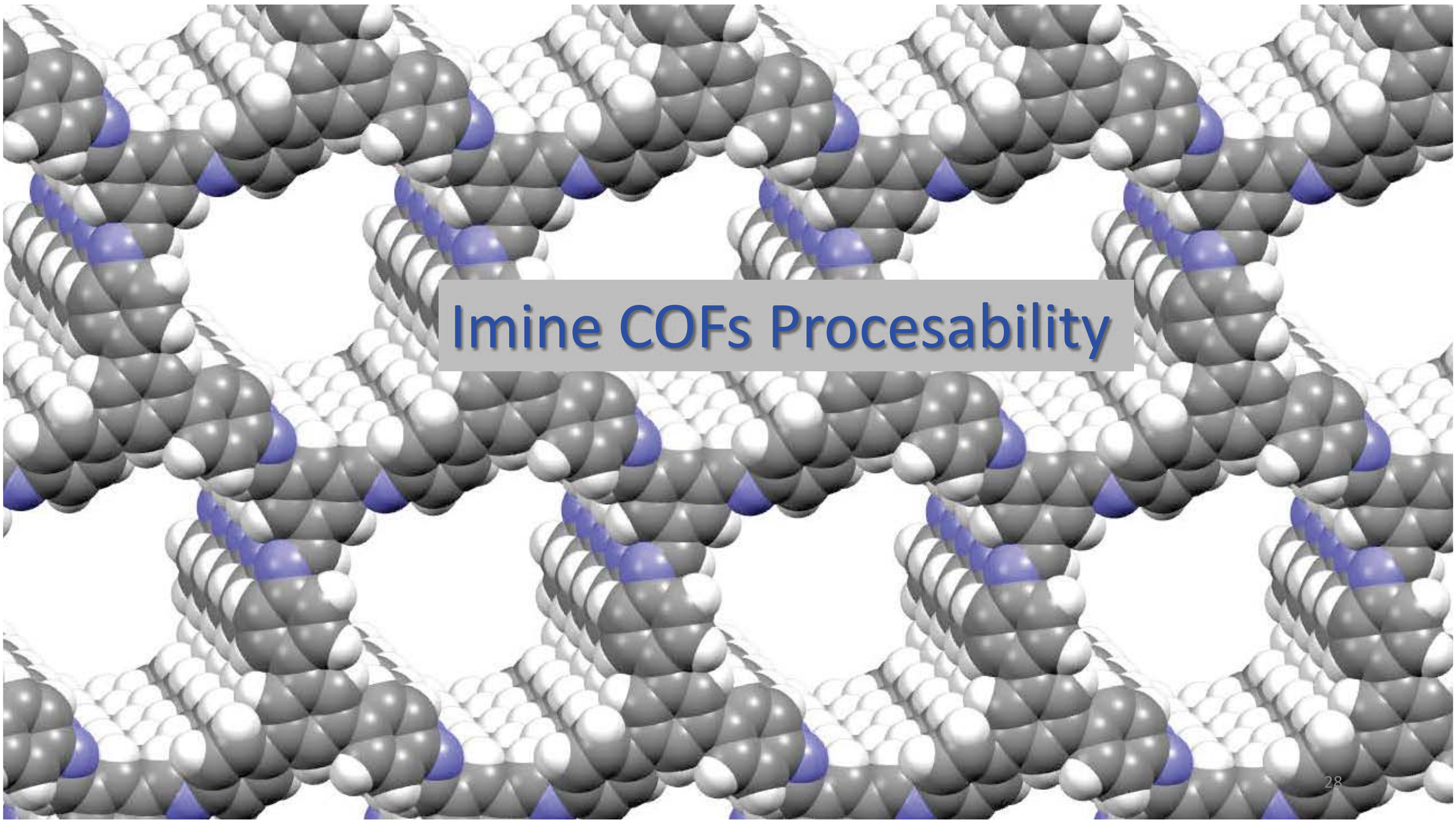
Timeline of COFs Developing



Chemical Design

&Processability

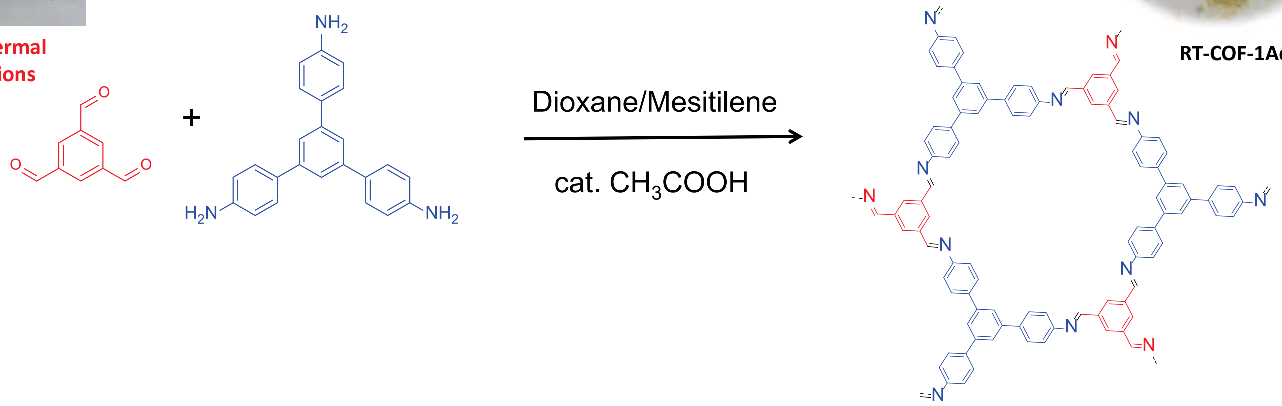
Banerjee et al. *J. Am. Chem. Soc.* (2019) 141, 1807



Imine COFs Procesability

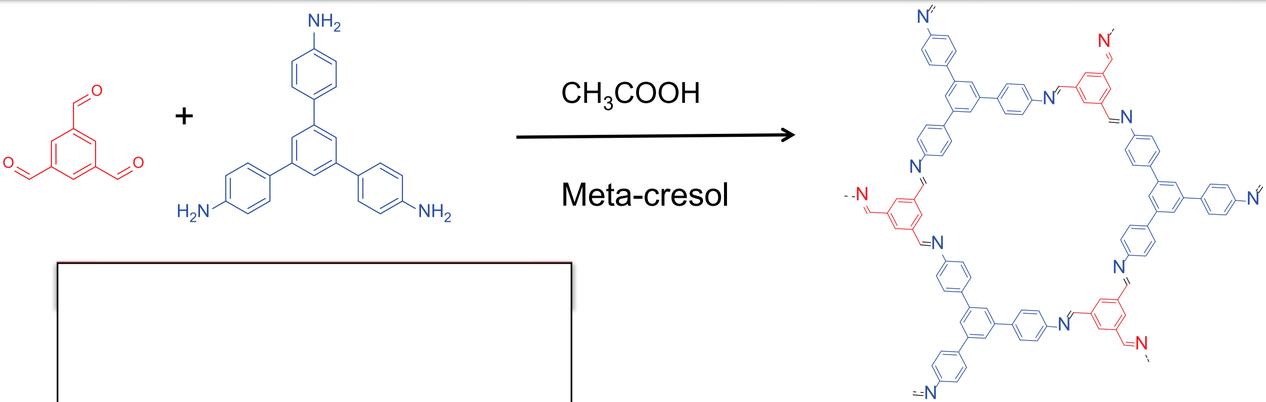
Solvothermal conditions

Hampering COF Processability



RT-COF-1Ac

Imine COF Formation at Room Temperature



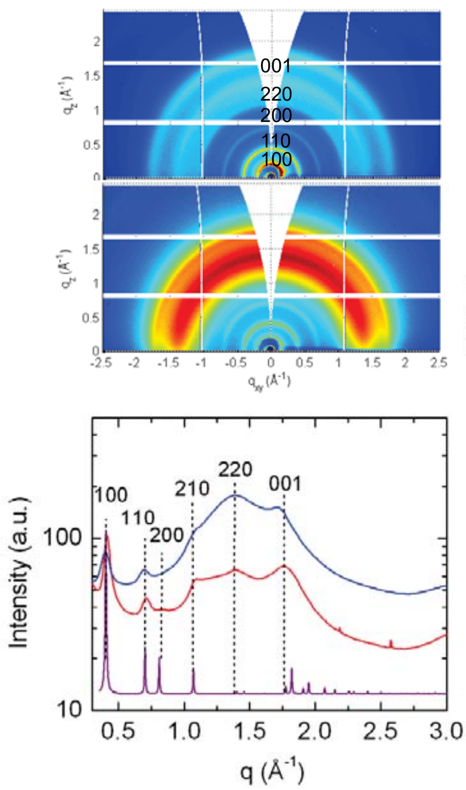
IR and NMR (in solid) spectra confirm imine formation

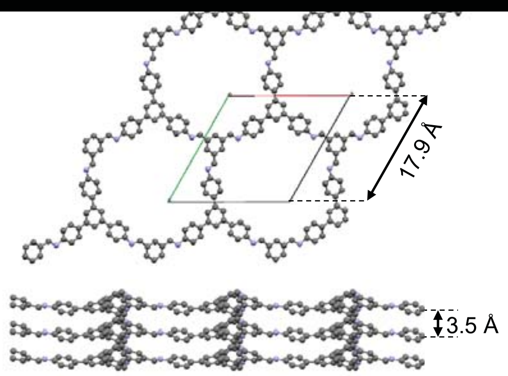
From 2005 !!

Very unusual gel based on 2D flakes

Zamora, F. et al *Chem-Eur J* **2015,** *21* , 10666-10670.

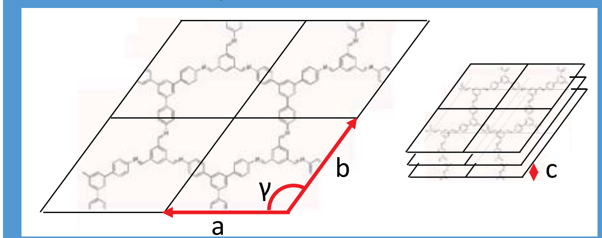
GIXRD measurements






Fabiola Liscio

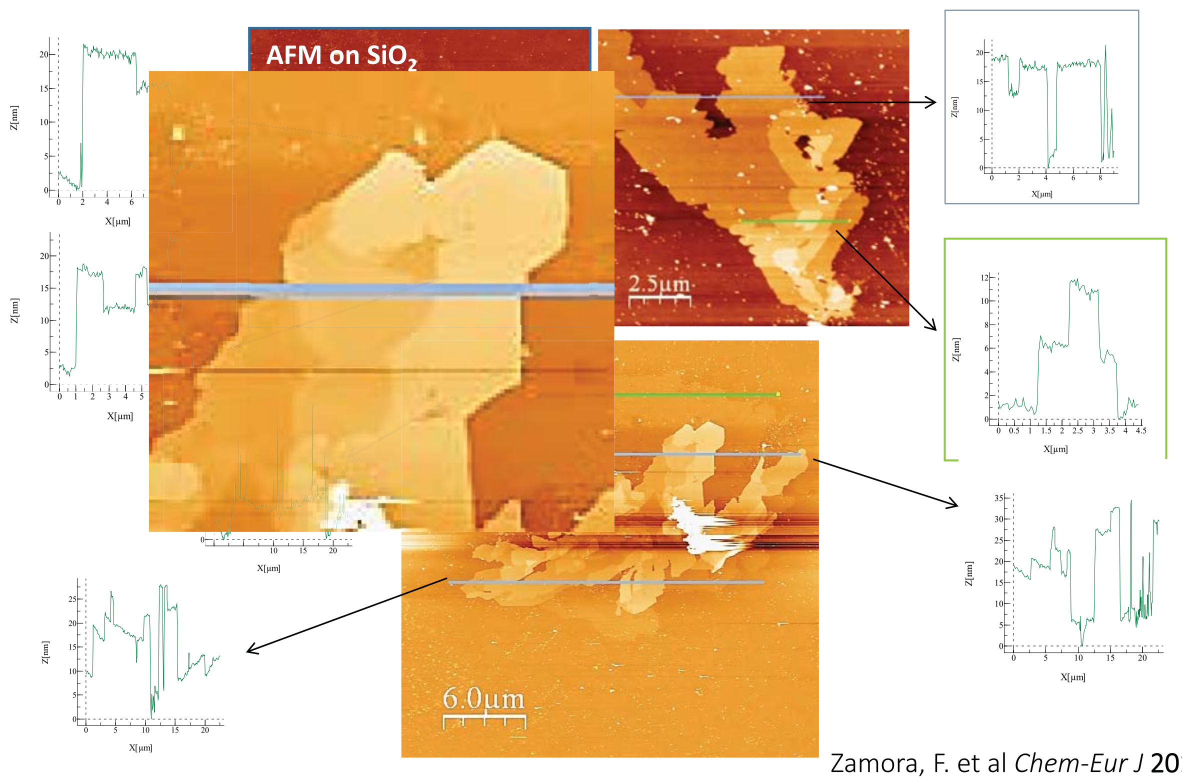
Unite cell: eclipsed structure



a=b=15 Å, c=3.5 Å, α=β=90°, γ=141°

Zamora, F. et al *Chem-Eur J* **2015,** *21* , 10666-10670.

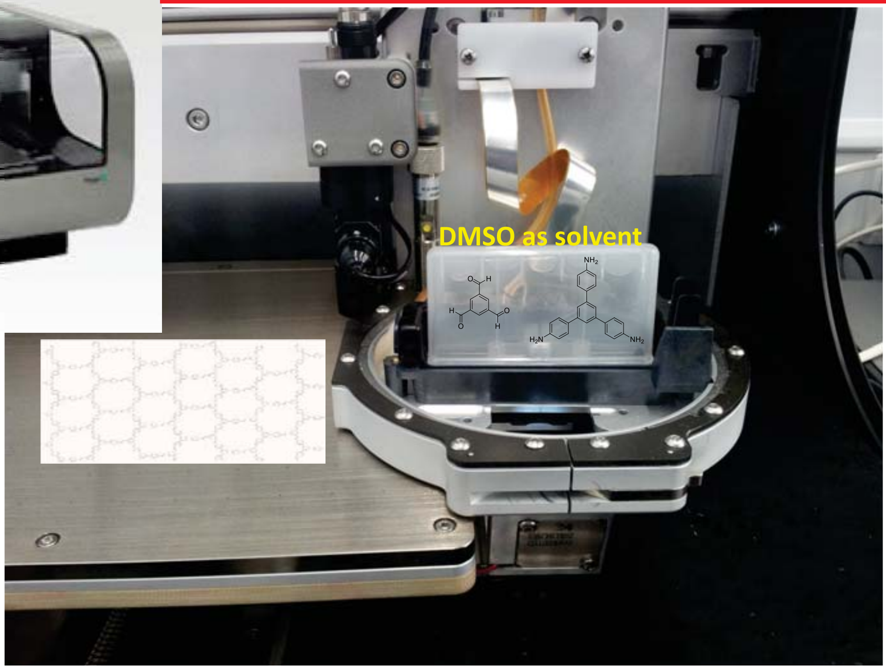
Nanolayer isolation: Atomic Force Microscopy



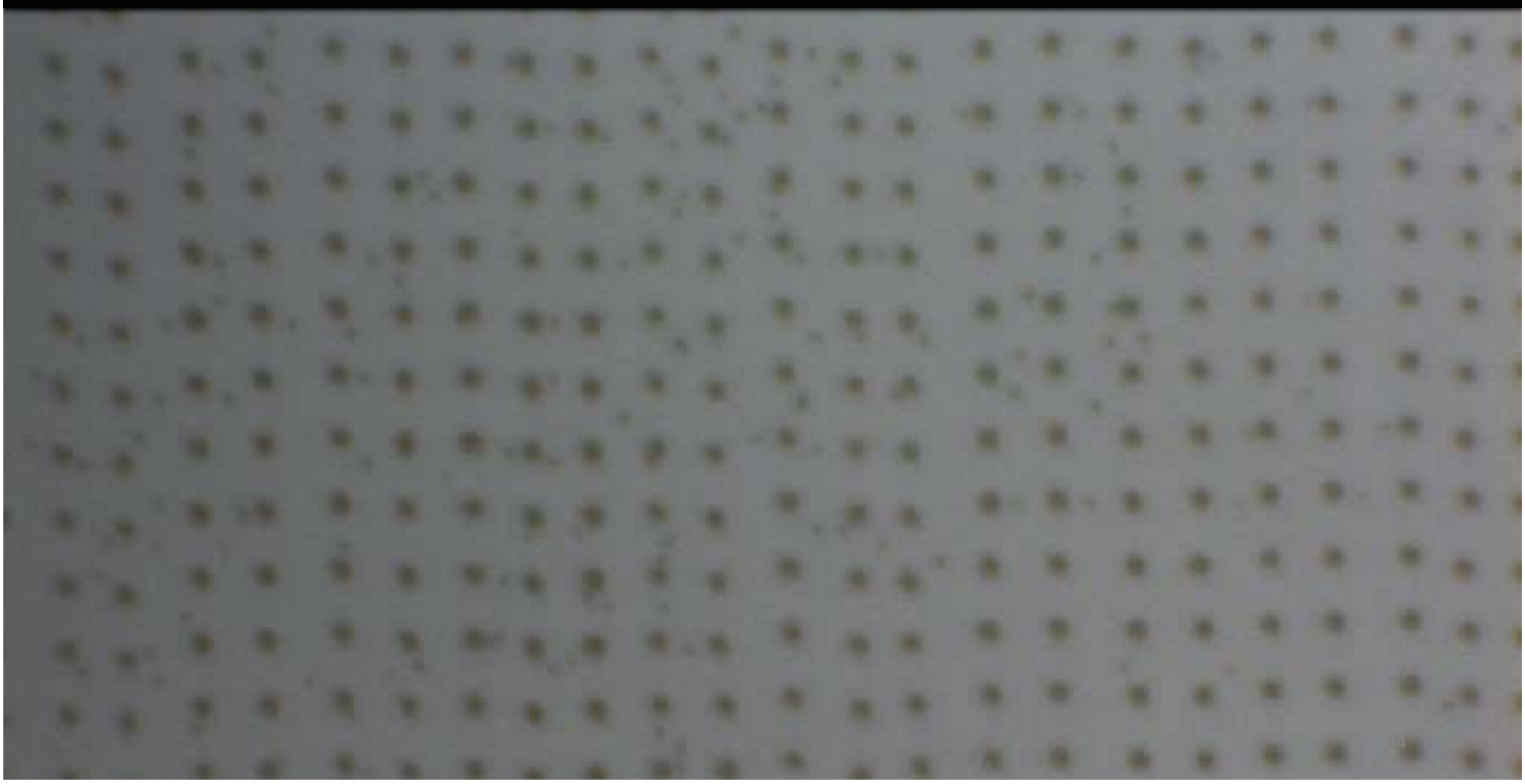
Zamora, F. et al *Chem-Eur J* **2015,** *21* , 10666.

COF-Processability: Ink-jet Printing

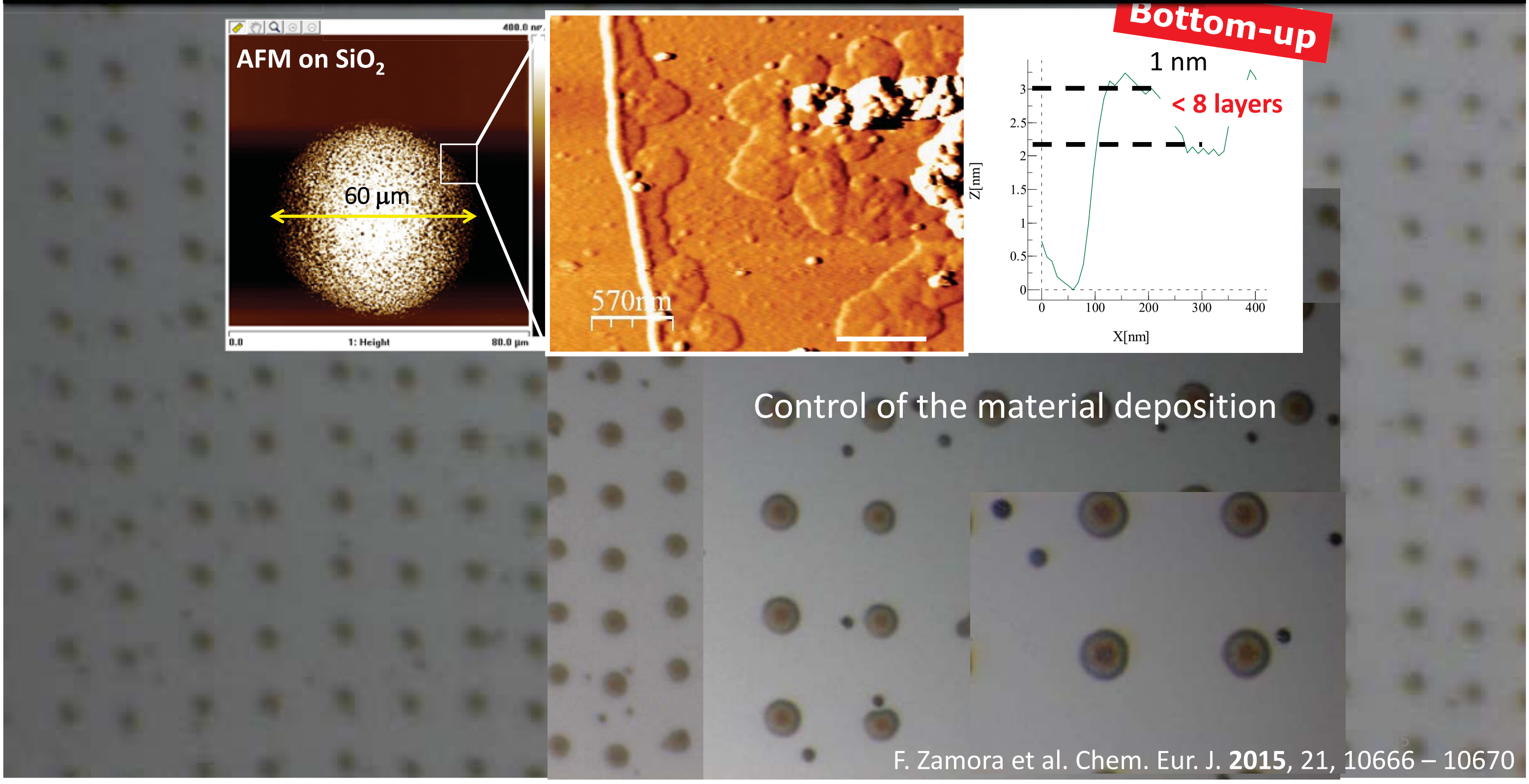
Fuji Dimatrix materials ink-jet printer DMP-2800



COF-Processability: Ink-jet Printing

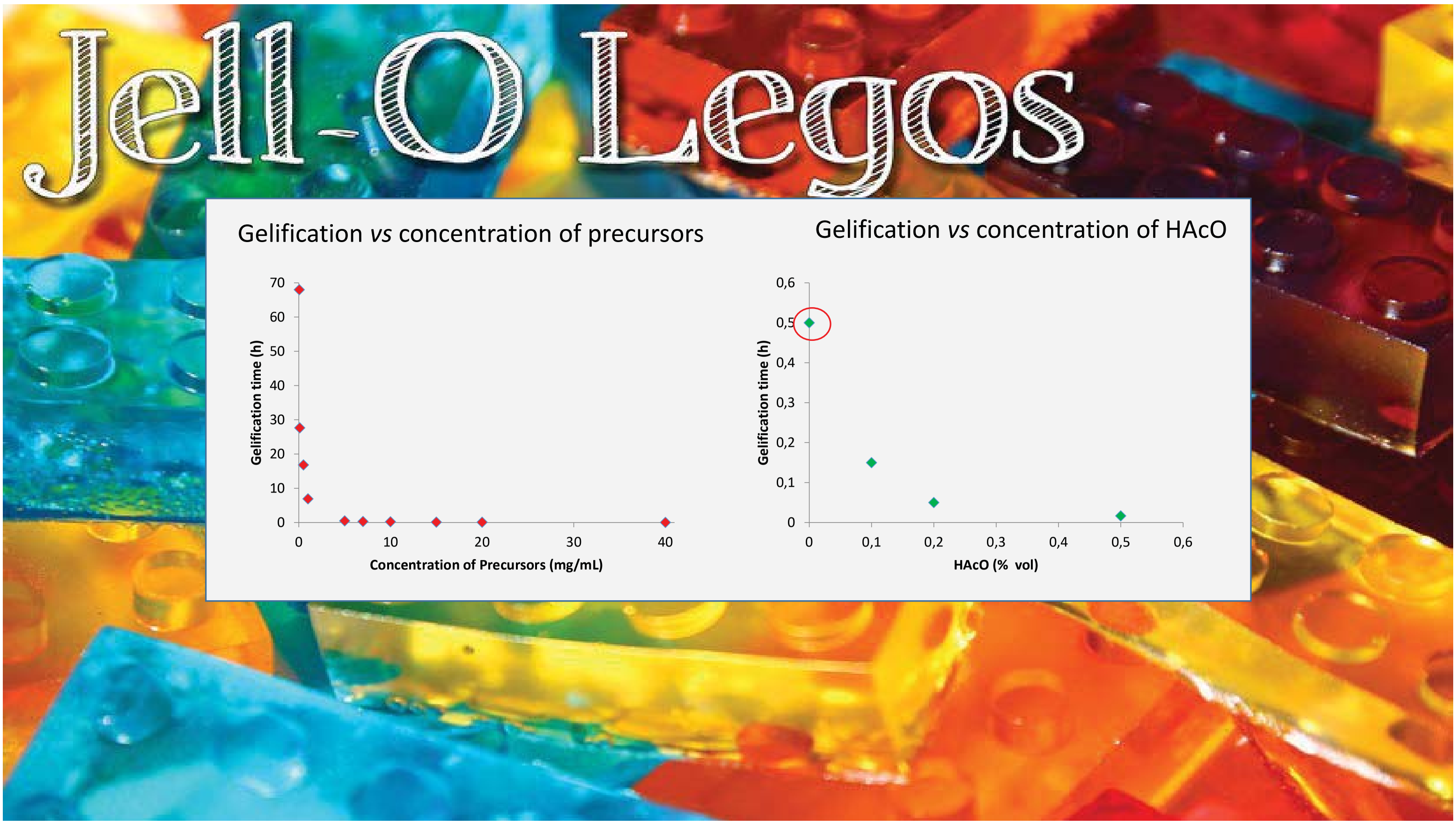


COF-Processability: Ink-jet Printing



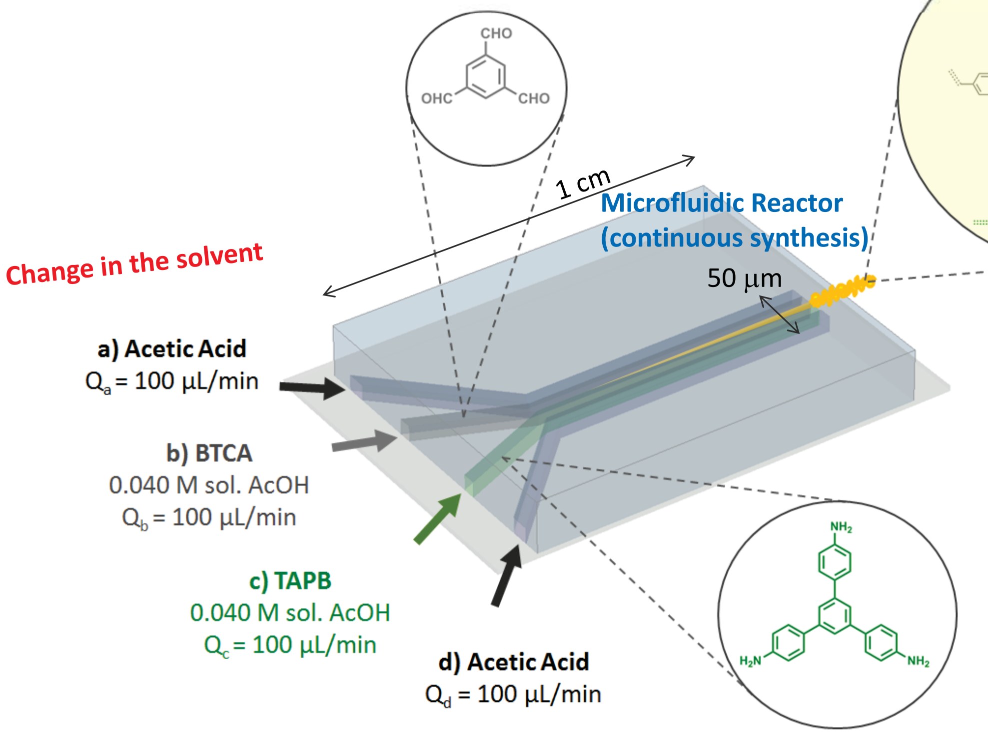
F. Zamora et al. Chem. Eur. J. **2015**, 21, 10666 – 10670

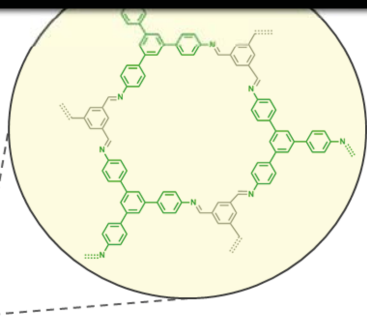
Jell-O Legos



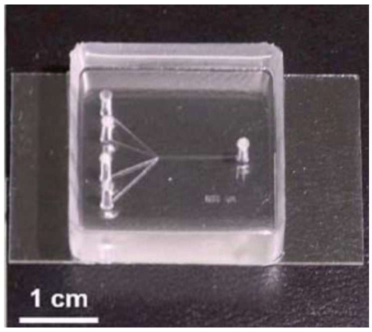
COF-Processability: Microfluidics

Josep Puig Martí-Luis





MF-COF-1

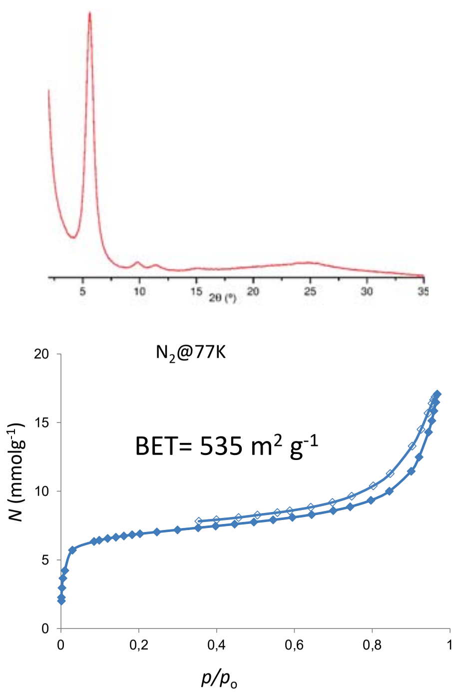


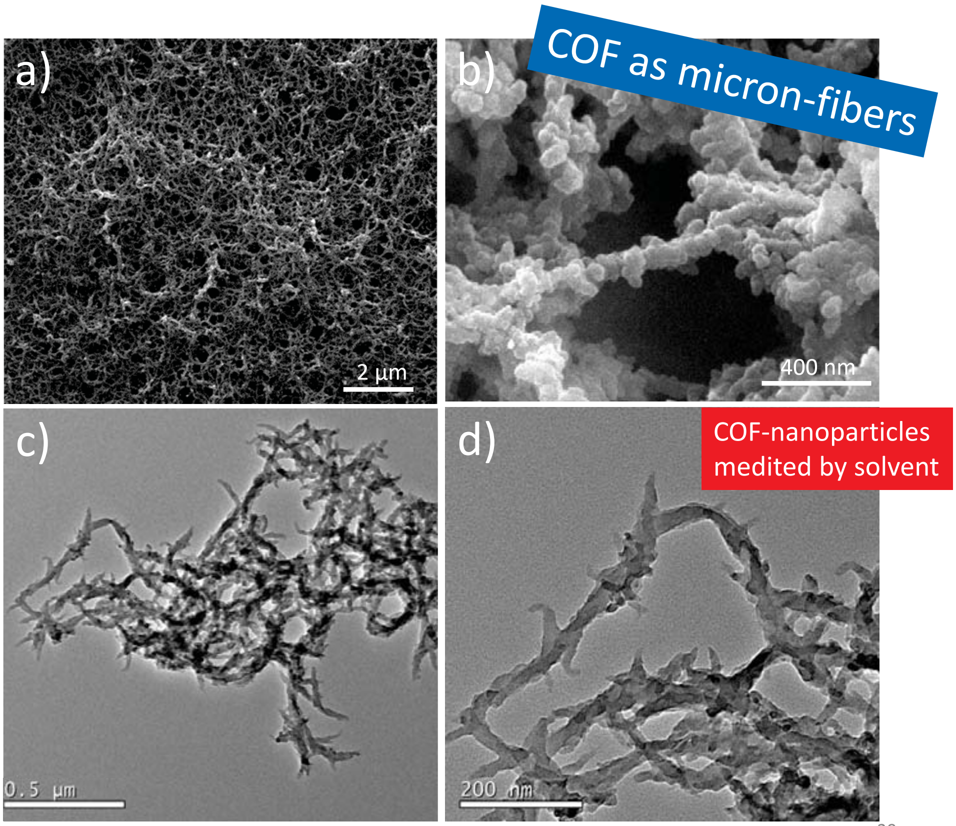
ChemCommun. 2016,52, 9212-9215

COF-Processability: Microfluidics

ChemCommun. 2016,52, 9212-9215

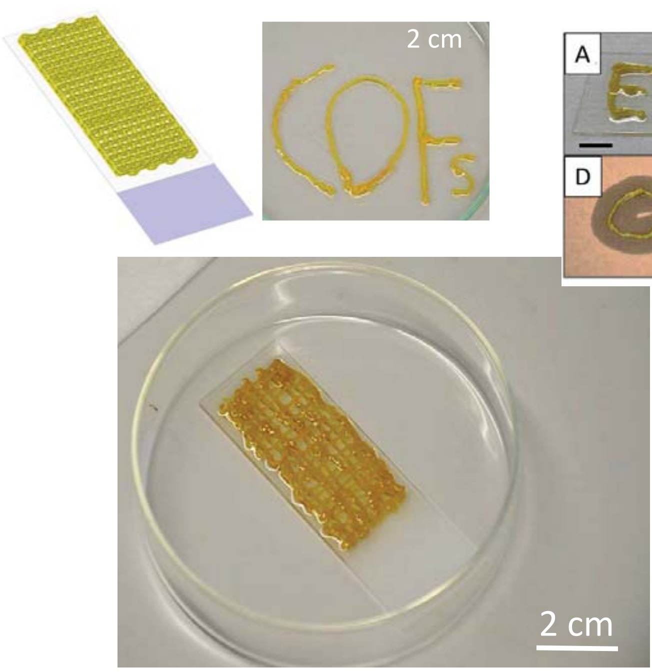
COF-1 fibrillar micro-structures

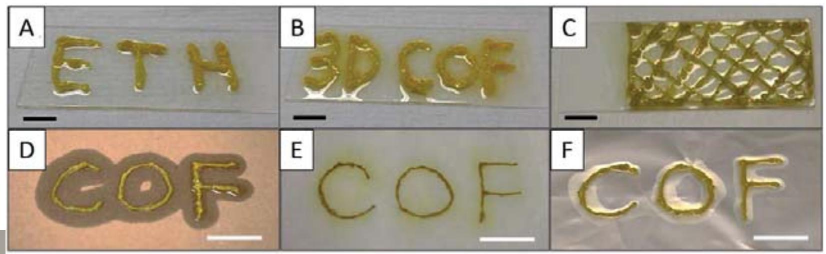




ChemCommun. 2016,52, 9212-9215

COF-1 fibrillar micro-structures mechanical stable for direct **3D drawing of objects on a surface**





Result: continuos 3D drawing

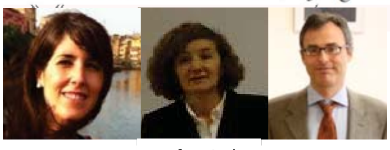
ChemCommun. 2016,52, 9212-9215

COF as a Membrane

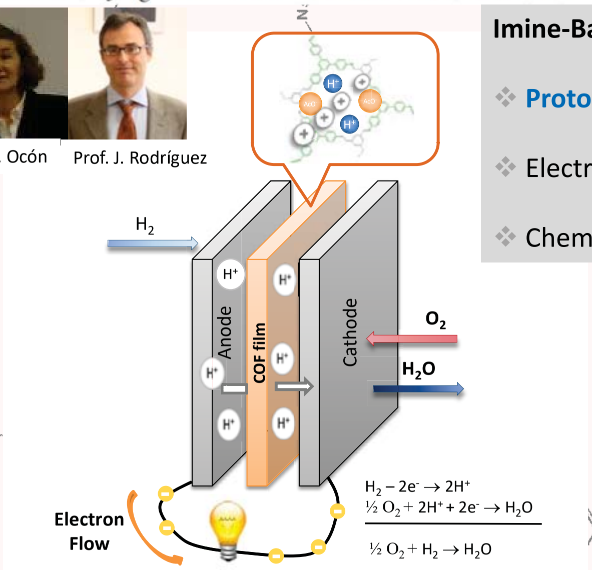
JACS JOURNAL OF THE AMERICAN CHEMICAL SOCIETY

Ionic Conductivity and Potential Application for Fuel Cell of a Modified Imine-Based Covalent Organic Framework

Carmen Montoro,† David Rodríguez-San-Miguel,† Eduardo Polo,† Ricardo Escudero-Cid,‡ Maria Luisa Ruiz-González,⊥ Jorge A. R. Navarro,§ Pilar Ocón,‡* and Félix Zamora*†∥



Dr. C. Montoro Prof. P. Ocón Prof. J. Rodríguez



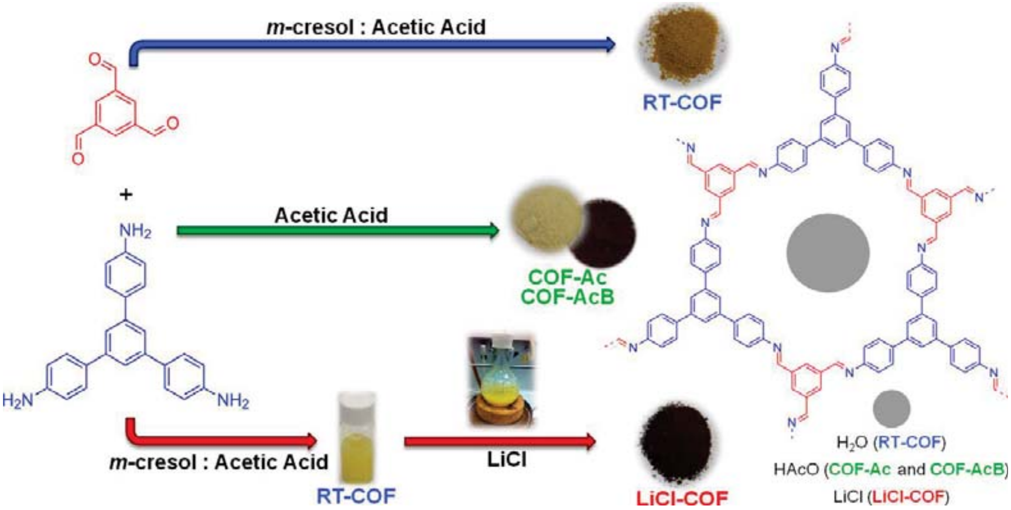
Imine-Based COFs:

- **Proton conductivity**
- Electronic insulator
- Chemically and thermally stable

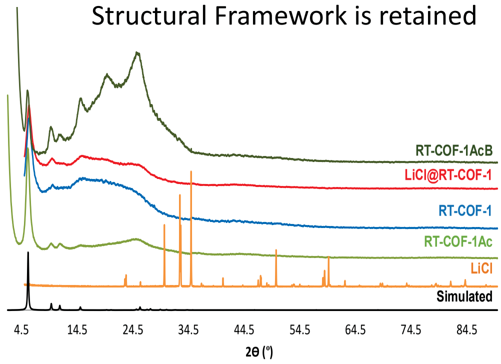
F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

Functionalized COFs for ionic conductivity

Evaluation of ion mobilities into an imine-COF framework



Structural Framework is retained

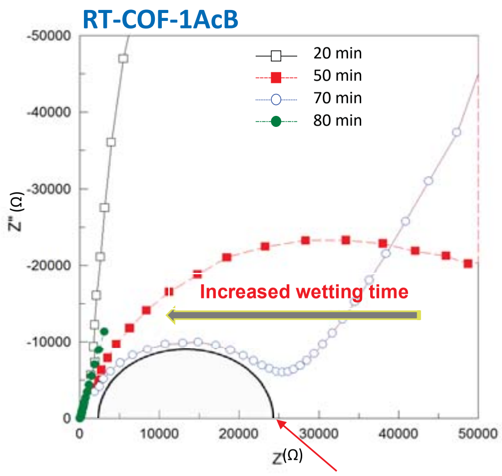


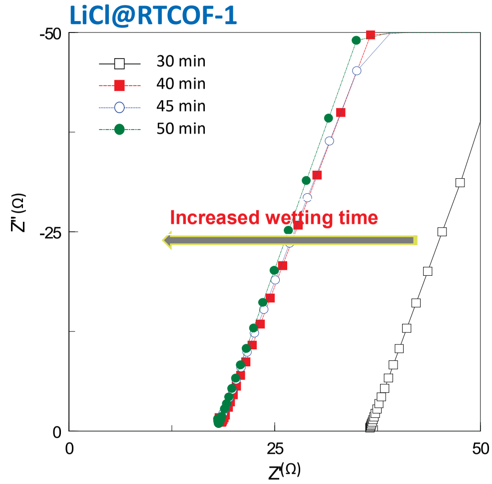
To evaluate Mass Transport

F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

Ionic Conductivity Measurements

Impedance Spectroscopy: **Nyquist plots at 100 % RH and 313 K**





	σ, Scm^{-1} at 313 K	
	22% RH	**100% RH**
RT-COF-1	< 1 × 10^{-10}	1.83 × 10^{-5}
RT-COF-1Ac	< 1 × 10^{-10}	1.07 × 10^{-4}
RT-COF-1AcB	< 1 × 10^{-9}	5.25 × 10^{-4}
LiCl@RT-COF-1	< 1 × 10^{-9}	**6.45 × 10^{-3}**

$$\sigma = \frac{l}{R_1 \cdot A}$$

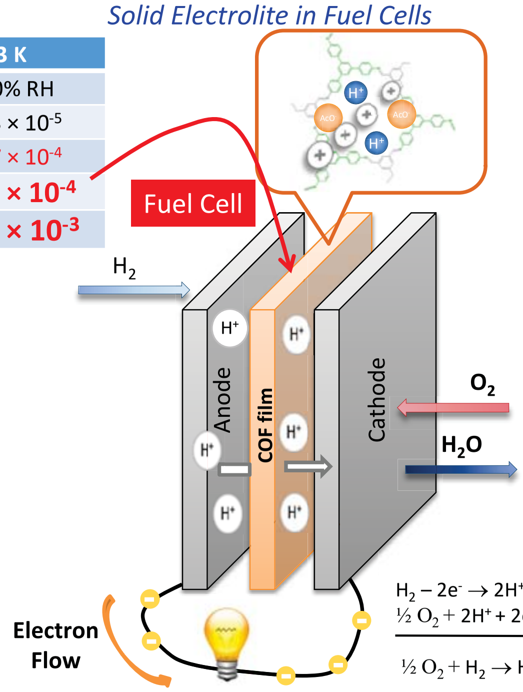
l: film thickness
R_1: electrolite resistance
A: electrode area

the highest ionic conductivity value reported so far for both COFs and MOFs under similar operative conditions, but still far from Nafion® (6.04 ×10^{-2} S cm^{-1} at 51% RH)

Performances as Proton Exchange Membranes

Solid Electrolite in Fuel Cells

	σ, Scm^{-1} at 313 K	
	22% RH	100% RH
RT-COF-1	< 1 × 10^{-10}	1.83 × 10^{-5}
RT-COF-1Ac	< 1 × 10^{-10}	1.07 × 10^{-4}
RT-COF-1AcB	**< 1 × 10^{-9}**	**5.25 × 10^{-4}**
LiCl@RT-COF-1	< 1 × 10^{-9}	**6.45 × 10^{-3}**



$H_2 - 2e^- \rightarrow 2H^+$
$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

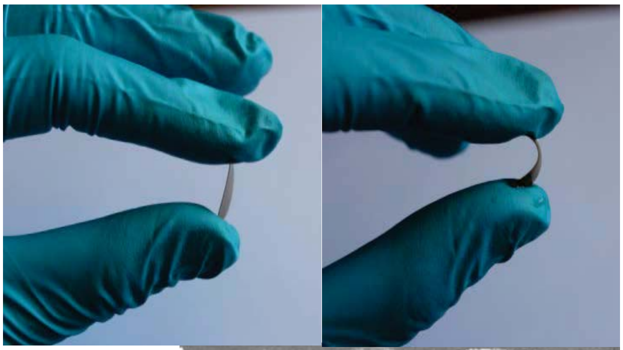
$\frac{1}{2} O_2 + H_2 \rightarrow H_2O$

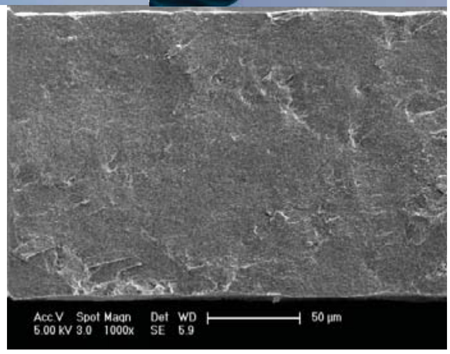
F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

RT-COF-1Ac : Membrane Formation under Pressure

RT-COF-1Ac

HAcO in the cavity





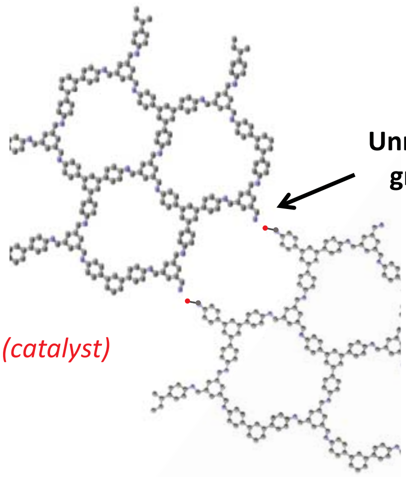
F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

Function of acetic acid as catalyst under the pressure

Imine condensation reaction at the material grain boundaries of the COF-polyimine layers giving rise to the formation of larger aggregates.

Our Hypothesis

Imine condensation at the grain boundaries



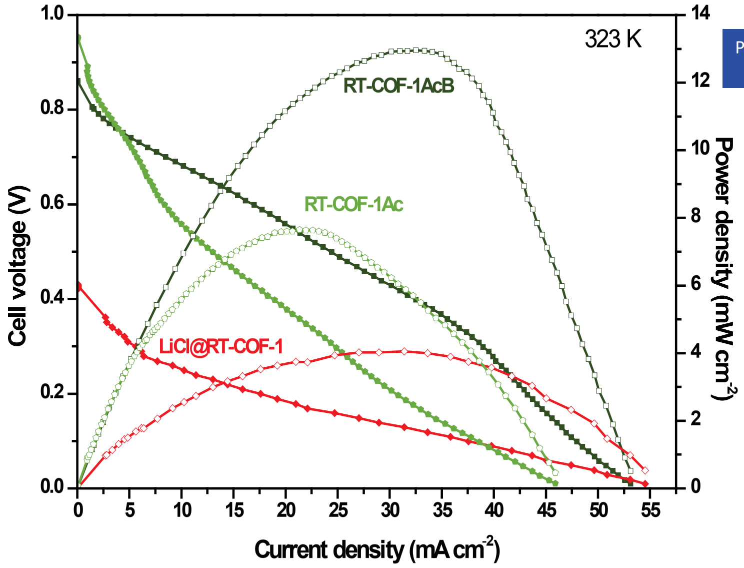
HAcO (catalyst)

Film: nanoparticle aggregation mediated by either ***solvent or new imine bonds***

F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

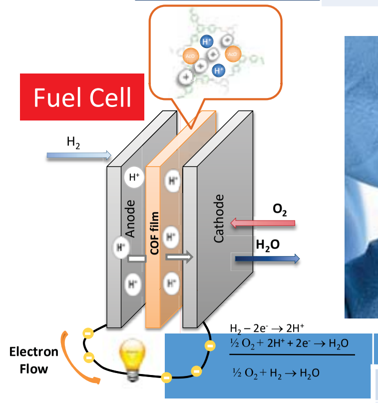
Fuel-cell measurements

Polarization and power density curves



Material	*Power Density, mW cm^{-2}*	*Current Density, mA cm^{-2}*
RT-COF-1Ac	7.64	45.9
RT-COF-1AcB	13	53.1
LiCl@RT-COF-1	4.1	54.5

Processability as Film *vs* Pellets



	σ, Scm^{-1} at 313 K	
	22% RH	100% RH
RT-COF-1	< 1 × 10^{-10}	1.83 × 10^{-5}
RT-COF-1Ac	< 1 × 10^{-10}	1.07 × 10^{-4}
RT-COF-1AcB	< 1 × 10^{-9}	5.25 × 10^{-4}
LiCl@RT-COF-1	< 1 × 10^{-9}	**6.45 × 10^{-3}**

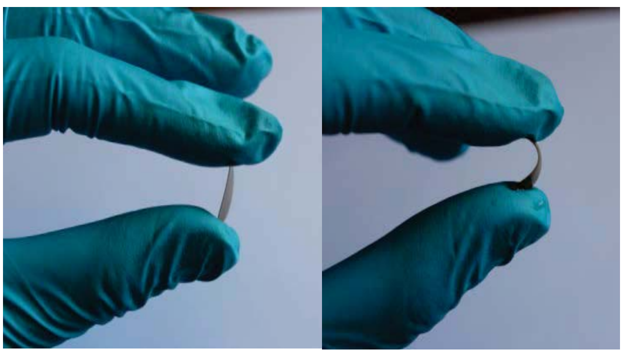
$H_2 - 2e^- \rightarrow 2H^+$
$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
$\frac{1}{2} O_2 + H_2 \rightarrow H_2O$

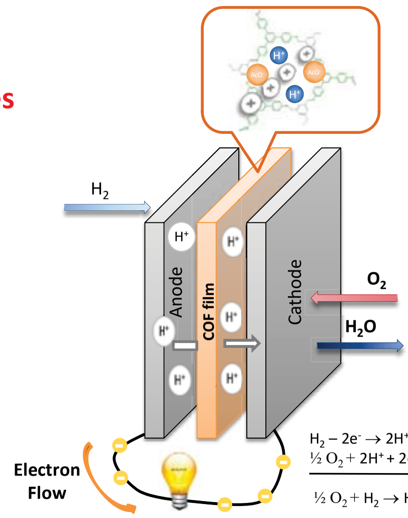
F. Zamora, *et al*. J. Am. Chem. Soc. 139, 10079 (2017)

Better Performances as Proton Exchange Membranes

Result: COF shapping - membranes

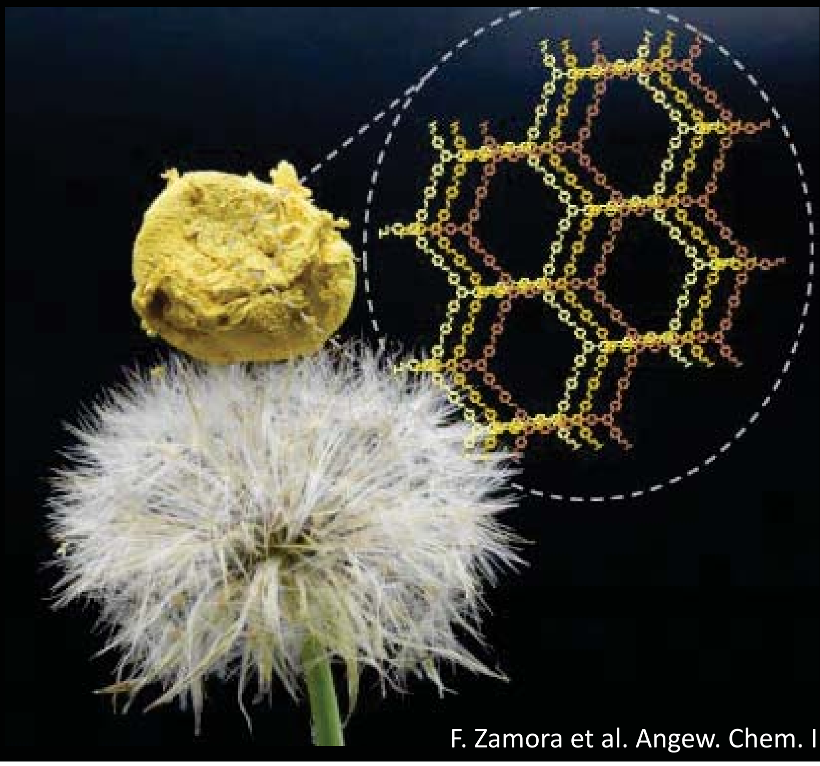
Excellent Mechanical Properties Enhance Performances





$H_2 - 2e^- \rightarrow 2H^+$
$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$
$\frac{1}{2} O_2 + H_2 \rightarrow H_2O$

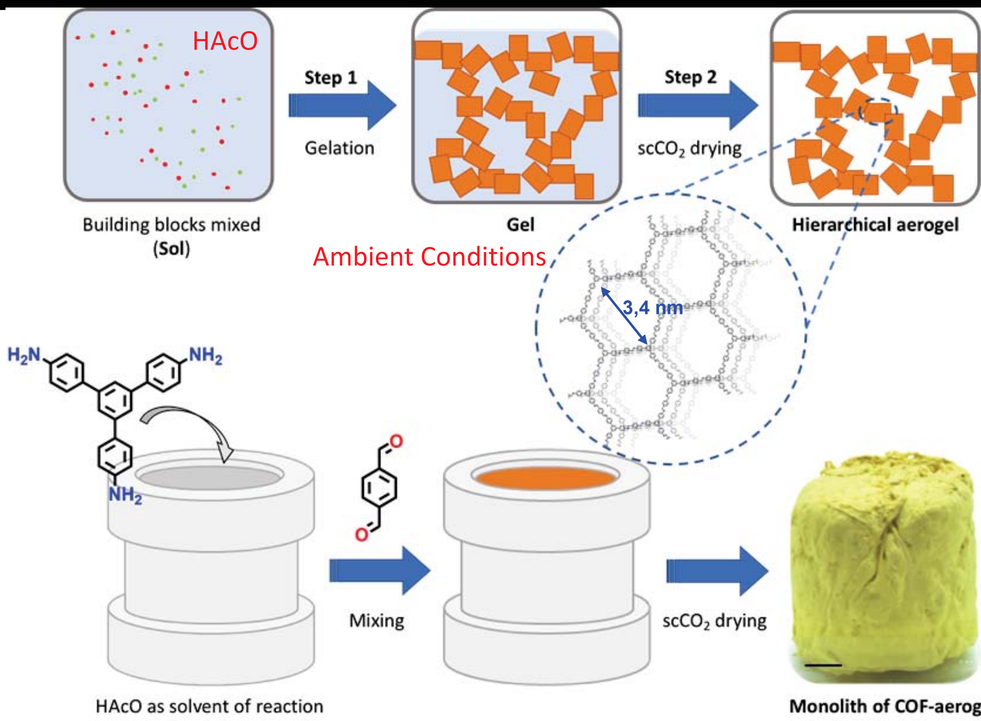
COF Aerogels



F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

How to make a COF Aerogel

Jesus A. Martín

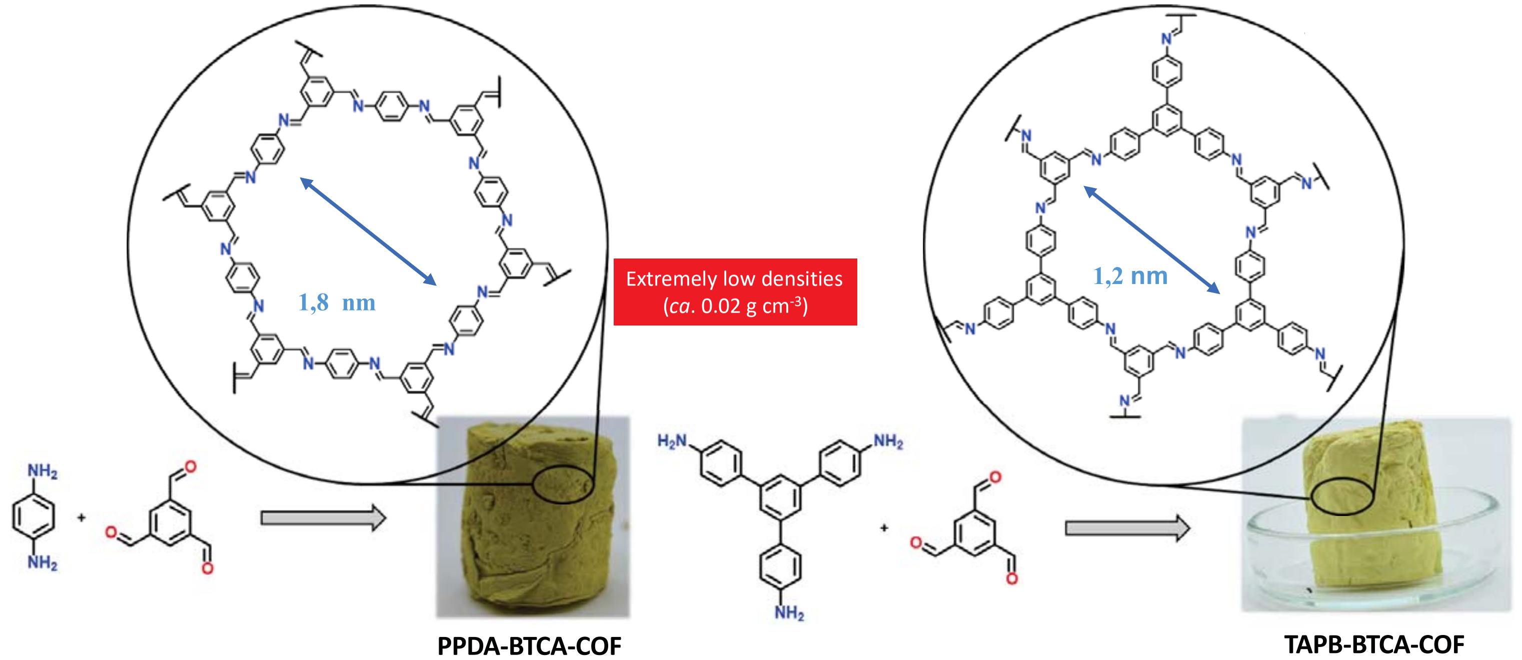


COF-nanoparticles medited by solvent

Ambient Conditions

F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

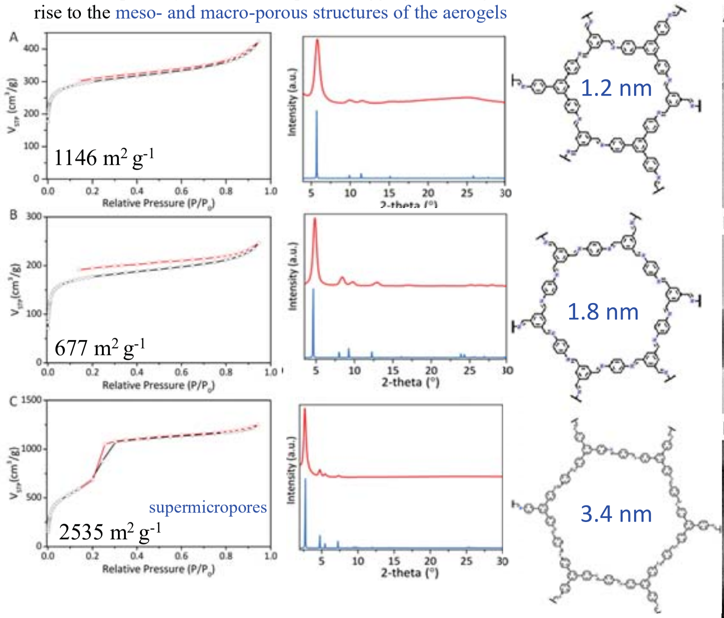
COF Aerogels



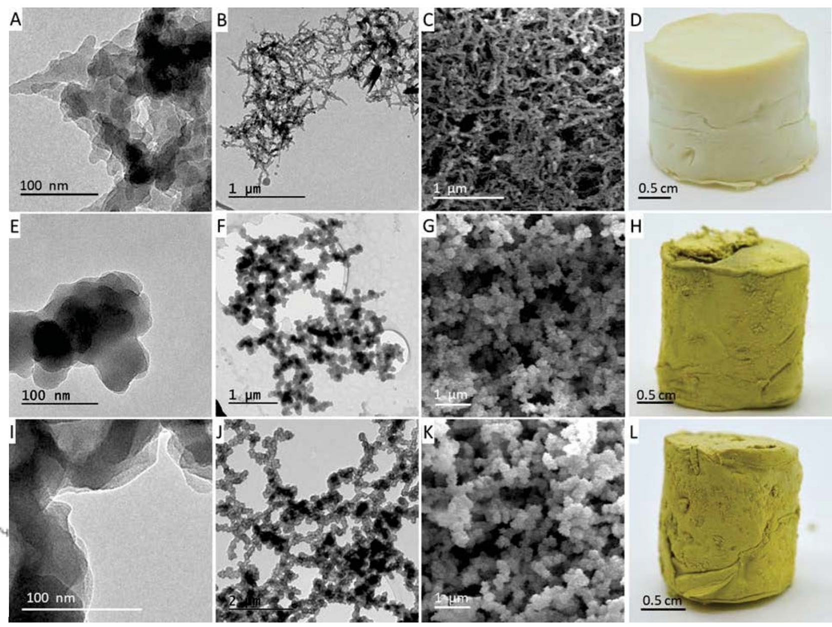
F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

COF Aerogels

disordered porosity to stable interparticle aggregates that give rise to the meso- and macro-porous structures of the aerogels



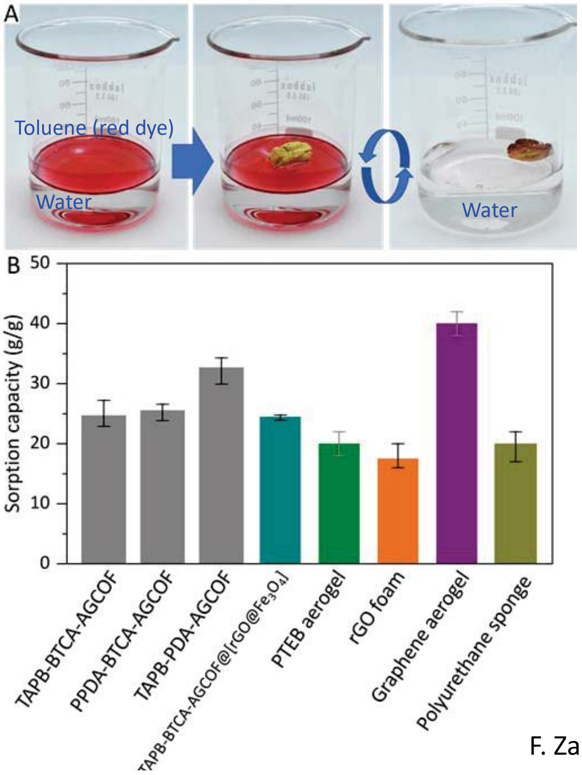
COF nanolayers connected to form 3D aerogel structure



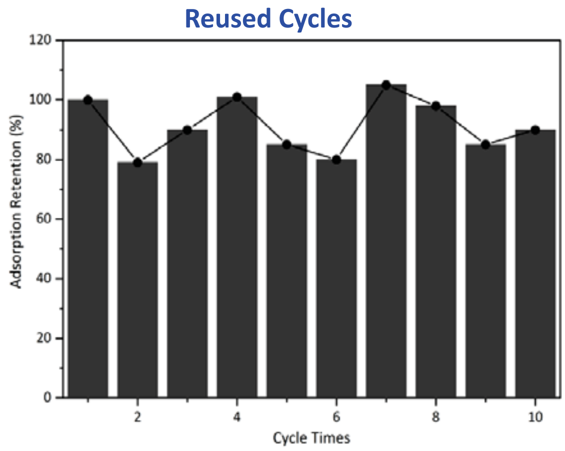
F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

Adsorption Properties of COF Aerogels

Proof-of-Concept

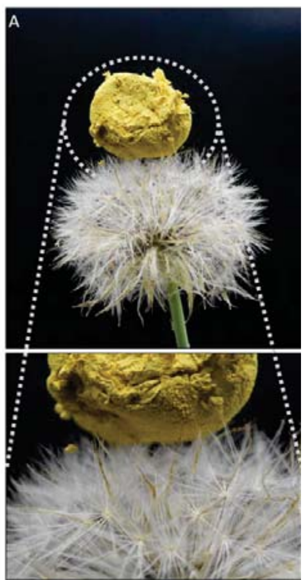


Versus Lower Adsorption for COF in powder form



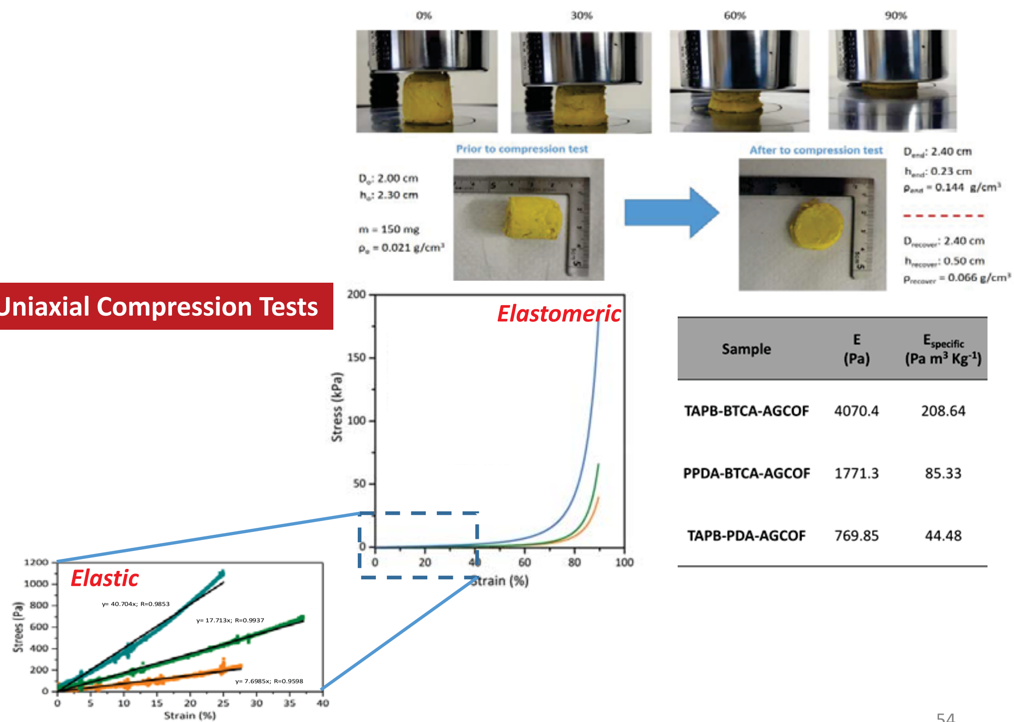
F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

Mechanical Properties of COF Aerogels



Extremely low densities
(*ca.* 0.02 g cm^{-3})

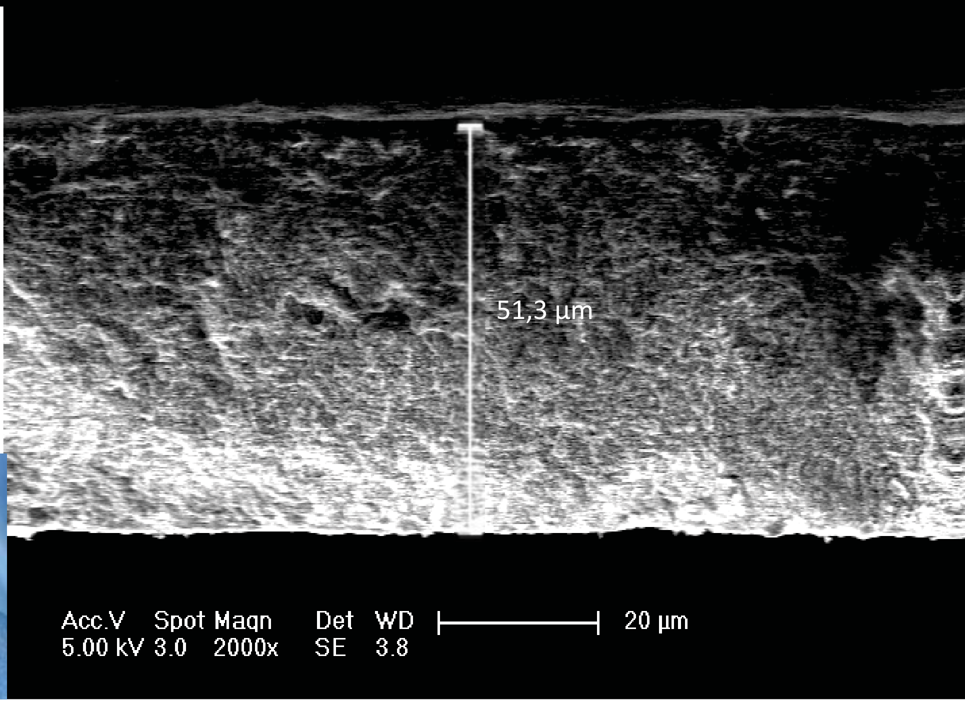
Uniaxial Compression Tests



Sample	E (Pa)	$E_{specific}$ (Pa m^3 Kg^{-1})
TAPB-BTCA-AGCOF	4070.4	208.64
PPDA-BTCA-AGCOF	1771.3	85.33
TAPB-PDA-AGCOF	769.85	44.48

F. Zamora et al. Angew. Chem. Int. Ed. 2021, 60, 13969–13977

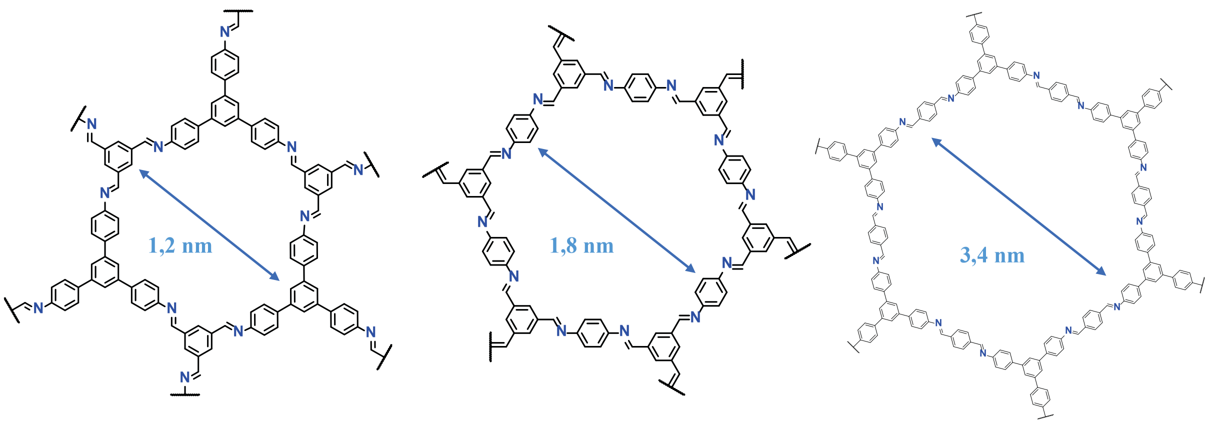
Membrane Formation under Pressure from COF Aerogels



F. Zamora et al. Adv. Sci. 2022, 2104643

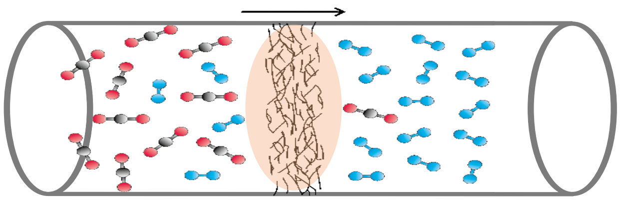
Gas Separation using COF membranes

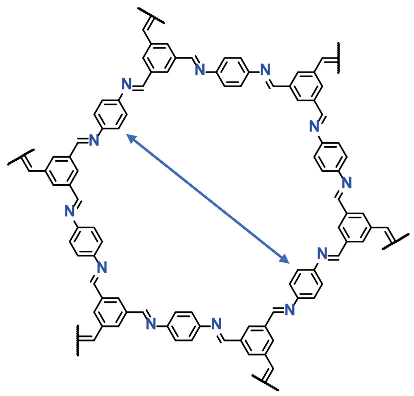
Prof. Dan Zhao

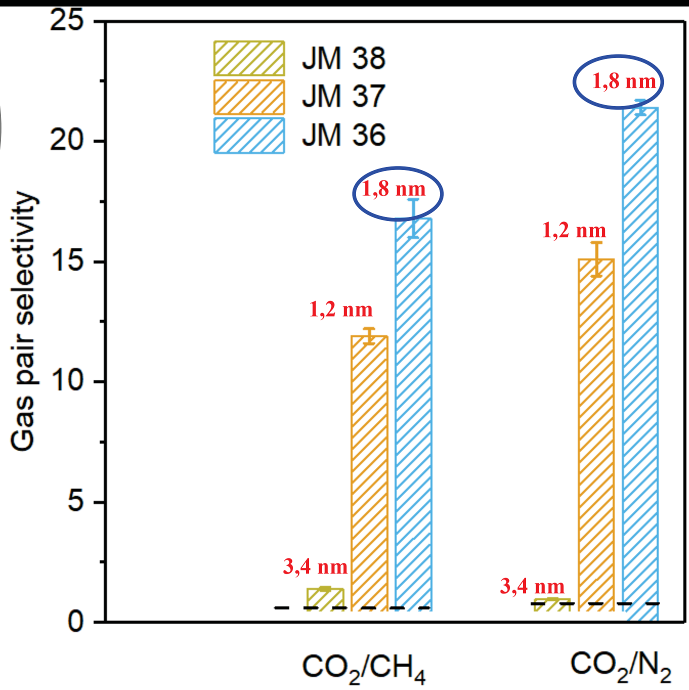


F. Zamora et al. Adv. Sci. 2022, 2104643

Gas Separation using COF membranes







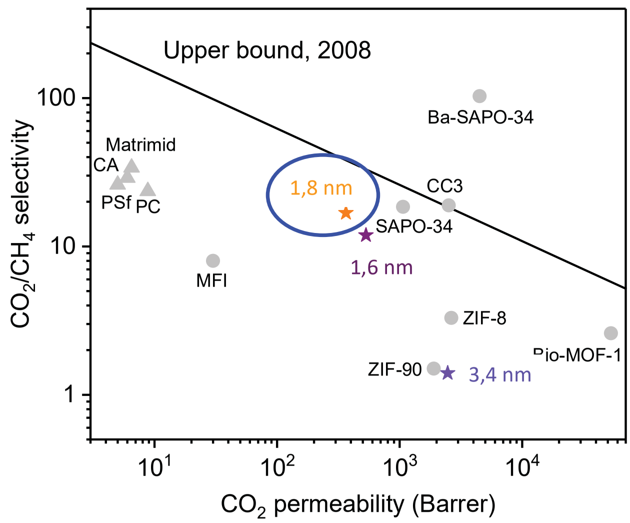
The mixed gas pair selectivity is higher compared to the ideal gas pair selectivity owing to the sorption and diffusion competition between the gas mixtures.

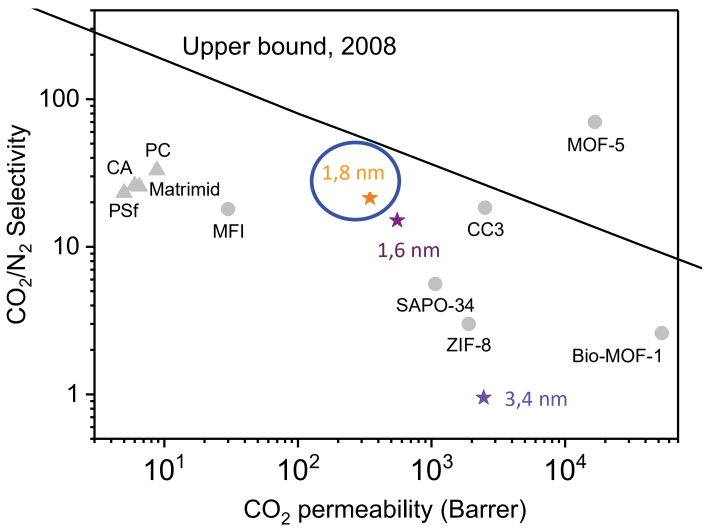
F. Zamora et al. Adv. Sci. 2022, 2104643

COF membranes Performances for Gas Separation

We plotted the separation performance of pure COF membranes and compared them with other membranes on the **Robeson upper bound plots**.

Our membrane shows **much higher CO_2 permeability compared with commercial membranes** and the **separation performance of our membranes is close to the 2008 upper bound limits**





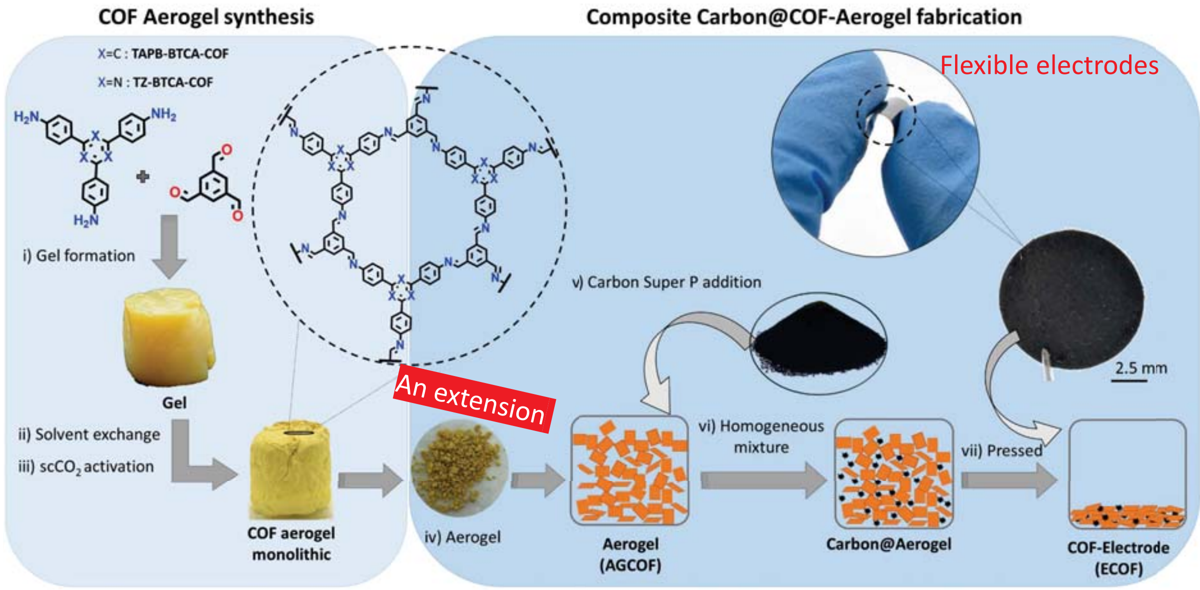
F. Zamora et al. Adv. Sci. 2022, 2104643

Covalent Organic Frameworks | **Hot Paper**

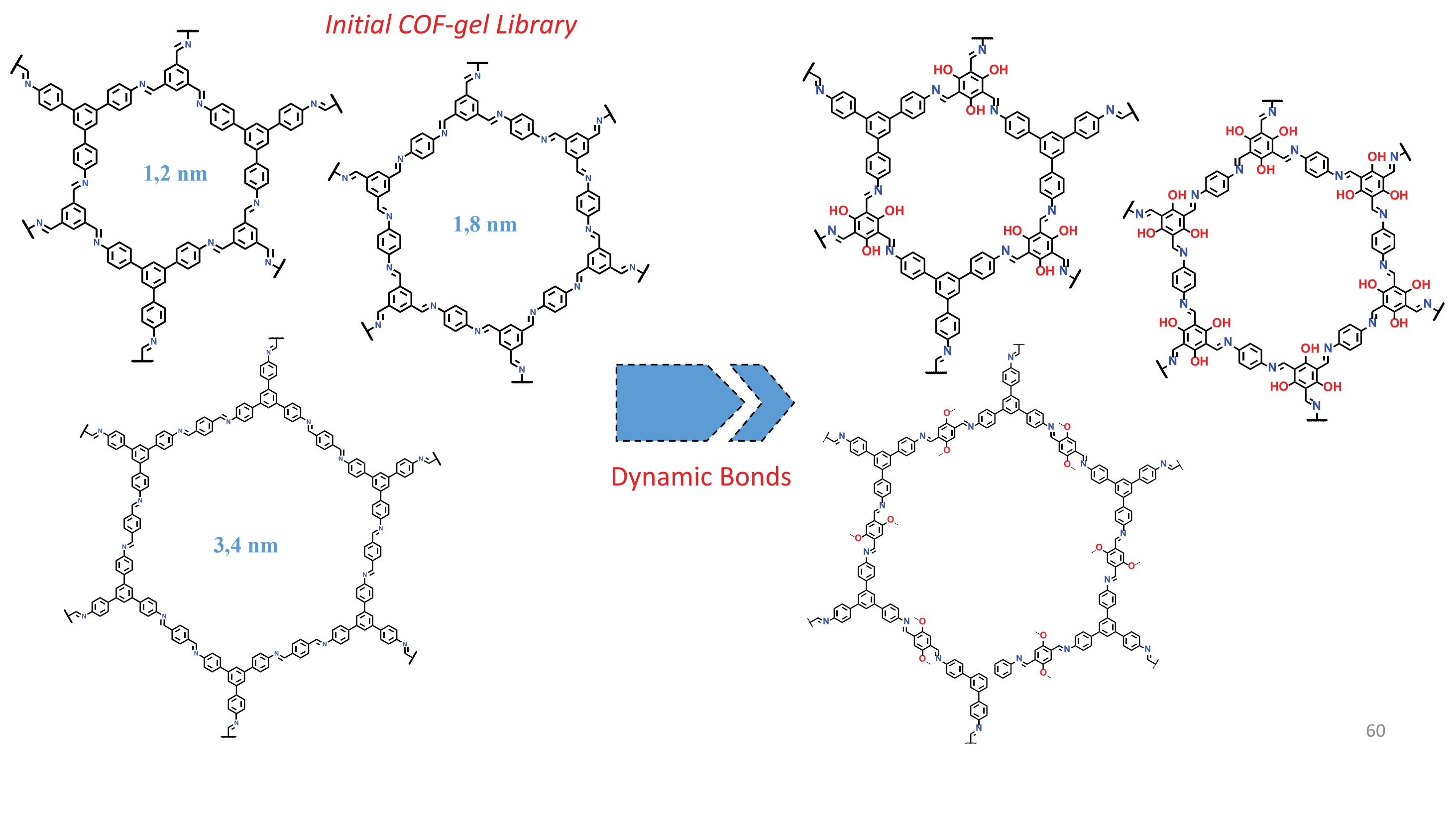
How to cite: *Angew. Chem. Int. Ed.* **2022**, *61*, e202213106
International Edition: doi.org/10.1002/anie.202213106
German Edition: doi.org/10.1002/ange.202213106

Electrochemical Double-Layer Capacitor based on Carbon@ Covalent Organic Framework Aerogels

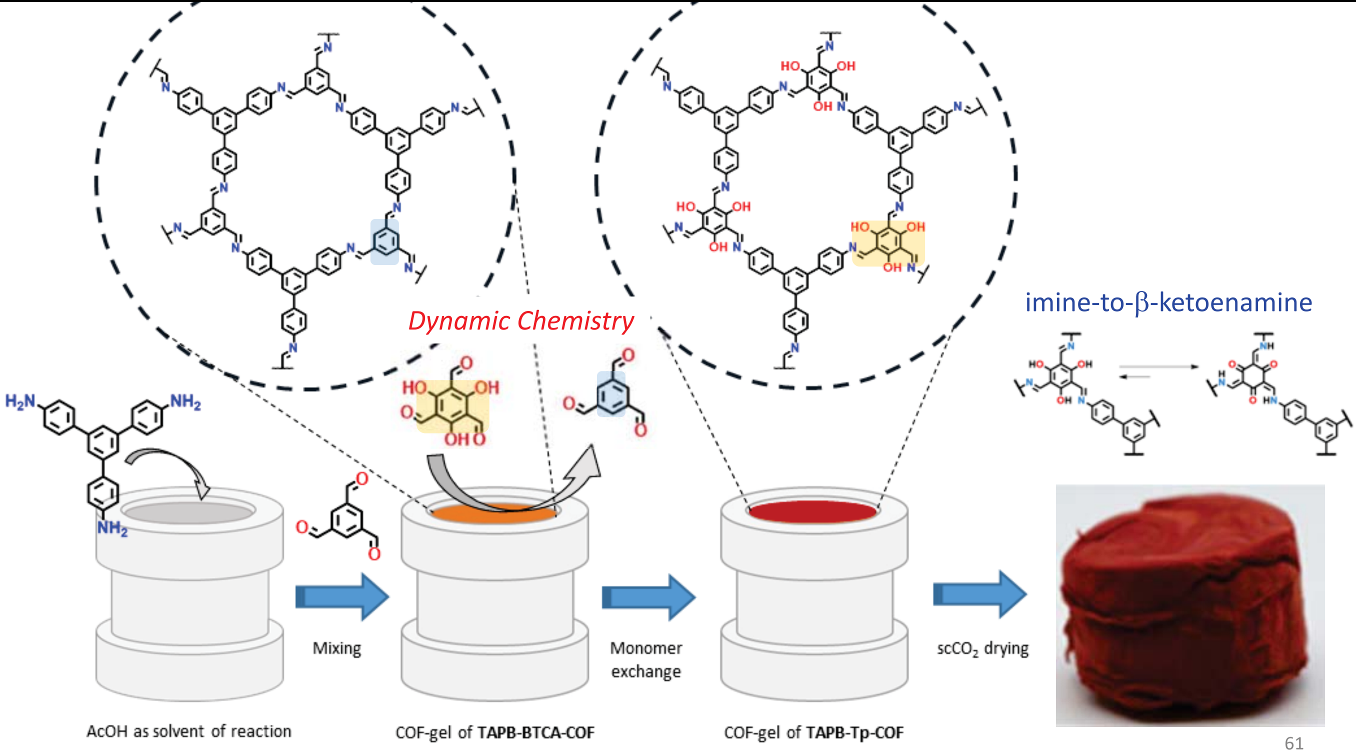
Jesús Á. Martín-Illán[+], Laura Sierra[+], Pilar Ocón, and Félix Zamora**



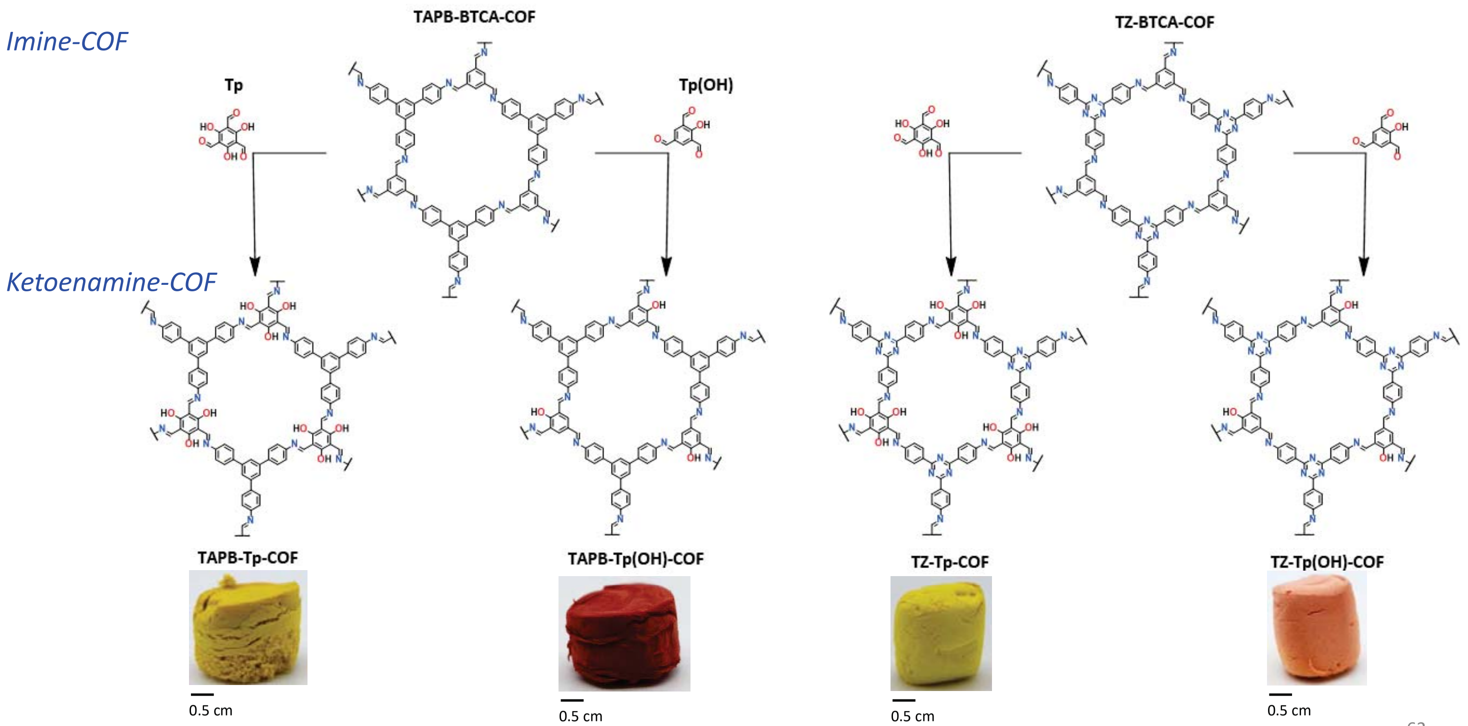
Imine-based COFs: Gel to Gel to Aerogel synthesis



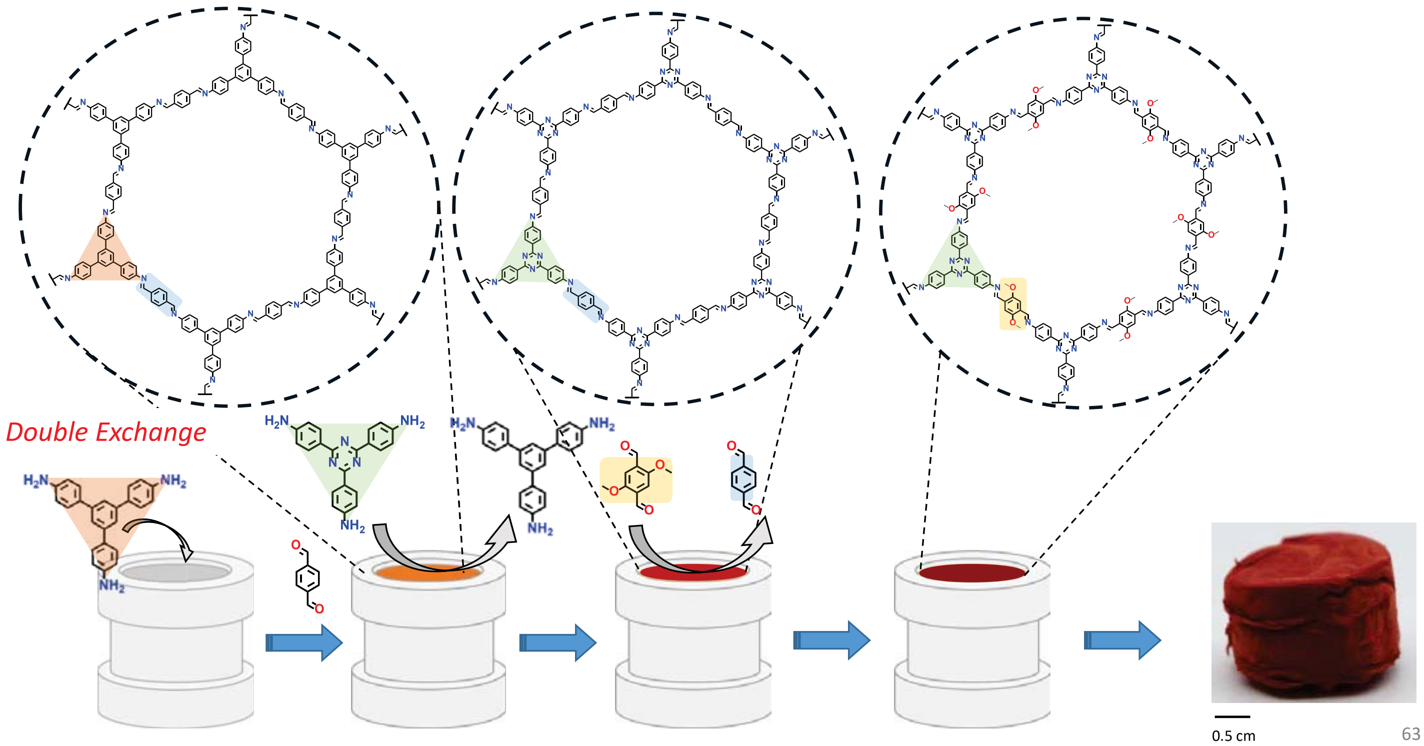
Imine-based COFs: Gel to Gel to Aerogel synthesis



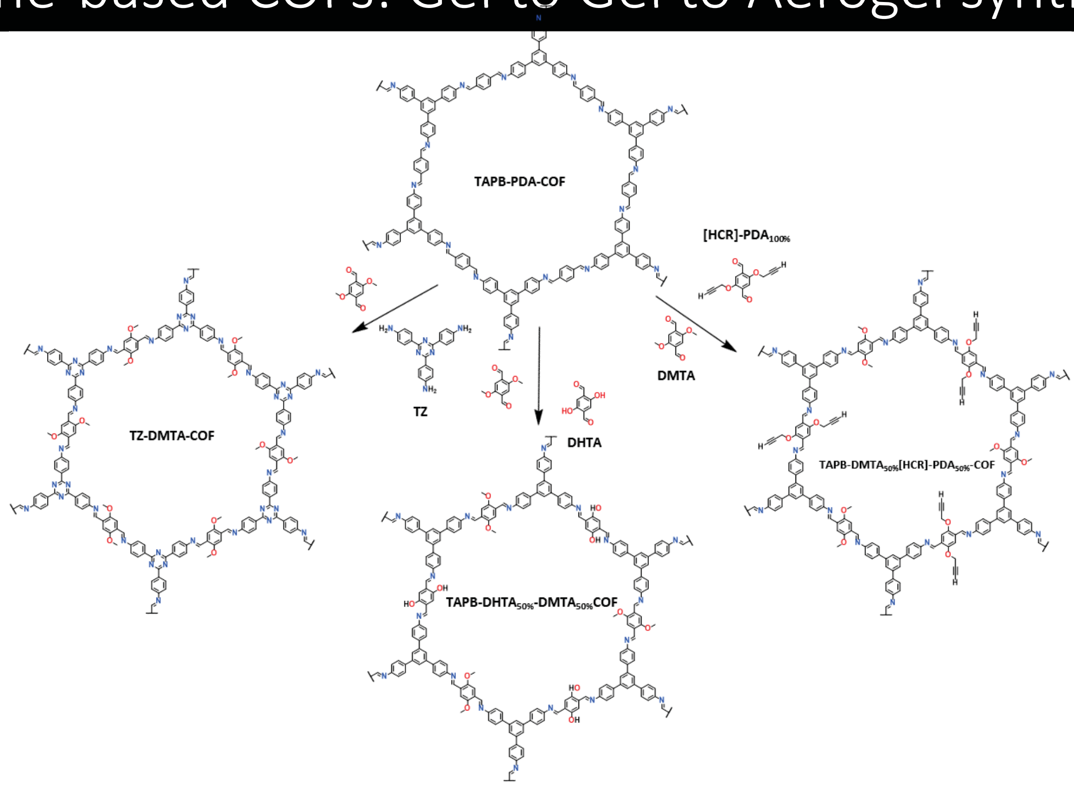
Imine-based COFs: Gel to Gel to Aerogel synthesis



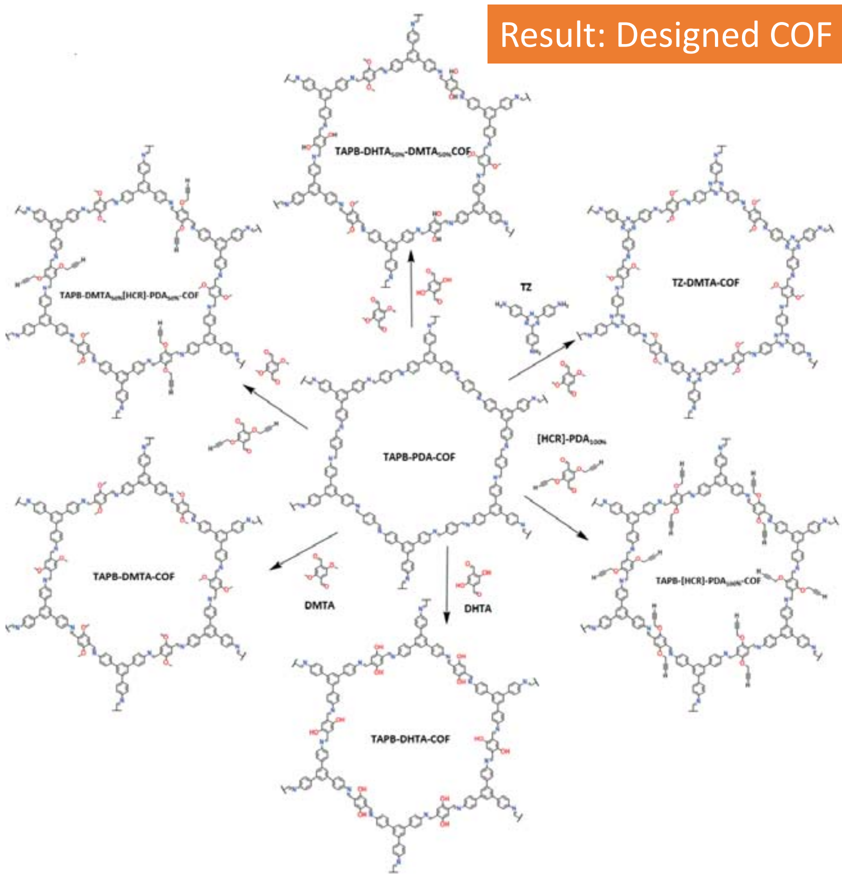
Imine-based COFs: Gel to Gel to Aerogel synthesis



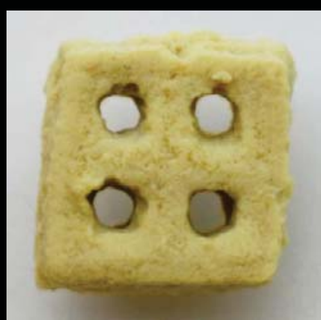
Imine-based COFs: Gel to Gel to Aerogel synthesis



Result: Designed COF membranes & aerogels



3D Printing COFs



3D Printing of COFs: Antecedents

GO@COF Composite

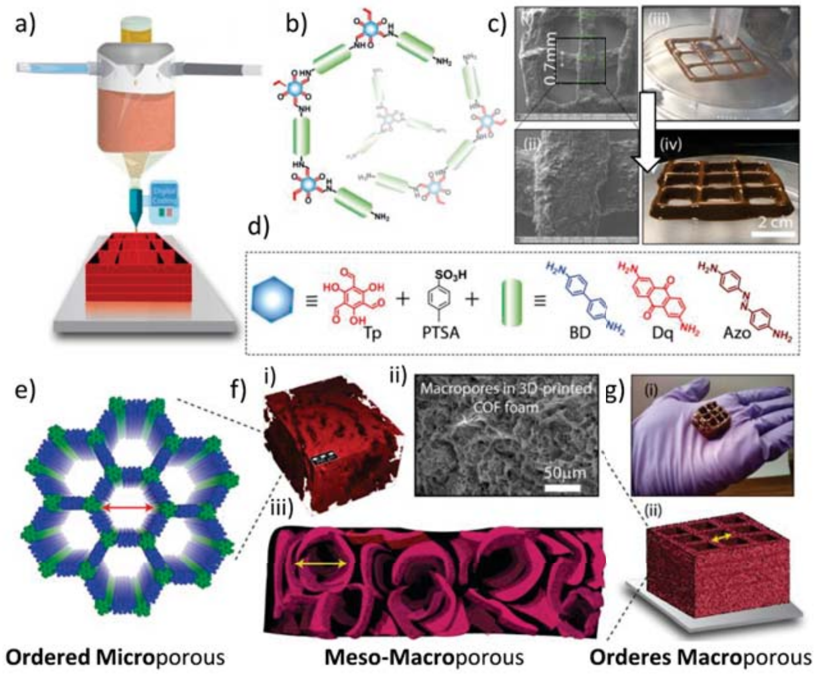


Fig. 10. A) illustration of the cof-go foam synthesis and 3d printing process. a hydrogel is created when graphene oxide, water, and cof precursors are combined. this hydrogel is employed in 3d printing. b) schematic depiction of the cofs' incomplete frameworks. at this point, we anticipate that the 3d printing ink will begin to form oligomers or incomplete framework structures. c) (i,ii) the sem image of a cof-go foam grid that was 3d printed at a millimeter scale with a print resolution of~ 0.7 mm and pore size of ~1.5 mm. c) (iii, iv) The digital images of a COF-GO foam grid that was 3D manufactured at a centimeter scale. d) The ingredients used to create COF-GO foam. e) The TpBD COF space-filled model. X-ray microtomography of TpBD foam created via 3D printing. It exhibits the macropores in the matrix of the COF-GO foam, the macropores in the matrix of the SEM picture of the TpBD foam monolith, and the macropores in the matrix of the graphical representation of the macroporous foam. g) A graphic representation of the nine-pore COF-GO foam grid and I a digital photograph of a 2.3 × 2.3 cm self-supported nine-pore COF-GO foam grid that was 3D printed. Adapted from reference 91 with permission of the copyright holders.

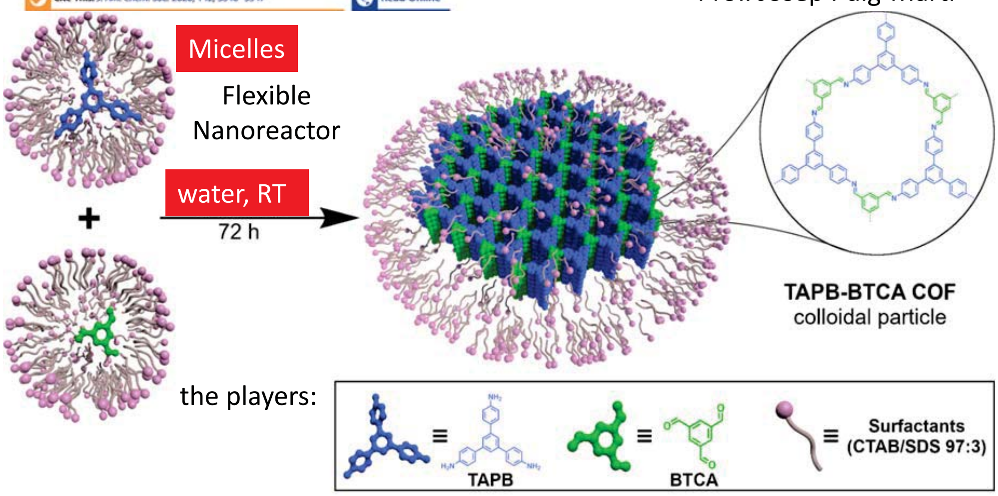
V. Singh, H.R. Byon, Mater. Adv. 2 (2021) 3188–3212

JACS
JOURNAL OF THE AMERICAN CHEMICAL SOCIETY
pubs.acs.org/JACS Article

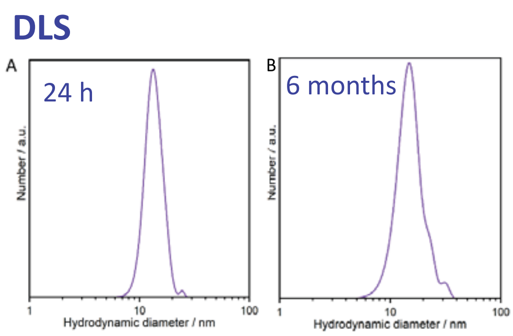
Biomimetic Synthesis of Sub-20 nm Covalent Organic Frameworks in Water

Carlos Franco, David Rodríguez-San-Miguel, Alessandro Sorrenti, Semih Sevim, Ramon Pons, Ana E. Platero-Prats, Marko Pavlovic, Istvan Szilágyi, M. Luisa Ruiz Gonzalez, José M. González-Calbet, Davide Bochicchio, Luca Pesce, Giovanni M. Pavan, Inhar Imaz, Mary Cano-Sarabia, Daniel Maspoch, Salvador Pané, Andrew J. de Mello, Felix Zamora,* and Josep Puigmartí-Luis*

Cite This: J. Am. Chem. Soc. 2020, 142, 3540–3547 Read Online

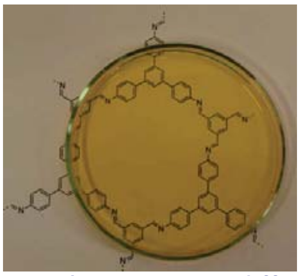


cationic hexadecyltrimethylammonium bromide (CTAB) and anionic sodium dodecyl sulfate (SDS) surfactants

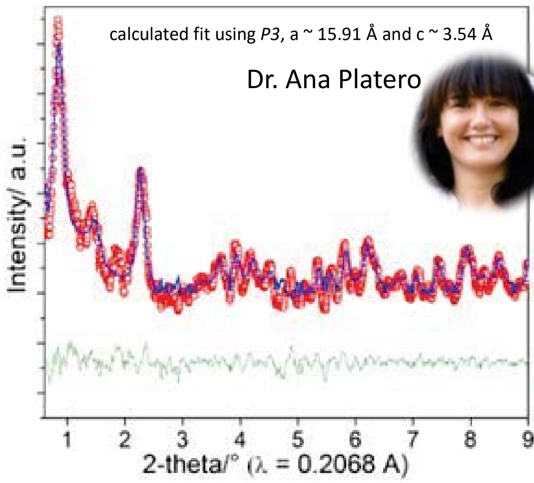


EP18179325.8 / WO2019243602

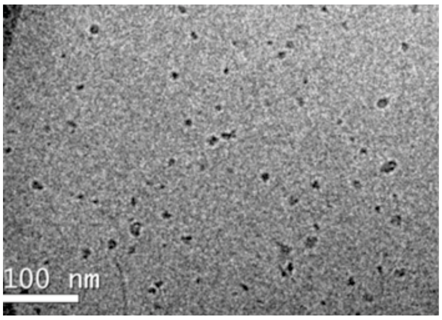
Characterization of TAPB-BTCA COF colloidal sub-20nm particles



Synchrotron X-ray diffraction pattern

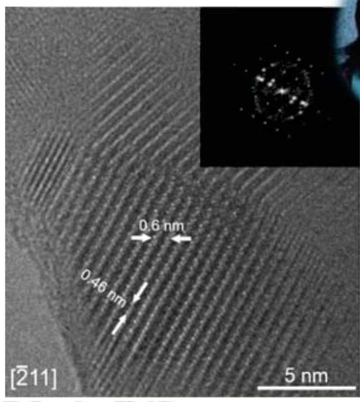


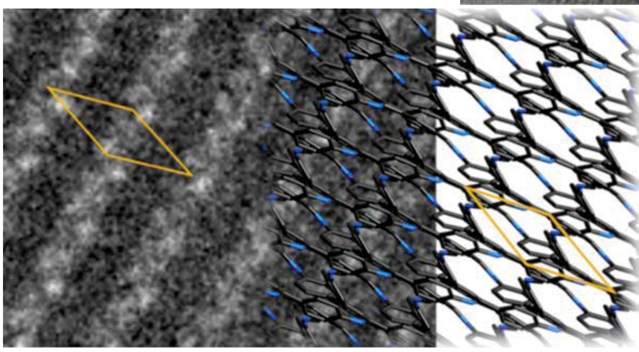
Cryo-TEM



HRTEM

Dr. Luisa Ruiz



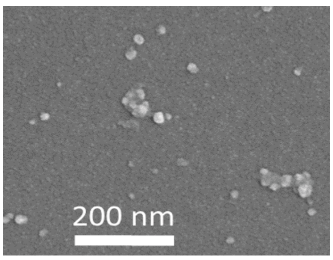


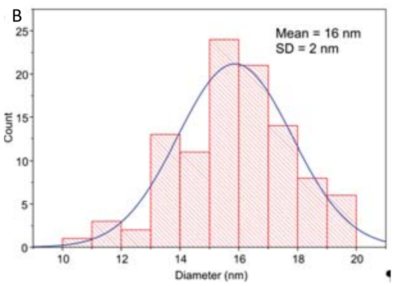
schematic structural model of TAPB-BTCA COF along the [-211] projection

Characterization of TAPB-BTCA COF sub-20nm particles

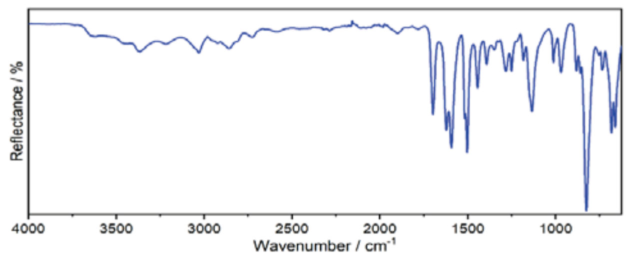
Particles are isolated by centrifugation

SEM

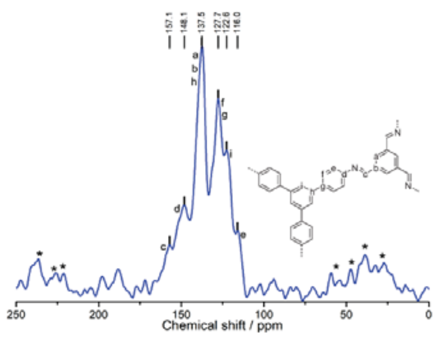




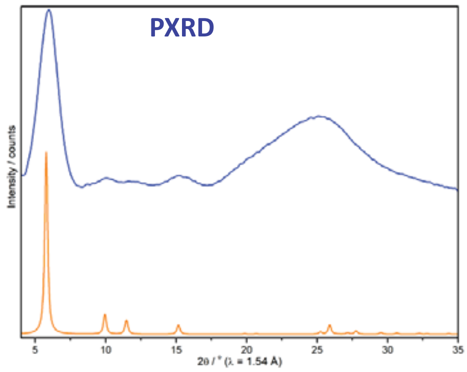
ATR-FT-IR



^{13}C CP-MAS NMR spectrum

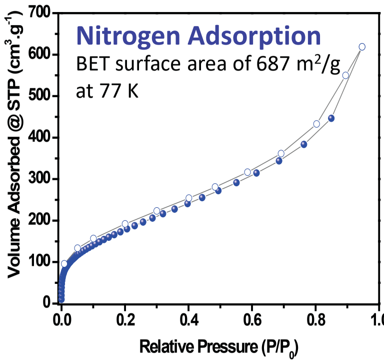


PXRD



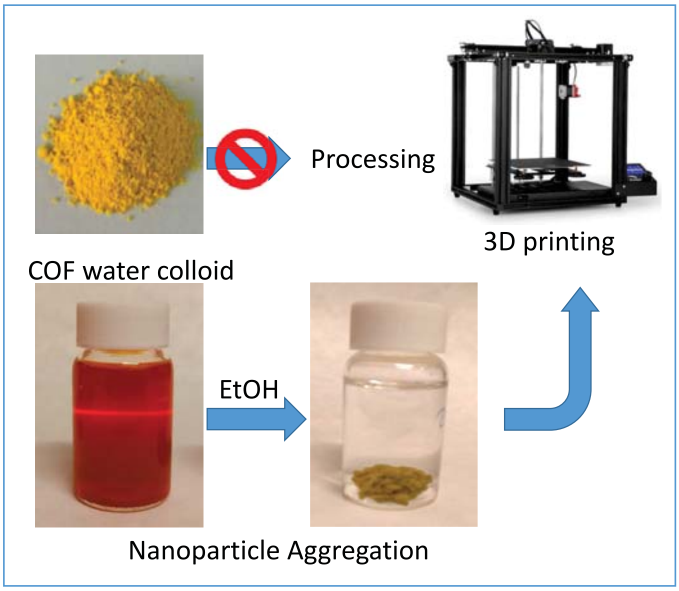
Nitrogen Adsorption

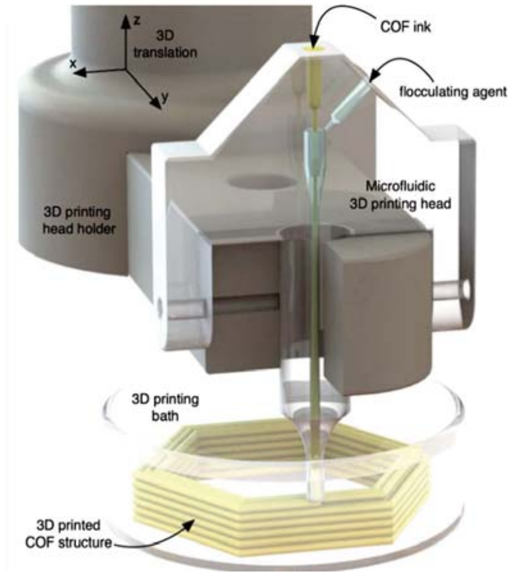
BET surface area of 687 m^2/g at 77 K



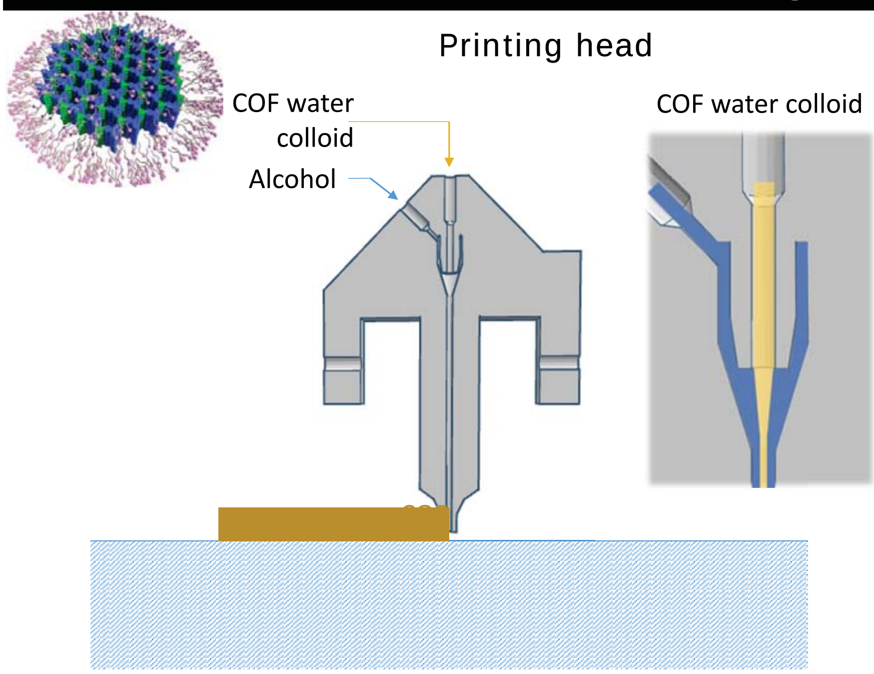
EP18179325.8 / WO2019243602

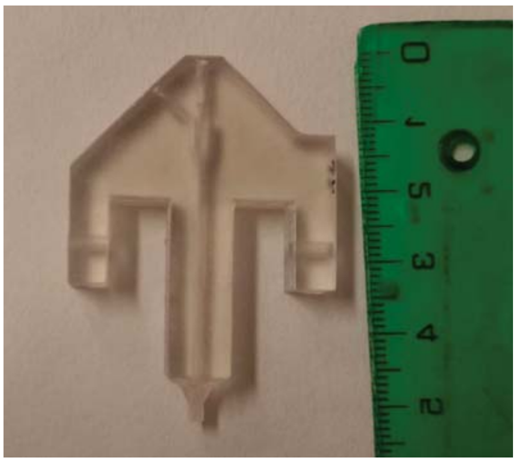
3D Printing of COFs



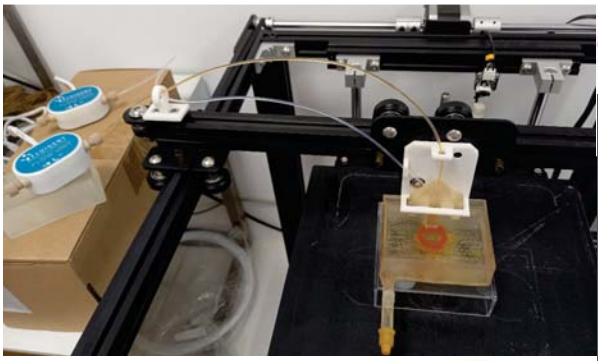


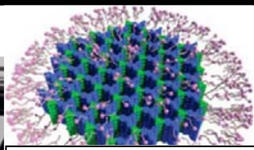
3D Printing of COFs



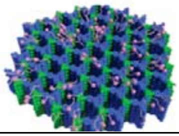


3D Printing of COFs



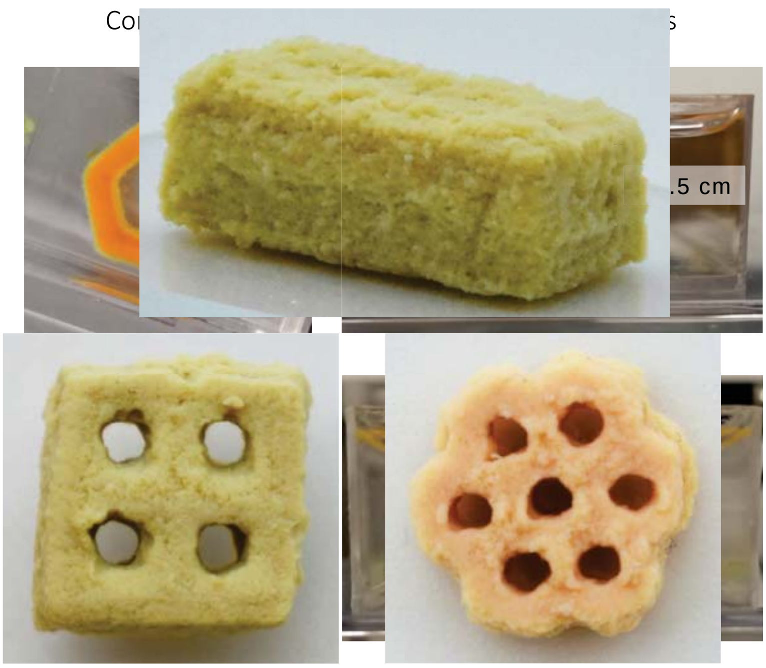


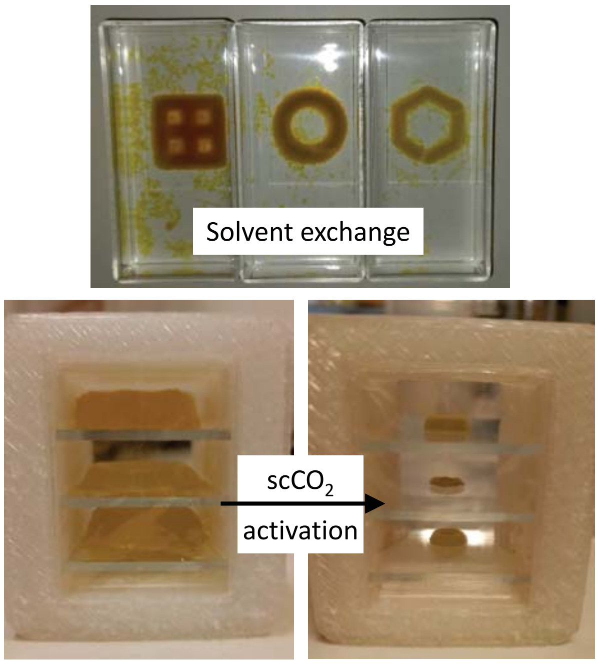
Printing into alcohol for direct surfactant removal



Dr. Sergio Royuela

3D Printing of COFs

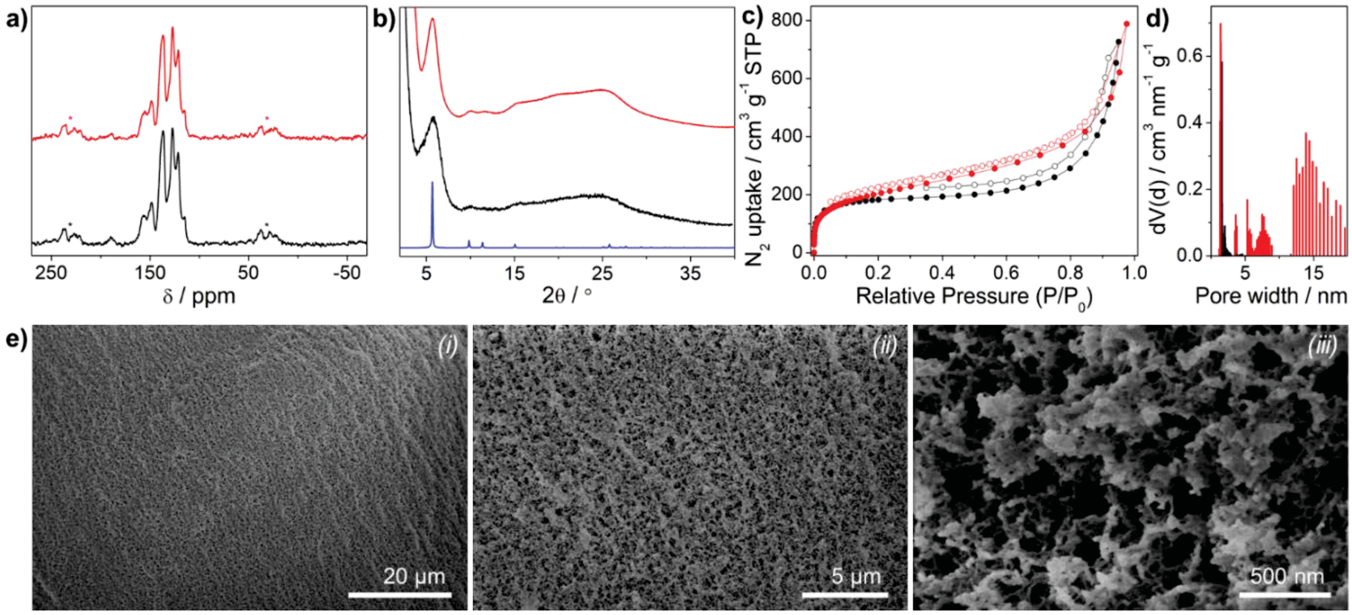




EP18179325.8 / WO2019243602

3D Printing of COFs

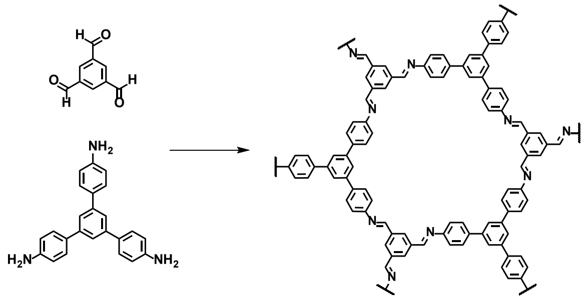
BET Surface Area: 483 m^2/g
Pore volume: 0.918 cm^3/g



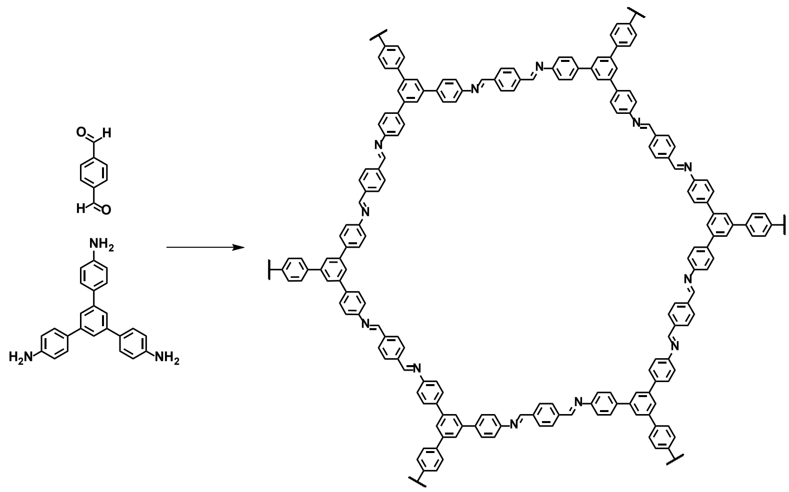
EP18179325.8 / WO2019243602

3D Printing of COFs

BTCA-TAPB-COF (COF-1):



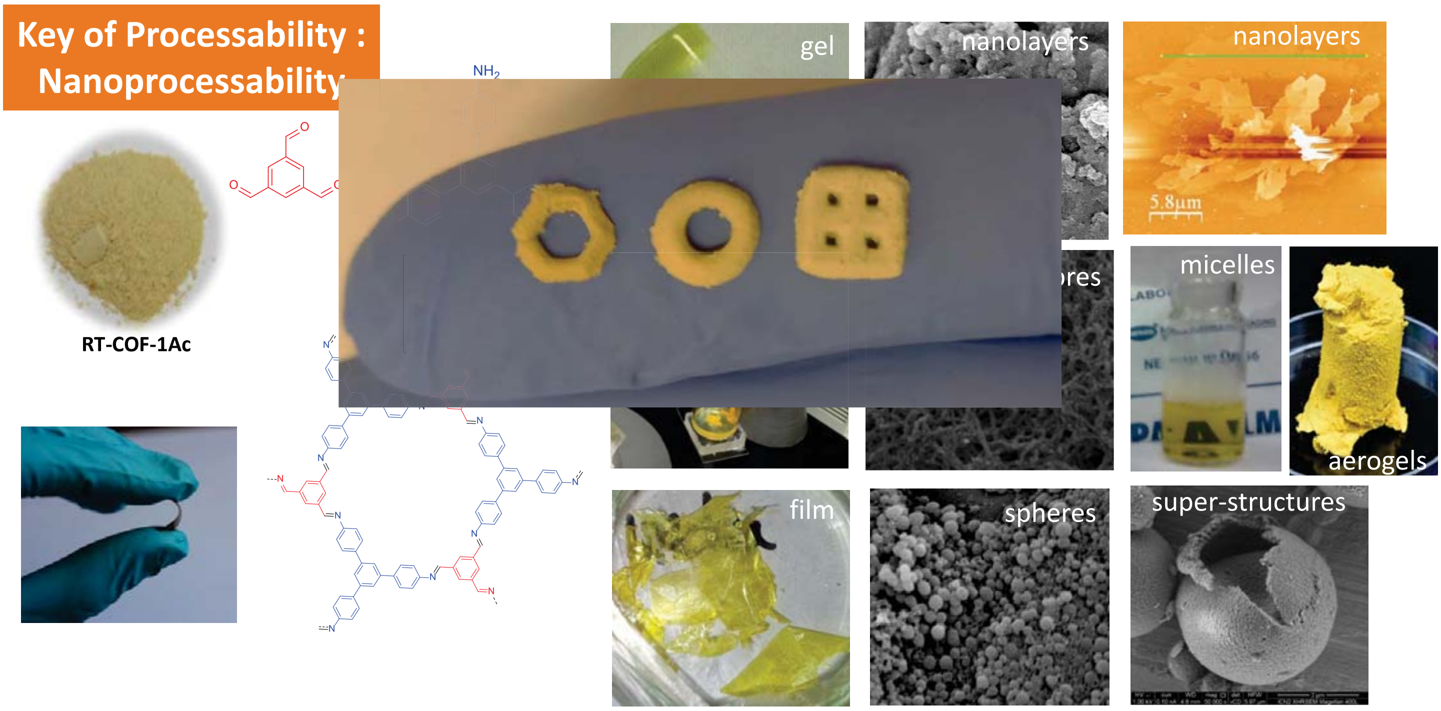
TA-TAPB-COF (COF 3+2):

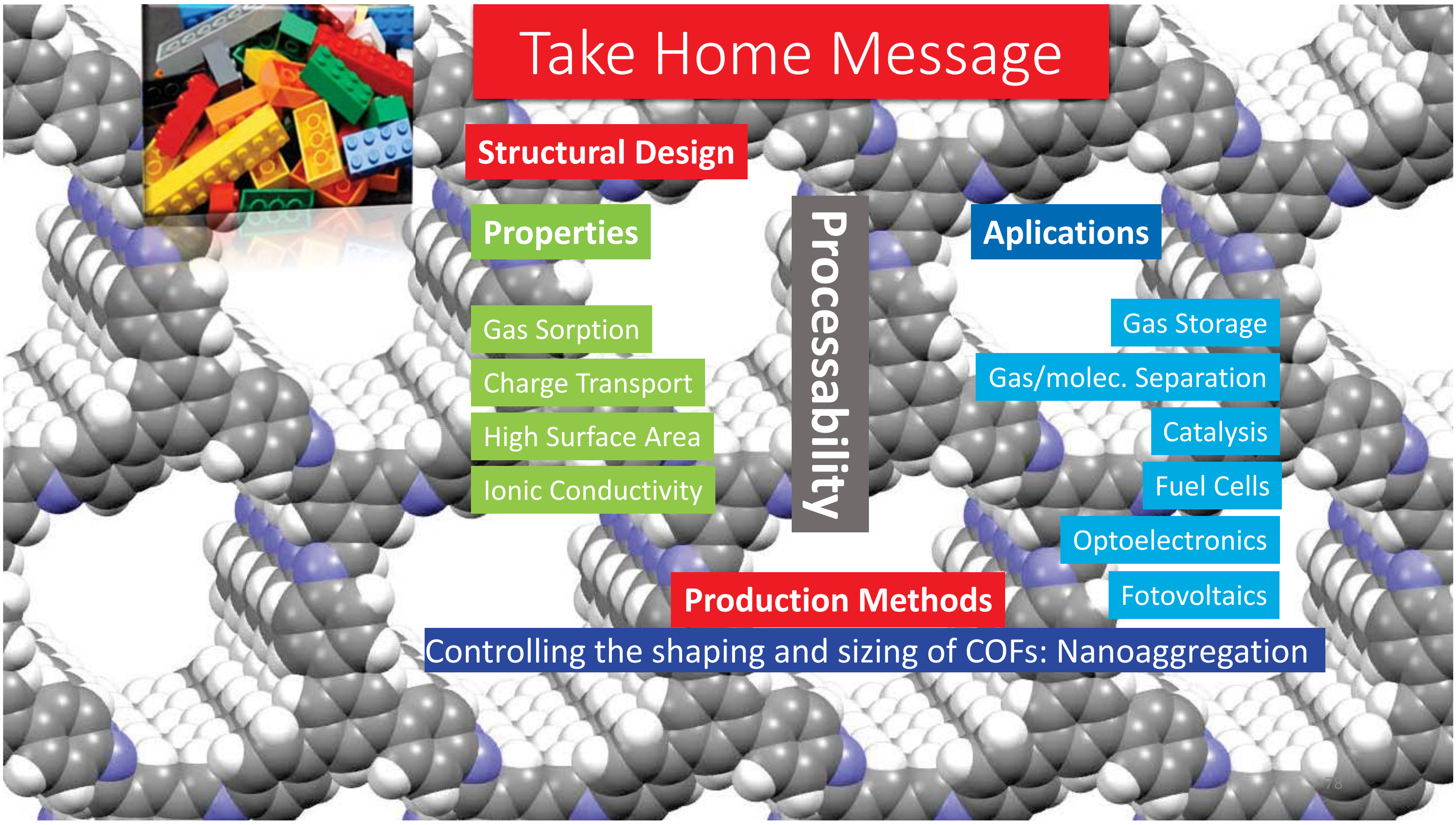


EP18179325.8 / WO2019243602

In Summary: Variety of Morphologies Enlarge Potential Applications of imine-COFs

Key of Processability : Nanoprocessability





Thanks:

Dr. Ana Platero

Prof. Jorge A. Rodriguez

Dr. David Rodriguez

Prof. José L. Segura

Dr. Josep Puig

Prof. D. Maspoch

Dr. Luisa Ruiz

Dr. Carmen Montoro

Dr. Pablo Albacete

Prof. Pilar Ocón

Dr. Alex de la Peña

Prof. Dan Zhao

Prof. K.P. Loh

Jesus A. Martín

nano Materials Lab

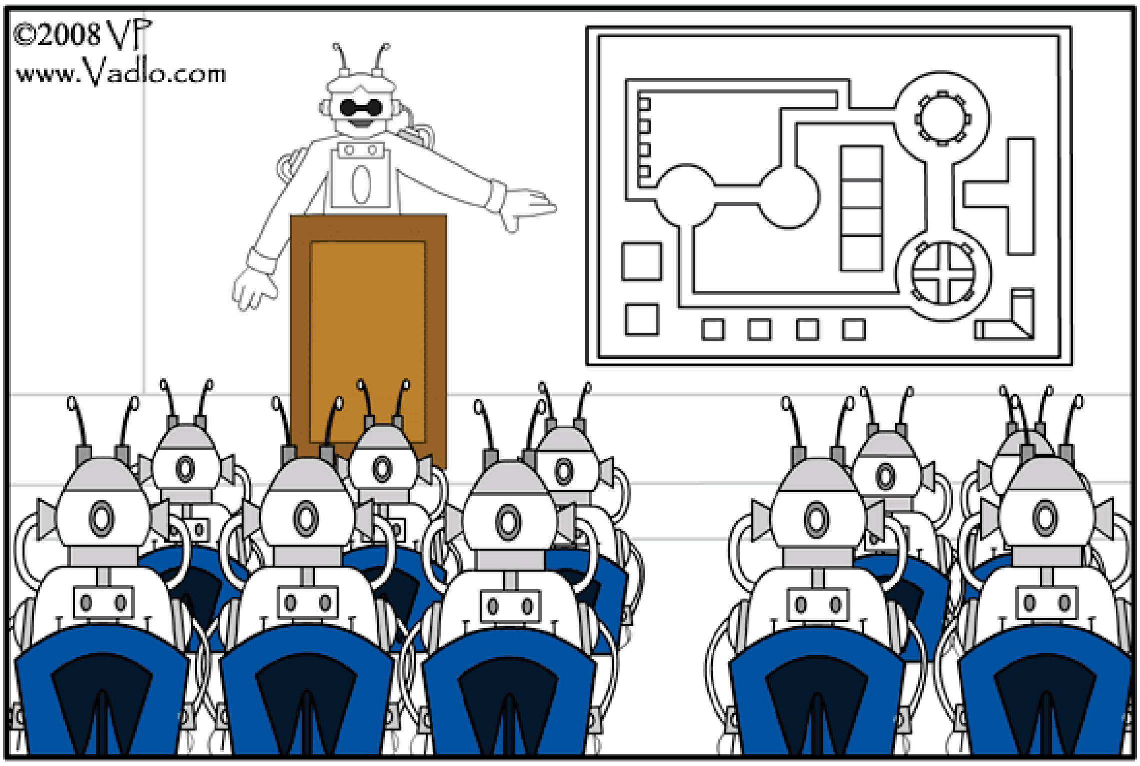
Nanomaterials Group
Dpto. Química Inorgánica
Universidad Autónoma de Madrid
E-mail: felix.zamora@uam.es
http://www.nanomater.es

IFiMaC

IAdChem
Institute for Advanced Research in Chemistry


Thanks for your kind attention !!

ROBOT SEMINARS



As we have just five minutes left, I will take only 3 million questions.

If you want to review this talk :

IFiMaC IAdChem instituto imdea nanociencia

From imine-based covalent organic frameworks design to their processability and applications

Félix Zamora / Química Inorgánica UAM

https://www.youtube.com/watch?v=9AVcVhVlDGU&t=1278s