



6 KEY CHALLENGES OF SCALING UP MOF PRODUCTION

Scaling-up manufacturing exposes a maze of physical, safety, supply chain, regulatory, and economic challenges that often don't materialise when working with lab processes.

Taking a new metal-organic framework (MOF) structure from the research laboratory to full-scale industrial production and worldwide supply isn't as straightforward as it may seem. In this article we explore some of the main challenges that MOF inventors should be aware of when developing new MOF structures when industrial-scale production is a key future goal.

1 REACTION KINETICS CHANGE WITH SCALE

Scaling up the synthesis of a MOF is not as simple as using a bigger flask, as reaction kinetics can change significantly at larger volumes. Reactions that run smoothly on the bench may behave

unpredictably in a much larger vessel due to mixing inefficiencies, or different surface-area-to-volume ratios in the vessel leading to slower heat and mass transfer rates. These issues are relevant to both batch and continuous-flow syntheses.

To address this, engineers must carefully tune various parameters, such as temperature profiles so that reaction kinetics at scale remain optimal. This is why "just make it bigger" rarely works without re-engineering synthetic processes and optimising mixing, timing, temperatures, solvents, cooling and downstream processing methods. All whilst ensuring the quality and performance of the MOF is maintained.



2 REPRODUCIBILITY IS THE FOUNDATION OF INDUSTRIAL VIABILITY

Producing the same MOF structure with consistent quality is notably harder to achieve at industrial scale as scaling up often changes aspects of the synthetic process. Raw material consistency, mixing intensity or heating rate can all affect the final structure of a MOF. As production volume increases reaction kinetics can change, and new synthetic processes may need to be developed. Even slight fluctuations in conditions that are easy to control in small-scale experiments can lead to irreproducible results in a large-scale manufacturing environment.



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Robust quality control (QC) systems must be implemented to monitor and ensure production consistency and alignment with customer requirements. Adapting what works at a small scale in the lab to the manufacturing plant requires expertise and becomes critical to successfully manufacturing a high-quality industrial scale product.

3 BIGGER VOLUMES BRING BIGGER SAFETY CONSIDERATIONS

Safety becomes a critical concern when moving synthesis from gram-scale lab experiments to kilogram or tonne-scale production. Large

volumes of flammable or toxic solvents can create fire, exposure, handling and environmental hazards that are far greater at scale than in a fume cupboard.

Along with specialised personal protective equipment and engineered safety systems, alternative synthetic processes using safer or more sustainable solvents may need to be developed. For example, reactions that release modest heat in a small flask can trigger thermal runaway or pressure buildup in larger reactors if cooling and venting are not properly designed. Scaled-up waste volumes may also require dedicated environmental controls.

These risks demand rigorous hazard analysis, engineering controls, relief systems and continuous monitoring to ensure that MOF scale-up can be carried out safely.

4 INDUSTRIAL VIABILITY DEPENDS ON A ROBUST SUPPLY CHAIN

Securing a reliable supply of cost-effective raw materials at the right purity is critical for manufacturing MOFs at industrial scale. A MOF's economic viability is influenced by the cost and availability of precursors, particularly the organic ligand. Many MOF linkers are laboratory-grade compounds that are well suited to research applications but not produced in the large volumes required for industrial manufacture. MOFs built from simple, inexpensive, mass-produced ligands and widely available metal ions are therefore advantageous for scale-up and ensuring business continuity plans are robust. When a precursor is not available at scale, the supply chain must be established or the synthesis modified to use an alternative. Supply-chain strategy is integral to scaling-up MOF production, influencing not just the procurement of components but decisions on structure selection, synthesis, and manufacturing processes.

5 TECHNO-ECONOMIC INSIGHT TURNS INNOVATION INTO BUSINESS

Scaling up MOF production for use in an industrial application is not only a chemical challenge but also a financial one. A synthesis route

that is straightforward in the lab may become prohibitively expensive or impractical at tonne scale. Techno-economic analysis (TEA) provides a structured framework, grounded in chemical engineering principles, for evaluating the true cost and viability of a process. In short, it helps unlock the difference between invention and innovation - value creation. By factoring in capital expenditure (CapEx) for plant, equipment, and infrastructure, along with operating expenditure (OpEx) for raw materials, energy, labour, and maintenance, TEA enables a realistic assessment of return on investment (ROI) and comparison with alternative technologies. This analysis offers a critical reality-check on whether a laboratory innovation can scale into a commercially viable product. TEA is often integrated with life-cycle analysis (LCA) to ensure that the scale-up pathway is not only cost-effective but also environmentally sustainable.

6 REGULATORY COMPLIANCE IS CRITICAL FOR INDUSTRIAL ADOPTION

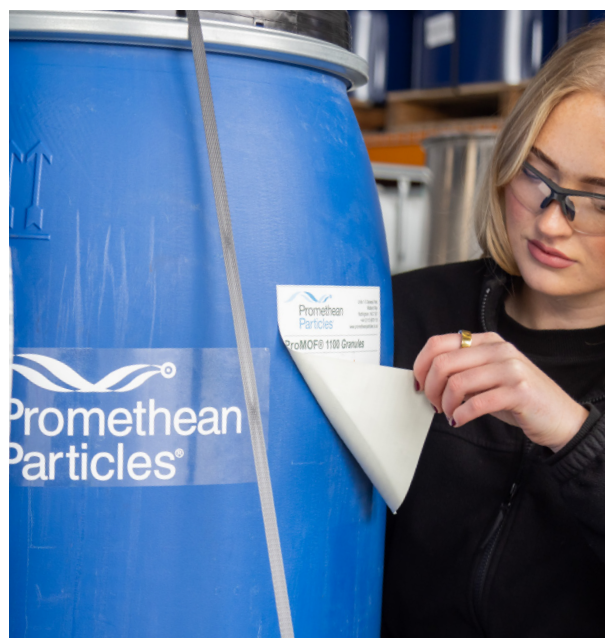
Scaling up MOF production carries significant regulatory responsibilities. In the European Union, all chemicals produced and supplied are subject to REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulations, which governs the manufacture and use of substances and assesses their environmental and health impacts. Where manufacture and/or supply of a chemical substance exceeds one tonne a year, then the substance is subject to registration with the European Chemicals Agency, the public body administering REACH. Other regions have their own regulatory frameworks and controls.

Navigating these requirements can be lengthy and costly. Scale-up projects must therefore integrate legal and safety expertise, including toxicological testing, environmental assessments, and comprehensive documentation to ensure compliance. Although these steps add

complexity, they are essential for enabling the safe, compliant, and ultimately successful industrial-scale adoption of MOFs.

BRIDGING THE GAP TO INDUSTRIAL SCALE MOF MANUFACTURING

Despite thousands of MOF structures being reported in the literature, only a few have been produced at industrial scale, in part due to the challenge of scaling up complex synthetic processes. Scaling a MOF from discovery to industrial reality demands far more than a successful laboratory synthesis; it requires rigorous engineering, robust economics, secure supply chains and full regulatory alignment.



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These challenges are significant, but they are surmountable with the right expertise. If you have a MOF structure exhibiting potential to move from concept to commercial production, contact us to discuss how our team can provide the technical, engineering, and regulatory support needed for successful scale-up.



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