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Recent Development and Future Aspects of Metal-Organic Frameworks (MOFs) as Adsorbents

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INTRODUCTION

- Metal-Organic Frameworks (MOFs), composed of metal nodes and organic ligands, are highly porous and chemically tunable materials, making them ideal for applications like carbon capture, toxic gas adsorption, water purification, and catalysis.
- This paper reviews recent advancements in MOF development, highlights challenges, and explores future prospects for enhancing their practical applications.

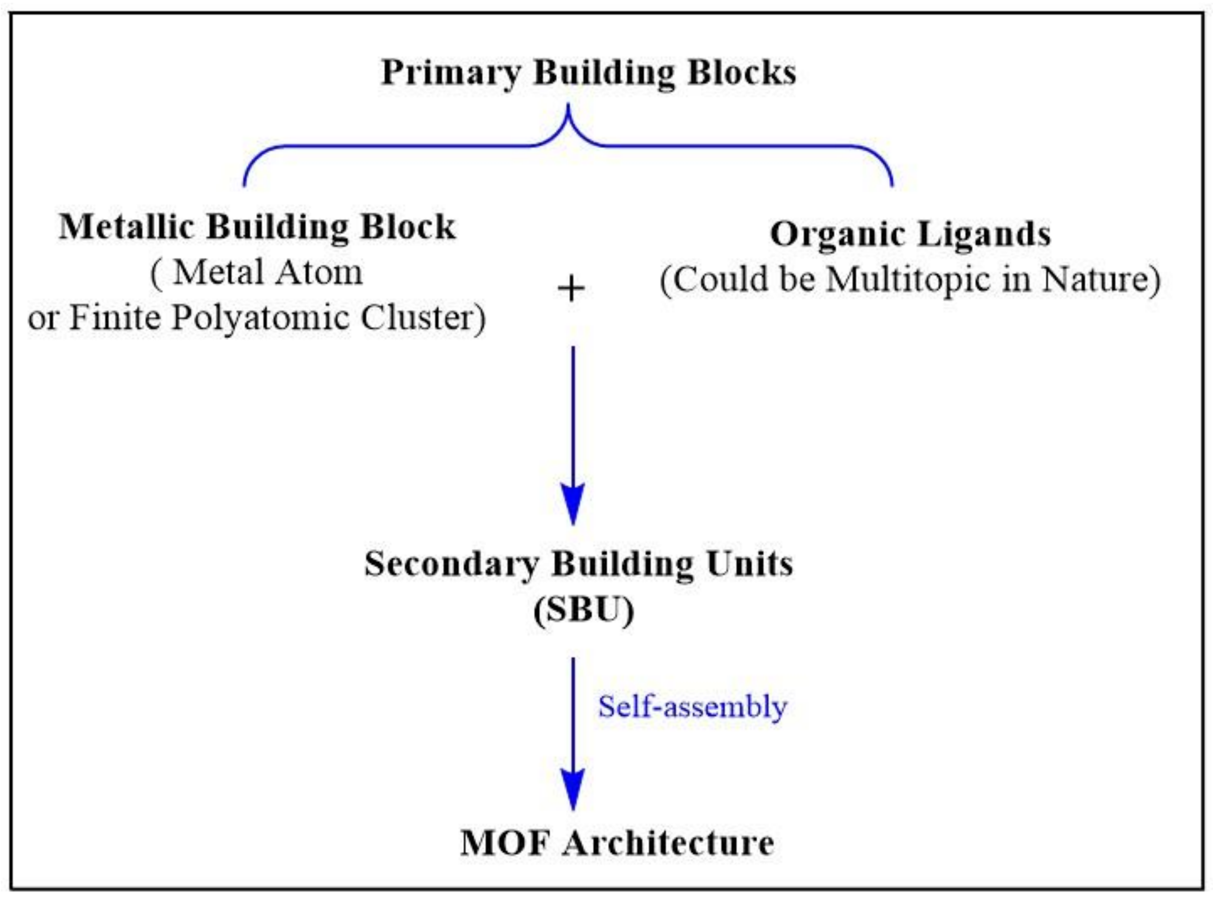

Fig 1. General Approach to MOF Synthesis Using Secondary Building Units (SBUs).

RECENT DEVELOPMENTS IN MOFs AS ADSORBENTS

- **Traditional Solvothermal Methods:** These widely used techniques produce highly crystalline MOFs with excellent adsorption performance, such as MOF-5 for gas adsorption and HKUST-1 for methane storage.
- **Green Synthesis:** Eco-friendly methods employ renewable organic ligands and non-toxic solvents like water or ethanol to minimize environmental impact, exemplified by MIL-53 and UiO-66.
- **Post-Synthetic Modification (PSM):** Functionalizing MOFs after synthesis enables the customization of adsorption sites, improving selectivity for CO_2 and heavy metal ions using amino-functionalized MOFs.
- **Carbon Capture:** MOFs such as Mg-MOF-74 and UiO-66 exhibit exceptional CO_2 uptake due to their high surface area and functionalized adsorption sites.
- **Toxic Gas Removal:** MOFs like ZIF-8 and MIL-101 effectively adsorb harmful industrial gases such as SO_2, NH_3, and H_2S, aiding in air purification.
- **Hydrogen and Methane Storage:** High-capacity MOFs such as MOF-177 and NU-100 are critical for clean energy applications, particularly in hydrogen and methane storage.
- **Heavy Metal Removal:** MOFs functionalized with amino, thiol, or carboxyl groups excel at adsorbing toxic ions like Pb^{2+}, Cd^{2+}, and Cr^{6+}, contributing to water purification.
- **Organic Contaminant Removal:** MOFs like MIL-100 and UiO-66 effectively remove organic pollutants, including dyes and pharmaceutical residues, ensuring sustainable water treatment.

SYNTHETIC METHODS

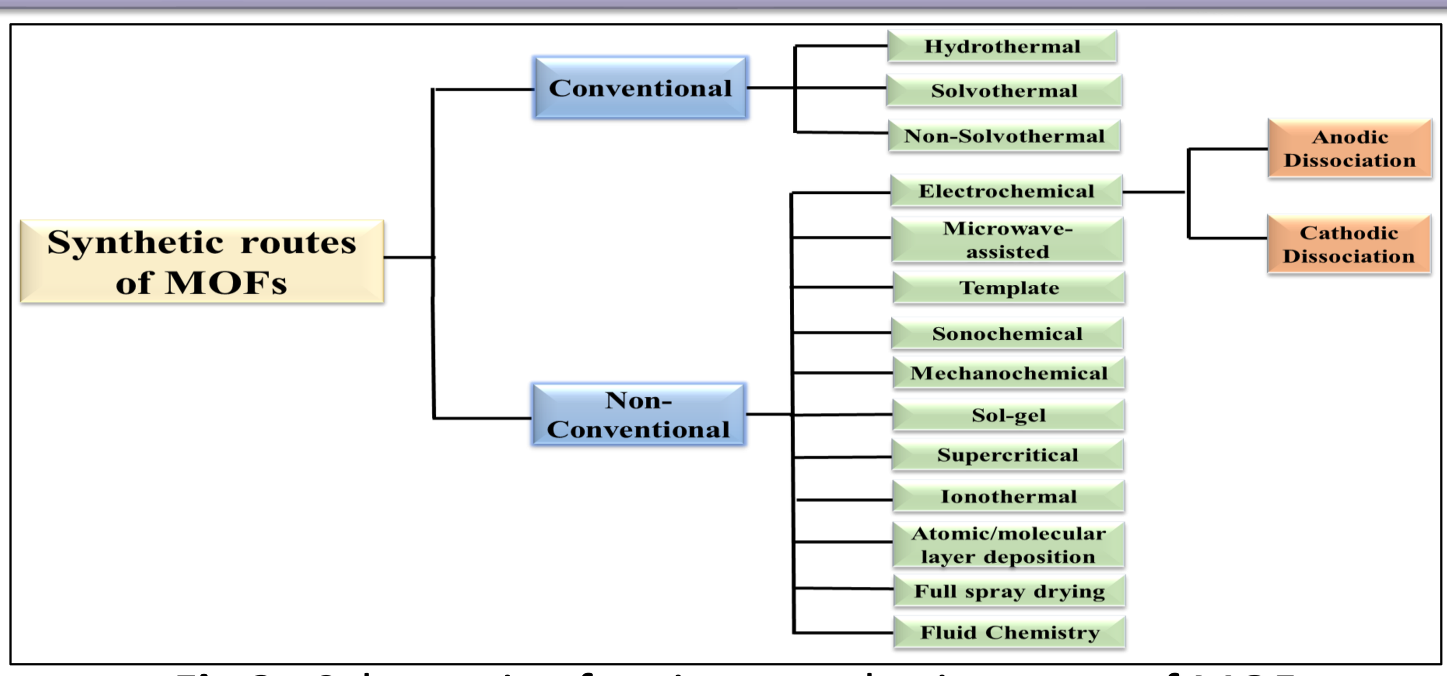

Fig 2. Schematic of various synthetic routes of MOFs

CHALLENGES AND LIMITATIONS

- **Scalability:** The large-scale production of MOFs with consistent quality is costly and resource-intensive, posing a challenge for industrial adoption.
- **Stability Issues:** Many MOFs exhibit sensitivity to moisture, temperature, and acidic environments, which limits their usability in harsh industrial conditions.
- **Regeneration Challenges:** Efficient desorption techniques are required to enable the reuse of MOFs without significant loss in performance or structural integrity.
- **Selectivity and Efficiency:** Developing MOFs with both high selectivity and adsorption capacity for specific applications is a complex and ongoing challenge.
- **Need for Innovation:** Addressing these limitations through advanced synthesis, stabilization techniques, and functional designs is critical for transitioning MOFs from research to real-world applications.

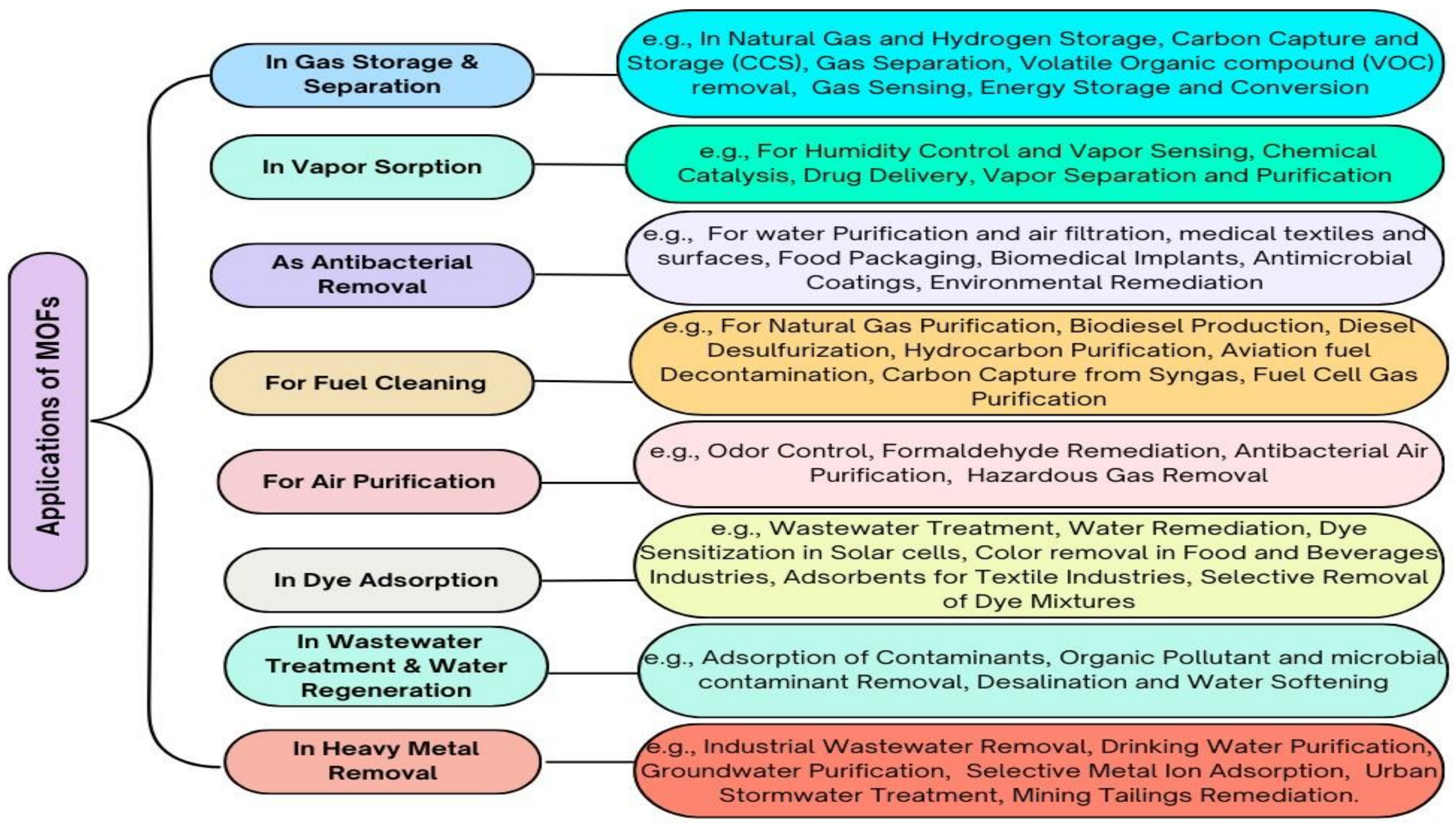

Fig 3. Various application areas utilizing adsorptive property of MOFs

FUTURE ASPECTS

- **Scalable and Sustainable Production:** Continuous flow reactors and mechanochemical synthesis offer cost-effective, energy-efficient, and scalable methods, making MOFs viable for industrial applications.
- **Enhanced Stability and Functionality:** Incorporation of stable metal clusters, MOF-polymer composites, and protective coatings improve durability against chemical, thermal, and environmental stresses.
- **Energy Storage Applications:** MOFs demonstrate excellent potential in renewable energy technologies, particularly for hydrogen and methane adsorption.
- **Biomedical Uses:** Their biocompatibility and customizable properties position MOFs as promising candidates for drug delivery and toxin removal.

CONCLUSION

Metal-Organic Frameworks (MOFs) have gained importance in adsorption technology, surpassing traditional adsorbents. Despite advancements in synthesis and application, challenges in stability, scalability, and regeneration persist. Future efforts must prioritize sustainable production, computational design, and hybrid material innovations. With ongoing progress, MOFs hold immense promise for clean energy, environmental remediation, and sustainable development.

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