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SUPPLEMENTARY INFORMATION

CO_2 adsorption-desorption performance of mesoporous zirconium hydroxide with robust water durability

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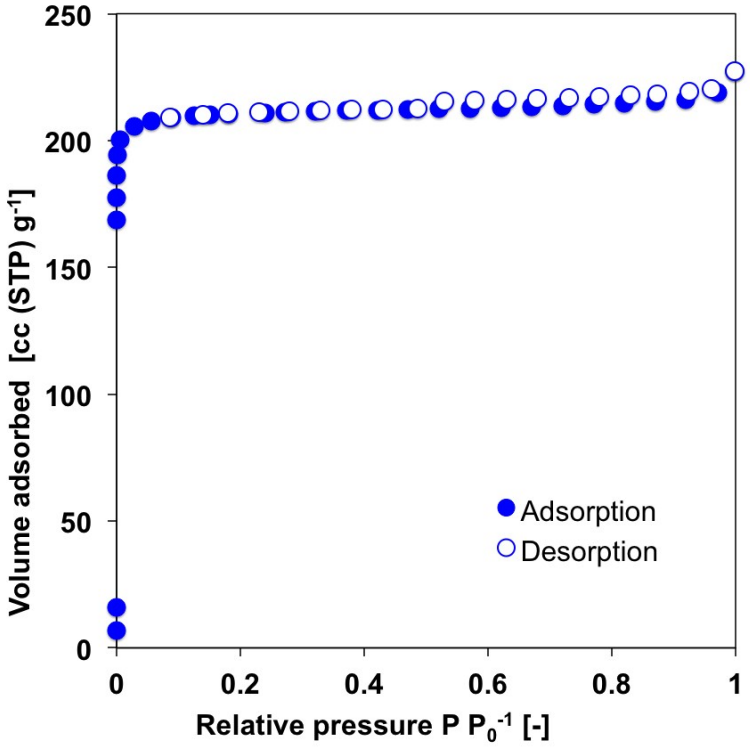

Figure S1. N_2 adsorption–desorption isotherms at 77.4 K obtained from the zeolite 13X. Filled and open symbols indicate the adsorption and desorption points, respectively. Prior to the measurement, the sample was degassed at 673 K for 8 h under vacuum.

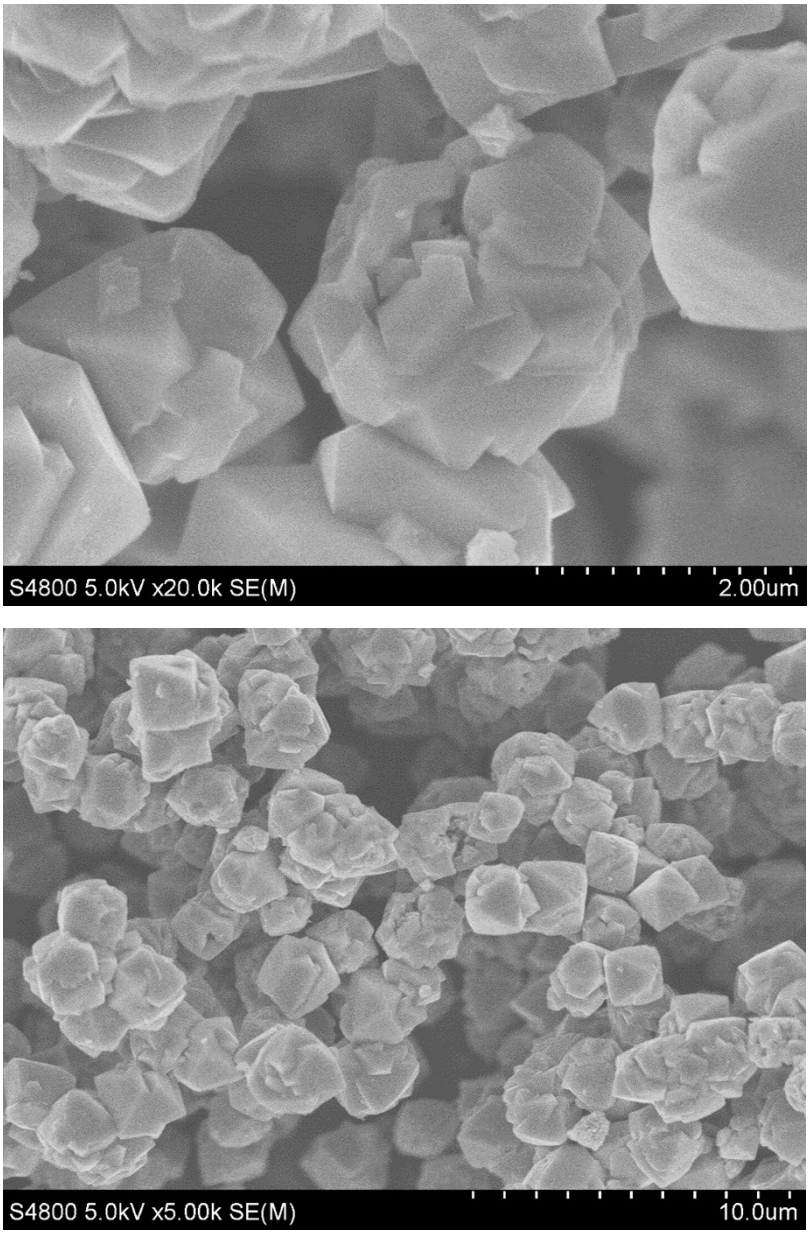

Figure S2. FE-SEM images of commercially available powder zeolite 13X observed at different magnifications.

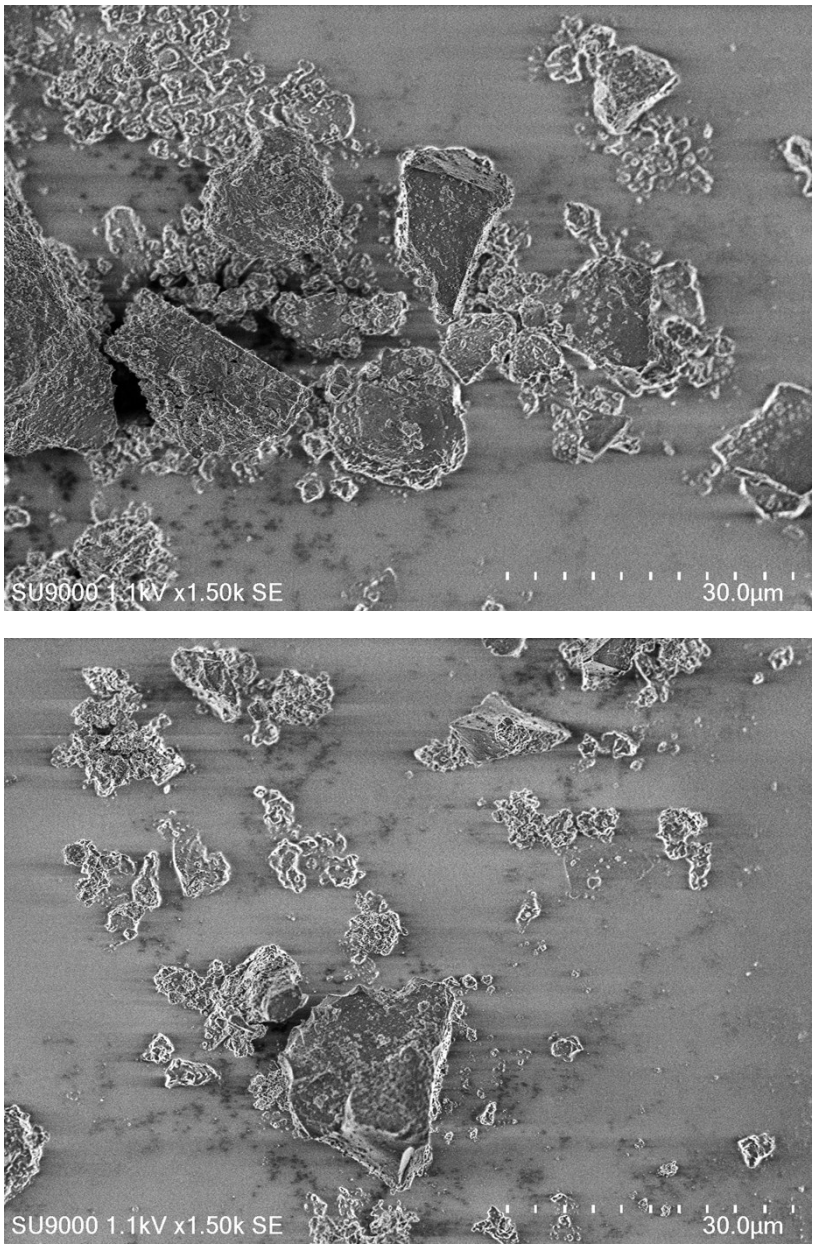

Figure S3. FE-SEM images of mesoporous zirconium hydroxides prepared in this study.

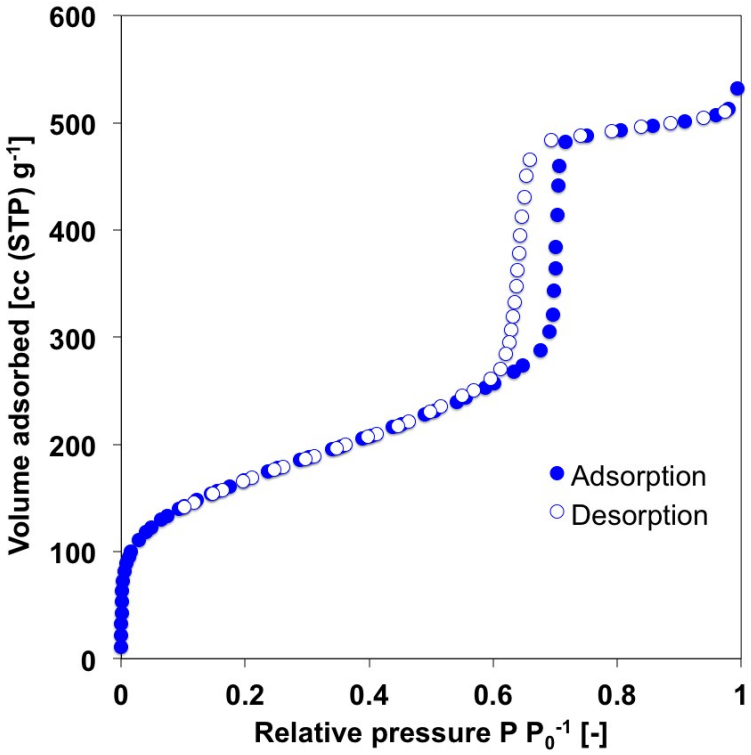

Figure S4. N_2 adsorption–desorption isotherms at 77.4 K obtained from the calcined SBA-15 synthesized in this study. Filled and open symbols indicate the adsorption and desorption points, respectively. Prior to the measurement, the sample was degassed at 573 K for 8 h under vacuum. Total pore volume (evaluated at $P\ P_0^{-1} = 0.95$) and BET surface area for the sample are 0.78 $cm^3\ g^{-1}$ and 607 $cm^2\ g^{-1}$, respectively.

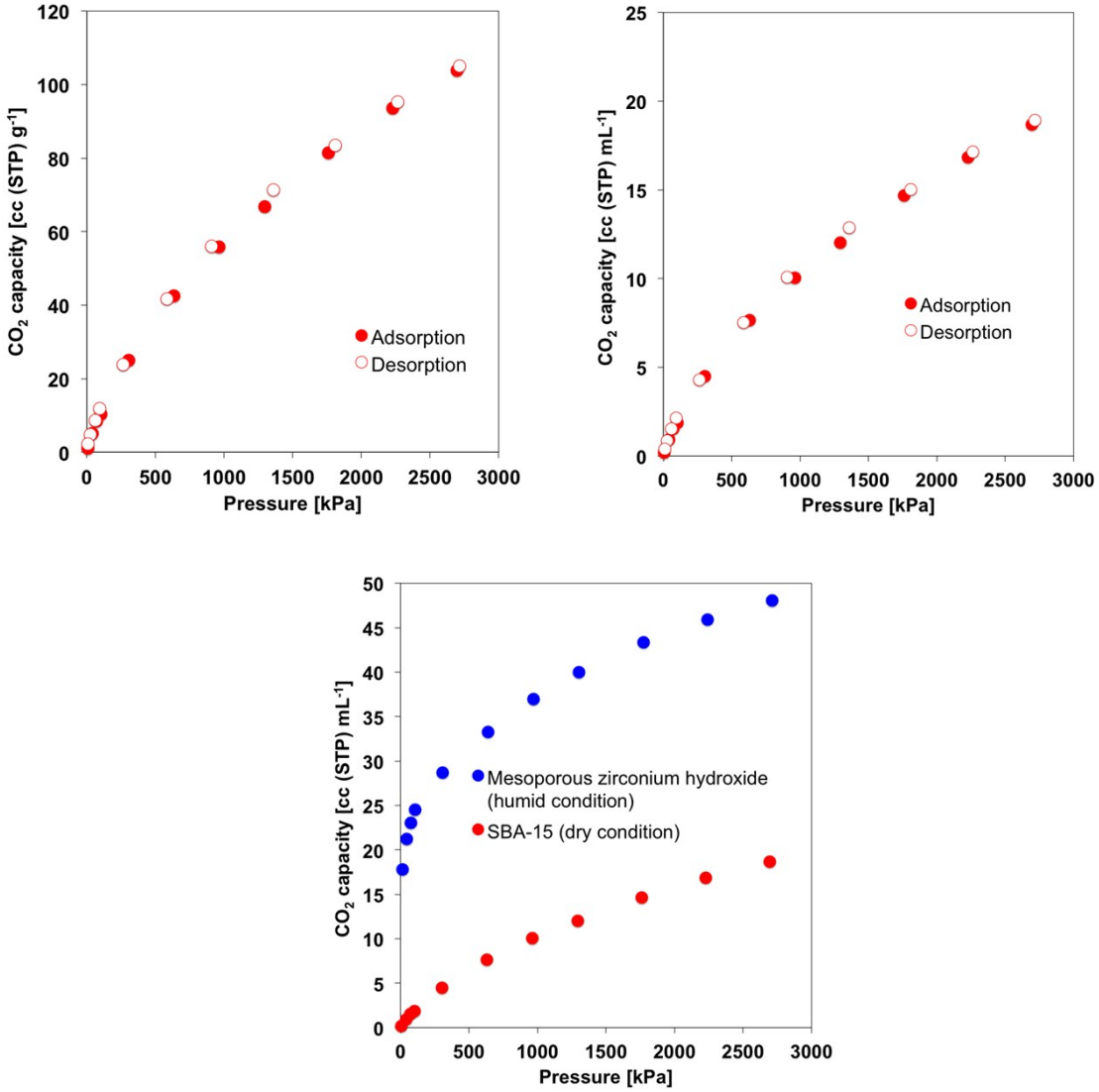

Figure S5. CO_2 adsorption–desorption isotherms at 298.15 K expressed in gravimetric basis (left) and volumetric basis (right) obtained from the calcined SBA-15 synthesized by our group. (Bottom) CO_2 adsorption isotherms at 298.15 K expressed in volumetric basis for mesoporous zirconium hydroxide (humid condition) and calcined SBA-15 (dry condition). Filled and open symbols indicate the adsorption and desorption points, respectively. Prior to the measurement, the sample was degassed at 573 K for 8 h under vacuum. CO_2 adsorption–desorption isotherms in gravimetric basis was converted into volumetric basis using tapping density of calcined SBA-15 (0.18 g cm^{-3}).

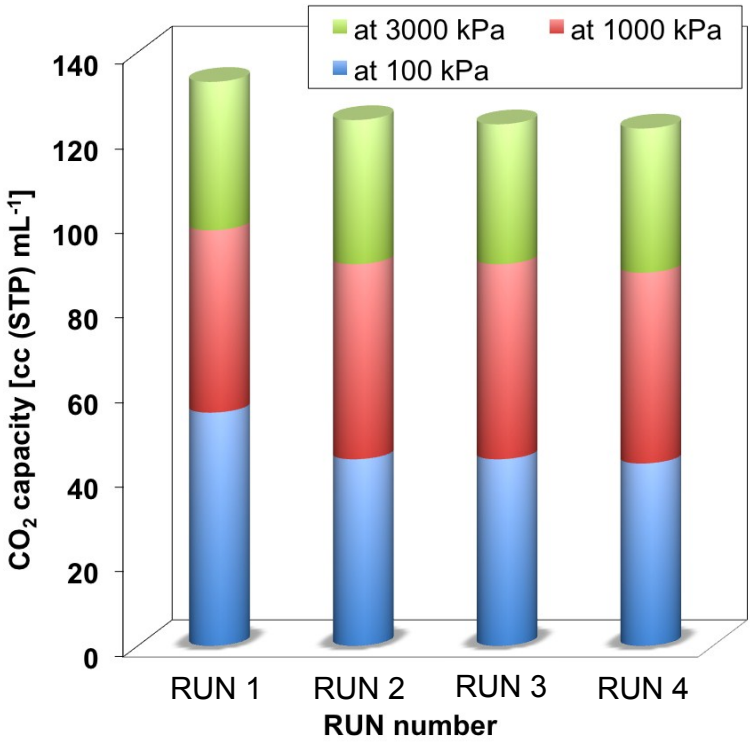

Figure S6. Pressure swing CO_2 adsorption–desorption cyclic studies of mesoporous zirconium hydroxide performed at 298.15 K in the pressure range of 0.01–3000 kPa. Prior to the each RUN 1, 2, 3, and 4 measurements, the sample was subjected to the vacuum for 24 h at 298.15 K.

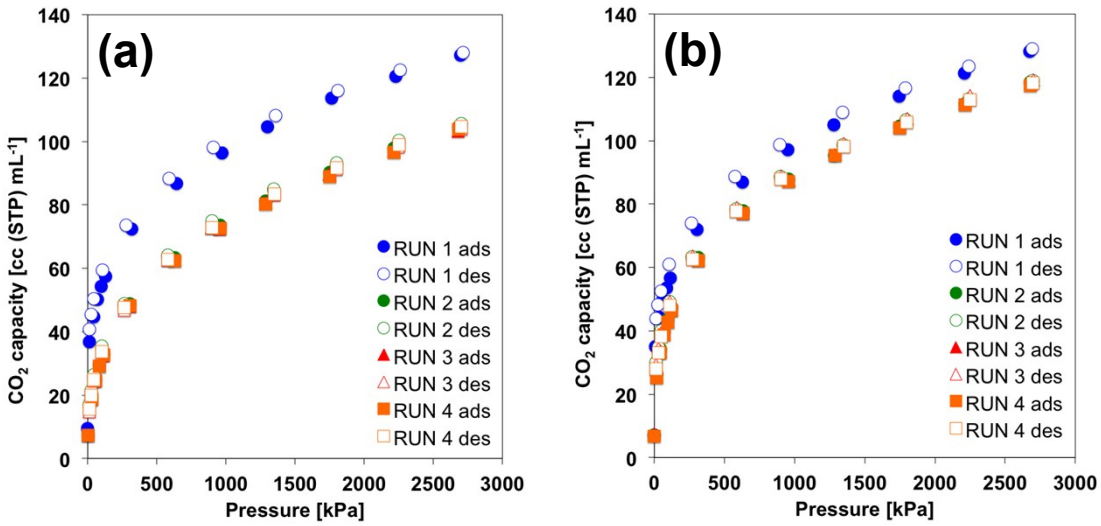

Figure S7. CO_2 adsorption–desorption isotherms in cyclic studies (four RUNs) of mesoporous zirconium hydroxide (dry condition) expressed on a volumetric basis (per volume) measured at 298.15 K and <3000 kPa. (a) Prior to the RUN 1 measurement, the sample was subjected to the vacuum for 24 h at 298.15 K. (b) Prior to the each RUN 1, 2, 3, and 4 measurements, sample was subjected to the vacuum for 24 h at 298.15 K. The closed and opened markers represent the adsorption and desorption data, respectively.

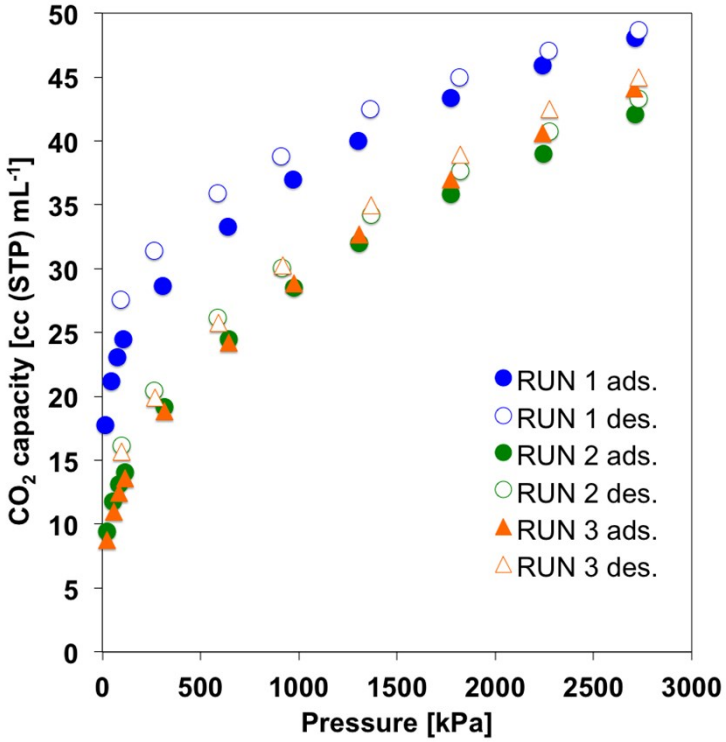

Figure S8. CO_2 adsorption–desorption isotherms in cyclic studies (three RUNs) of mesoporous zirconium hydroxide (humid condition) expressed on a volumetric basis (per volume) measured at 298.15 K and <3000 kPa. The closed and opened markers represent the adsorption and desorption data, respectively.

Synthesis of mesoporous silica SBA-15

SBA-15 was synthesized according to the previous literature reported by Sayari et al. [*J. Am. Chem. Soc.*, 2004, **126**, 14348]. 4 g of Pluronic 123 (Sigma Aldrich) was dissolved in a 120 g of 2N HCl (Wako Chemical) followed by an addition of 30 g of ultra-purified water. Obtained mixture was transferred to the round bottom flask, and mixed thoroughly using magnetic stirrer for 27 h at 308 K in water bath. Then, 8.5 g of tetraethylorthosilicate (TEOS) was added to the (P123+HCl+water) solution and stirred for 5 min at 308 K in water bath. Subsequently, (P123+HCl+water+TEOS) solution was transferred to the Teflon-lined stainless steel autoclave and subjected to the hydrothermal treatment for 24 h at 373 K in an oven. After the hydrothermal treatment, sample was collected by the filtration and washed thoroughly with ultra-purified water until the neutral pH. Finally, the sample was dried at 373 K for 10 h, and then, sample was calcined at 823 K for 5 h to obtain the product.

Tapping density measurement of SBA-15

The tapping density was determined by introducing the powder SBA-15 (calcined) in a 10 mL measuring glass cylinder and tapped 1000 times vertically on the table to level the surface. Then, the final volume was read and recorded, and the compacted sample was weighed on a balance. The obtained tapping density was ca. 0.18 g cm^{-3} for calcined SBA-15.