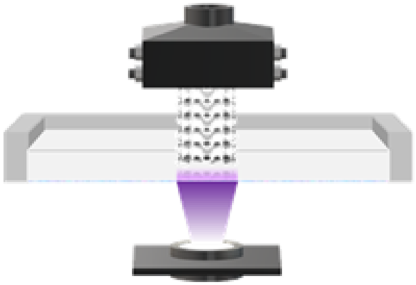
Beyond Conventional Designs: Development and Industrial Prospects of 3D-Printed Photocatalytic Reactors

突破傳統構型：3D列印光觸媒反應器的技術發展與工業化展望

Chien-Hua (Jeffery) Chen, PhD

Associate Professor
Dept. of Chemical Engineering
National Taiwan University of Science and Technology
jefferychen@mail.ntust.edu.tw



AMPM
ADDITIVE MANUFACTURING & POROUS MATERIALS LABORATORY

About Jeffery

Curriculum Vitae

Chien-Hua (Jeffery) Chen | 陳建樺
Associate Professor
Department of Chemical Engineering
National Taiwan University of Science and Technology
No. 43, Sec. 4, Keelung Rd., Da'an Dist., Taipei City 106335, Taiwan
jefferychen@mail.ntust.edu.tw / jeffery.ampm@gmail.com

Metric	All	Since 2021
Citations	1,467	1,023
h-index	22	18
i10-index	27	25

Current Positions

Associate Professor	Department of Chemical Engineering, National Taiwan University of Science and Technology (NTUST)	08.2024–Present
Board Director	Additive Manufacturing Society of Taiwan｜台灣積層製造學會	07.2026–Present
Board Director	Taiwan Filtration and Separation Society｜台灣過濾與分離學會	01.2024–Present

Research Interests

✦ Additive Manufacturing and Printing Materials ✦ Nanoporous Materials ✦ Membrane Science and Technology

Educations

PhD	Department of Chemical Engineering, National Taiwan University (NTU)	08.2012–01.2018
MS	Department of Chemical Engineering, Chung Yuan University (CYCU)	08.2009–07.2011
BS	Department of Chemical Engineering, Chung Yuan University (CYCU)	08.2005–07.2009

Research Interests:

Advanced Process Development in Additive Manufacturing Technology

Mechanism Design, Printing Strategies, Post-Processing, Circular Economy

Ceramic 3D Printing Slurry Development and Applications

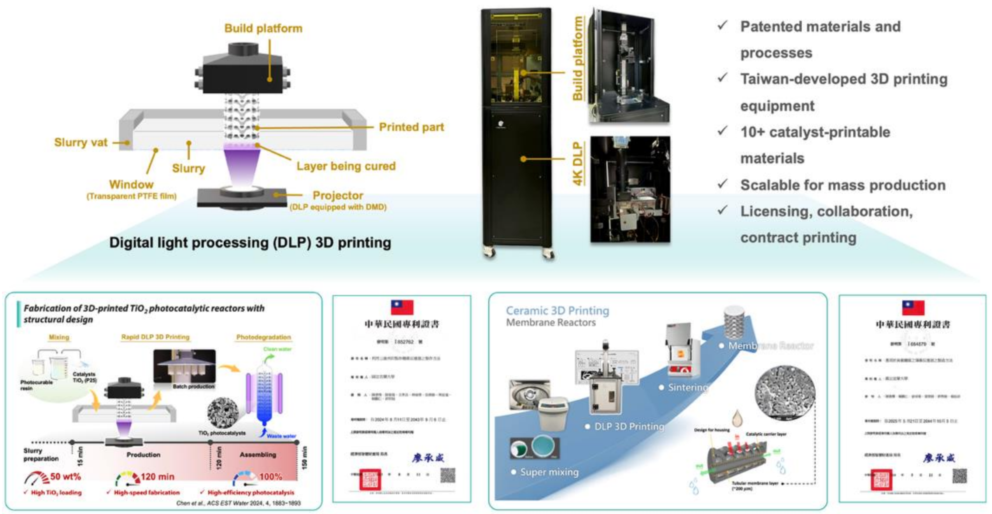
ZrO_2, Al_2O_3, TiO_2, SiO_2, ZnO, SiC

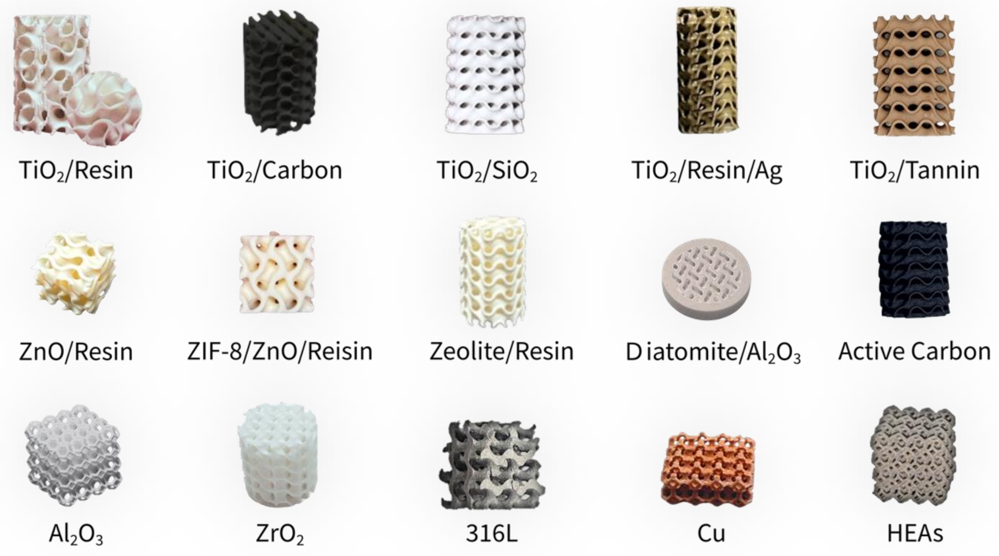
Metal 3D Printing Slurry Development and Applications

316L, 174PH, Ni-alloy, Cu, HEAs

Catalyst 3D Printing Slurry Development and Applications

ZnO, Zeolites, Graphene, g-C_3N_4,MOFs,





About Jeffery

Curriculum Vitae

Chien-Hua (Jeffery) Chen | 陳建樺
Associate Professor
Department of Chemical Engineering
National Taiwan University of Science and Technology
No. 43, Sec. 4, Keelung Rd., Da'an Dist., Taipei City 106335, Taiwan
jefferychen@mail.ntust.edu.tw / jeffery.ampm@gmail.com

Metric	All	Since 2021
Citations	1,467	1,023
h-index	22	18
i10-index	27	25

Current Positions

Associate Professor	Department of Chemical Engineering, National Taiwan University of Science and Technology (NTUST)	08.2024–Present
Board Director	Additive Manufacturing Society of Taiwan｜台灣積層製造學會	07.2026–Present
Board Director	Taiwan Filtration and Separation Society｜台灣過濾與分離學會	01.2024–Present

Research Interests

✦ Additive Manufacturing and Printing Materials ✦ Nanoporous Materials ✦ Membrane Science and Technology

Educations

PhD	Department of Chemical Engineering, National Taiwan University (NTU)	08.2012–01.2018
MS	Department of Chemical Engineering, Chung Yuan University (CYCU)	08.2009–07.2011
BS	Department of Chemical Engineering, Chung Yuan University (CYCU)	08.2005–07.2009

Research Interests:

- **Advanced Process Development in Additive Manufacturing Technology**

  Mechanism Design, Printing Strategies, Post-Processing, Circular Economy

- **Ceramic 3D Printing Slurry Development and Applications**

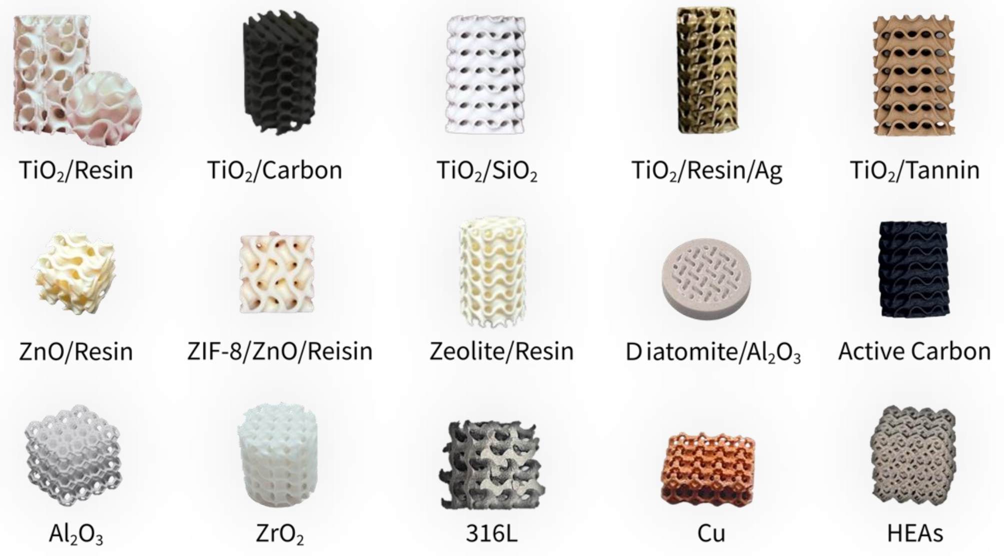
  ZrO_2, Al_2O_3, TiO_2, SiO_2, ZnO, SiC

- **Metal 3D Printing Slurry Development and Applications**

  316L, 174PH, Ni-alloy, Cu, HEAs

- **Catalyst 3D Printing Slurry Development and Applications**

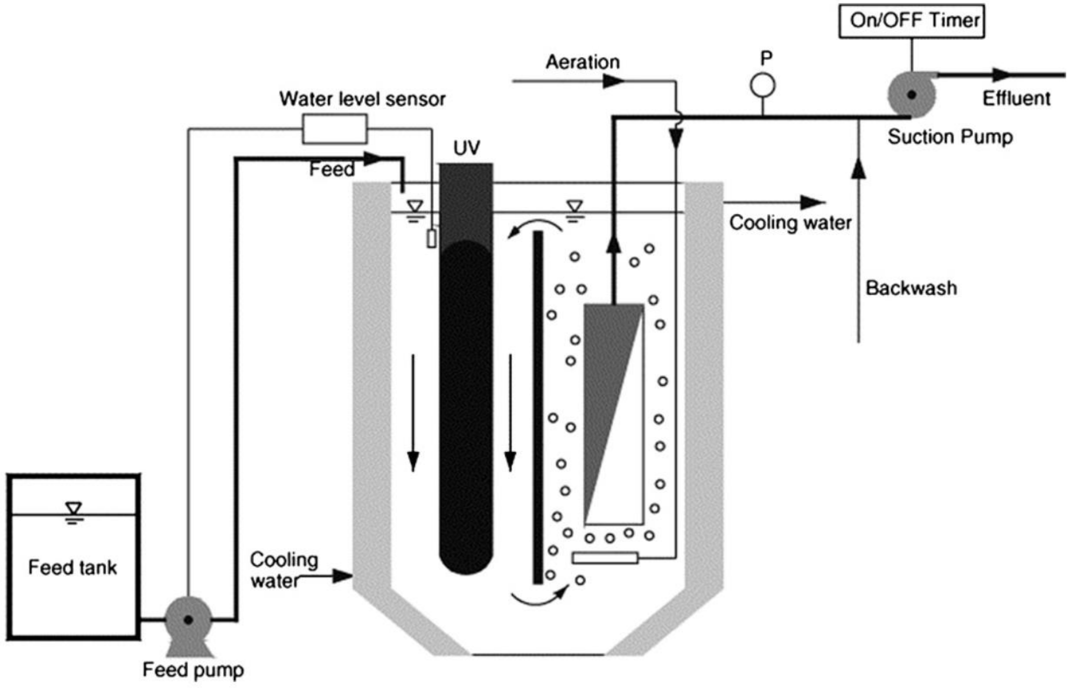
  ZnO, Zeolites, Graphene, g-C_3N_4,MOFs,

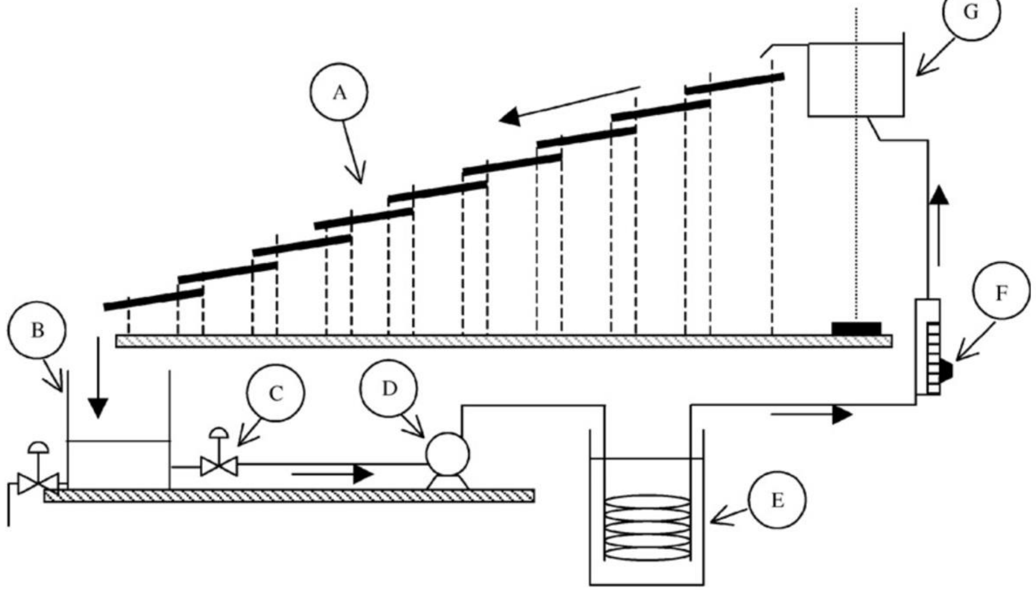


Photocatalytic reactor configuration

(1) Reactors with suspended photocatalyst particles

(2) Reactors with photocatalyst immobilized onto continuous inert carrier





(1) Suspended-Slurry Photocatalytic Reactor

Fu et al. (2006)

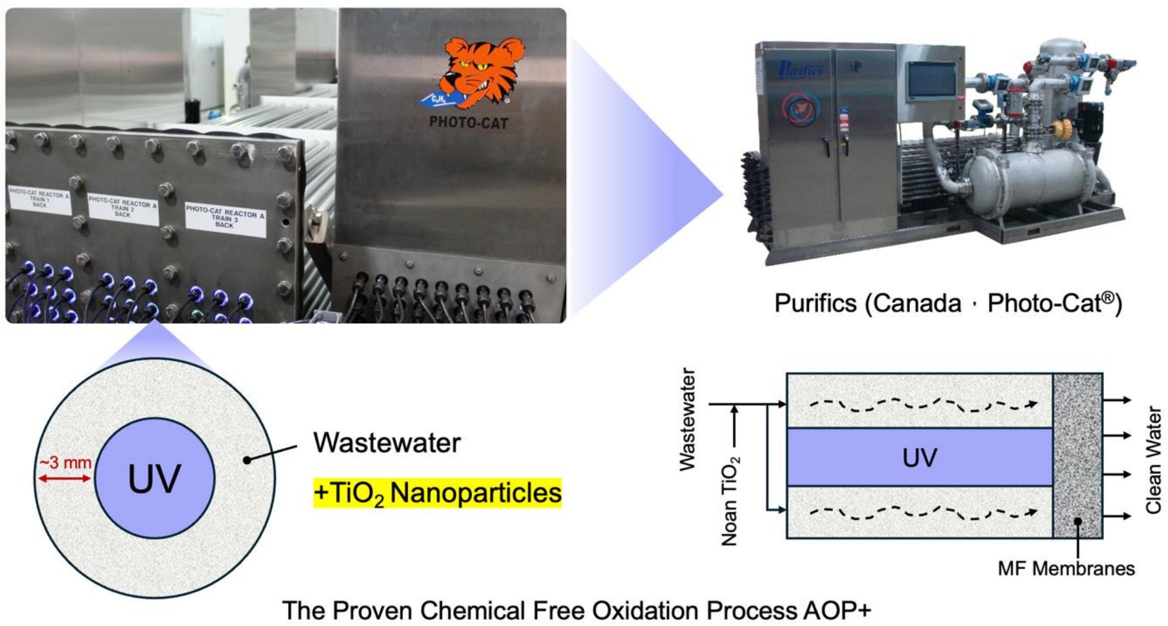
(2) Immobilized Photocatalytic Reactor

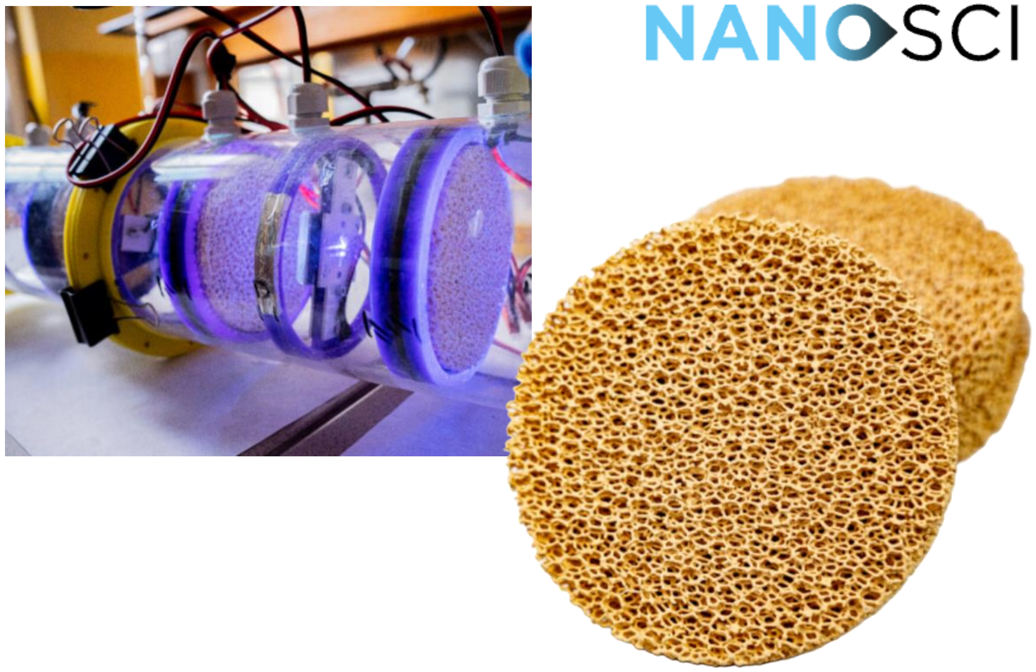
Chan et al. (2003)

Photocatalytic reactor configuration

(1) Reactors with suspended photocatalyst particles

(2) Reactors with photocatalyst immobilized onto continuous inert carrier





(1) Suspended-Slurry Photocatalytic Reactor

(2) Immobilized Photocatalytic Reactor

3D Printing Turns Reactor Geometry into a Design Variable

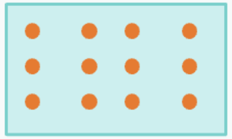
Photocatalytic reactor performance depends on two geometry-sensitive factors

1 **Irradiated catalyst surface area per unit reactor volume**

2 **Light distribution inside the reactor**

Traditional reactor trade-off

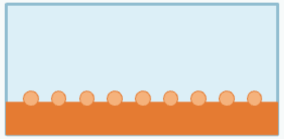
Slurry-type



+ High catalyst surface area

- Separation and light attenuation

Immobilized layer



+ Easy catalyst recovery

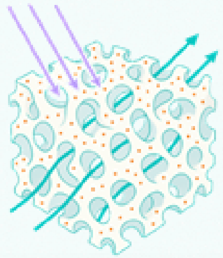
- Limited area and mass transfer

Conventional fabrication restricts reactor geometry

Adapted from Pareek et al., Asia-Pac. J. Chem. Eng. 3, 171-201 (2008). DOI: 10.1002/apj.129

3D-printed photocatalytic reactors

Geometry engineered for light and flow



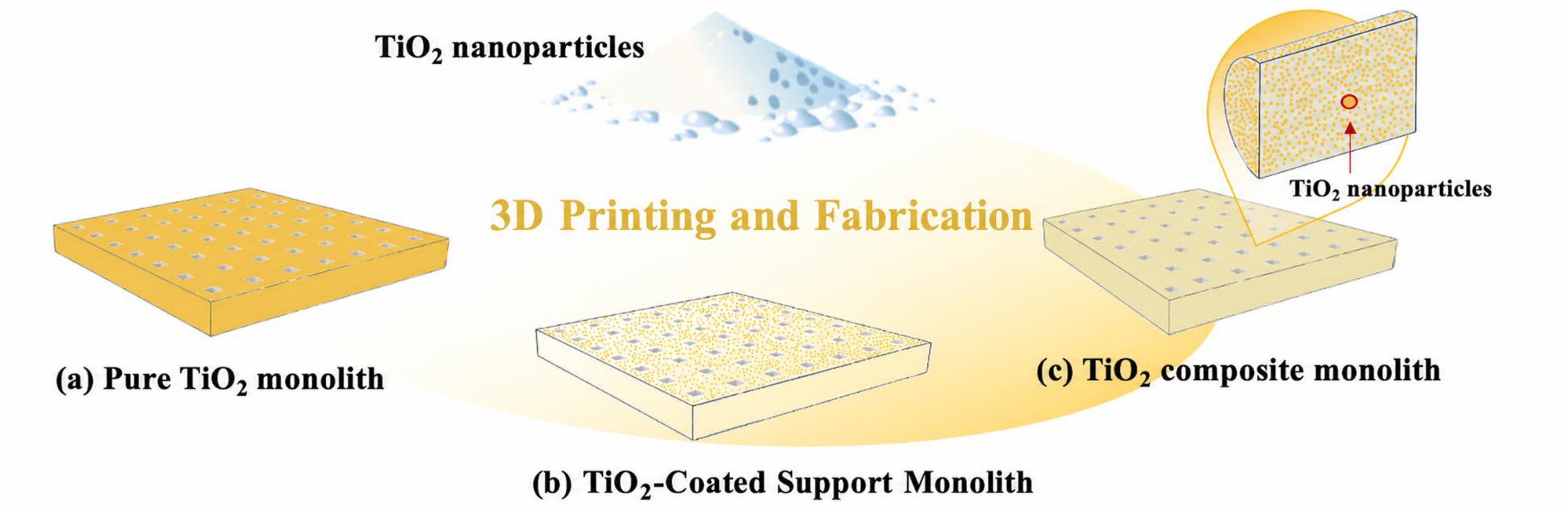
- **Engineered surface area**
  More illuminated active sites
- **Tailored light paths**
  Reduced dark zones and shielding
- **Optimized flow channels**
  Improved mixing and mass transfer
- **Monolithic architecture**
  Easy recovery and modular scale-up

High geometric freedom enables simultaneous optimization of light, surface area, and transport.

Geometry becomes a performance variable

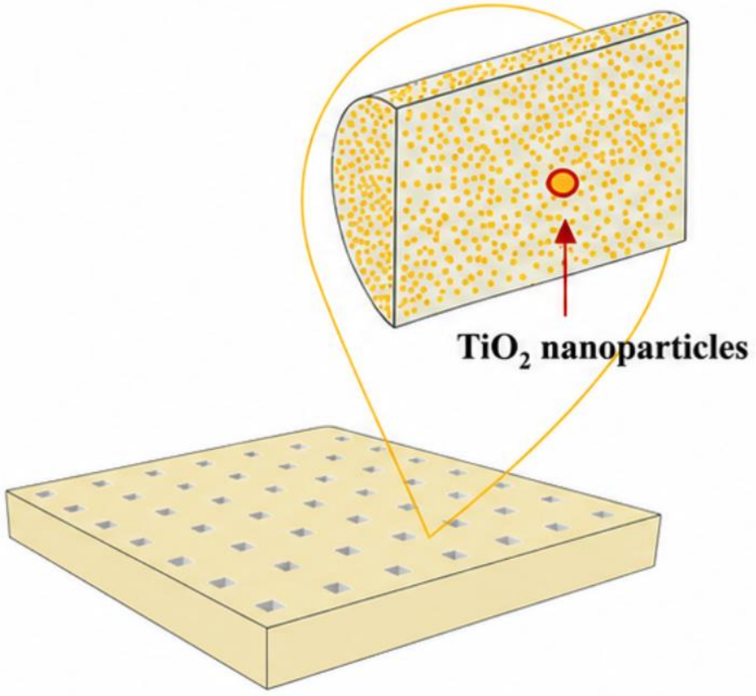
3D-Printed Immobilized Photocatalytic Monoliths

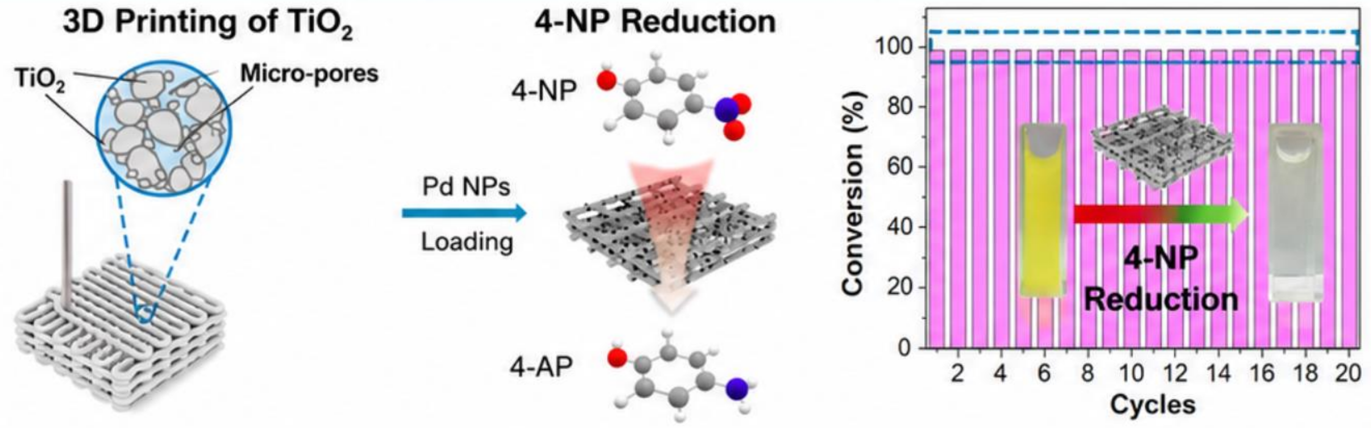
3D-printed immobilized photocatalyst monoliths can be classified into three categories according to how TiO_2 is incorporated into the supporting structure.



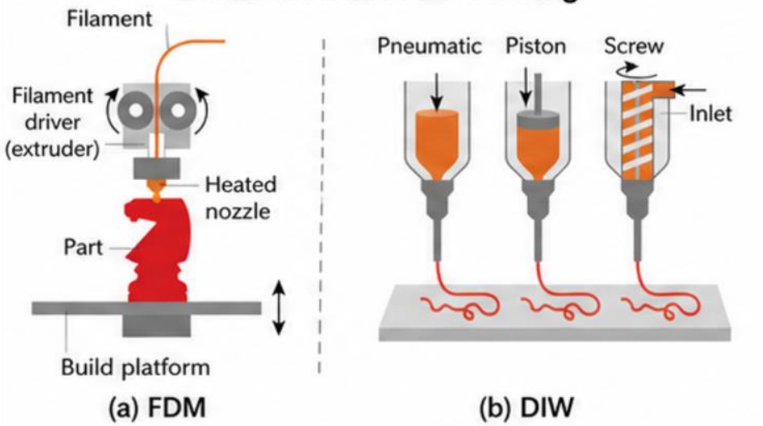
3D-Printed Immobilized Photocatalytic Monoliths

(c) 3D-Printed TiO_2 Composite Monolith





Liu et al., ACS Appl. Mater. Interfaces 12, 28100–28109 (2020)



Truby and Lewis, Nature 540, 371–378 (2016)

Advantages
- Low equipment cost
- Simple operation

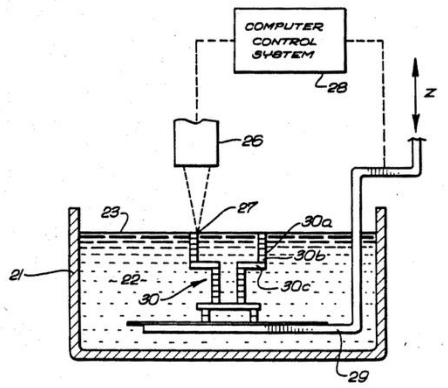
Limitations
- Limited printing resolution
- Slow printing speed

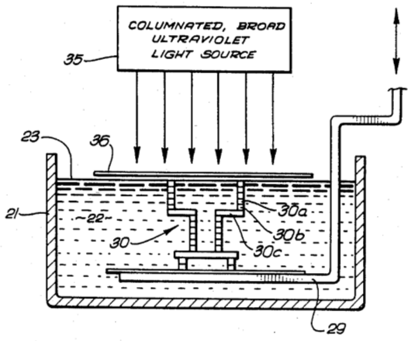
Need for higher resolution and faster fabrication → Vat Photopolymerization

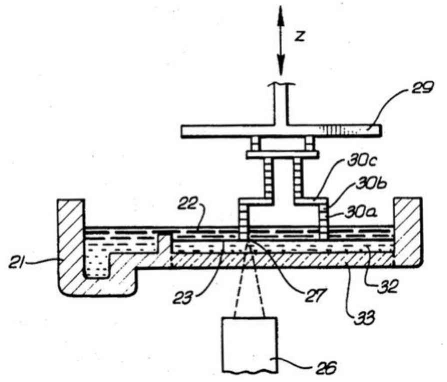
DLP 3D Printing

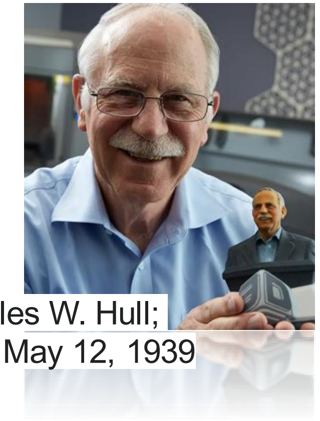
① Development History of 3DP

- Apparatus for production of three-dimensional objects by stereolithography (**1984**, US4575330A, 3D Systems Inc.)

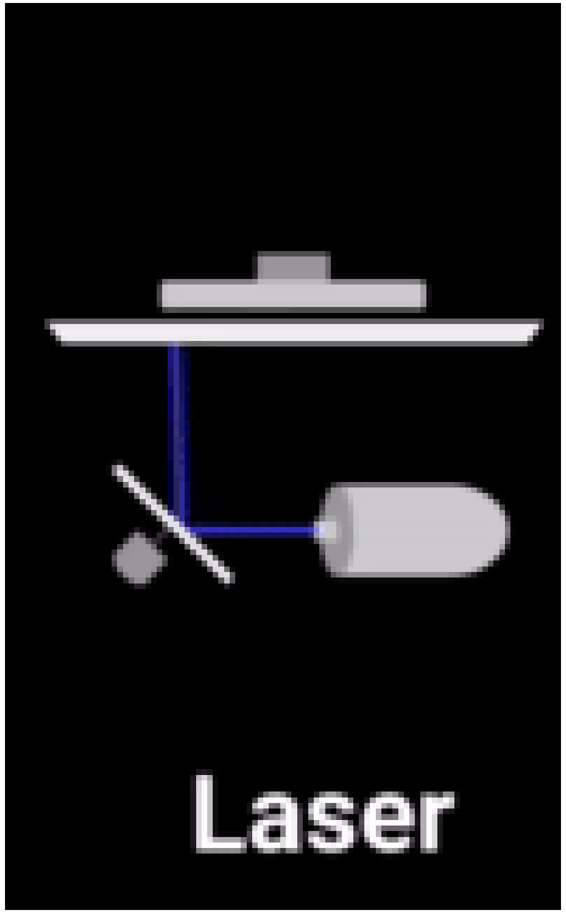






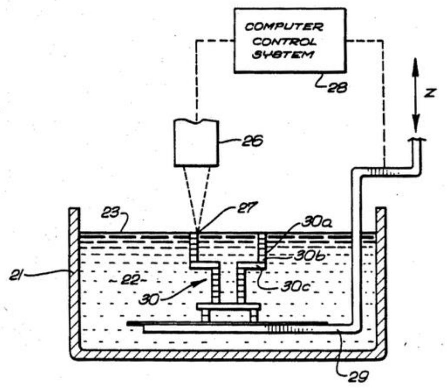

Charles W. Hull;
born May 12, 1939

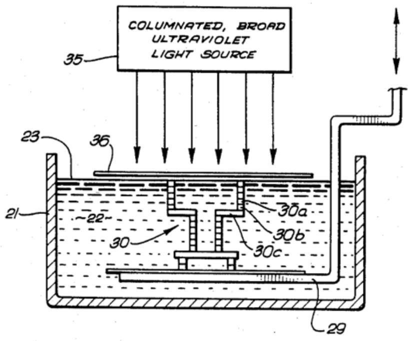
- Forming principle of the **S**tereo**L**ithography **A**pparatus (**SLA**)

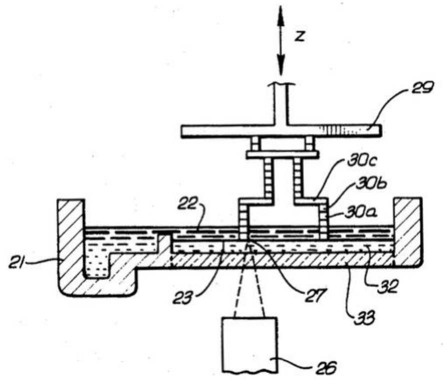


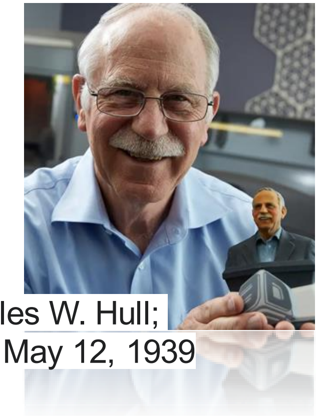
① Development History of 3DP

- Apparatus for production of three-dimensional objects by stereolithography (**1984**, US4575330A, 3D Systems Inc.)



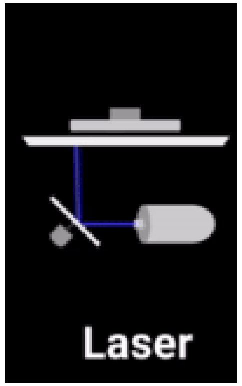


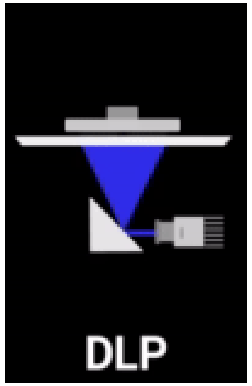


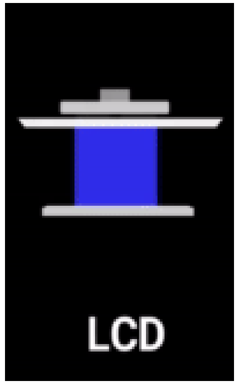


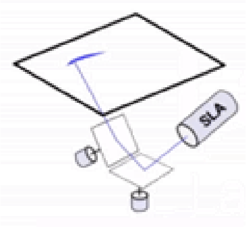
Charles W. Hull;
born May 12, 1939

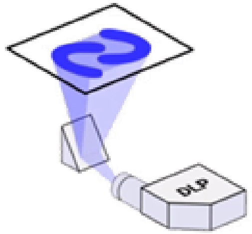
- Light source types (**Point** vs **Area**)

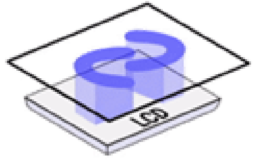












300-500 USD

✓ **Fastest**

Texas Instruments unveiled DLP projection technology in 1992

✓ **Cheapest**

LCD-based projection technologies became mature in the 2010s

Mass Production via DLP 3D Printing

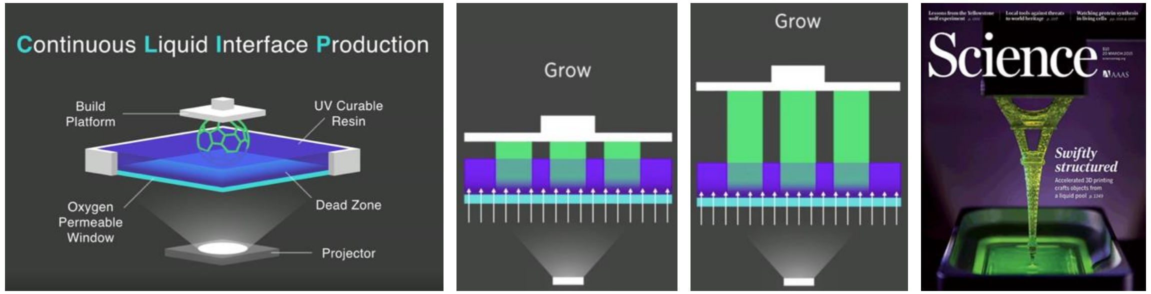
- **VP-based Digital Light Processing (DLP)**

vat photopolymerization, *n*—an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

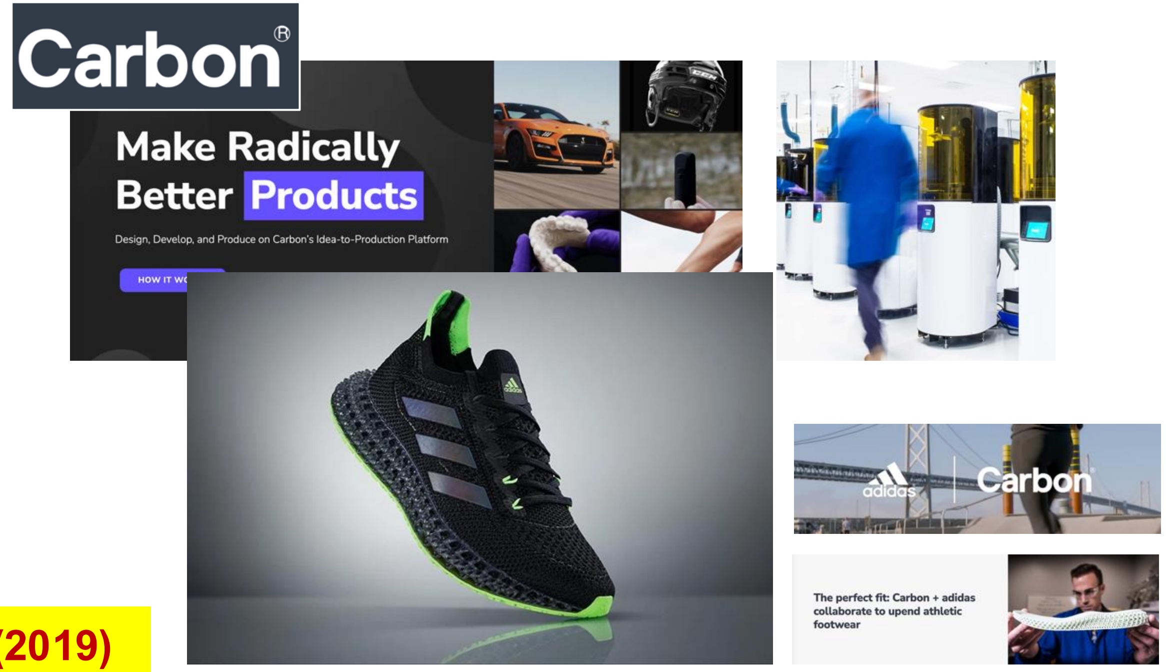
ASTM INTERNATIONAL Designation: F2792 – 12a

Last publicly reported valuation: approximately US$2.4 billion (2019)

- Photopolymer resin 3D printing: the most breakthrough technologies and leading companies



Joseph M. DeSimone, Science (1979). 347 (2015) 1349–1352



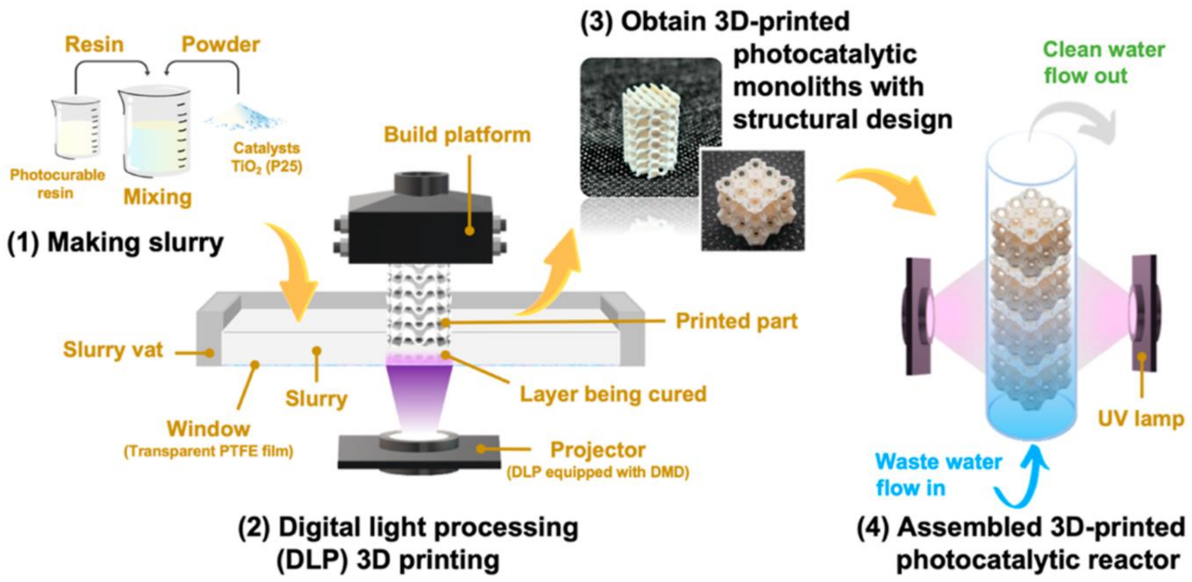
3D-Printed Photocatalytic Reactors

ACS ES&T Water

High-Efficiency Photocatalytic Reactors Fabricated via Rapid DLP 3D Printing: Enhanced Dye Photodegradation with Optimized TiO_2 Loading and Structural Design

Published as part of ACS ES&T Water virtual special issue "3D Printing Technologies for Environmental and Water Applications".

Chien-Hua Chen,* Shi-Cheng Wang, Hua-Wei Chen, Ting-Yi Chou, and Chieh-Sheng Chang



● Printability of the TiO_2 Slurry

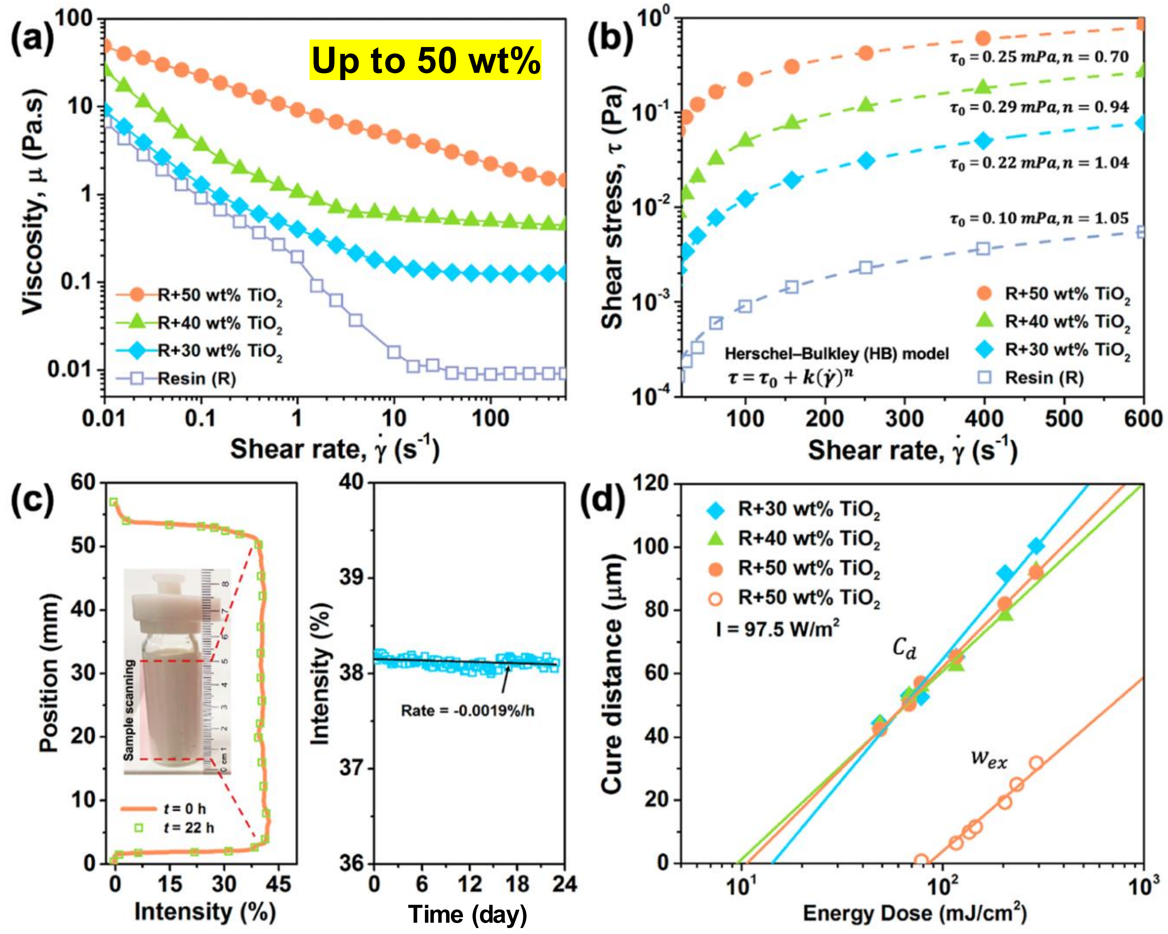
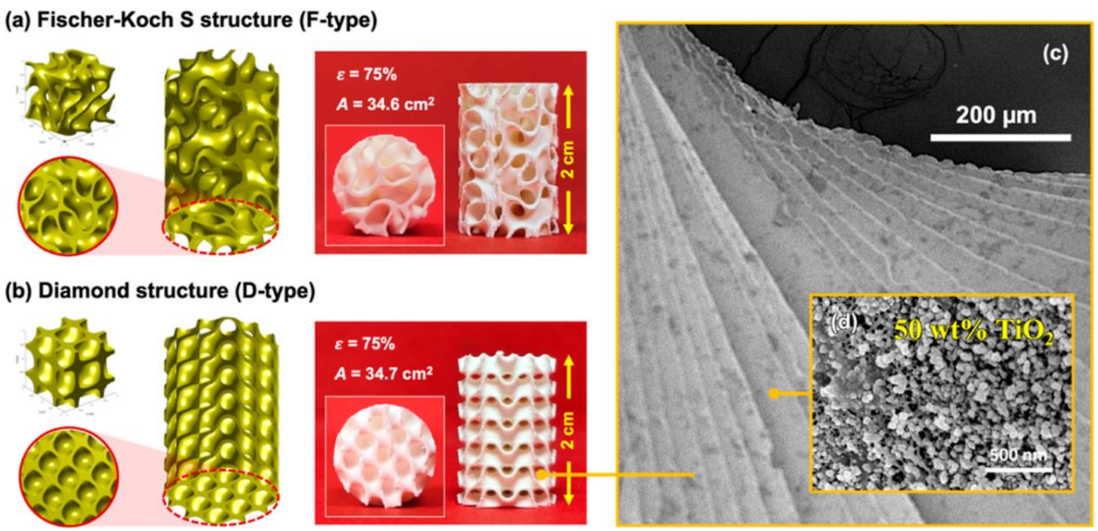
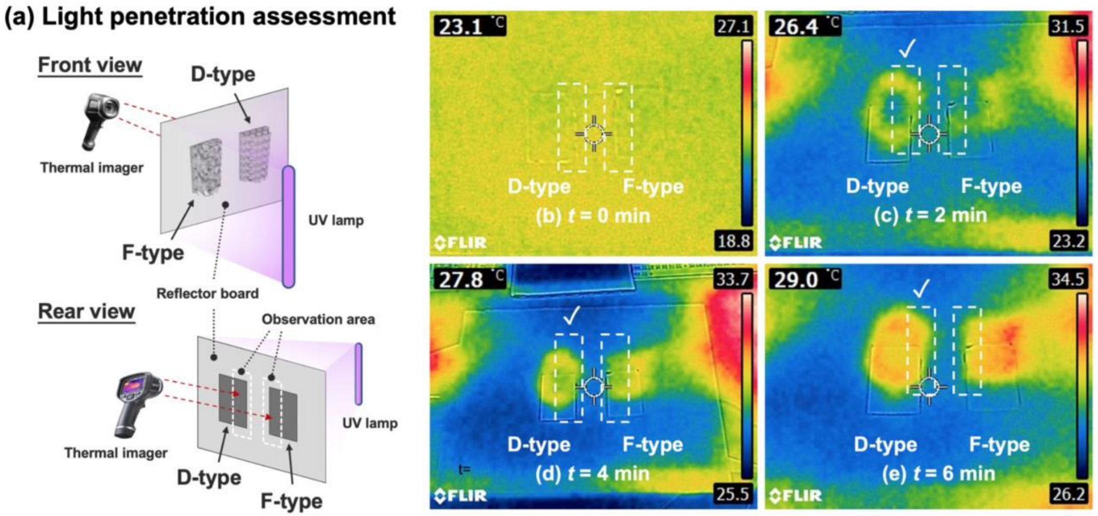


Figure 2. (a) Viscosity vs shear rate for slurries with different TiO_2 loadings; (b) shear stress vs shear rate for slurries with different TiO_2 loadings; (c) dispersion stability analysis for the slurry R+50 wt % TiO_2 by backscattering; (d) working curves and broadening curves of the prepared slurries.

Chen et al., ACS EST Water 2024, 4, 1883−1893

3D-Printed Photocatalytic Reactors





● Dye Photodegradation

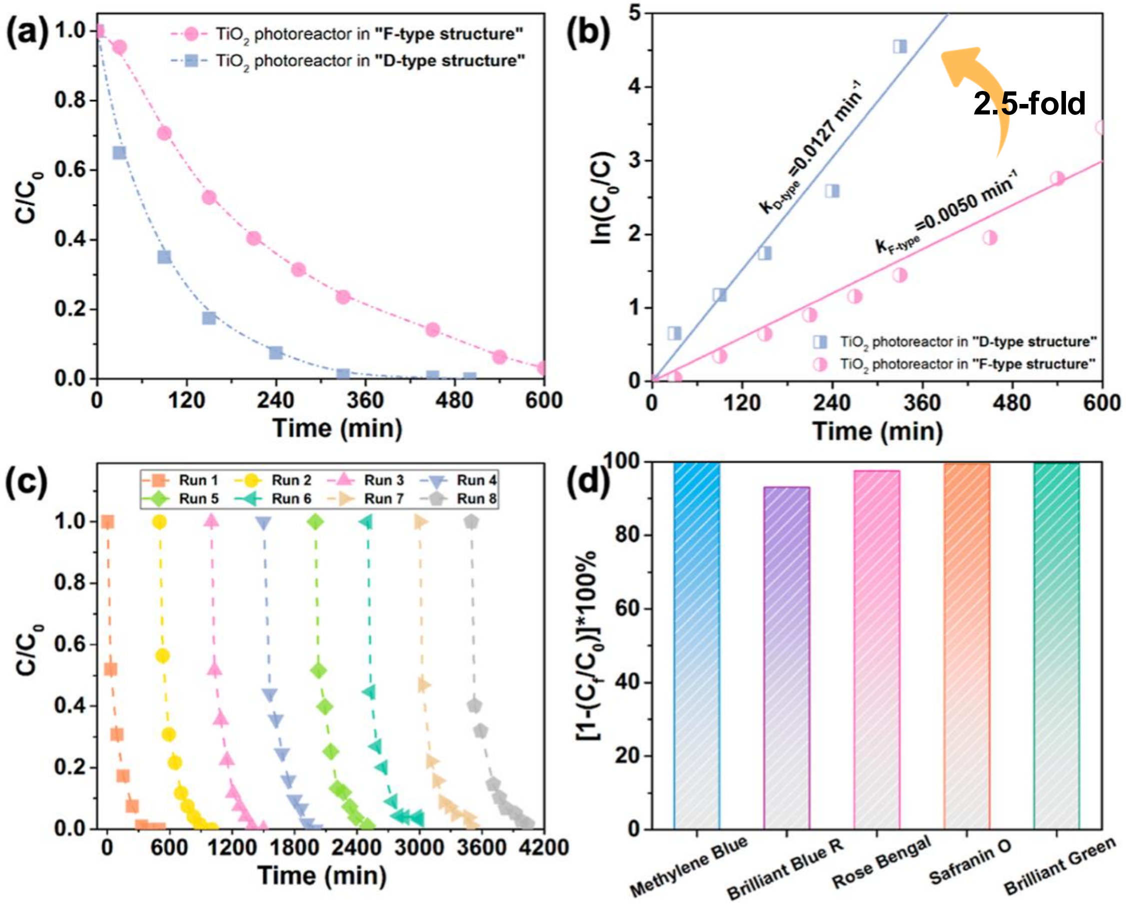
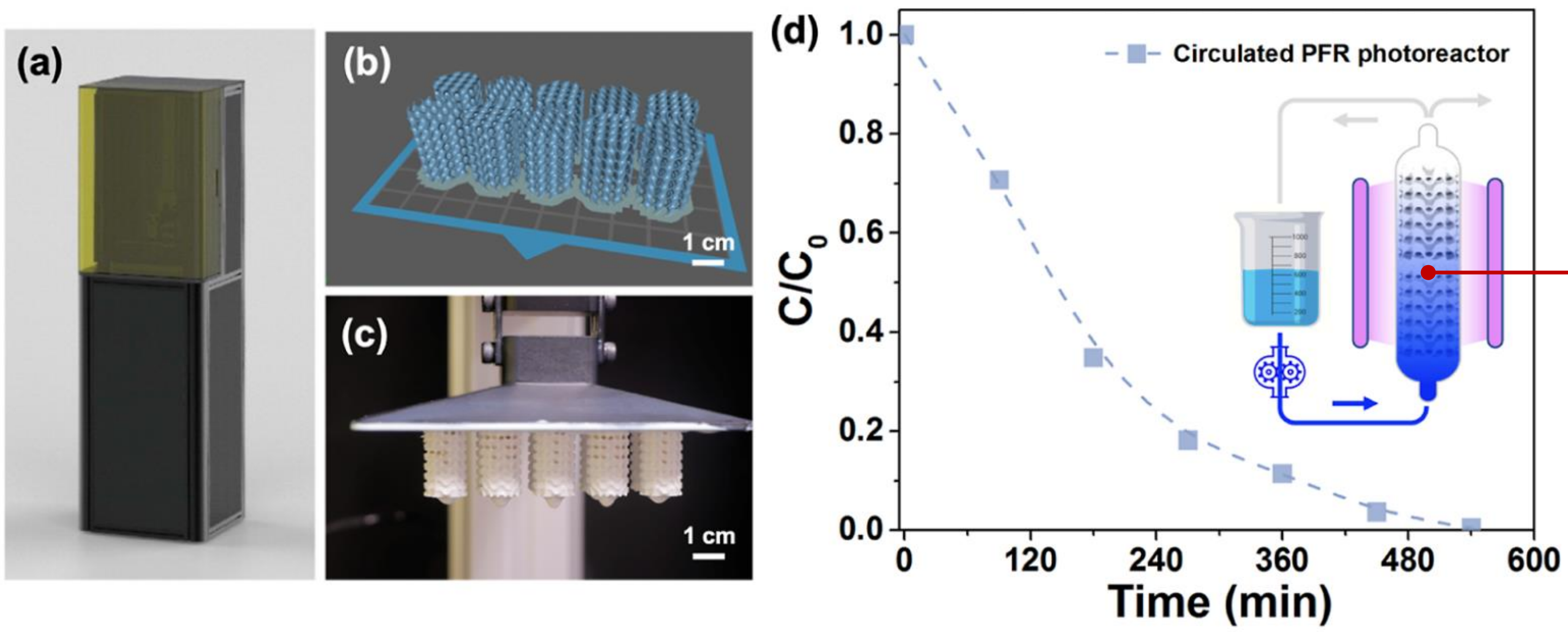
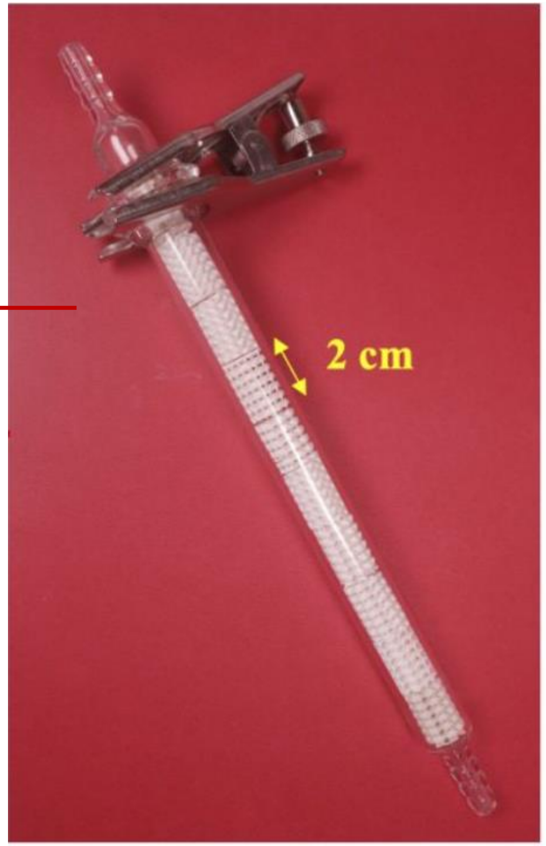


Figure 6. (a) Plot of C/C_0 vs time for the photodegradation reactions; (b) corresponding linear fitted plot of $\ln(C/C_0)$ vs time for pseudo-first-order kinetics using the 3D-printed reactors with different TPMS structures; (c) recycling photodegradation experiment; and (d) photodegradation study of the 3D-printed reactors toward various dyes.

Chen et al., ACS EST Water 2024, 4, 1883−1893

3D-Printed Photocatalytic Reactors





10 monoliths in series

中華民國發明第 I852762 號：
利用三維列印製作觸媒反應器
之製作方法。

Chen et al., ACS EST Water 2024, 4, 1883−1893

Photocatalytic solar hydrogen production from water on a 100-m^2 scale

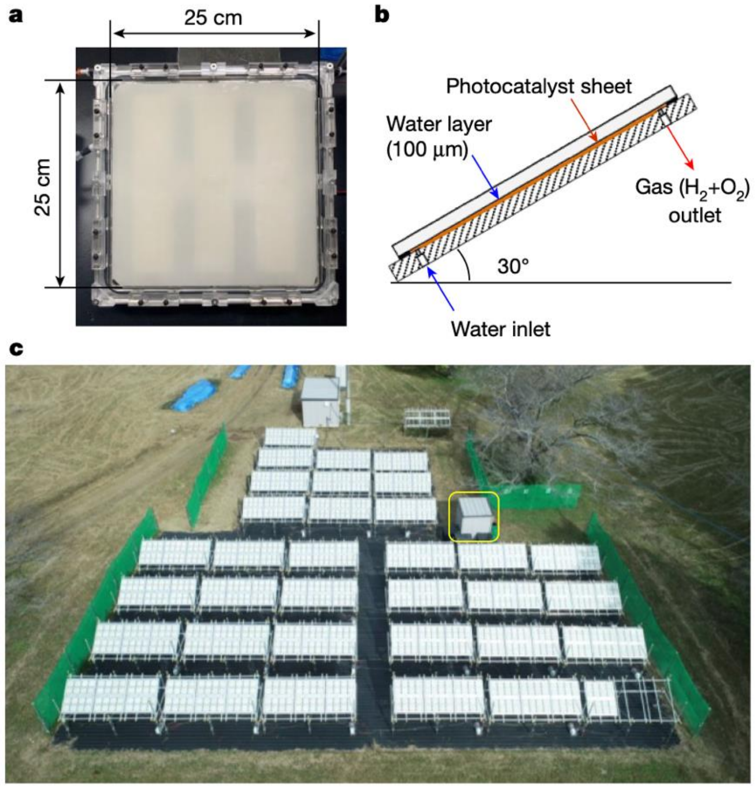
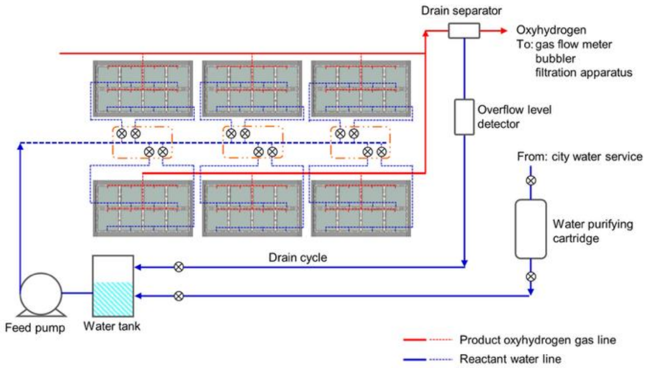


Fig. 1 | The 100-m^2 water splitting photocatalyst panel reactor. **a**, A photographic image of a panel reactor unit (625 cm^2). **b**, The structure of the panel reactor unit viewed from the side. **c**, An overhead view of the 100-m^2 solar hydrogen production system consisting of 1,600 panel reactor units and a hut housing a gas separation facility (indicated by the yellow box).



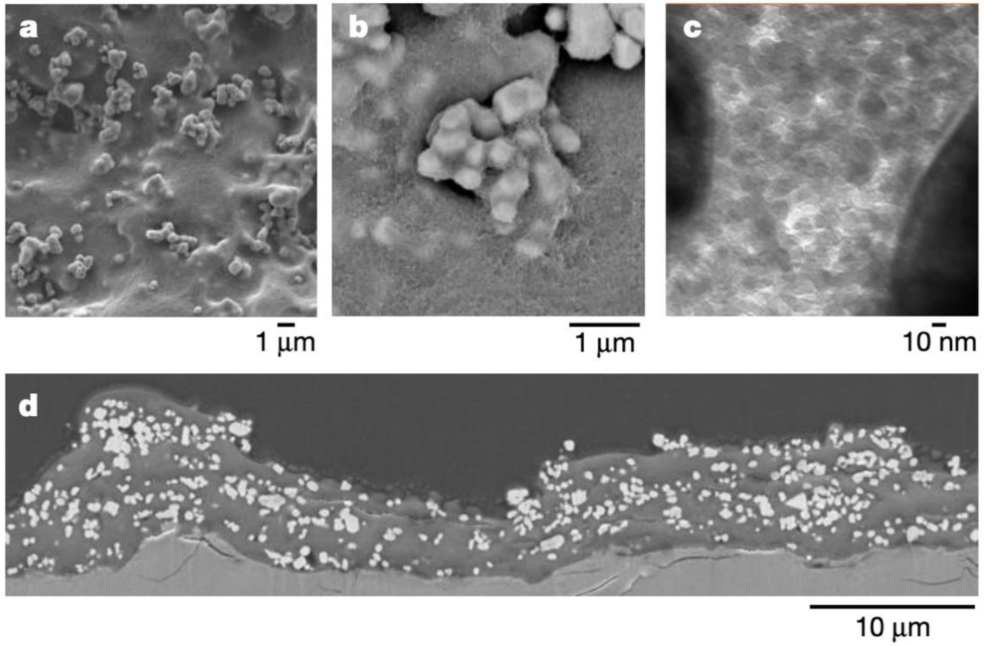
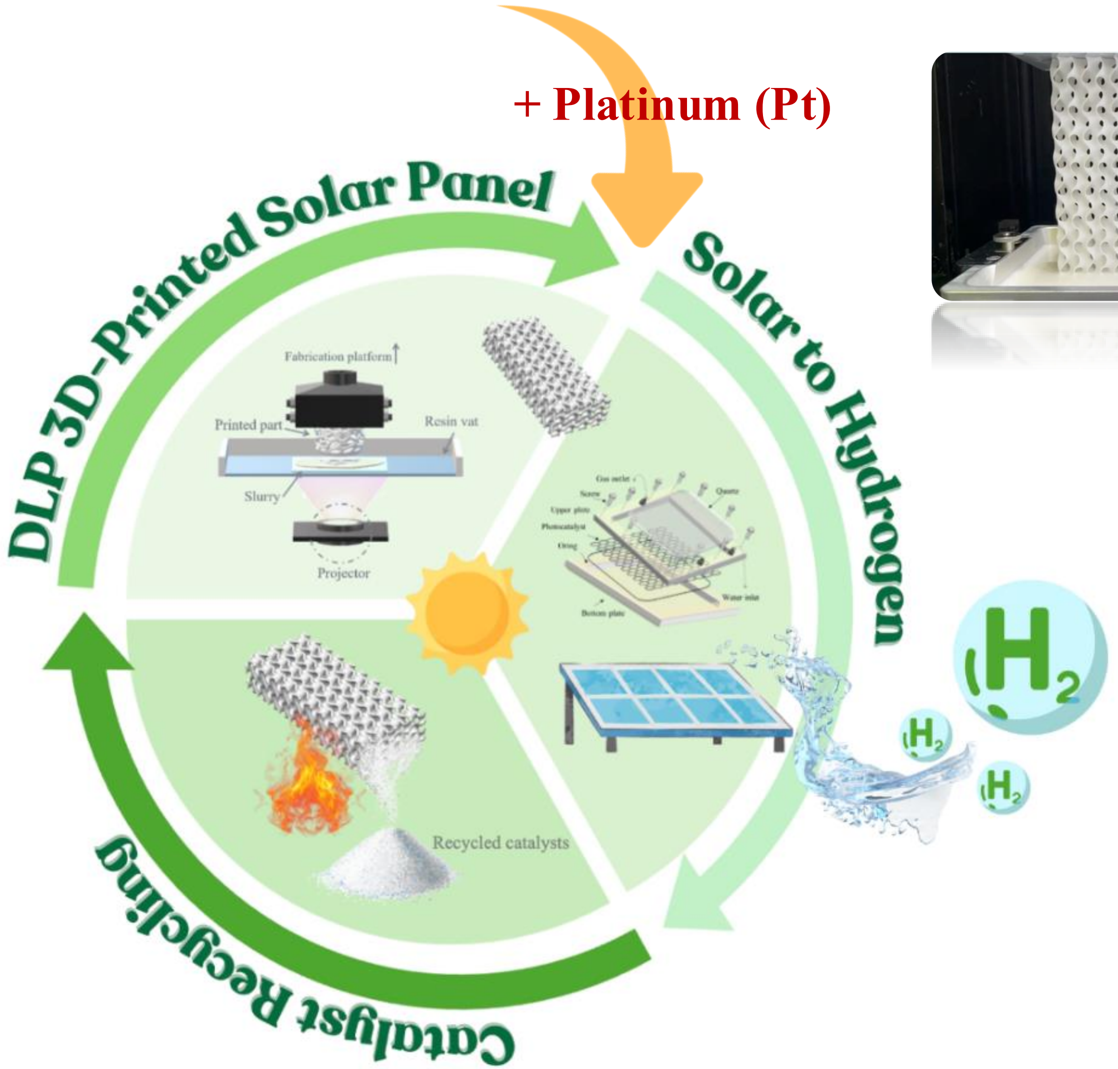
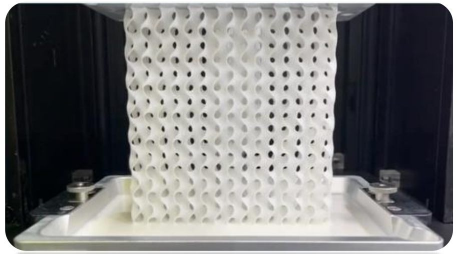


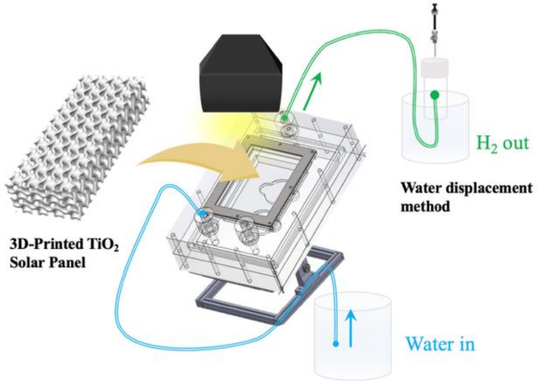
Fig. 2 | Electron microscopy images of photocatalyst sheets. **a**, **b**, Top-view secondary electron (**a**) and backscattered electron (**b**) images acquired by scanning electron microscopy. **c**, A cross-sectional image acquired by transmission electron microscopy. **d**, A cross-sectional backscattered electron image acquired by scanning electron microscopy. These specimens were fabricated by depositing the photocatalyst on frosted glass sheets using a program-controlled sprayer.

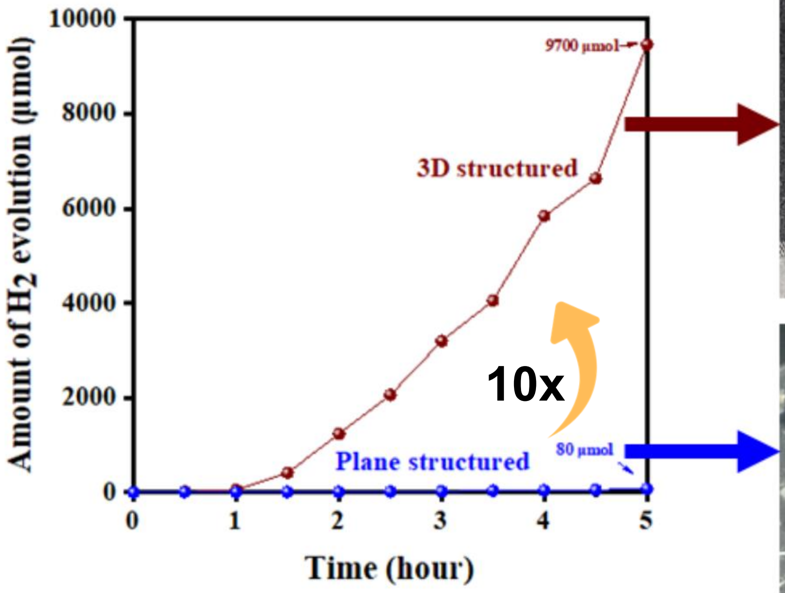
Kazunari Domen's group in the University of Tokyo, Nature, 598, 14 (2021).

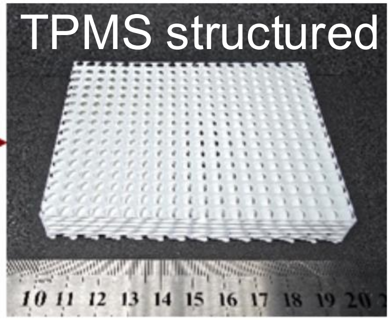
3D-Printed Photocatalytic Reactors for H_2 production

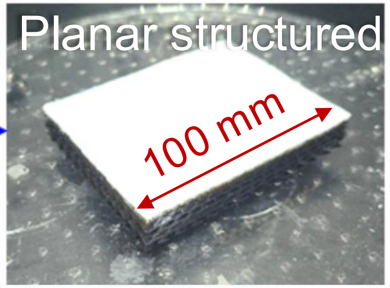






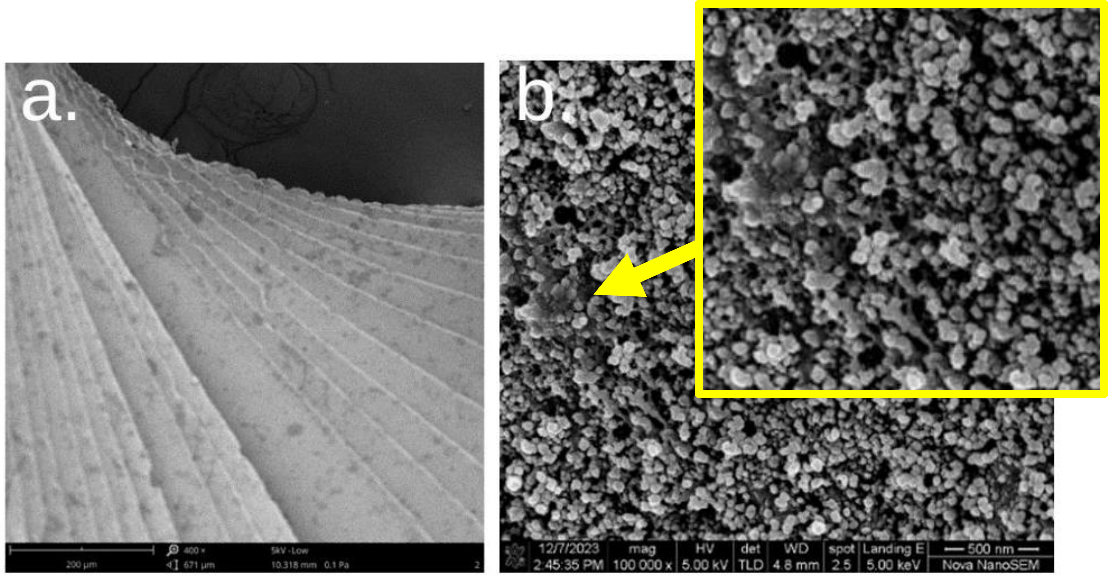


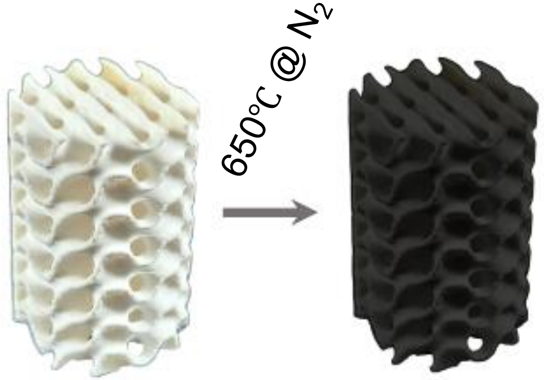




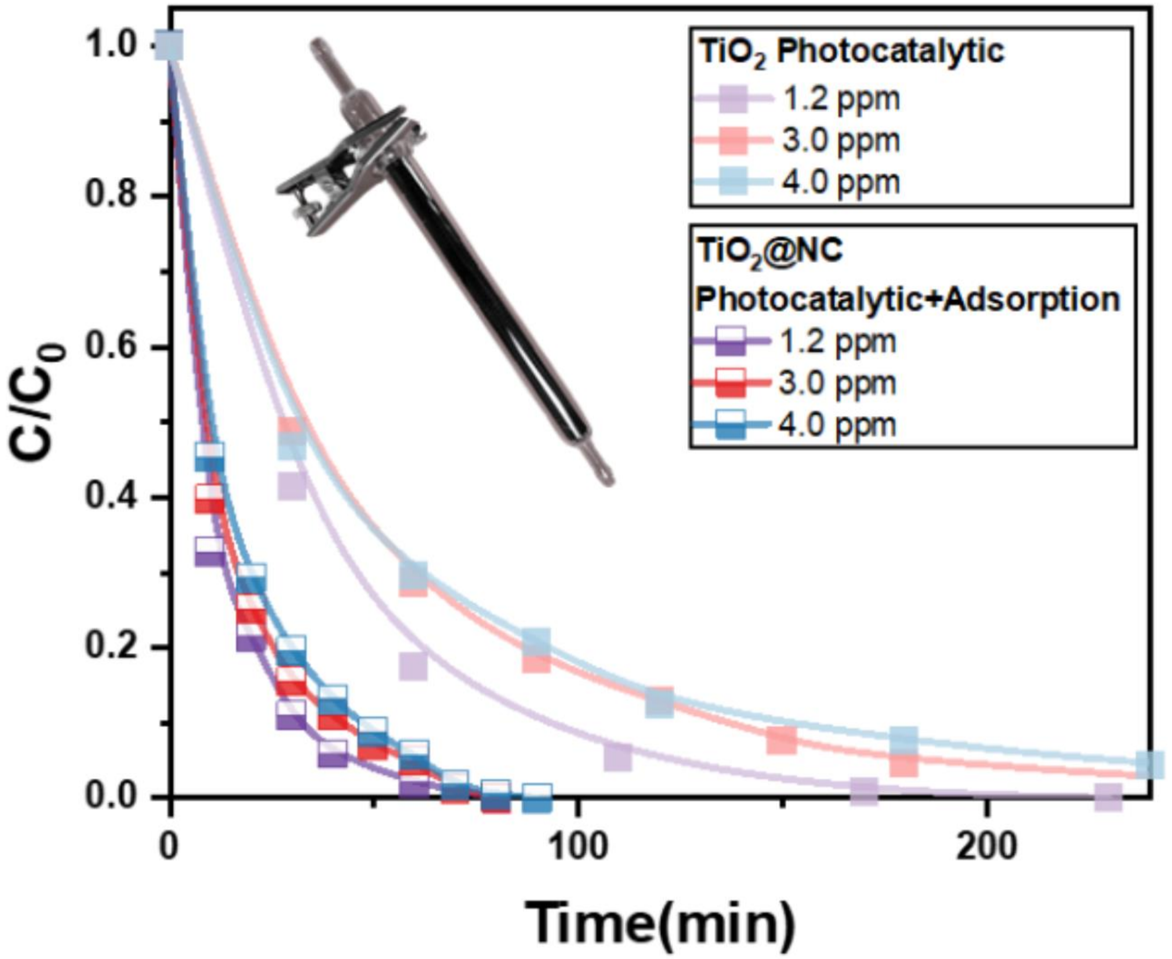
3D-Printed Photocatalytic Reactors

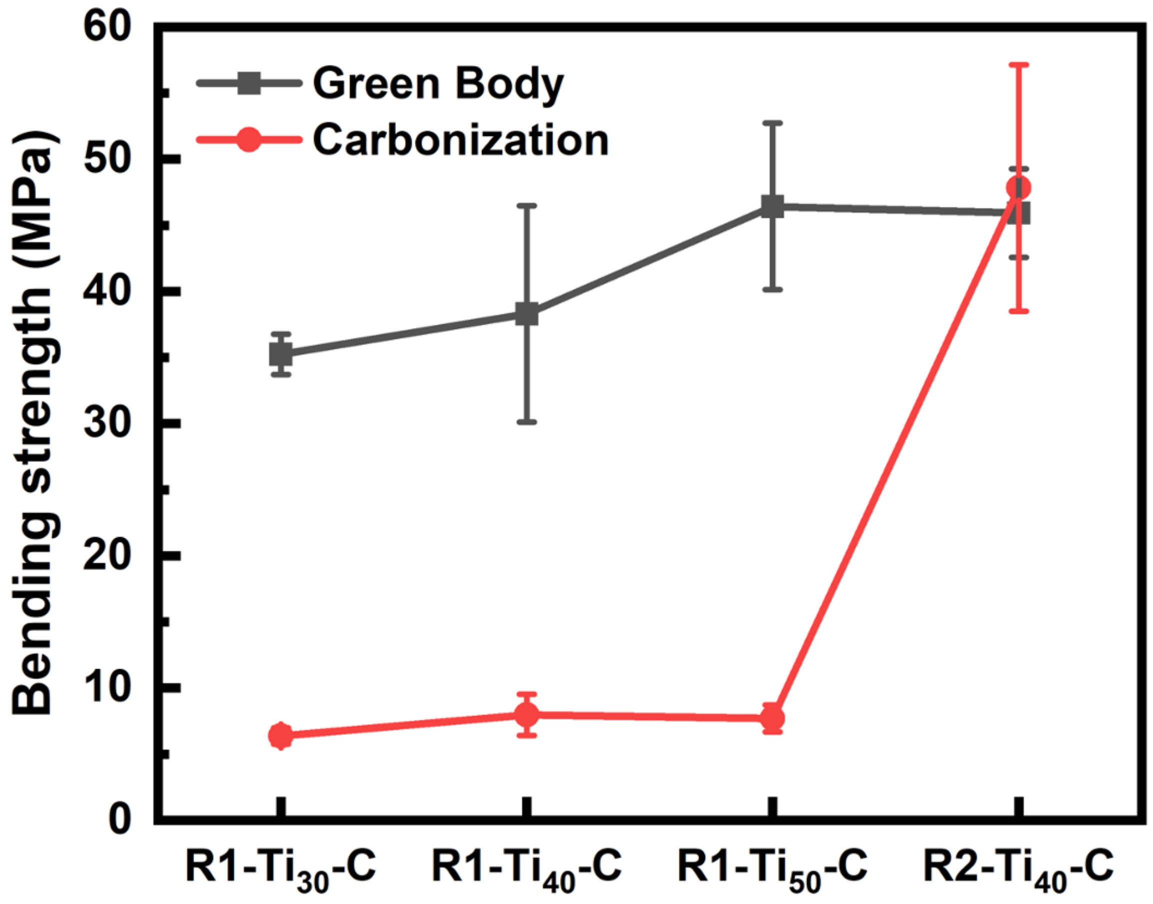
Sample	BET Surface Area (m²/g)	Total Pore Volume (cm³/g)	Micropore Volume (cm³/g)	Mesopore Volume (cm³/g)
TiO_2 powder (P25)	50 ± 15	–	–	–
3DP TiO_2	3.0386	0.0138	0.000304	0.0135





Carbonized 3D-Printed Photocatalytic Reactors

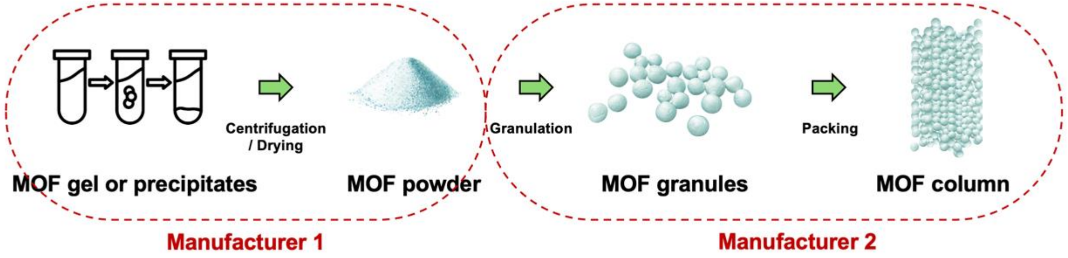




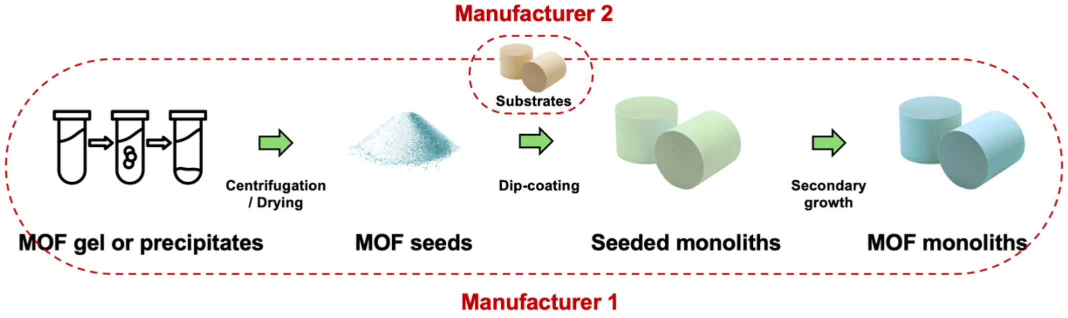
3D-Printed MOF Monoliths for Photocatalysis

Conventional approaches typically rely on:

1. **Conventional MOF Reactor Fabrication (I): Particle-Packed Bed Configuration**

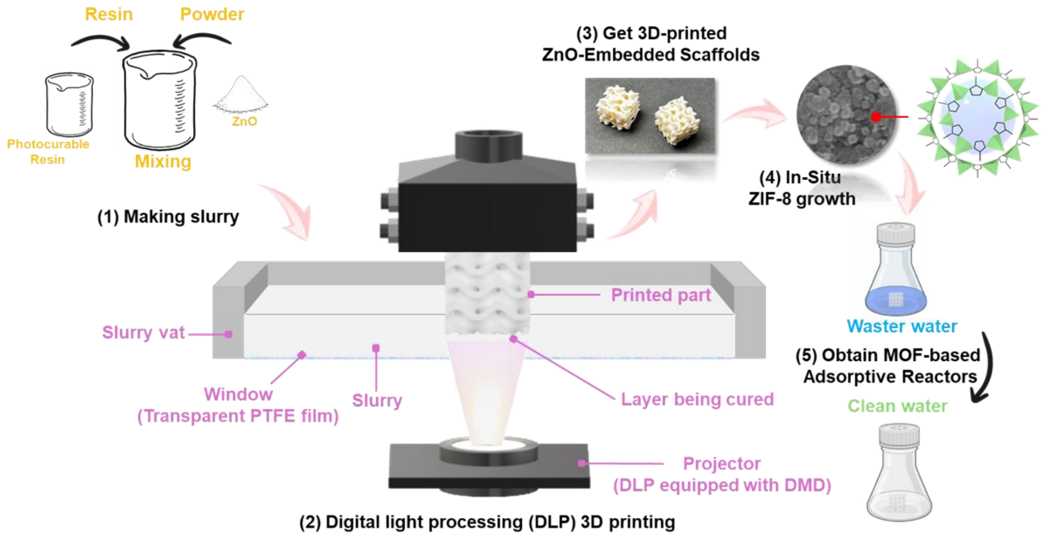


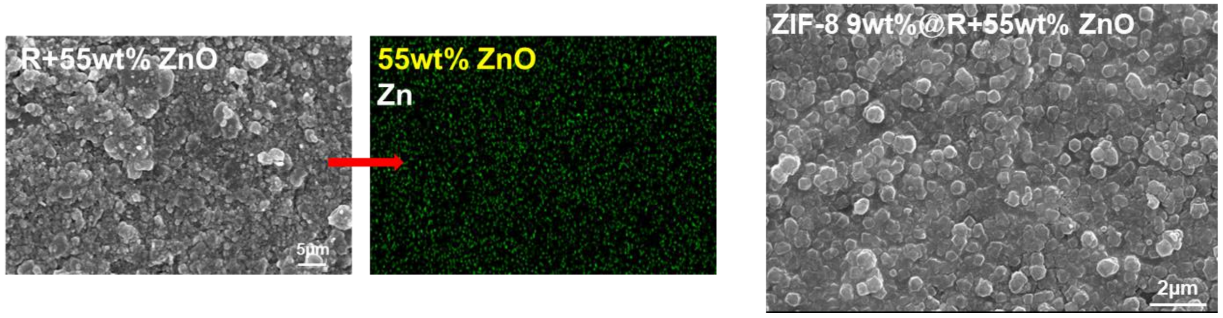
2. **Conventional MOF Reactor Fabrication (II): Heterogeneous Catalytic Reactor Configuration**



Limitations in mass transfer and structural controllability!

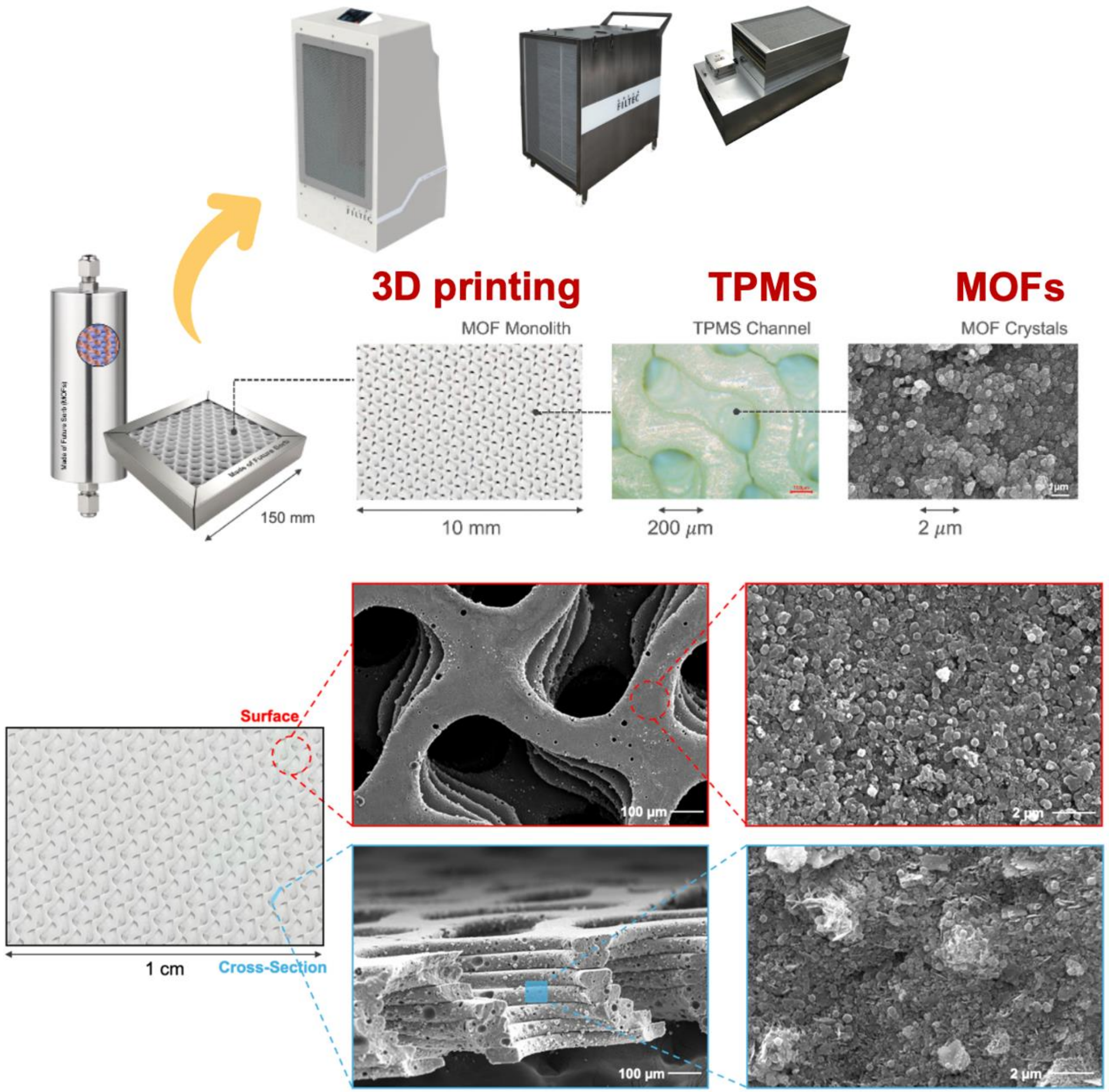
NEW | One-Stop Digital Manufacturing for Structured MOF Monoliths





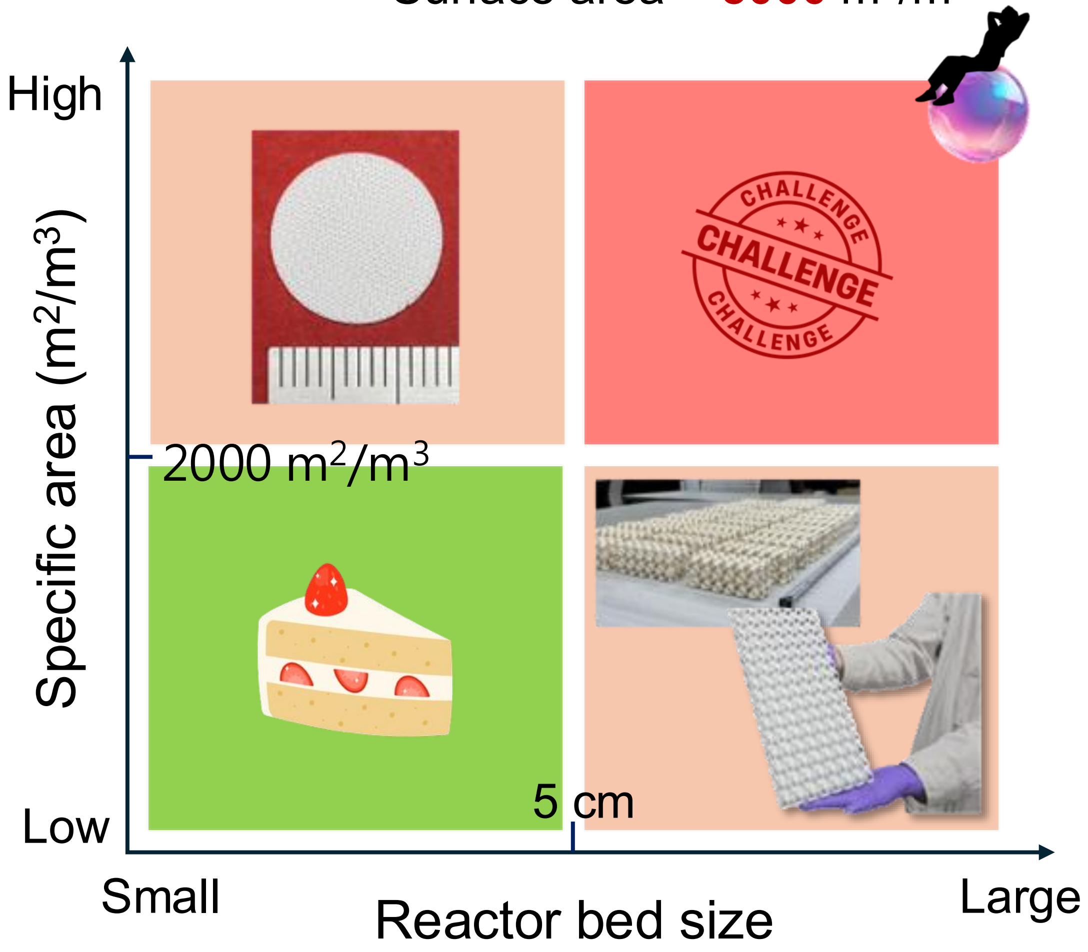
Chen et al., A Method for Fabricating a Metal-Organic Framework (MOF) Adsorption-Catalysis Reactor and Its Uses, Taiwan Patent (Approved, 2026.08.04)

3D-Printed MOF Monoliths for Photocatalysis



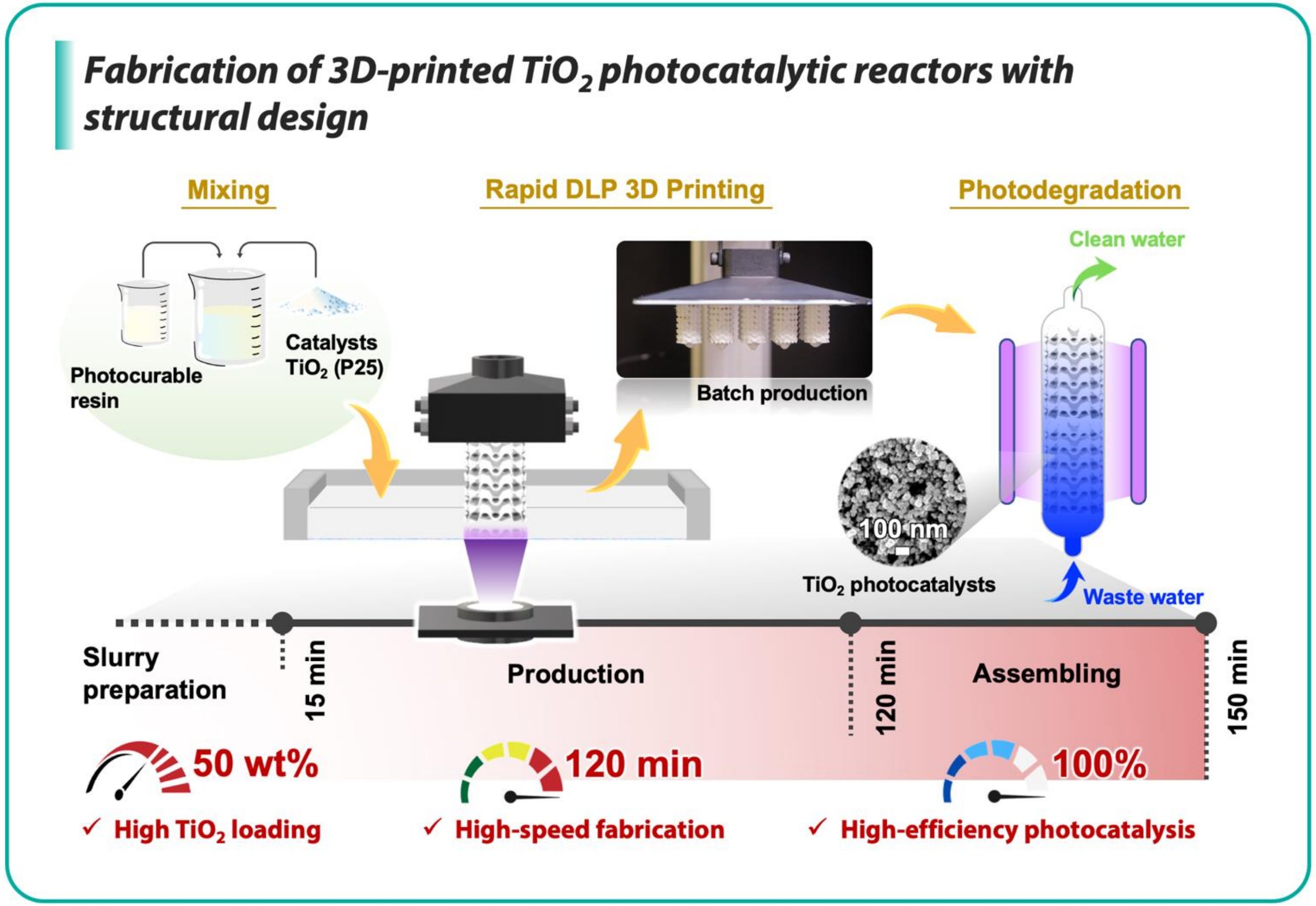
Bed size > 380 mm × **380** mm × **210** mm

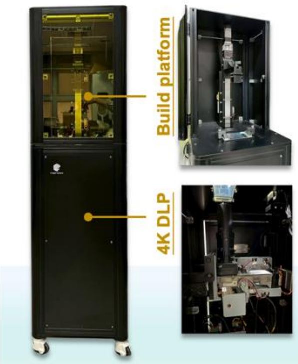
Surface area > **5000** m^2/m^3



Chen et al., A Method for Fabricating a Metal-Organic Framework (MOF) Adsorption-Catalysis Reactor and Its Uses, Taiwan Patent (Approved, 2026.08.04)

Summary





- ✓ Patented materials and processes
- ✓ Taiwan-developed 3D printing equipment
- ✓ 10+ catalyst-printable materials
- ✓ Scalable for mass production
- ✓ Licensing, collaboration, contract printing

🌟數位製造技術突破光觸媒反應器的傳統構型，提升光催化效率。

🌟可工業化的專利列印製程與配方。

🌟製程彈性敏捷，可加速新穎觸媒從開發到落地應用之進程。

Chen et al., ACS EST Water 2024, 4, 1883-1893 (IF: 4.8)

Acknowledgments

Students from AMPM Group @ NIU

翁于倫(NTUST)	姚秀美	郭明翰	Rafi
曾祥瑞	趙麒珍	張傑勝	HariharanNi
賴煜承	廖子熙	楊鈺祈	haal
王世昌	林信華	蔡銘駿	Ashwin
周庭儀	陳銘泓	張子健	Kanishkaa
賴鵬仁	盧達賢	徐譽恩	Mohith
林倫齊	李昀倩	藍宇晨	Vignesh
林昱廷	徐楷喆	邱栩晨	Nitthish
阮景寧	陳佳慶	林暉恩	Athul
葉祖豪	游俊祐	田宸瑋	Jewel
林宏任	黃至愷	陳丞澤	
	楊蔡政育	周晉民	
	廖偉捷	黃馨儀	
	賴靖方	陳妤喬	
	趙思淳	黃雅雯	

- **MOST 109-2222-E-197-001**
- **MOST 110-2221-E-197 -007 -MY2**
- **NSTC 112-2221-E-197-002-MY3**
- **Start fund from National Ilan University**
- **NSRRC PEC 2024-1-224-1, PXM**

NSTC 國家科學及技術委員會 National Science and Technology Council
NSRRC 國家同步輻射研究中心 National Synchrotron Radiation Research Center
國立宜蘭大學 National Ilan University NIU
ITRI Industrial Technology Research Institute
帆益科技 FREENTITY
porite

MADE OF

FUTURE SORB | THANK YOU

AMPM
ADDITIVE MANUFACTURING &
POROUS MATERIALS LABORATORY

TAIWAN TECH
NATIONAL TAIWAN UNIVERSITY OF
SCIENCE AND TECHNOLOGY