MSI Journal of
Medicine and Medical Research (MSIJMMR)

Volume: 3, Issue: 2 (May-August 2026)
Published by *MSI Publishers*
ISSN 3049-1401 (Online)

Received: 15-06-2026
Accepted: 18-08-2026
Published: 22-08-2026

Review: Recent Advances in Metal Organic Frameworks Functionalized with Bioinspired Ligands for Selective Catalysis and Sensing

Authors Details

Reham H. Najem[1*]
Presidency of Al-Nahrain University, Al-Nahrain University.

Hind Ibrahim Khaleel[2]
Department of Chemistry, College of Science, University of Baghdad.

Fatimah Abdulsattar Mohammed[3]
Department of scholarships and cultural relations, Ministry of higher education and scientific research.

Corresponding Author: *Reham H. Najem*

ABSTRACT: Metal-organic frameworks (MOFs) is one of the versatile classes of crystalline porous materials owing to their exceptionally high surface areas, tunable pore architecture and flexible metal-ligand chemistry. In recent years, the integration of bioinspired ligands and MOFs' principal design has gained attention as an effective strategy to enhance their selectivity, efficiency and functionality in catalytic and sensing applications. This review provides a comprehensive overview of recent advances in synthesis, functionalization strategies such as defect engineering, post-synthetic modification and composite formation are highlighted as powerful tools for tailoring active sites and improving stability and performance. Furthermore, recent developments in MOF-based sensing platforms are reviewed, illustrating how bioinspired MOfs function as Nanozymes, optical transducers and electrochemical sensors for the selective detection of biomolecules. This review aims to provide valuable insight for the rational design of next generation MOFs materials for sustainable catalysts and advanced sensing technologies.

 DOI: ***10.5281/zenodo.22054167***

Keywords: *Metal-organic framework, Catalysis, Sensing, Bioinspired ligands*

1. Introduction

Since the discovery of metal organic frameworks (MOFs) in 1990, they have become one of the important classes of modern chemistry and material science. MOFs were under the attention of the researchers because of their incredible tunability, highly porous structures and high surface areas [1-4].

The crystalline porous coordination polymers differ in shape and size. The inorganic building blocks like organic ligands and clusters or metal ions link them together. The diversity of these compounds comes from the variety of linkers and clusters, furthermore, the coordination bonds orientations, customizable functions and tunable porosities, making the MOFs highly versatile for variety of applications [1,4-6].

Compared to the classic porous materials such as activated carbons and Zeolites, MOFs have exceptional structural variety and chemical flexibility, which leads to a customized function that are needed for particular technical requirements [7-9].

MOFs were under the interest of researchers' investigations of MOFs use in the gas environment such as real time carbon dioxide (CO2) captured from vehicle emissions or variable emissions from chemical facilities, gas separation, water purification, catalysis, sensing and even biomedical drug delivery [9-12].

It is easier to regulate the characteristics within the pore region of MOFs due to their organized crystalline structure. MOFs can be significantly altered to meet their intended uses by altering the metal ions or organic linkers [13-15].

Over the years, the synthesis methods of MOFs have developed significantly the variety of methods are used to control the size, shape and functionality. The traditional synthesis methods such as hydrothermal and solvothermal, still widely used because of their ability to produce well defined structures with highly crystalline materials. However, an alternative synthesizing method was needed to address the challenges such as, cost efficiency, environmental sustainability and scalability. The alternative methods explored included sonochemistry, electrochemical methods, the URAM process, precipitation methods and microwave assisted synthesis [16-21].

 DOI: *10.5281/zenodo.22054167*

MOFs are now being hybridized with advanced materials such as graphene, carbon nanotubes and covalent organic frameworks (COFs) to create multifunctional systems that combine high selectivity, enhanced mechanical strength and improved charge transport properties [22-25].

Recent progress in the synthesis and functionalization of metal-organic frameworks (MOFs) has been pivotal in overcoming early limitations in stability, processability and applicability.

2. Synthesis and Functionalization

Recent progress in the synthesis and functionalization of metal-organic frameworks (MOFs) has been pivotal in overcoming early limitations in stability, processability and applicability.

Contemporary strategies can be grouped into alternative synthesis routes which enables scalability and greener processing, defect engineering and deliberate non-stoichiometry to create active sites, post-synthetic modification (PSM) techniques to introduce functionality without destroying MOF integrity and lastly formation of composites and MOF-derived materials to enhance mechanical, electrical or chemical properties [26-30].

The traditional synthesis routes of metal-organic frameworks.

2.1. solvothermal/Hydrothermal synthesis

In the low-temperature reaction organic linker and the metal salt are mixed in the solvent and heated in vials. The reaction is called hydrothermal reaction when the solvent used is water, when the solvent used have a higher boiling point it’s called solvothermal synthesis [31].

2.2. Slow Diffusion method

This method to obtain MOF single crystal by mixing the ligand solution and the metal ions in an appropriate ratio to form single crystals over time due to diffusion of two different densities of solvents to form a better quality and larger single crystal [32-33].

DOI: *10.5281/zenodo.22054167*

2.3. Microwave-assisted method

The method is used in preparing an organic and nanoporous inorganic material. The advantages of this method are the low cost, the high yield and the short time required to obtain the product, another advantage to this method is that the microwave facilitate the motion of the molecules leading to the formation of the crystals with the ability to control the shape and size by adjusting the temperature and concentration of the reaction appropriately [34-37].

2.4. Mechanochemical method

This method is based on using mechanical forces instead of solvent at room temperature to form coordination bonds by using the automatic ball mills or less used by manual grinding sometimes to obtain one-dimensional, two-dimensional and three-dimensional coordination polymer by adding a small amount of solvent into the solid mixture of the reaction. This method accelerates the reaction time by facilitating heats, mass transfer, reduces particle size and locally melts the reagent, using this method in synthesizing MOFs have an important advantage being an alternative to the high temperature and pressure solvo/hydrothermal synthesis but its main disadvantage is the isolation of amorphous product, unsuitable for the X-ray structural studies of the single crystal [38-42].

3. Bio-inspired functionalization strategies

Enzymatic catalysis had the attention of the chemists because of the selectivity and high efficiency but due to the vulnerability and structural complexity hampers the potential of enzymes in the application. So, to satisfy the practical demand the researchers began trying to produce enzymes active sites molecular analogue. The concept of artificial enzymes was first promoted by Breslow and Overman, but the fruitful results and mimicking enzymes were achieved by researchers such as Groves, Gray, Lippard, Rauchfuss, Darensboug and Halm [43-48]. Figure 1 illustrates the design of metalloenzyme-inspired active sites inside MOFs.

 DOI: *10.5281/zenodo.22054167*

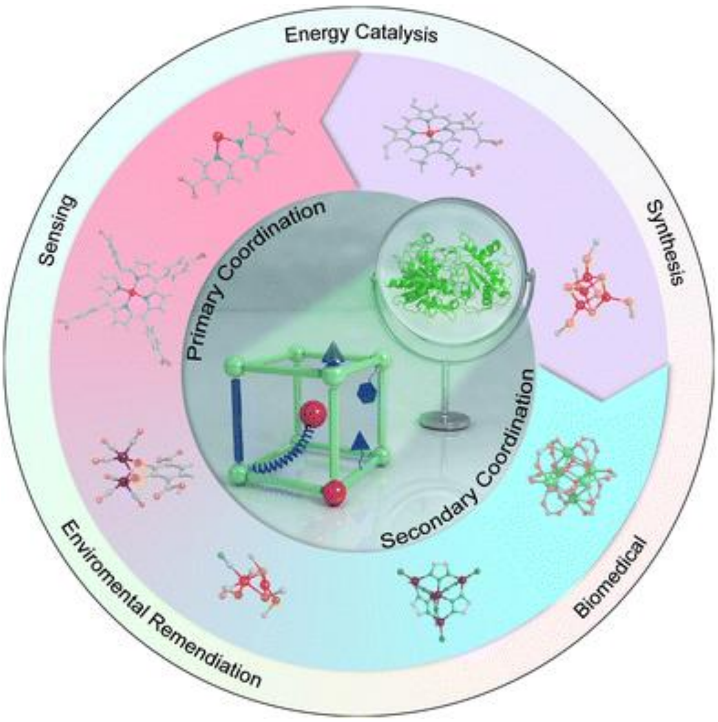

Figure 1: Design of metalloenzyme-inspired active sites inside MOFs for diverse catalytic applications at the atomic level [44].

3.1 Bioinspired metal active site design

Metalloenzymes in nature rely heavily on metal cofactors to drive the chemical reactions required for life. Each enzymes' metal ion supports a distinct function and involvements in catalysis and the result of natural selection. Monometallic sites like heme-containing oxygenase and Zn-OH center of metallohydrolase and multi-metallic clusters like multicopper oxidases, Fe4S4, FeMo nitrogenase, Ni-Fe and Fe-Fe hydrogenase, make up the majority of metal cofactors among all metalloenzymes [49-50].

MOFs have the ability to mimic the catalytic sites vividly at the atomic scale due to the diversity and spatially isolated metal ions. Secondary building units (SBUs) and organic linkers are the focus two main buildings in the construction of enzyme like active pockets MOFs [49].

Various metal classes and ligands such as TCPP, Imidazole, thiolate, enable biomimetic MOFs to accurately replicate the metal coordination structures of metalloenzymes [49-51].

3.2 Alternative Synthesis Routes – Scale, Speed and Sustainability

Cambridge crystallographic data Centre (CCDC) has more than 12500 MOF structures reported. Some of these structures demonstrate highly promising outcomes in variety of

 DOI: ***10.5281/zenodo.22054167***

applications including Biomedicine, catalysis, water harvesting, Carbon capture and hydrogen storage [54-55].

Optimized protocols were developed in order to produce higher yields of metal-organic frameworks (MOFs) in laboratory pilot scale (kilogram scale) instead of laboratory scale (gram scale). Different parameters such as the type and speed of mixing, mass, the type of reactions, heat transfer and reactors are important for the pilot scale production process [56-61].

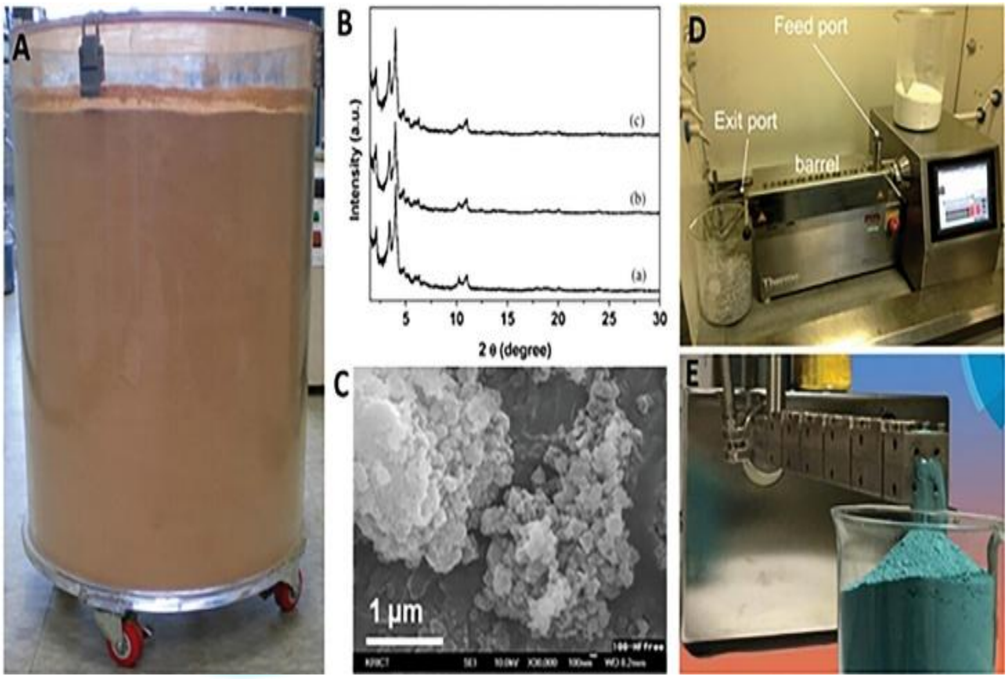

Figure 2: A. poly (methyl methacrylate) transparent box B. PXRD pattern a) before exposure to boiling water b) after 3 days of exposure c) 5 days [62] C. SEM image of MIL-100(Fe) D. twin-screw extruder showing the different parts. E. MOF production using the screw extruder [64]. Reproduced with permission [62, 64]. Copyright 2023. Elsevier.

A large-scale synthesis of MOF was explored, since the reporting of the mechanochemical synthesis of porous MOF Cu $(INA)_2$. Ball milling preparing the MOF was in scale less than 1g [62,64-66]. Figure 3

Green and bio-inspired synthesis- using water, benign solvents, biomass-derived linkers or room-temperature conditions has expanded producing (Bio-MOFs) and frameworks with lower environmental footprints. The movement toward greener synthesis seeks to couple material performance with lifecycle sustainability.

 DOI: *10.5281/zenodo.22054167*

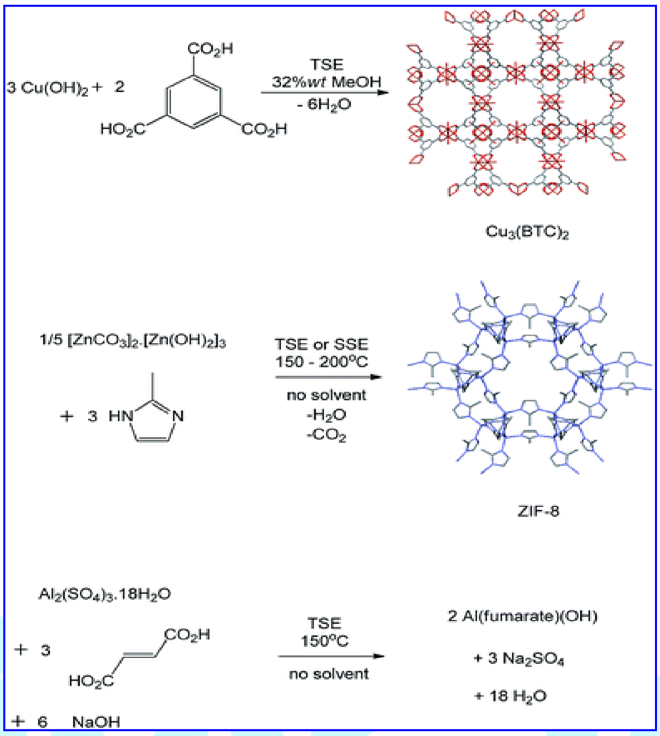

Figure 3: illustrating scheme of MOF $Cu_3(BTC)_2$(HKUST-1), Zn(methylimidazolate)$_2$(ZIF-8) synthesis reaction by TSE or SSE and Al(fumarate)(OH) [52].

3.3 Green methodologies for MOF synthesis

The green chemistry's 12 principles can be adapted in MOF synthesis process. MOF can be synthesized by the basis of the green methodologies standard aspects such as **(a)** safe reaction media (such as water and supercritical solvents), **(b)** biocompatible building blocks, **(c)** continuous production approaches **(d)** reduced energy input and **(e)** performance design of MOFs through theoretical predictions [67-70]. Green and bio-inspired synthesis- using water, benign solvents, biomass-derived linkers or room-temperature conditions has expanded producing (Bio-MOFs) and frameworks with lower environmental footprints. The movement toward greener synthesis seeks to couple material performance with lifecycle sustainability.

a. Solvent-based synthesis: an integral step in synthesizing MOFs is selecting the solvent since its important role in regulating the coordination environment formation. Solvent can take a part in the coordination process by coordinating with metal ions as well as being structure-directing agent [69,71]. Using water as solvent resulted in the discovery of anew

 DOI: 10.5281/zenodo.22054167

variety of archetype MOFs, such as MOF-74, CaU-22(Zn) and MIL-91(Ti), yet some MOFs are water-sensitive especially those containing carboxylate group such as $Cu_3(BTC)_2$ and Mg-MOF74 [69,72-74].

Due to the sensitivity of these MOFs the existence of water might result in crystallinity loss, structural decomposition and phase changes. However, UiO-66 (carboxylate containing MOF) has water stability due to several stereotypes and chemical factors. The use of water in the process would offer lower environmental impacts would be welcomed by the industry. The eco-friendly MOFs that lead the way in the direction of using MOFs in toxic adsorption from the gaseous or aqueous systems [74-78].

3.4 Defect Engineering of MOFs

This process in the synthesis of MOFs opens an avenue in terms of their physical properties such as conductance and mechanical response. Also, it provides new opportunities in the catalysis and adsorption fields [29].

Some incredible characteristics are obtained by the defects of the metal-organic frameworks. Since in MOFs these defects might have extremely subtle effects on them, the enhancement of MOFs both functional and structural can be obtained by certain degree of defects [79-81].

A change of properties might be accompanied by structural defects due to the electron localization, lattice distortion, fracture and recombination of the chemical bonds. These defects provide a potential active site because some of the atoms in MOFs crystals become unsaturated due to the defect's existence. [82-84]

Defect engineering is utilizing MOFs crystals already existence defects are considered a treasure for the enhancement of MOFs performance for potential applications [26].

3.5 Post-synthetic modification methods (PSM)

PSM is a chemical modification of linkers, grafting of functional moieties or exchange/metalation of secondary building units after framework assembly remains a powerful route to introduce catalytic sites, chelators, polymer brushes or sensing groups [85-87].

DOI: ***10.5281/zenodo.22054167***

Post-synthetic modification is under the interest of many researchers for providing a solution for the unpredictable product [87,88].

PSM is utilized in synthesizing new scaffolds with enhanced properties when compared to the original frameworks. The aspect of PSM lies in the fact that the enhanced MOFs cannot be obtained by the classic synthesis methods [89-91].

By changing the chemical composition of MOFs, they gain new physical and chemical properties leading to the expansion of the applications of MOFs. [92-94].

PSM yields MOFs optimized for CO_2 chemisorption, selective separations or anchoring of catalytic nanoparticles, PSM also underpins membrane functionalization for molecular separation [95-97].

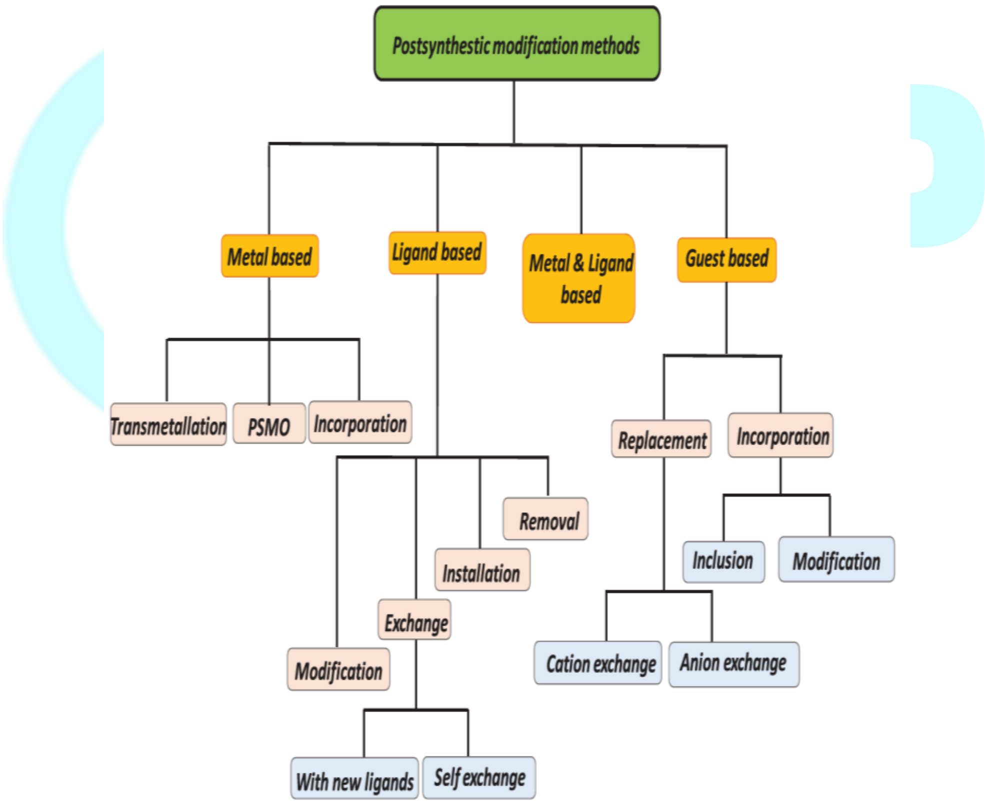

Figure 4: Photosynthetic modification methods

3.6 Composites, hybridization and MOF-derived materials

Combining MOFs with carbon materials such as graphene, carbon nanotubes (CNTs), activated carbons, polymers, nanocellulose or inorganic supports typically improves conductivity, mechanical robustness and processability [24, 98].

 DOI: *10.5281/zenodo.22054167*

MOFs-derived carbons which obtained via controlled pyrolysis have the ability to preserve hierarchical porosity and embed catalytically active metal species producing highly active electrocatalysis and adsorption media [99-101].

4. Bio-inspired selective catalysis and sensing functions

MOFs have the ability to act as biosensors and enzyme mimics (nano-enzymes) due to its bioinspired functionalization. For example, Cu- and Fe- based MOFs with histidine- or catechol derived linkers catalyze oxidation and peroxidation reactions similar to natural enzymes, offering enhanced durability compared to proteins [102,103].

Redox transformation by mimicking cofactor-dependent enzymes is led by the hybrid frameworks which contain either porphyrin-like or flavin-like linkers. In biosensing, coordination sites and biomimetic ligands platforms provided by the bioinspired MOFs are utilized for the selective detection of dopamine, Glucose and nucleic acids through specific recognition [104-106].

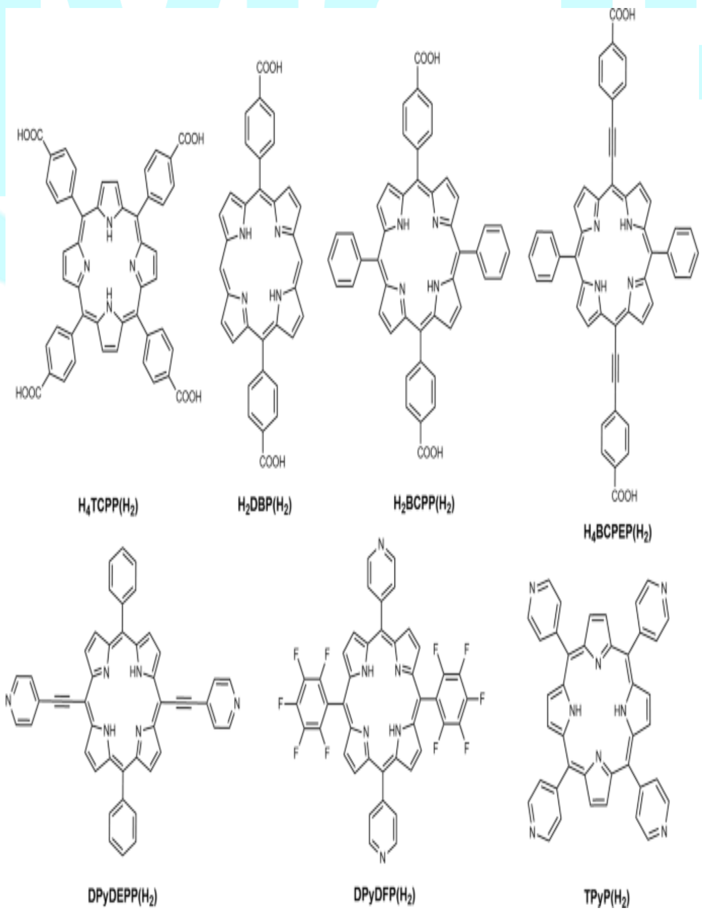

Figure 5: porphyrin derived MOF linkers [105]

 DOI: ***10.5281/zenodo.22054167***

4.1 Selective catalytic function

In the past two decades MOFs went through considerable effort in order to regulate its pore size/shape and porosity by optimizing the structures and components, which is conductive not only the realization of the size-selective catalysis but also, the molecules diffusion. Some researchers made modifications on order to defect the MOFs catalysis and control their size/morphologies by adding modifiers into the precursors [107-111].

- **Metal coordination mimicry**

Ligands featuring histidine, cysteine or carboxylate groups reproduce the coordination geometry of metalloproteins enabling redox reactions with high turnover rates [112,113].

- **Microenvironmental control**

Hydrophilic and hydrophobic patches around the catalytic site regulate substrate access and transition-state stabilization, leading to substrate-specific catalysis [114].

- **Cofactor-inspired reactivity**

Incorporating porphyrin-, flavin- or nicotinamide-like fragments reproduces enzymatic redox cycles, crucial for selective oxidation and reduction reactions [115].

- **Hydrogen bonding and π-π interaction**

Bioinspired linkers often utilize non-covalent interactions to control substrate orientation, reducing undesired side reactions [116].

a) Bioinspired MOFs for selective oxidation reactions

Selective oxidation is one of the most significant applications of bioinspired MOFs

Fe- and Cu-based MOFs functionalized with catechol or histidine ligands exhibit high activity in selective hydroxylation of phenols and alkanes, mimicking tyrosinase and methane monooxygenases enzymes [117].

Mn-porphyrins MOFs have shown remarkable selectivity for epoxidation of olefins avoiding overoxidation due to the enzyme-like confinement effects [118,119].

 DOI: 10.5281/zenodo.22054167

Incorporation of biotinylated linkers enables site-specific anchoring of substrates, enhancing product specificity [119].

b) Selective reduction and hydrogenation

Bioinspired ligands also enable controlled reduction and hydrogenation reactions. Nickel and cobalt based MOFs containing amino acid or imidazole-derived ligands mimic hydrogenases active sites, showing selective CO2-to-CO or formate conversion with minimal H2 evolution [112, 117,119].

The incorporation of nicotinamide-like ligands provides hydride transfer capability akin to NADH, promoting mild and selective reduction of carbonyl compounds [16, 51, 58].

Peptide-functionalized MOFs provide chiral environments, achieving enantioselective hydrogenation of prochiral ketones and alkenes [120].

c) Enantioselective and regioselective transformations

The incorporation of chiral, bioinspired ligands has enabled MOFs to perform reactions previously limited to enzymes or homogeneous catalysts.

According to He et al., the amino acid-modified Zr-MOFs catalyze asymmetric aldol and Diels-Alder reactions with enantiomeric excesses exceeding 95%. While the DNA- and peptide-grafted MOFs exhibit substrate-shape recognition through hydrogen bonding, producing regioselective transformations in carbon-carbon coupling [121].

Biomimetic pocket engineering, where bulky side groups create substrate channels, has enhanced regioselectivity in oxidation of long-chain hydrocarbons [122].

4.2 Sensing function of MOFs

The integration of bioinspired design principles into metal-organic frameworks (MOFs) has opened a transformative pathway for developing next-generation chemical and biological sensors. MOFs- renewed for their exceptionally high surface area, tunable porosity and customizable metal-ligand chemistry offer an ideal scaffold for the selective detection of small molecules, ions and biomacromolecules. However, conventional MOFs,

 DOI: ***10.5281/zenodo.22054167***

while structurally versatile, often lack the molecular recognition capability required for precise sensing in complex biological or environmental systems [7,102, 112]

Recent advances demonstrate that bioinspired MOFs can act as nano-enzymes, optical transducers and electrochemical sensors capable of detecting a broad spectrum of targets from toxic gases and metal ions to glucose, dopamine and nucleic acid with high selectivity and sensitivity [114, 122].

The intrinsic catalytic sites often mimicking metalloenzymes such as peroxidase or oxidase provide signal amplification mechanism that allow for low detection limits even in complex samples. Furthermore, the incorporation of bioligands such as amino acids, peptides, cofactors and DNA fragments, endows MOFs with biocompatibility enabling their application in biosensing and medical diagnostics [49, 86]

Affinity-based recognition grafting peptides, aptamers, antibodies or small bioactive ligands to MOF surfaces introduces highly selective binding pockets for target analytes such as proteins, nucleic acids and small metabolites. Peptide-functionalized ZIF or UiO derivatives have been used as signal amplifying tags in immunoassays [120].

Nanozyme catalytic amplification MOFs bearing bioinspired ligands like catechol, histidine, porphyrin analogues or encapsulated metal centers act as enzyme mimics such as peroxidase/oxidase-like, catalyzing colorimetric or electrochemical signal generation and thus enabling low-concentration detection of H_2O_2, glucose, and other analytes [53,122].

Photoelectrochemical / luminescent transduction porphyrin and flavin like ligands or fluorophore tagged bioligands create MOFs with tailored light absorption / emission that change upon guest binding such optical shifts are used for ratiometric or turn-on sensing of metal ions, volatile organics and biomolecules [123].

Electrochemical sensing (conductive composites) bioinspired MOFs combined with conductive carbon, MXenes or noble-metal nanoparticles yield sensitive electrochemical sensors for neurotransmitters and metabolites in complex matrices (blood, sweat). Integration into flexible/wearable devices has been demonstrated for health monitoring [124].

 DOI: ***10.5281/zenodo.22054167***

Mass-based (QCM) and microcantilever sensing immobilizing selective bioligands on MOF-coated QCM chips yields high mass sensitivity and improved selectivity for small molecules and proteins by exploiting the porous uptake of the MOF and the ligand's affinity.

The advantages of bioinspired MOF sensors are improved selectivity through biomolecular recognition elements, Dual function recognition and amplification combining affinity ligands with nanozyme activity or optical reporters in the same MOF gives built-in signal amplification. Also, stability and protection encapsulation or immobilization within MOFs protects fragile biomolecules like enzymes and aptamers from denaturation and matrix interference.

5 Conclusion

Metal organic framework is considered a platform for bridging the gap between the synthetic materials and biological systems by integrating enzyme mimicking metal sites, and multi-functionality that were limited previously to the homogeneous and natural enzyme. In this review we highlighted the advances in MOF significant expansion in the structural diversity and practical applicability of bioinspired MOFs.

The bioinspired MOFs demonstrated an exaptational potential in chemical and biological sensing; their molecular recognition and signal amplification capability allows for the sensitive and selective detection in complex environments.

Despite these advances, challenges remain in achieving long-term stability under operational conditions, precise control over defect populations and large-scale industrial implementation.

Future research efforts should focus on rational active-site engineering, integration of computational design tools and development of sustainable, cost-effective production routes. With continued interdisciplinary collaboration, bioinspired MOFs are expected to play a pivotal role in the development in next-generation catalysts and sensors for environmental, industrial and biomedical applications.

Conflicts of Interest: "The authors declare no conflict of interest."

 DOI: ***10.5281/zenodo.22054167***

References

1. Zohra Zeggai F, Ait-Touchente Z, Bachari K, Elaissari A. Investigation of Metal-Organic Frameworks (MOFs): Synthesis, Properties, and Applications-An In-Depth Review. Chemical Physics Impact. 2025 Mar 16:100864. https://doi.org/10.1016/j.chphi.2025.100864
2. Gagliardi L, Yaghi OM. Three future directions for metal–organic frameworks. Chemistry of Materials. 2023 Aug 8;35(15):5711-2. https://doi.org/10.1021/acs
3. Hu Z, Wang Y, Zhao D. The chemistry and applications of hafnium and cerium (IV) metal–organic frameworks. Chemical Society Reviews. 2021;50(7):4629-83. https://doi.org/10.1039/D0CS00920B
4. Jiao L, Seow JY, Skinner WS, Wang ZU, Jiang HL. Metal–organic frameworks: Structures and functional applications. Materials Today. 2019 Jul 1;27:43-68. https://doi.org/10.1016/j.mattod.2018.10.038
5. Jin CT, Civalleri B. Metal–organic frameworks and hybrid materials: from fundamentals to applications. CrystEngComm. 2015;17:197-8., https://doi.org/10.1039/C4CE90162B.
6. Peedikakkal AM, Adarsh NN. Porous coordination polymers. InFunctional polymers 2019 (pp. 181-223). Springer, Cham. https://doi.org/10.1007/978-3-319-92067-2_5-1
7. Li N, Pang J, Lang F, Bu XH. Flexible metal–organic frameworks: from local structural design to functional realization. Accounts of Chemical Research. 2024 Aug 8;57(16):2279-92. https://doi.org/10.1021/acs.accounts.4c00253.
8. He T, Kong XJ, Li JR. Chemically stable metal–organic frameworks: rational construction and application expansion. Accounts of chemical research. 2021 Jul 14;54(15):3083-94. https://doi.org/10.1021/acs.accounts.1c00280.
9. Mouctar MH, Hassan MG, Bimbo N, Abbas SZ, Shigidi I. Comparative assessment and deployment of zeolites, MOFs, and activated carbons for CO2 capture and geological sequestration applications. Inventions. 2025 Aug 28;10(5):78. https://doi.org/10.3390/inventions10050078.
10. Mahajan S, Lahtinen M. Recent progress in metal-organic frameworks (MOFs) for CO2 capture at different pressures. Journal of Environmental Chemical Engineering. 2022 Dec 1;10(6):108930. https://doi.org/10.1016/j.jece.2022.108930.

 DOI: ***10.5281/zenodo.22054167***

11. Li D, Yadav A, Zhou H, Roy K, Thanasekaran P, Lee C. Advances and applications of metal-organic frameworks (MOFs) in emerging technologies: a comprehensive review. Global Challenges. 2024 Feb;8(2):2300244. https://doi.org/10.1002/gch2.202300244.
12. Ahmad K, Oh TH. Recent Progress in MOFs and MOF-Derived Materials for Gas Sensing Applications. Chemosensors. 2025 Mar 9;13(3):100. https://doi.org/10.3390/chemosensors13030100.
13. Teo WL, Zhou W, Qian C, Zhao Y. Industrializing metal–organic frameworks: Scalable synthetic means and their transformation into functional materials. Materials Today. 2021 Jul 1;47:170-86. https://doi.org/10.1016/j.mattod.2021.01.010.
14. Teo WL. Towards industrializing metal-organic frameworks: scalable synthetic means and their transformation into functional textile materials. https://doi.org/10.32657/10356/153504.
15. Zhang W, Taheri-Ledari R, Saeidirad M, Qazi FS, Kashtiaray A, Ganjali F, Tian Y, Maleki A. Regulation of porosity in MOFs: a review on tunable scaffolds and related effects and advances in different applications. Journal of Environmental Chemical Engineering. 2022 Dec 1;10(6):108836. https://doi.org/10.1016/j.jece.2022.108836.
16. Zhang C, Lu K, Li L, Lei W, Xia M, Wang F. A water-stabilized Tb-MOF can be used as a sensitive and selective fluorescence sensor for the detection of oxytetracycline hydrochloride. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2024 Jan 5;304:123379. https://doi.org/10.1016/j.saa.2023.123379.
17. Chen W, Du L, Wu C. Hydrothermal synthesis of MOFs. InMetal-organic frameworks for biomedical applications 2020 Jan 1 (pp. 141-157). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-816984-1.00009-3.
18. Ghoorchian A, Afkhami A, Madrakian T, Ahmadi M. Electrochemical synthesis of MOFs. InMetal-organic frameworks for biomedical applications 2020 Jan 1 (pp. 177-195). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-816984-1.00011-1.

 DOI: ***10.5281/zenodo.22054167***

19. Akhavan-Sigari R, Zeraati M, Moghaddam-Manesh M, Kazemzadeh P, Hosseinzadegan S, Chauhan NP, Sargazi G. Porous Cu-MOF nanostructures with anticancer properties prepared by a controllable ultrasound-assisted reverse micelle synthesis of Cu-MOF. BMC chemistry. 2022 Mar 5;16(1):10. https://doi.org/10.1186/s13065-022-00804-2.
20. Jhung SH, Lee JH, Forster PM, Férey G, Cheetham AK, Chang JS. Microwave Synthesis of hybrid inorganic–organic porous materials: phase-selective and rapid crystallization. Chemistry–A European Journal. 2006 Oct 16;12(30):7899-905. https://doi.org/10.1002/chem.200600270.
21. Li X, Wu Z, Tao X, Li R, Tian D, Liu X. Gentle one-step co-precipitation to synthesize bimetallic CoCu-MOF immobilized laccase for boosting enzyme stability and Congo red removal. Journal of Hazardous Materials. 2022 Sep 15;438:129525. https://doi.org/10.1016/j.jhazmat.2022.129525.
22. Guo C, Duan F, Zhang S, He L, Wang M, Chen J, Zhang J, Jia Q, Zhang Z, Du M. Heterostructured hybrids of metal–organic frameworks (MOFs) and covalent–organic frameworks (COFs). Journal of Materials Chemistry A. 2022;10(2):475-507. https://doi.org/10.1039/D1TA06006F.
23. Nazir MA, Javed MS, Islam M, Assiri MA, Hassan AM, Jamshaid M, Najam T, Shah SS, ur Rehman A. MOF@ graphene nanocomposites for energy and environment applications. Composites communications. 2024 Jan 1;45:101783. https://doi.org/10.1016/j.coco.2023.101783
24. Jayaramulu K, Mukherjee S, Morales DM, Dubal DP, Nanjundan AK, Schneemann A, Masa J, Kment S, Schuhmann W, Otyepka M, Zboril R. Graphene-based metal–organic framework hybrids for applications in catalysis, environmental, and energy technologies. Chemical reviews. 2022 Nov 1;122(24):17241-338. https://doi.org/10.1021/acs.chemrev.2c00270.
25. Naser SA, Badmus KO, Khotseng L. Synthesis, properties, and applications of metal organic frameworks supported on graphene oxide. Coatings. 2023 Aug 18;13(8):1456. https://doi.org/10.3390/coatings13081456.
26. Rajesh RU, Mathew T, Kumar H, Singhal A, Thomas L. Metal-organic frameworks: Recent advances in synthesis strategies and applications. Inorganic

 DOI: ***10.5281/zenodo.22054167***

Chemistry Communications. 2024 Apr 1;162:112223. https://doi.org/10.1016/j.inoche.2024.112223.

27. Kalaj M, Cohen SM. Postsynthetic modification: an enabling technology for the advancement of metal–organic frameworks. ACS central science. 2020 Jul 2;6(7):1046-57. https://doi.org/10.1021/acscentsci.0c00690.

28. Schertenleib T, Karve VV, Stoian D, Asgari M, Trukhina O, Oveisi E, Mensi M, Queen WL. A post-synthetic modification strategy for enhancing Pt adsorption efficiency in MOF/polymer composites. Chemical Science. 2024;15(22):8323-33. https://doi.org/10.1039/D4SC00174E.

29. Qiu X, Wang R. From construction strategies to applications: Multifunctional defective metal-organic frameworks. Coordination Chemistry Reviews. 2025 Mar 1;526:216356. https://doi.org/10.1016/j.ccr.2024.216356.

30. Kalaj M, Cohen SM. Postsynthetic modification: an enabling technology for the advancement of metal–organic frameworks. ACS central science. 2020 Jul 2;6(7):1046-57. https://doi.org/10.1021/acscentsci.0c00690.

31. Biswas A. Metal Organic Frameworks (MOFs): An Overview of Synthesis Methods. https://doi.org/10.31674/book.2024scibe.011.

32. Raptopoulou CP. Metal-organic frameworks: synthetic methods and potential applications. Materials. 2021 Jan 9;14(2):310. https://doi.org/10.3390/ma14020310.

33. Halper SR, Do L, Stork JR, Cohen SM. Topological control in heterometallic metal− organic frameworks by anion templating and metalloligand design. Journal of the American Chemical Society. 2006 Nov 29;128(47):15255-68. https://doi.org/10.1021/ja0645483.

34. Hu Y, Liu C, Zhang Y, Ren N, Tang Y. Microwave-assisted hydrothermal synthesis of nanozeolites with controllable size. Microporous and Mesoporous Materials. 2009 Mar 1;119(1-3):306-14. https://doi.org/10.1016/j.micromeso.2008.11.005.

35. Klinowski J, Paz FA, Silva P, Rocha J. Microwave-assisted synthesis of metal–organic frameworks. Dalton Transactions. 2011;40(2):321-30. https://doi.org/10.1039/C0DT00708K.

 DOI: ***10.5281/zenodo.22054167***

36. Lin ZJ, Yang Z, Liu TF, Huang YB, Cao R. Microwave-assisted synthesis of a series of lanthanide metal–organic frameworks and gas sorption properties. Inorganic Chemistry. 2012 Feb 6;51(3):1813-20. https://doi.org/10.1021/ic202082w.
37. Seo YK, Hundal G, Jang IT, Hwang YK, Jun CH, Chang JS. Microwave synthesis of hybrid inorganic–organic materials including porous Cu3 (BTC) 2 from Cu (II)-trimesate mixture. Microporous and Mesoporous Materials. 2009 Mar 1;119(1-3):331-7. https://doi.org/10.1016/j.micromeso.2008.10.035.
38. Friščić T, Halasz I, Beldon PJ, Belenguer AM, Adams F, Kimber SA, Honkimäki V, Dinnebier RE. Real-time and in situ monitoring of mechanochemical milling reactions. Nature chemistry. 2013 Jan;5(1):66-73. https://doi.org/10.1038/nchem.1505.
39. Garay AL, Pichon A, James SL. Solvent-free synthesis of metal complexes. Chemical Society Reviews. 2007;36(6):846-55. https://doi.org/10.1039/B600363J.
40. Głowniak S, Szczęśniak B, Choma J, Jaroniec M. Mechanochemistry: Toward green synthesis of metal–organic frameworks. Materials Today. 2021 Jun 1;46:109-24. https://doi.org/10.1016/j.mattod.2021.01.008.
41. Wang W, Chai M, Zulkifli MY, Xu K, Chen Y, Wang L, Chen V, Hou J. Metal–organic framework composites from a mechanochemical process. Molecular Systems Design & Engineering. 2023;8(5):560-79. https://doi.org/10.1039/D2ME00211F.
42. Han X, Li J, Tao S, Dou G, Mansur S, Zhang X. Synthesis of organic–inorganic hybrid perovskite/MOF composites from Pb–MOF using a mechanochemical method. Molecules. 2023 Jun 27;28(13):5021. https://doi.org/10.1016/j.mattod.2021.01.008.
43. Wang KY, Zhang J, Hsu YC, Lin H, Han Z, Pang J, Yang Z, Liang RR, Shi W, Zhou HC. Bioinspired framework catalysts: From enzyme immobilization to biomimetic catalysis. Chemical Reviews. 2023 Apr 12;123(9):5347-420. https://doi.org/10.1021/acs.chemrev.2c00879.
44. Breslow R, Overman LE. " Artificial enzyme" combining a metal catalytic group and a hydrophobic binding cavity. Journal of the American Chemical Society. 1970 Feb;92(4):1075-7. https://doi.org/10.1021/ja00707a062.

 DOI: ***10.5281/zenodo.22054167***

45. Holm RH, Lo W. Structural conversions of synthetic and protein-bound iron–sulfur clusters. Chemical Reviews. 2016 Nov 23;116(22):13685-713. https://doi.org/10.1021/acs.chemrev.6b00276.

46. Goh C, Segal BM, Huang J, Long JR, Holm RH. Polycubane clusters: Synthesis of [Fe4S4 (PR3) 4] 1+, 0 (R= But, Cy, Pri) and [Fe4S4] 0 core aggregation upon loss of phosphine. Journal of the American Chemical Society. 1996 Nov 27;118(47):11844-53. https://doi.org/10.1021/ja9620200.

47. Friesner RA, Baik MH, Gherman BF, Guallar V, Wirstam M, Murphy RB, Lippard SJ. How iron-containing proteins control dioxygen chemistry: a detailed atomic level description via accurate quantum chemical and mixed quantum mechanics/molecular mechanics calculations. Coordination Chemistry Reviews. 2003 Mar 1;238:267-90. https://doi.org/10.1016/S0010-8545(02)00284-9.

48. Groves JT, Haushalter RC, Nakamura M, Nemo TE, Evans BJ. High-valent iron-porphyrin complexes related to peroxidase and cytochrome P-450. Journal of the American Chemical Society. 1981 May;103(10):2884-6. https://doi.org/10.1021/ja00400a075

49. Wang X, Wang R, Xu Y, Wei G. Recent advances in biohybrid membranes for water treatment: preparation strategies, nano-hybridization, bioinspired functionalization, applications, and sustainability analysis. Journal of Materials Chemistry A. 2025;13(33):26967-7000. https://doi.org/10.1039/D5TA04214C.

50. Shi J, Liu Z, Ren X, Wang W, Zhang H, Wang Y, Liu M, Yao Q, Wu W. Bioinspired adhesive polydopamine-metal-organic framework functionalized 3D customized scaffolds with enhanced angiogenesis, immunomodulation, and osteogenesis for orbital bone reconstruction. International Journal of Biological Macromolecules. 2025 Jan 1;284:137968. https://doi.org/10.1016/j.ijbiomac.2024.137968.

51. Zhou W, Long Z, Xu C, Zhang J, Zhou X, Song X, Huo P, Guo Y, Xue W, Wang Q, Zhou C. Advances in Functionalized Biocomposites of Living Cells Combined with Metal–Organic Frameworks. Langmuir. 2024 Jul 11;40(29):14749-65. https://doi.org/10.1021/acs.langmuir.4c00404

 DOI: ***10.5281/zenodo.22054167***

52. Wang Q, Astruc D. State of the art and prospects in metal–organic framework (MOF)-based and MOF-derived nanocatalysis. Chemical reviews. 2019 Jun 27;120(2):1438-511. https://doi.org/10.1021/acs.chemrev.9b00223
53. Wang, Y., Yang, Y., Liu, J., Zi, X., Zhu, H., Sun, X., ... & Fu, Y. (2024). Revolutionizing nanozyme technology with metal-organic frameworks: Classification, catalytic mechanisms, regulation and applications in biotechnology. *Chemical Engineering Journal*, *500*, 156850. https://doi.org/10.1016/j.cej.2024.156850
54. Xu W, Wu Y, Gu W, Du D, Lin Y, Zhu C. Atomic-level design of metalloenzyme-like active pockets in metal–organic frameworks for bioinspired catalysis. Chemical Society Reviews. 2024;53(1):137-62. https://doi.org/10.1039/D3CS00767G.
55. Lee SH, Choi DS, Kuk SK, Park CB. Photobiocatalysis: activating redox enzymes by direct or indirect transfer of photoinduced electrons. Angewandte Chemie International Edition. 2018 Jul 2;57(27):7958-85. https://doi.org/10.1002/anie.201710070.
56. Ginovska B, Gutiérrez OY, Karkamkar A, Lee MS, Lercher JA, Liu Y, Raugei S, Rousseau R, Shaw WJ. Bioinspired catalyst design principles: progress in emulating properties of enzymes in synthetic catalysts. ACS Catalysis. 2023 Aug 25;13(18):11883-901. https://doi.org/10.1021/acscatal.3c00320.
57. Trogadas P, Xu L, Coppens MO. From biomimicking to bioinspired design of electrocatalysts for CO2 reduction to C1 products. Angewandte Chemie International Edition. 2024 Jan 2;63(1):e202314446. https://doi.org/10.1002%2Fanie.202314446.
58. Wang Y, Zhao Y, Tan Q, Xiao G, Baeyens J, Su H. Bioinspired bi-amino acid Ce-MOFs boosting oxidase-like activity: Dual-mode aflatoxin detection and antimicrobial activity platform. Chemical Engineering Journal. 2025 May 15;512:161977. https://doi.org/10.1016/j.cej.2025.161977.
59. Horcajada P, Gref R, Baati T, Allan PK, Maurin G, Couvreur P, Férey G, Morris RE, Serre C. Metal–organic frameworks in biomedicine. Chemical reviews. 2012 Feb 8;112(2):1232-68. https://doi.org/10.1021/cr200256v.
60. Li JR, Sculley J, Zhou HC. Metal–organic frameworks for separations. Chemical reviews. 2012 Feb 8;112(2):869-932. https://doi.org/10.1021/cr200190s.

 DOI: ***10.5281/zenodo.22054167***

61. Chakraborty D, Yurdusen A, Mouchaham G, Nouar F, Serre C. Large-scale production of metal–organic frameworks. Advanced Functional Materials. 2024 Oct;34(43):2309089. https://doi.org/10.1002/adfm.202309089.
62. Gao GK, Wang YR, Zhu HJ, Chen Y, Yang RX, Jiang C, Ma H, Lan YQ. Rapid production of metal–organic frameworks based separators in industrial-level efficiency. Advanced Science. 2020 Dec;7(24):2002190. https://doi.org/10.1002/advs.202002190.
63. Chen Y, Zhang S, Cao S, Li S, Chen F, Yuan S, Xu C, Zhou J, Feng X, Ma X, Wang B. Roll-to-Roll Production of Metal-Organic Framework Coatings for Particulate Matter Removal. Advanced Materials (Deerfield Beach, Fla.). 2017 Jan 19;29(15). https://doi.org/10.1002/adma.201606221.
64. Gkaniatsou E, Chen C, Cui FS, Zhu X, Sapin P, Nouar F, Boissiere C, Markides CN, Hensen J, Serre C. Producing cold from heat with aluminum carboxylate-based metal-organic frameworks. Cell Reports Physical Science. 2022 Feb 16;3(2). https://doi.org/10.1016/j.xcrp.2021.100730.
65. Kumar S, Jain S, Nehra M, Dilbaghi N, Marrazza G, Kim KH. Green synthesis of metal–organic frameworks: A state-of-the-art review of potential environmental and medical applications. Coordination Chemistry Reviews. 2020 Oct 1;420:213407. https://doi.org/10.1016/j.ccr.2020.213407.
66. Seo YK, Yoon JW, Lee JS, Lee UH, Hwang YK, Jun CH, Horcajada P, Serre C, Chang JS. Large scale fluorine-free synthesis of hierarchically porous iron (III) trimesate MIL-100 (Fe) with a zeolite MTN topology. Microporous and Mesoporous Materials. 2012 Jul 15;157:137-45. https://doi.org/10.1016/j.micromeso.2012.02.027.
67. Crawford D, Casaban J, Haydon R, Giri N, McNally T, James SL. Synthesis by extrusion: continuous, large-scale preparation of MOFs using little or no solvent. Chemical science. 2015;6(3):1645-9. https://doi.org/10.1039/C4SC03217A.
68. Seo, Y. K., Yoon, J. W., Lee, J. S., Lee, U. H., Hwang, Y. K., Jun, C. H., ... & Chang, J. S. (2012). Large scale fluorine-free synthesis of hierarchically porous iron (III) trimesate MIL-100 (Fe) with a zeolite MTN topology. *Microporous and Mesoporous Materials*, *157*, 137-145. https://doi.org/10.1016/j.micromeso.2012.02.027.

 DOI: *10.5281/zenodo.22054167*

69. Crawford, D., Casaban, J., Haydon, R., Giri, N., McNally, T., & James, S. L. (2015). Synthesis by extrusion: continuous, large-scale preparation of MOFs using little or no solvent. *Chemical science*, *6*(3), 1645-1649. https://doi.org/10.1039/C4SC03217A.
70. Kumar, S., Jain, S., Nehra, M., Dilbaghi, N., Marrazza, G., & Kim, K. H. (2020). Green synthesis of metal–organic frameworks: A state-of-the-art review of potential environmental and medical applications. *Coordination Chemistry Reviews*, *420*, 213407. https://doi.org/10.1016/j.ccr.2020.213407
71. Julien, P. A., Mottillo, C., & Friščić, T. (2017). Metal–organic frameworks meet scalable and sustainable synthesis. *Green Chemistry*, *19*(12), 2729-2747. https://doi.org/10.1039/c7gc01078h
72. Seetharaj, R., Vandana, P. V., Arya, P., & Mathew, S. (2019). Dependence of solvents, pH, molar ratio and temperature in tuning metal organic framework architecture. *Arabian journal of chemistry*, *12*(3), 295-315. https://doi.org/10.1016/j. arabjc.2016.01.003.
73. Rocío-Bautista, P., Taima-Mancera, I., Pasán, J., & Pino, V. (2019). Metal-organic frameworks in green analytical chemistry. *Separations*, *6*(3), 33. https://doi.org/10.3390/separations6030033.
74. Al Obeidli A, Salah HB, Al Murisi M, Sabouni R. Recent advancements in MOFs synthesis and their green applications. International Journal of Hydrogen Energy. 2022 Jan 12;47(4):2561-93. https://doi.org/10.1016/j.ijhydene.2021.10.180.
75. T. C. C. D. Centre, CSD MOF Collection, https://www.ccdc.cam.ac.uk/free-products/csd-mof-collection/, (accessed: Oct 27, 2025).
76. Pichon, A., Lazuen-Garay, A., & James, S. L. (2006). Solvent-free synthesis of a microporous metal–organic framework. *CrystEngComm*, *8*(3), 211-214. https://doi.org/10.1039/B513750K.
77. Yuan, W., Garay, A. L., Pichon, A., Clowes, R., Wood, C. D., Cooper, A. I., & James, S. L. (2010). Study of the mechanochemical formation and resulting properties of an archetypal MOF: Cu3 (BTC) 2 (BTC= 1, 3, 5-benzenetricarboxylate). *CrystEngComm*, *12*(12), 4063-4065. https://doi.org/10.1039/C0CE00486C.

 DOI: ***10.5281/zenodo.22054167***

78. Silva, P., Vilela, S. M., Tomé, J. P., & Paz, F. A. A. (2015). Multifunctional metal–organic frameworks: from academia to industrial applications. *Chemical Society Reviews*, *44*(19), 6774-6803. https://doi.org/10.1039/C5CS00307E.
79. Wu D, Zhang PF, Yang GP, Hou L, Zhang WY, Han YF, Liu P, Wang YY. Supramolecular control of MOF pore properties for the tailored guest adsorption/separation applications. Coordination Chemistry Reviews. 2021 May 1; 434:213709. https://doi.org/10.1016/j.ccr.2020.213709.
80. Wu D, Yan W, Xu H, Zhang E, Li Q. Defect engineering of Mn-based MOFs with rod-shaped building units by organic linker fragmentation. Inorganica Chimica Acta. 2017 Apr 24;460:93-8. https://doi.org/10.1016/j.ica.2016.07.022.
81. Vo TK, Nguyen HM. Synergistic effects of defect engineering and functionalizing ionic liquids within UiO-66 (Zr)-NH2 frameworks towards improving removal efficiency of phosphate and methyl orange. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2024 Nov 5;700:134735. https://doi.org/10.1016/j.colsurfa.2024.134735
82. Xiong T, Zhang Y, Lee WS, Xue J. Defect engineering in manganese-based oxides for aqueous rechargeable zinc-ion batteries: a review. Advanced Energy Materials. 2020 Sep;10(34):2001769. https://doi.org/10.1002/aenm.202001769
83. Yin Z, Wan S, Yang J, Kurmoo M, Zeng MH. Recent advances in post-synthetic modification of metal–organic frameworks: New types and tandem reactions. Coordination Chemistry Reviews. 2019 Jan 1;378:500-12. https://doi.org/10.1016/j.ccr.2017.11.015
84. Vo TK, Nguyen HM. Synergistic effects of defect engineering and functionalizing ionic liquids within UiO-66 (Zr)-NH2 frameworks towards improving removal efficiency of phosphate and methyl orange. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2024 Nov 5;700:134735. https://doi.org/10.1016/j.colsurfa.2024.134735
85. He W, Lv D, Guan Y, Yu S. Post-synthesis modification of metal–organic frameworks: synthesis, characteristics, and applications. Journal of Materials Chemistry A. 2023;11(45):24519-50. https://doi.org/10.1039/D3TA05158G.

 DOI: ***10.5281/zenodo.22054167***

86. Chen T, Zhao D. Post-synthetic modification of metal-organic framework-based membranes for enhanced molecular separations. Coordination Chemistry Reviews. 2023 Sep 15;491:215259. https://doi.org/10.1016/j.ccr.2023.215259.

87. Mandal S, Natarajan S, Mani P, Pankajakshan A. Post-synthetic modification of metal–organic frameworks toward applications. Advanced Functional Materials. 2021 Jan;31(4):2006291. https://doi.org/10.1002/adfm.202006291.

88. Tanabe KK, Cohen SM. Postsynthetic modification of metal–organic frameworks—a progress report. Chemical Society Reviews. 2011;40(2):498-519. https://doi.org/10.1039/C0CS00031K.

89. Karagiaridi O, Bury W, Mondloch JE, Hupp JT, Farha OK. Solvent-assisted linker exchange: an alternative to the de novo synthesis of unattainable metal–organic frameworks. Angewandte Chemie International Edition. 2014 Apr 25;53(18):4530-40. https://doi.org/10.1002/anie.201306923.

90. Smith KT, Stylianou KC. Multivariate metal–organic frameworks generated through post-synthetic modification: impact and future directions. Dalton Transactions. 2023;52(45):16578-85. https://doi.org/10.1039/D3DT01936E.

91. Khan SN, Zhao M. Green solvents assisted de-novo synthesis and defect-engineered UiO-66 for improved CO2 adsorption and kinetics-experimental and DFT approach. Carbon Capture Science & Technology. 2024 Dec 1;13:100335. https://doi.org/10.1016/j.ccst.2024.100335.

92. Lee S, Lee G, Oh M. Induced Production of Atypical Naturally Nonpreferred Metal–Organic Frameworks and Their Detachment via Provoking Post-Mismatching. Small. 2023 Sep;19(36):2303580. https://doi.org/10.1002/smll.202303580

93. Su X, Zhong Z, Yan X, Xu Y, Zhang T, Ma Y, Chen L. De Novo Design and Facile Synthesis of Highly Crystalline 2D Conductive Metal–Organic Frameworks: A "Rotor-Stator" Strategy. Journal of the American Chemical Society. 2024 Mar 20;146(13):9036-44. https://doi.org/10.1021/jacs.3c13985.

94. He M, Shi S, Liu Z, Wu Y, Wang L. Design, synthesis, and applications of defective metal–organic frameworks in water treatment. Chemical Communications. 2025;61(27):5072-83. https://doi.org/10.1039/D4CC06812B.

 DOI: ***10.5281/zenodo.22054167***

95. Choi GM, Mandal M, Jung HJ, Panda J, Kwon YJ, Zhang K, Vivek E, Shon M, Ravi K, Baek KY, Kwon HT. Post-synthetic modifications (PSM)-induced defects in hybrid metal-organic frameworks (MOFs) to unleash potential in gas separation membrane applications. Journal of Materials Science & Technology. 2024 Dec 1;201:95-118. https://doi.org/10.1016/j.jmst.2024.03.015.

96. Mahdavi H, Robin A, Eden NT, Khosravanian A, Sadiq MM, Konstas K, Smith SJ, Mulet X, Hill MR. Engineering insights into tailored metal–organic frameworks for CO2 capture in industrial processes. Langmuir. 2024 Aug 8;40(33):17387-95. https://doi.org/10.1021/acs.langmuir.4c01500.

97. Mohsenpour Tehrani M, Chehrazi E. Metal–organic-frameworks based mixed-matrix membranes for CO2 separation: an applicable- Interfaces. 2024 Jun 22;16(26):32906-29. https://doi.org/10.1021/acsami.4c06914.

98. Ahmad A, Nazar M, Ismail M, Abdulazeez I, Bustam MA, Al Hamouz OC. The role of carbon nanotubes and graphene oxide on the performance of metal-organic frameworks for CO2 capture. Physica B: Condensed Matter. 2025 Jun 30:417551. https://doi.org/10.1016/j.physb.2025.417551

99. Huang Y, Chen Y, Xu M, Ly A, Gili A, Murphy E, Asset T, Liu Y, De Andrade V, Segre CU, Deriy AL. Catalysts by pyrolysis: Transforming metal-organic frameworks (MOFs) precursors into metal-nitrogen-carbon (MNC) materials. Materials Today. 2023 Oct 1;69:66-78. https://doi.org/10.1016/j.mattod.2023.08.007

100. Gadipelli S, Li Z, Lu Y, Li J, Guo J, Skipper NT, Shearing PR, Brett DJ. Size-related electrochemical performance in active carbon nanostructures: a MOFs-derived carbons case study. Advanced Science. 2019 Oct;6(20):1901517. https://doi.org/10.1002/advs.201901517

101. Huang Y, Chen Y, Xu M, Gili de Villasante A, Asset T, Liu Y, Ly A, Pan X, Atanassov P, Zenyuk IV. Pyrolysis of metal organic frameworks (MOF): transformations leading to formation of transition metal-nitrogen-carbon catalysts. InElectrochemical Society Meeting Abstracts 239 2021 May 30 (No. 9, pp. 476-476). The Electrochemical Society, Inc.. https://doi.org/10.1149/MA2021-019476mtgabs

 DOI: ***10.5281/zenodo.22054167***

102. Zhang Y, Zhang C, Qian W, Lei F, Chen Z, Wu X, Lin Y, Wang F. Recent advances in MOF-based nanozymes: Synthesis, activities, and bioapplications. Biosensors and Bioelectronics. 2024 Nov 1;263:116593. https://doi.org/10.1016/j.bios.2024.116593
103. Chandio I, Ai Y, Wu L, Liang Q. Recent progress in MOFs-based nanozymes for biosensing. Nano Research. 2024 Jan;17(1):39-64. https://doi.org/10.1007/s12274-023-5770-3
104. Hassanzadeh Goji N, Ramezani M, Sh. Saljooghi A, Alibolandi M. Porphyrin-based metal–organic frameworks: focus on diagnostic and therapeutic applications. Journal of Nanostructure in Chemistry. 2024 Apr;14(2):167-208. https://doi.org/10.1007/s40097-022-00500-6
105. Rajasree SS, Li X, Deria P. Physical properties of porphyrin-based crystalline metal–organic frameworks. Communications Chemistry. 2021 Apr 1;4(1):47. https://doi.org/10.1038/s42004-021-00484-4
106. Liu B, Jiang M, Zhu D, Zhang J, Wei G. Metal-organic frameworks functionalized with nucleic acids and amino acids for structure-and function-specific applications: A tutorial review. Chemical Engineering Journal. 2022 Jan 15;428:131118. https://doi.org/10.1016/j.cej.2021.131118
107. Shen Y, Pan T, Wang L, Ren Z, Zhang W, Huo F. Programmable logic in metal–organic frameworks for catalysis. Advanced Materials. 2021 Nov;33(46):2007442. https://doi.org/10.1002/adma.202007442
108. Lee J, Farha OK, Roberts J, Scheidt KA, Nguyen ST, Hupp JT. Metal–organic framework materials as catalysts. Chemical Society Reviews. 2009;38(5):1450-9. https://doi.org/10.1039/B807080F
109. Wang S, McGuirk CM, d'Aquino A, Mason JA, Mirkin CA. Metal–organic framework nanoparticles. Advanced Materials. 2018 Sep;30(37):1800202. https://doi.org/10.1002/adma.201800202
110. Dissegna S, Epp K, Heinz WR, Kieslich G, Fischer RA. Defective metal-organic frameworks. Advanced Materials. 2018 Sep;30(37):1704501. https://doi.org/10.1002/adma.201704501
111. Chen L, Xu Q. Metal-organic framework composites for catalysis. Matter. 2019 Jul 10;1(1):57-89. https://doi.org/10.1016/j.matt.2019.05.018

 DOI: ***10.5281/zenodo.22054167***

112. Sun, Z., Liao, Y., Zhao, S., Zhang, X., Liu, Q., & Shi, X. (2022). Research progress in metal–organic frameworks (MOFs) in CO 2 capture from post-combustion coal-fired flue gas: characteristics, preparation, modification and applications. *Journal of Materials Chemistry A*, *10*(10), 5174-5211. https://doi.org/10.1039/D1TA07856A
113. Sun, Z., Lu, J., Zhang, X., Shan, X., Wu, Q., Li, C., ... & Tian, L. (2022). Electrospun nanofibers containing CdTe@ ZnNi-MOF for electrochemiluminescent determination of chlorpyrifos. Microchimica Acta, 189(12), 473. https://doi.org/10.1007/s00604-022-05574-1
114. Binaeian, E., Nabipour, H., Ahmadi, S., & Rohani, S. (2023). The green synthesis and applications of biological metal–organic frameworks for targeted drug delivery and tumor treatments. Journal of Materials Chemistry B, 11(48), 11426-11459. https://doi.org/10.1039/D3TB01959D
115. Kuang, G., Wang, Z., Bilal, M., Wang, Z., Feng, Y., Du, Y., & Cui, J. (2025). Metal-Organic Frameworks: A Potential Platform from Enzyme Immobilization to Mimetic Enzyme. *Aggregate*, *6*(3), e724. https://doi.org/10.1002/agt2.724
116. Akbari Oryani, M., Tarin, M., Rahnama Araghi, L., Rastin, F., Javid, H., Hashemzadeh, A., & Karimi-Shahri, M. (2025). Synergistic cancer treatment using porphyrin-based metal-organic frameworks for photodynamic and photothermal therapy. Journal of Drug Targeting, 33(4), 473-491. https://doi.org/10.1080/1061186X.2024.2433551
117. Al-Attas, T., Khan, M. A., Goncalves, T. J., Yasri, N. G., Roy, S., Zeraati, A. S., ... & Kibria, M. G. (2023). Bioinspired multimetal electrocatalyst for selective methane oxidation. Chemical Engineering Journal, 474, 145827. https://doi.org/10.1016/j.cej.2023.145827
118. Tang, C., Li, X., Hu, Y., Du, X., Wang, S., Chen, B., & Wang, S. (2024). Porphyrin-based metal-organic framework materials: design, construction, and application in the field of photocatalysis. Molecules, 29(2), 467. https://doi.org/10.3390/molecules29020467
119. Medel, E., & Vargas, R. (2025). Non-covalent interactions in MOFs: a quantum approach to gas adsorption and molecular encapsulation. Frontiers in Chemistry, 13, 1579977. https://doi.org/10.3389/fchem.2025.1579977

 DOI: ***10.5281/zenodo.22054167***

120. Li, Y., Gao, H., Jin, Y., Zhao, R., & Huang, Y. (2023). Peptide-derived coordination frameworks for biomimetic and selective separation. Analytical and Bioanalytical Chemistry, 415(18), 4079-4092. https://doi.org/10.1007/s00216-023-04761-0
121. Long, Q., Wang, Y., Zhao, R., Wang, T., Lai, F., Hu, X., & Zeng, X. (2023). Precise manipulation of amino groups in Zr-MOFs for efficient adsorption performance. Crystals, 13(6), 856. https://doi.org/10.3390/cryst13060856
122. Zhang, Z., Li, Y., Yuan, Z., Wu, L., Ma, J., Tan, W., ... & Chai, H. (2025). MOF nanozymes: active sites and sensing applications. *Inorganic Chemistry Frontiers*, *12*(2), 400-429. https://doi.org/10.1039/D4QI02555E
123. Yuan, Z., Chai, H., Huang, Y., Zhang, Z., Tan, W., Sun, Y., ... & Zhang, G. (2025). Porphyrin-engineered metal− organic frameworks for photo/electrochemical sensing: Preparation and mechanisms. *Coordination Chemistry Reviews*, *527*, 216385. https://doi.org/10.1016/j.ccr.2024.216385
124. Zhao, H., Tan, X., Chai, H., Hu, L., Li, H., Qu, L., ... & Zhang, G. (2025). Recent advances in conductive MOF-based electrochemical sensors. *Chinese Chemical Letters*, *36*(8), 110571. https://doi.org/10.1016/j.cclet.2024.110571

 DOI: ***10.5281/zenodo.22054167***