Geologically-inspired monoliths for sustainable release of essential minerals into drinking water

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SUPPORTING INFORMATION CONTENT

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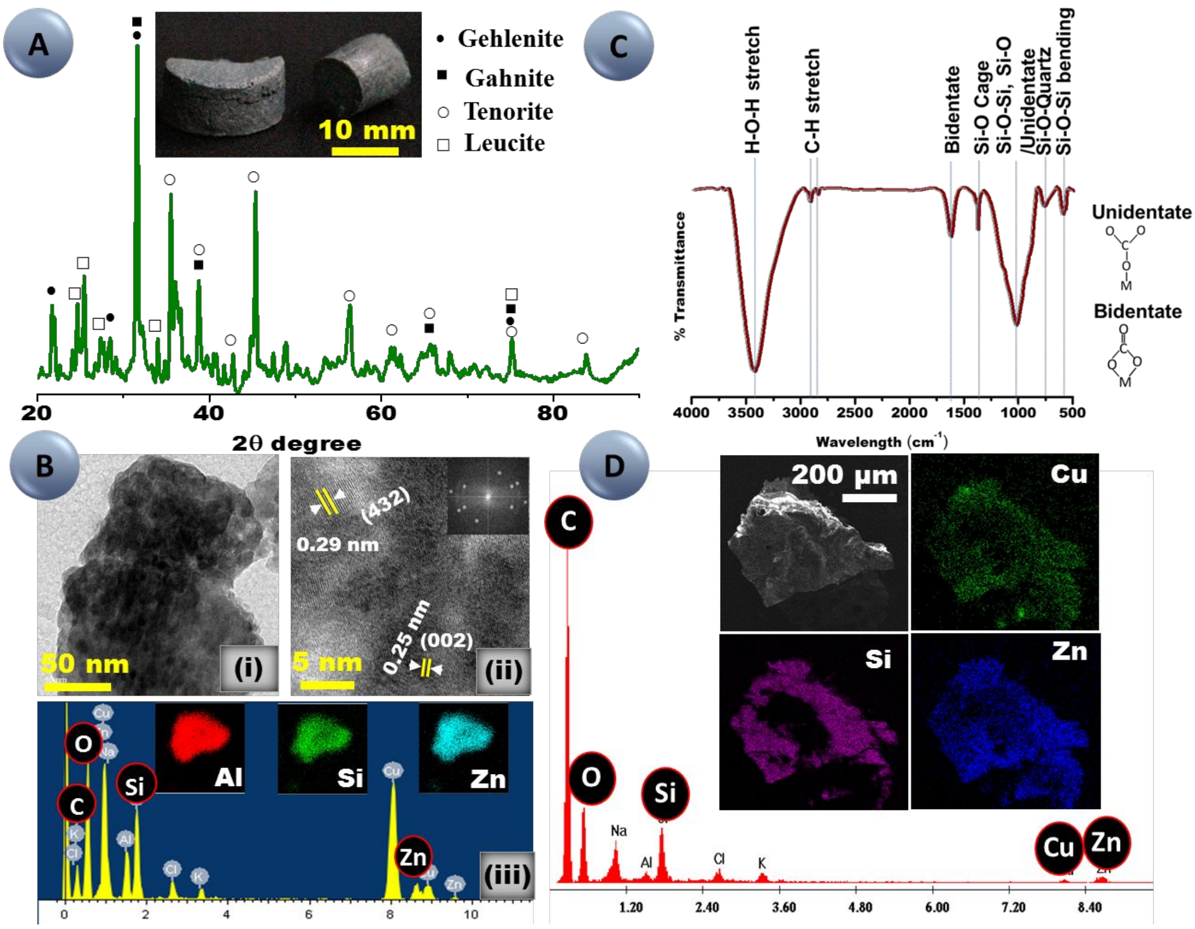

Figure S1. Characterization of microstructure and chemical composition of the sustained copper and zinc releasing monolith, $M2_{(Na\text{-}Cu\text{-}Zn)}$. (A) Powder XRD pattern of the sintered monolith compared with Gehlenite ($Ca_2Al(AlSi)O_7$), Gahnite ($ZnAl_2O_4$), Tenorite (CuO) and Leucite ($KAl(Si_2O_6)$). Inset shows the photograph of the monolith. (B) (i) TEM image of a grain of the material, (ii) the lattice resolved image of the same grain and its FFT pattern (inset) and (iii) the corresponding EDS spectra along with the elemental maps. As the TEM grid is made of copper, its mapping is not shown. (C) Infrared spectrum of the mineral composite. (D) SEM image of the material and the corresponding EDS spectrum along with elemental maps.

Supporting information 2

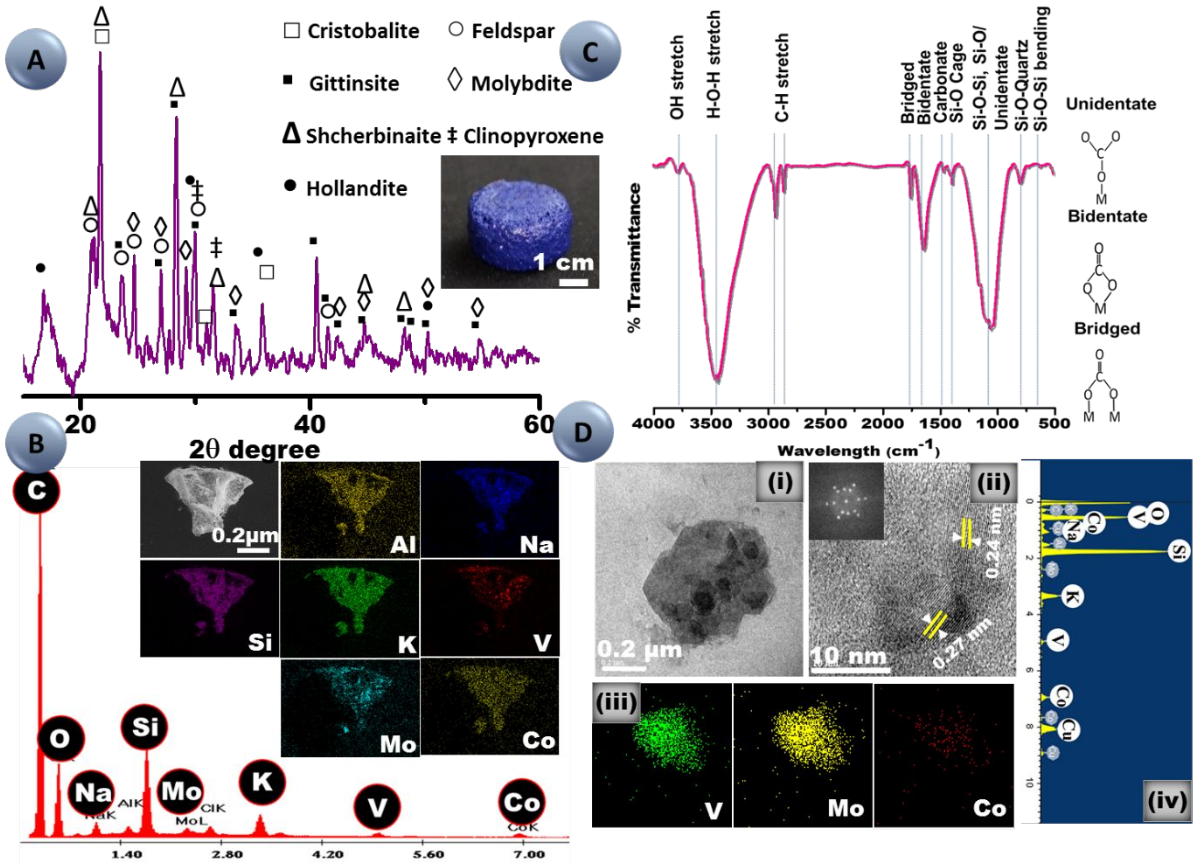

Figure S2. Characterization of microstructure and chemical composition of monolith, $M3_{(K\text{-}Co\text{-}Mo\text{-}V)}$ releasing oligo/trace elements namely cobalt, molybdenum and vanadium. (A) Powder XRD pattern of the sintered monolith and the photograph of the pellet (Inset). The material $M3_{(K\text{-}Co\text{-}Mo\text{-}V)}$ is matched with Cristobalite (SiO_2), Feldspar sanidine ($KAlSi_3O_8$) and other silicate phases like Clinopyroxene ($Na_1O_6Si_2V$), Hollandite ($K_{0.8}O_{17}V_{10}$) and Molybdite (MoO_3), Shcherbinaite (V_2O_5). (B) SEM image of the material and the corresponding EDS spectrum along with the elemental maps. (C) Infrared spectrum of the mineral composite (D) (i) TEM image of a grain of material and (ii) the lattice resolved image of the same grain with the FFT pattern (inset). The corresponding elemental maps (iii) and the EDS spectrum (iv).

Supporting information 3

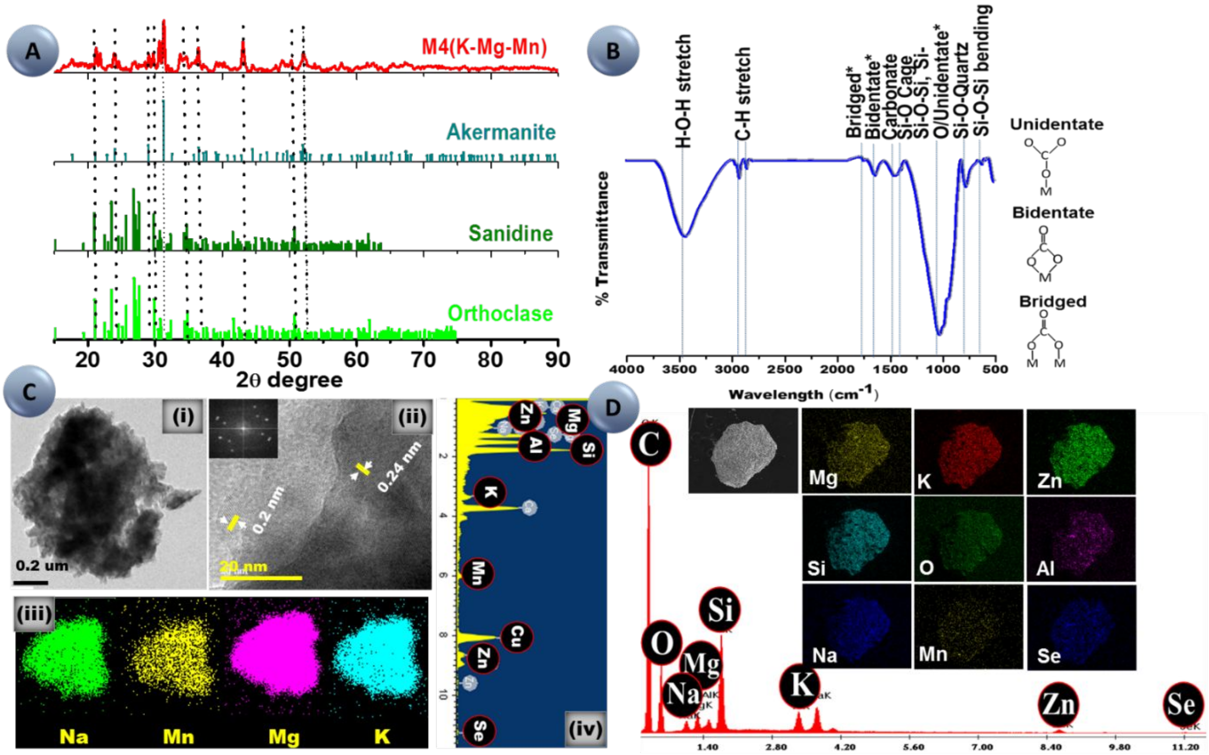

Figure S3. Characterization of microstructure and chemical composition of monolith - $M4_{(K\text{-}Mg\text{-}Mn)}$ releasing magnesium / manganese. The material was incorporated with 6 elements to show a simultaneous release from the single system. (A) Powder XRD pattern of the material, compared with Akermanite ($Ca_2Mg[Si_2O_7]$), Sanidine ($K(AlSi_3O_8)$) and Orthoclase ($KAlSi_3O_8$). (B) Infrared spectrum of the mineral composite. (C) (i) TEM image of a grain of the material and (ii) the lattice resolved image of the same grain with the FFT pattern (Inset). The corresponding elemental maps (iii) and the EDS spectrum (iv). (D) SEM image of the material and corresponding EDS spectrum with elemental maps.

Supporting information 4

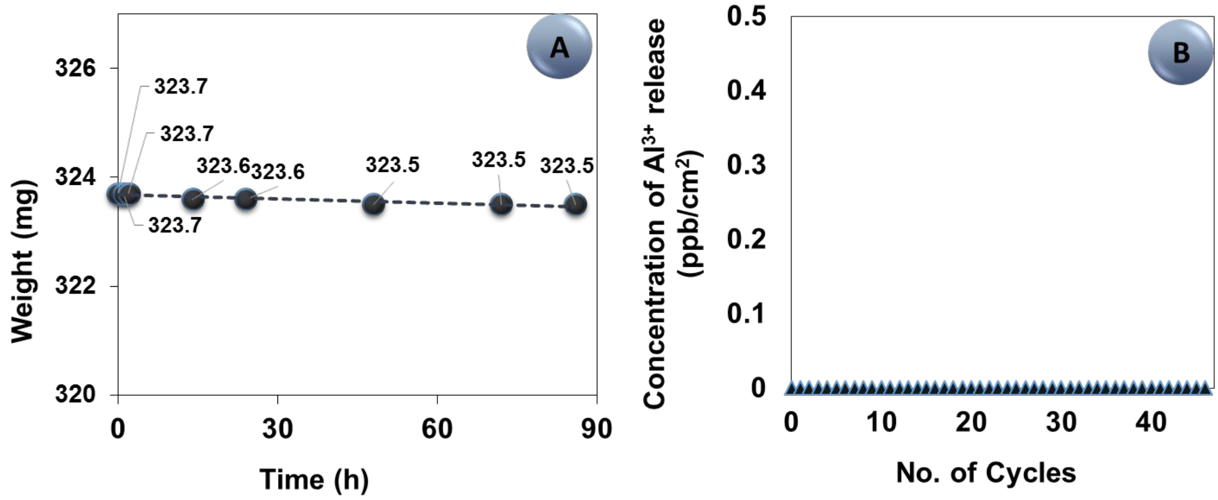

Figure S4. Stability of scaffold material in test water (A) Weight loss per cm^2 of the monoliths immersed in water as a function of time. (B) Concentration of Al^{3+} release in water.

Supporting information 5

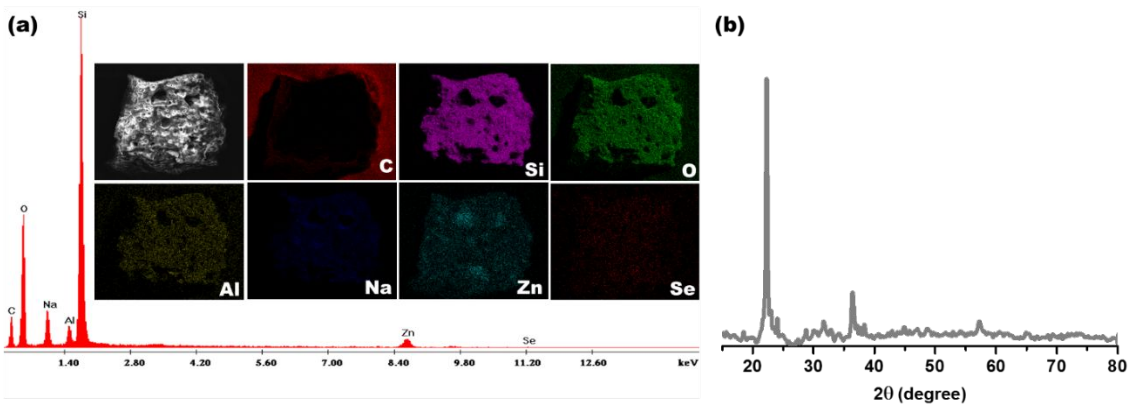

Figure S5. Characterization and chemical composition of monolith – $M1_{(Na\text{-}Zn\text{-}Se)}$ after 120 cycles of leaching (a) SEM image and the corresponding EDS spectra along with the elemental maps (b) Powder XRD pattern.

Supporting information 6

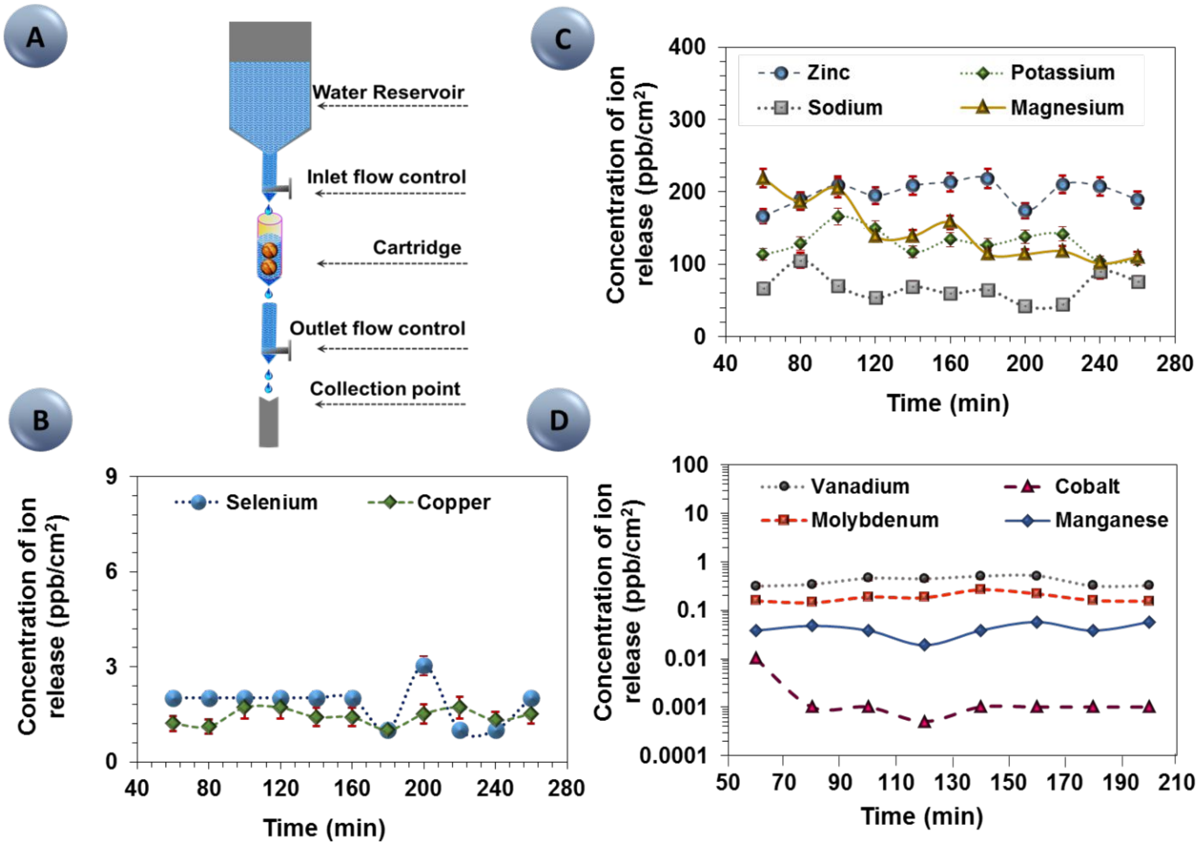

Figure S6. Mineral release trend from the designed prototype. The release of selected metal ions in a sustained fashion under continuous flow of water at a pilot scale at a flow rate of 2 mL per minute. (a) Schematic representation of the prototype design. (b-d) Release of select mineral ions as a function of time.

Supporting information 7

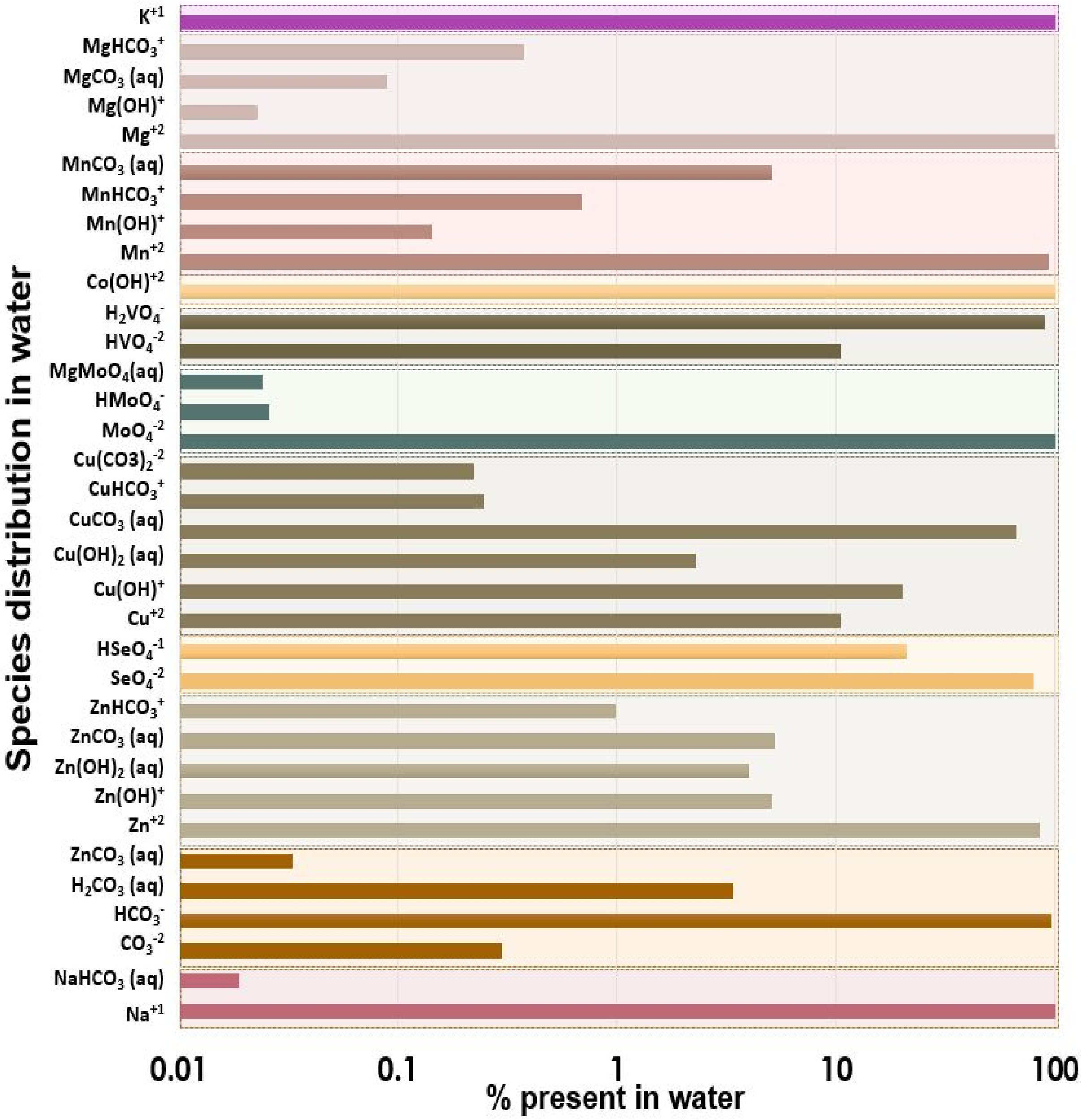

Figure S7. Speciation of mineral ions formed in water after the release. The speciation diagram was prepared using simulations run on Visual MINTEQ software version 3.1 (freeware, available at, http://vminteq.lwr.kth.se).

Equations used for the evaluation of sustainability metrics

Equation (1) : $$\text{Mass intensity} = \frac{\text{mass of all products used excluding water}}{\text{mass of product}} \text{kg/kg product}$$

Equation (2) : $$\text{Water intensity } (W_P) = \frac{\text{mass of all water used}}{\text{mass of product}} \text{kg/kg product}$$

Equation (3) : $$\text{Reaction mass efficiency (RME)} = \frac{\text{mass of product}}{\text{mass of all reactants}} \times 100\%$$

Equation (4) : $$\text{Energy Intensity} = \frac{\text{amount of non renewable energy used}}{\text{mass of product}} \text{kW.h/kg}$$

Equation (5) : $$\text{E factor} = \frac{[\text{kg(raw materials)} - \text{kg(desired product)}]}{\text{kg(total product including water)}}$$

Table S1: CO_2 emission **(**including raw material manufacture and monolith production).

A cradle-to-gate assessment of the [M2$_{\mathbf{(Na\text{-}Cu\text{-}Zn)}}$] material's CO_2 emission including the manufacture of raw materials and production of designed monolith is presented below. The CO_2 emission due to transportation and disposal finished goods are not included and therefore it is not a cradle-to-grave assessment.

List of raw materials used in M2$_{\mathbf{(Na\text{-}Cu\text{-}Zn)}}$	**CO_2 emission by manufacture of raw materials (kg/kg)**	**CO_2 emission by production of designed monolith (kg/kg)**	**Total (kg/kg)**
SiO_2	0.373	-	0.373
Al_2O_3	0.492	-	0.492
Na_2CO_3	0.059	$4x10^{-5}$	0.05904
$CuCO_3$	0.200	$4x10^{-5}$	0.20004
ZnO	0.582	-	0.582
KCl	0.0138	-	0.0138

Table S2: LD-50 of the raw materials used for the synthesis of material

Elements used	**LD-50 (mg/kg)**
SiO_2	500
Al_2O_3	5000
Na_2CO_3	2800
K_2CO_3	2000
ZnO	7950
SeO_3	1.6
$MgCO_3$	NA
$CuCO_3$	1350
CoO	202
MnO	2000
V_2O_5	474
MoO	2689
KCl	2600