

Table S1 Bond lengths in $\text{Na}_3\text{SO}_4\text{F}_{0.5}\text{Cl}_{0.5}$ and $\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$

Bonds	Bond length (Å)	
	$\text{Na}_3\text{SO}_4\text{F}_{0.5}\text{Cl}_{0.5}$	$\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$
S-O	1.49408	--
Se-O	--	1.66467
Cl-Na	2.81835	2.86087
F-Na	2.23499	2.23508

Table S2 Calculated reaction energies or experimental data (Exp), with data for stable phases taken from the Materials Project webpage: <https://www.materialsproject.org>

Reactions	Productions	Calculated Energy	Exp
		(eV/atom)	(eV/atom)
$\text{Na}_2\text{SO}_4+2\text{H}_2\text{O}$	$2\text{NaOH}+\text{H}_2\text{SO}_4$	0.24	-
$\text{Na}_2\text{SeO}_4+2\text{H}_2\text{O}$	$2\text{NaOH}+\text{H}_2\text{SeO}_4$	0.227	-
$\text{NaCl}+\text{H}_2\text{O}$	$\text{NaOH}+\text{HCl}$	0.358	-
$\text{NaF}+\text{H}_2\text{O}$	$\text{NaOH}+\text{HF}$	0.337	-
$4\text{NaCl}+\text{O}_2$	$2\text{Na}_2\text{O}+2\text{Cl}_2$	0.811	0.939
$4\text{NaF}+\text{O}_2$	$2\text{Na}_2\text{O}+2\text{F}_2$	1.494	1.508
$\text{Na}_2\text{S}+\text{H}_2\text{O}$	$\text{Na}_2\text{O}+\text{H}_2\text{S}$	0.20	-
$\text{P}_2\text{S}_5+8\text{H}_2\text{O}$	$2\text{H}_3\text{PO}_4+5\text{H}_2\text{S}$	-0.014	-
$\text{Na}_2\text{S}+2\text{O}_2$	Na_2SO_4	-1.768	-1.515
$2\text{P}_2\text{S}_5+15\text{O}_2$	$2\text{P}_2\text{O}_5+10\text{SO}_2$	-1.78	-

Table S3 The colours for the ions in the videos of $\text{O}_2|\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$ and $\text{H}_2\text{O}|\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$.

Ions	Na	Se	S	Cl	F	O	H
Colour	yellow	purple	blue	green	silver	red	white

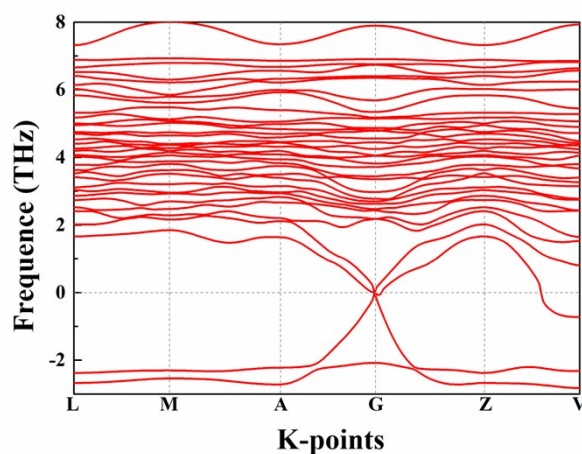


Fig. S1 Calculated phonon band structure for $\text{Na}_3\text{S}_{0.5}\text{Se}_{0.5}\text{O}_4\text{Cl}$, which is dynamically unstable.

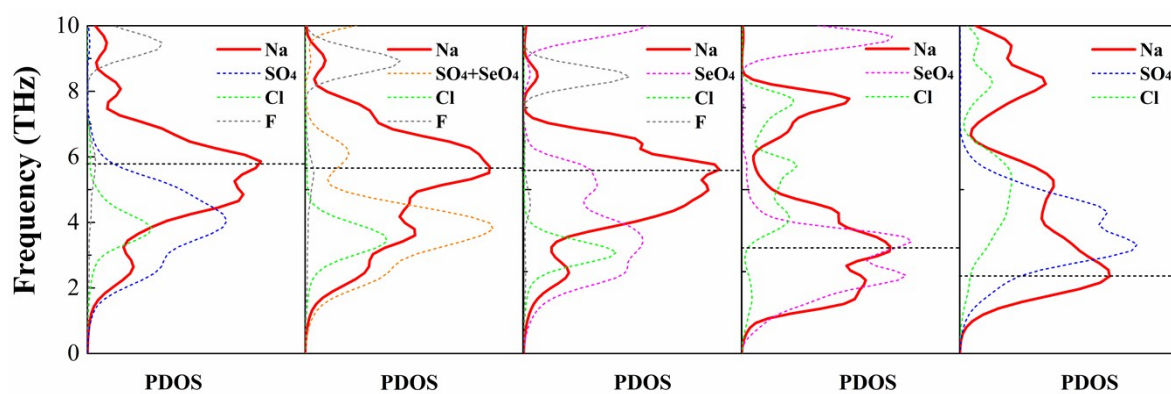


Fig. S2 Calculated phonon PDOS for the stable structures of (a) $\text{Na}_3\text{SO}_4\text{F}_{0.5}\text{Cl}_{0.5}$, (b) $\text{Na}_3\text{S}_{0.5}\text{Se}_{0.5}\text{O}_4\text{F}_{0.5}\text{Cl}_{0.5}$, (c) $\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$, (d) $\text{Na}_3\text{SeO}_4\text{Cl}$ and (e) $\text{Na}_3\text{SO}_4\text{Cl}$.

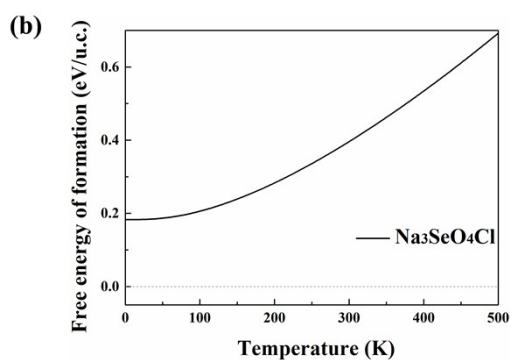


Fig. S3 (a) Phase diagrams for $\text{Na}_3\text{SeO}_4\text{Cl}$ at 0 K, with respect to their correspondingly stable constituents (NaCl , and Na_2SeO_4); (b) Free energy of formation per unit cell (u.c.) for $\text{Na}_3\text{SeO}_4\text{Cl}$.

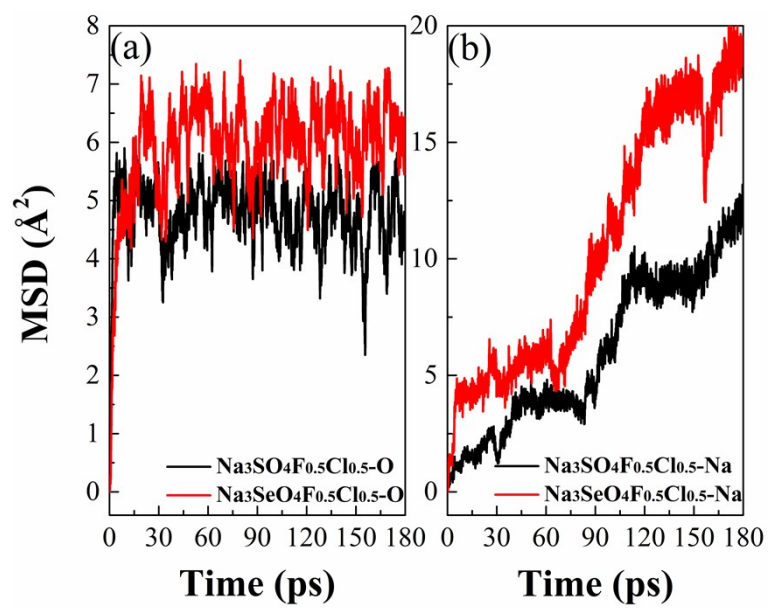


Fig. S4 MSD of (a) O^{2-} and (b) Na^+ in $\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$ (in red) and $\text{Na}_3\text{SO}_4\text{F}_{0.5}\text{Cl}_{0.5}$ (in black) carried out at 1000 K.

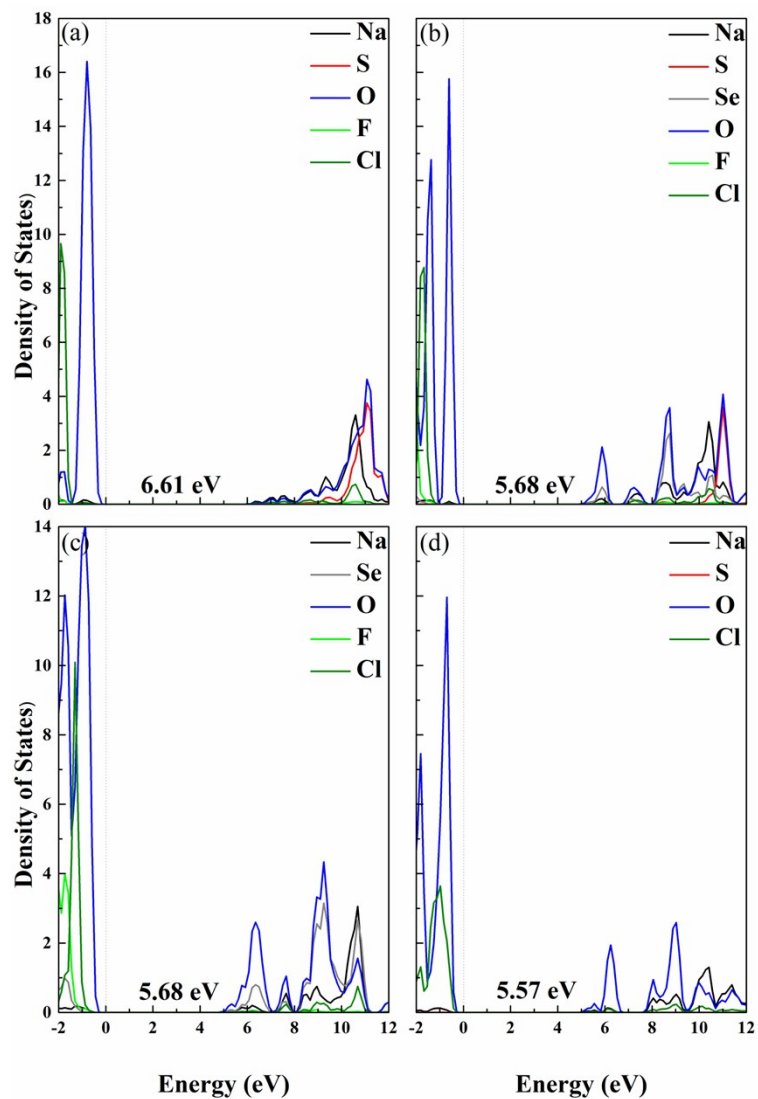


Fig. S5 The projected density of states calculated using the HSE06 functional: (a) $\text{Na}_3\text{SO}_4\text{F}_{0.5}\text{Cl}_{0.5}$, (b) $\text{Na}_3\text{S}_{0.5}\text{Se}_{0.5}\text{O}_4\text{F}_{0.5}\text{Cl}_{0.5}$, (c) $\text{Na}_3\text{SeO}_4\text{F}_{0.5}\text{Cl}_{0.5}$ and (d) $\text{Na}_3\text{SO}_4\text{Cl}$.