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Supplementary information

for

Photocatalytic Polymers of Intrinsic Microporosity for Hydrogen Production from Water

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1. General methods

All reagents were obtained from Sigma-Aldrich, TCI, ABCR, or Fluorochem and used as received. Polymer photocatalysts P2, P35 and S-CMP3 were made using previously reported procedures.^{1,2} Water for the hydrogen evolution experiments was purified using an ELGA LabWater system with a Purelab Option S filtration and ion exchange column ($\rho = 15 \text{ M}\Omega \text{ cm}$) without pH level adjustment, Inductively coupled plasma optical emission spectrometry (ICP-OES) analysis was performed on an ICP-OES Agilent 5110 with equipped with a collision/reaction cell after a microwave digest of the materials in nitric acid (67-69%, trace metal analysis grade) in a microwave. The solutions were diluted with water before the measurement and the instrument was calibrated with Pd standards in aqueous solution and Y-89 as the internal standard. Thermogravimetric analysis was performed on an EXSTAR6000 by heating samples at 10 °C min⁻¹ under air in open platinum pans from 25 to 800 °C. The UV-visible absorption spectra of the polymers were recorded on a Shimadzu UV-2550 UV-Vis spectrometer as powders in the solid state. Photoluminescence spectra of the polymer powders were measured with a Shimadzu RF-5301PC fluorescence spectrometer at room temperature. Time-correlated single photon counting (TCSPC) experiments were performed on an Edinburgh Instruments LS980-D2S2-STM spectrometer equipped with picosecond pulsed LED excitation sources and a R928 detector, with a stop count rate below 5%. An EPL-375 diode ($\lambda = 370.5$ nm, instrument response 100 ps, fwhm) was used. Suspensions were prepared by ultrasonicating the polymer in water. The instrument response was measured with colloidal silica (LUDOX® HS-40, Sigma-Aldrich) at the excitation wavelength. Decay times were fitted in the FAST software using suggested lifetime estimates. PXRD measurements were performed on a PANalytical X'Pert PRO MPD, with a Cu X-ray source, used in high throughput transmission mode with K α focusing mirror and PIXCEL 1D detector. Static light scattering measurements were performed on a Malvern Mastersizer 3000 Particle Sizer, polymers were dispersed in water/methanol/triethylamine (1:1:1) mixture by 10 minutes of ultrasonication and the resultant suspensions were injected into a stirred Hydro SV quartz cell, containing more of the water/methanol/triethylamine (1:1:1) mixture, to give a laser obscuration of 5–10%. Particle sizes were fitted according to Mie theory, using the Malvern 'General Purpose' analysis model, for non-spherical particles with fine powder mode turned on. A polymer refractive index of 1.59, polymer absorbance of 0.1 and solvent refractive index of 1.37 were used for fitting. Surface areas were measured by nitrogen adsorption and desorption at 77.3 K. Powder samples were degassed offline at 110 °C for 15 hours under dynamic vacuum (10⁻⁵ bar) before analysis. Isotherms were measured using a Micromeritics 2420 volumetric adsorption analyzer. Surface areas were calculated in the relative pressure (P/P_0) range from 0.01 to 0.10 of the adsorption branches.

Kinetic hydrogen evolution measurements. A flask was charged with the polymer powder (25 mg), water, triethylamine, methanol (1:1:1 vol. mixture, 25 mL), and sealed with a septum. The resulting suspension was ultrasonicated until the photocatalyst was dispersed before degassing thoroughly by N_2

bubbling for 30 minutes. The reaction mixture was illuminated with a 300 W Newport Xe light-source (Model: 6258, Ozone free) for the time specified at a fixed distance under atmospheric pressure. The Xe-light source was cooled by water circulating through a metal jacket. Gas samples were taken with a gas-tight syringe and run on a Bruker 450-GC gas chromatograph equipped with a Molecular Sieve 13X 60-80 mesh 1.5 m × $\frac{1}{8}$ " × 2 mm *ss* column at 50 °C with an argon flow of 40 mL min⁻¹. Hydrogen was detected with a thermal conductivity detector, referencing against standard gases with known concentrations of hydrogen. Hydrogen dissolved in the reaction mixture was not measured and the pressure increase generated by the evolved hydrogen was neglected in the calculations. The rates were determined from a linear regression fit and the error is given as the standard deviation of the amount of hydrogen evolved. No hydrogen evolution was observed for a mixture of water/methanol/triethylamine under $\lambda > 295$ nm illumination in absence of a photocatalyst.

Isotope labelling experiments. P38 (25 mg) was dispersed in a D_2O /triethylamine mixture (95:5, volume, 20 mL) by ultrasonication before degassing thoroughly by N_2 bubbling for 30 minutes. The mixture was placed in a quartz vessel and sealed in a reactor under nitrogen. The sample was illuminated with a 300 W Newport Xe light source (Model: 6258, Ozone free) for the time specified at a fixed distance under atmospheric pressure. The Xe light source was cooled by water circulating through a metal jacket. Gas samples from the 1.3 mL headspace of the reactor were analyzed at the time periods specified by a customized HPR-70 batch sampling system from Hiden Analytical using a HAL3F/301 triple filter mass spectrometer with a faraday detector for analysis.

External Quantum Efficiencies. EQEs were measured using LEDs controlled by an IsoTech IPS303DD power supply. The photocatalysts (12 mg) were suspended in water, triethylamine, methanol (1:1:1 vol. mixture, 8 mL). An area of 8 cm² was illuminated and the light intensity was measured with a ThorLabs S120VC photodiode power sensor controlled by a ThorLabs PM100D Power and Energy Meter Console. The external quantum efficiencies were estimated using the equation below:

 $EQE (\lambda) = 2 \times \frac{moles \ of \ hydrogen \ evolved}{moles \ of \ incident \ photons} \times 100\%$

(TD-)DFT Calculations. All (TD-)DFT calculations were performed using Turbomole 7.01, the m3 integration grid and the parameters given in the main text.

2. Monomer and polymer synthesis



Figure S-1. Synthesis of 5.

Compounds 2-5 were made using procedures previously reported by Chao et al.³:

Synthesis of 2: A 500 mL two-neck round-bottom flask was charged with magnesium turnings (3.4 g, 141 mmol) and a small piece of iodine. The flask was evacuated and refilled with argon three times. After addition of diethyl ether (200 mL), 2-bromothiophene (21.1 g, 129 mmol) were slowly added at 0 °C. The mixture was stirred at room temperature for 3 hours, resulting in a Grignard solution. In another 1 L three-neck round-bottom flask, [Pd(dppf)Cl₂] (898 mg, 1.2 mmol) were placed, and the flask was evacuated and refilled with argon three times. After addition of diethyl ether (300 mL) and 2,3-dibromothiophene (29.70 g, 123 mmol), the Grignard solution was slowly transferred to this flask. The mixture was stirred at room temperature overnight. Then, methanol was slowly added to quench the reaction, and the mixture was washed with water and extracted with diethyl ether. The combined organic layer was washed with brine and dried over MgSO₄. After solvent was evaporated, product was purified by column chromatography (silica gel, *n*-hexane). Compound **2** was obtained as colorless oil (27 g, 90%). ¹H NMR (CDCl₃, 400 MHz) δ : 7.03 (d, *J* = 5 Hz, 1H), 7.11 (m, 1H), 7.19 (d, *J* = 5 Hz, 1H), 7.36 (dd, *J* = 1 & 5 Hz, 1H), 7.43 (dd, *J* = 1 & 4 Hz, 1H). Anal. Calcd for C₈H₅BrS: C, 39.20; H, 2.06.



Synthesis of 3: A 100 mL two-neck round-bottom flask was evacuated and refilled with argon three times. After addition of diisopropylamine (2.60 g, 26 mmol) and THF (30 mL), *n*-BuLi in hexanes (2.6 M, 9.5 mL, 24.8 mmol) was added slowly at -78 °C. The mixture was stirred for 15 minutes. Then, compound 2 (2.76 g, 11.28 mmol) in THF (20 mL) was added to reaction mixture at -78 °C. After the mixture was stirred for 20 minutes, trimethylsilyl chloride (4.29 g, 39.5 mmol) was added at -78 °C. The mixture was stirred at room temperature for 1 hour, and then washed with water and extracted with dichloromethane three times. The combined organic layer was washed with brine and dried over MgSO4. After the solvent was evaporated, product was purified by column chromatography (silica gel, dichloromethane / *n*-hexane = 1/4). Compound **3** was obtained as colourless oil (4.2 g, 95%). ¹H NMR (CDCl₃, 400 MHz) δ : 0.35 (s, 9H), 0.37 (s, 9H), 7.13 (s, 1H), 7.22 (d, *J* = 4 Hz, 1H), 7.53 (d, *J* = 4 Hz, 1H). Anal. Calcd for C₁₄H₂₁BrS₂Si₂: C, 43.17; H, 5.43. Found: C, 43.24; H, 5.58.



Figure S-3. ¹H NMR spectrum of 3 in CDCl₃.

Synthesis of 4: A 200 mL two-neck round-bottom flask was charged with compound 8 (3.37 g, 8.7 mmol), and evacuated and refilled with argon three times. After addition of diethyl ether (50 mL), *n*-BuLi in hexanes (2.6 M, 3.4 mL, 8.7 mmol) was added slowly at -78 °C. The mixture was stirred at room temperature for 1 hour. Then, 2,7-dibromo-9-fluorenone (3.0 g, 8.7 mmol) was added into mixture at -78 °C, and the resulting solution was stirred at room temperature overnight. The mixture was washed with water and extracted with EtOAc three times. The combined organic layer was washed with brine and dried over MgSO₄. After the solvent was evaporated, product was purified by column chromatography (silica gel, dichloromethane / *n*-hexane = 1/3). Compound **4** was obtained as white solid (4.9 g, 88%). ¹H NMR (CDCl₃, 400 MHz) δ : 0.22 (s, 9H), 0.39 (s, 9H), 2.44 (s, 1H), 6.03 (d, *J* = 3 Hz, 1H), 6.63 (d, *J* = 3 Hz, 1H), 7.21 (d, *J* = 8 Hz, 2H), 7.35 (d, *J* = 2 Hz, 1H), 7.37 (d, *J* = 2 Hz, 1H), 7.42 (d, *J* = 1 Hz, 2H), 7.73 (s, 1H). Anal. Calcd for C₂₇H₂₈Br₂OS₂Si₂: C, 50.00; H, 4.35. Found: C, 49.68; H, 4.43.



Figure S-4. ¹H NMR spectrum of 4 in CDCl₃.

Synthesis of 5: A 500 mL two-neck round-bottom flask was charged with compound 9 (571 mg, 0.9 mmol). After addition of *n*-hexane (300 mL), CH₃COOH (25 mL) was added slowly at 60 °C, and the resulting mixture was stirred for 10 minutes. Then, H₂SO₄ (2.5 mL) was added into flask dropwise. The mixture was stirred at 60 °C for 2 hours and poured into NaHCO₃ solution. After the organic solvent was evaporated, the mixture of NaHCO₃ layer and concentrated organic layer was washed with water and extracted with EtOAc three times. The combined organic layer was washed with brine and dried over MgSO₄. After the solvent was evaporated, product was purified by column chromatography (silica gel, dichloromethane / *n*-hexane = 1/4). The compound **5** was obtained as white solid (400 mg, 87%). ¹H NMR (CDCl₃, 400 MHz) δ : 6.41 (d, *J* = 5 Hz, 2H), 6.96 (d, *J* = 2 Hz, 2H), 7.12 (d, *J* = 5 Hz, 2H), 7.49 (dd, *J* = 2 & 8 Hz 2H), 7.63 (d, *J* = 8 Hz, 2H). Anal. Calcd for C₂₁H₁₀Br₂S₂: C, 51.87; H, 2.07. Found: C, 51.83; H, 1.98.



Figure S-5. ¹H NMR spectrum of 5 in CDCl₃.

General procedure for the synthesis of all materials via Suzuki-Miyaura-type polycondensation in DMF: A flask was charged with the monomers, N,N-dimethylformamide, and an aqueous solution of K₂CO₃ (2 M). The mixture was degassed by bubbling with N₂ for 30 minutes, before [Pd(PPh₃)₄] was added and heated to 150 °C for 2 days. The mixture was cooled to room temperature and poured into water. The precipitate was collected by filtration and washed with H₂O and methanol. Further purification of the polymers was carried out by Soxhlet extraction with chloroform to remove any lowmolecular weight by-products and the product was dried under reduced pressure.



Synthesis of P36: 2,7-Dibromo-9,9-spirobifluorene (0.237 g, 0.5 mmol), 1,4-benzenediboronic acid bis(pinacol)ester (0.115 g, 0.5 mmol), *N*,*N*-dimethylformamide (30 mL), K_2CO_3 (2 M, 5.6 mL), and $[Pd(PPh_3)_4]$ (20 mg, 3.6 mol%) were used in this polycondensation reaction. After work-up and Soxhlet the product was obtained as a grey solid (127.2 mg, 81%). Anal. Calcd for $(C_{20}H_{16}Si)_n$: C, 95.35; H, 4.35%; Found C, 89.85; H, 4.65%. Pd content: 0.30%.



Synthesis of P37: Monomer 5 (0.243 g, 0.5 mmol), 1,4-benzenediboronic acid bis(pinacol)ester (0.115 g, 0.5 mmol), *N*,*N*-dimethylformamide (30 mL), K_2CO_3 (2 M, 5.6 mL), and $[Pd(PPh_3)_4]$ (20 mg, 3.6 mol%) were used in this polycondensation reaction. After work-up and Soxhlet the product was obtained as a dark green solid (184 mg, 81%). Anal. Calcd for $(C_{28}H_{24})_n$: C, 80.56; H, 3.51; S, 15.93%; Found C, 75.81; H, 3.54; S: 14.88%. Pd content: 0.86%.



Synthesis of P38: 2,7-Dibromo-9,9-spirobifluorene (0.237 g, 0.5 mmol), 3,7-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)dibenzo[*b*,*d*]thiophene sulfone (0.234 g, 0.5 mmol), *N*,*N*-dimethylformamide (30 mL), K_2CO_3 (2 M, 5.6 mL), and [Pd(PPh_3)_4] (20 mg, 3.6 mol%) were used in this polycondensation reaction. After work-up and Soxhlet the product was obtained as a black solid (87 mg, 44%). Anal. Calcd for ($C_{53}H_{36}$)_{*n*}: C, 84.07; H, 3.81, S, 6.06%; Found C, 78.40; H, 3.80, S, 5.67%. Pd content: 0.42%.



Synthesis of P39: Monomer 5 (0.243 g, 0.5 mmol), 3,7-bis(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)dibenzo[*b*,*d*]thiophene sulfone (0.234 g, 0.5 mmol), *N*,*N*-dimethylformamide (22 mL), K₂CO₃ (2 M, 4.1 mL), and [Pd(PPh₃)₄] (14.5 mg, 3.6 mol%) were used in this polycondensation reaction. After work-up and Soxhlet the product was obtained as a grey solid (71 mg, 54%). Anal. Calcd for $(C_{20}H_{16})_n$: C, 73.31; H, 2.98; S, 17.79%; Found C, 67.47; H, 3.15; S, 16.11%. Pd content: 0.64%.

3. UV-Vis Spectra



Figure S-6. Absorption spectra of polymers measured in the solid-state.



Figure S-7. Tauc plots for the polymers based on measurements in the solid-state.

4. Photoluminescence spectra



Figure S-8. Photoluminescence spectra of all polymer photocatalysts measured as powders in the solidstate ($\lambda_{exc} = 350$ nm).

5. Powder X-ray diffraction



Figure S-9. PXRD patterns of the polymers.

6. Sorption isotherms



Figure S-10. Nitrogen sorption isotherm for **P38** (left) and **P37** (right) measured at 77.3 K and up to 1 bar (desorption curves shown as open symbols).



Figure S-11. Nitrogen sorption isotherm for **P39** (left) and **P36** (right) measured at 77.3 K and up to 1 bar (desorption curves shown as open symbols).





Figure S-12. Fluorescence life-time decays of P36 and P37 in THF suspension.



Figure S-13. Fluorescence life-time decays of P38 and P39 in THF suspension.



Figure S-14. Fluorescence life-time decays of P2 and P10 in THF suspension.

	τ ₁	B ₁	τ ₂	B ₂	τ ₃	B ₃	2	τ _{AVG}
Polymer	/ ns	/ %	/ ns	/ %	/ ns	/ %	χ-	/ ns
P2	0.06	0.43	0.57	74.59	0.67	24.99	1.30	0.59
P10	0.88	73.42	3.43	21.91	14.18	4.67	1.17	2.06
P38	0.28	32.35	0.67	66.37	2.922	1.28	1.15	0.58
P37	0.04	18.33	0.65	79.79	2.17	1.89	1.09	0.56
P39	0.36	30.64	1.04	61.34	3.35	8.02	1.34	1.01
P36	0.11	8.60	0.26	31.78	0.45	59.62	0.93	0.36

Table S-1. Estimated fluorescence lifetimes for all materials in THF suspension.

[a] Fluorescence life-times for all polymers in THF suspension obtained from fitting time-correlated single photon counting decays to a sum of three exponentials, which yield τ_1 , τ_2 , and τ_3 according to

$$\sum_{i=1}^{n} (A + B_i exp^{\text{ind}}(-t/\tau_i)).$$

$$\tau_{AVG} \text{ is the}$$

e weighted average lifetime calculated as
$$\sum_{i=1}^{n} B_i \tau_i$$
.



Figure S-15. Fluorescence life-time decays of P2 and P7 in TEA/MeOH/H₂O suspension.



Figure S-16. Fluorescence life-time decays of P10 and P35 in TEA/MeOH/H₂O suspension.



Figure S-17. Fluorescence life-time decays of P36 and P37 in TEA/MeOH/H₂O suspension.



Figure S-18. Fluorescence life-time decays of P38 and P39 in TEA/MeOH/H₂O suspension.



Figure S-19. Fluorescence life-time decays of S-CMP3 in TEA/MeOH/H₂O suspension.

	τ_1	B ₁	$ au_2$	B ₂	τ ₃	B ₃	2	τ _{AVG}
Polymer	/ ns	/ %	/ ns	/ %	/ ns	/ %	χ²	/ ns
P2	0.102	84.68	0.502	13.87	4.818	1.44	0.691	0.23
P7	0.206	57.44	0.765	35.26	3.186	7.29	0.843	0.62
P10	0.196	64.39	0.808	28.01	3.815	7.59	0.9	0.64
P35	0.111	72.01	0.465	24.58	2.471	3.41	0.743	0.28
P36	0.024	95.15	0.287	4.35	2.644	0.49	0.784	0.048
P37	0.226	68.26	0.607	29.36	3.394	2.38	0.705	0.41
P38	0.017	99.27	0.366	0.64	2.526	0.095	0.591	0.022
P39	0.359	5.45	1.548	0.90	7.109	0.39	0.853	0.65
S-CMP3	0.026	92.79	0.37	5.46	1.459	1.74	0.678	0.070

Table S-2. Estimated fluorescence lifetimes for all materials in TEA/MeOH/H₂O suspension.

[a] Fluorescence life-times for all polymers in TEA/MeOH/H₂O suspension obtained from fitting timecorrelated single photon counting decays to a sum of three exponentials, which yield τ_1 , τ_2 , and τ_3

according to
$$\sum_{i=1}^{n} (A + B_i exp^{init}(-t/\tau_i)).$$

 τ_{AVG} is the v

 τ_{AVG} is the weighted average lifetime calculated as $i = 1^n B_i \tau_i$.

8. Static light scattering



Figure S-20: Static light scattering experiments of polymers in H₂O/MeOH/TEA.

Tabl	e S-3.	Particl	e sizes	by	static	ligh	nt scattering
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Daluman	$D_x 50^{[a]}$	D [4,3] ^[b]	D[3,2] ^[c]	Relative external surface area ^[d]	
rotymer	/ μm	/ μm	/ μm	$/ m^2 kg^{-1}$	
P36	15.6	15.7	7.63	786.1	
P37	8.91	9.73	5.40	1110	
P38	9.70	11.0	4.61	1302	
P39	5.12	6.37	3.45	1741	

[a] 50th percentile of particle size volume distribution; [b] Volume mean diameter; [c] Surface area mean diameter (Sauter mean diameter);^{5,6} [d] Relative extrinsic surface area calculated by dividing the total surface area of the particles by the total mass, assuming a density of 1 g cm⁻³.

9. Thermogravimetric analysis



Figure S-21: Thermogravimetric analysis of the polymers in air with a heating rate of 10 °C min⁻¹.

10. Pore Size Distribution

11.Scanning Electron Microscopy



Figure S-22: SEM images of P36 (left) and P37 (right).



Figure S-23: SEM images of P38 (left) and P39 (right).

12. Hydrogen evolution experiments



Figure S-24: Photocatalytic hydrogen evolution of **P36**, **P37** and **P39** from water/methanol/triethylamine mixtures under a visible light (25 mg photocatalyst in 25 mL, 300 W Xe light source, $\lambda > 420$ nm).



Figure S-25: Hydrogen evolution of **P38** (10 mg photocatalyst) from a water/methanol/triethylamine mixture (1:1:1, 25 mL) in the dark for the first 3 hours followed by illumination under visible light (300 W Xe light source, $\lambda > 420$ nm).



Figure S-26: Time course of the gas production of **P38** (25 mg) in a D₂O/triethylamine mixture (95:5, volume, 20 mL). The reactions were carried out under visible illumination (Newport 300 W Xe light source, $\lambda > 420$ nm) with side-illumination through a quartz window, Partial pressures were measured by mass spectrometry.



Figure S-27: Photocatalytic hydrogen evolution of **P38** loaded with additional of 0.5 wt. % and 1 wt. % palladium by photodeposition of $[Pd(NH_4)_2Cl_4]$ under a visible light (25 mg photocatalyst in 25 mL water/methanol/triethylamine, 300 W Xe light source, $\lambda > 420$ nm).

13. Photocatalytic stability



Figure S-28: Solid-state UV-vis and photoluminescence spectra of **P38**. After 30 hours under visible light irradiation ($\lambda > 420$ nm, 300 W Xe light source) showing no significant changes.



Figure S-29: Transmission FT-IR spectra of P38. After 30 hours under visible light irradiation (λ > 420 nm, 300 W Xe light source) showing no significant changes when compared to the as synthesized material.

14. HER vs materials properties



Figure S-30: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus BET surface area of photocatalysts.



Figure S-31: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in $TEA/MeOH/H_2O$ mixture under a visible light plotted versus predicted EA of photocatalysts.



Figure S-32: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus predicted EA^{*} of photocatalysts.



Figure S-33: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H2O mixture under a visible light plotted versus predicted IP of photocatalysts.



Figure S-34: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus optical gaps of photocatalysts.



Figure S-35: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus particle size of photocatalysts.



Figure S-36: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in $TEA/MeOH/H_2O$ mixture under a visible light plotted versus Pd content of photocatalysts.



Figure S-37: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus the PL lifetime of the photocatalysts in THF.



Figure S-38: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in $TEA/MeOH/H_2O$ mixture under a visible light plotted versus the PL lifetime of the photocatalysts in $TEA/MeOH/H_2O$ mixture.



Figure S-39: Photoluminescence life-time of the polymer photocatalysts in THF and the water/methanol/TEA reaction mixture used in the experiments.



Figure S-40: Photocatalytic hydrogen evolution rates (HER) of the polymer photocatalysts in TEA/MeOH/H₂O mixture under a visible light plotted versus transmittance of photocatalysts.



Figure S-41: Optical gap of catalyst from calculations plotted against the optical gap of the catalyst as determined by experimental measurement.



Figure S-42: Polymers suspended in TEA/MeOH/H₂O mixture (concentration = 1 mg mL⁻¹).

15. References

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