Supplementary Materials

The Influence of Cerium to Manganese Ratio and Preparation Method on the Activity of Ceria-Manganese Mixed Metal Oxide Catalysts for VOC Total Oxidation

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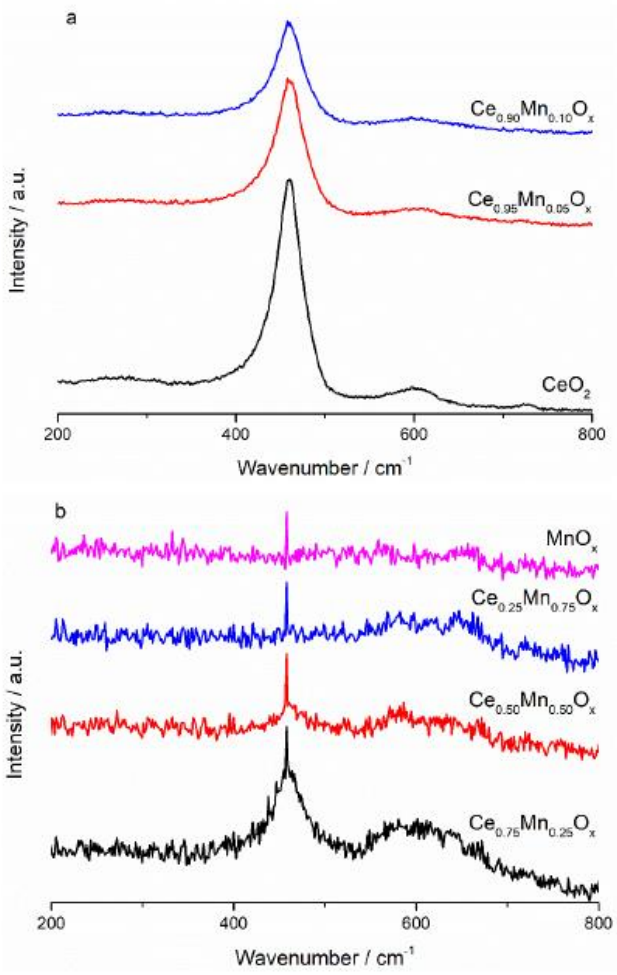
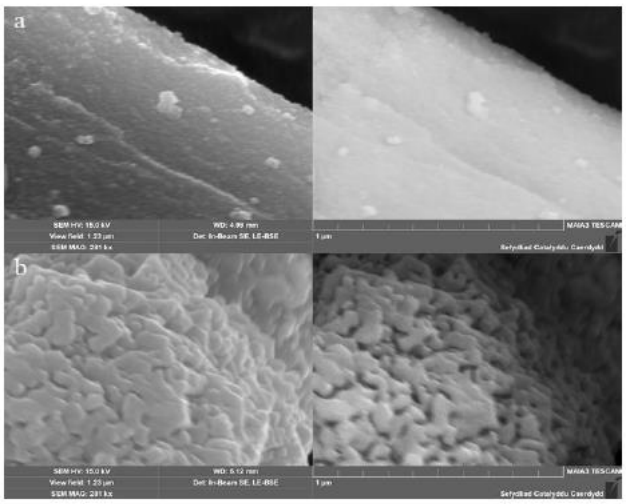


Figure S1. Raman spectra of cerium-manganese mixed metal oxides prepared by sodium carbonate co-precipitation. Laser wavelength = 514 nm.

i.



ii.

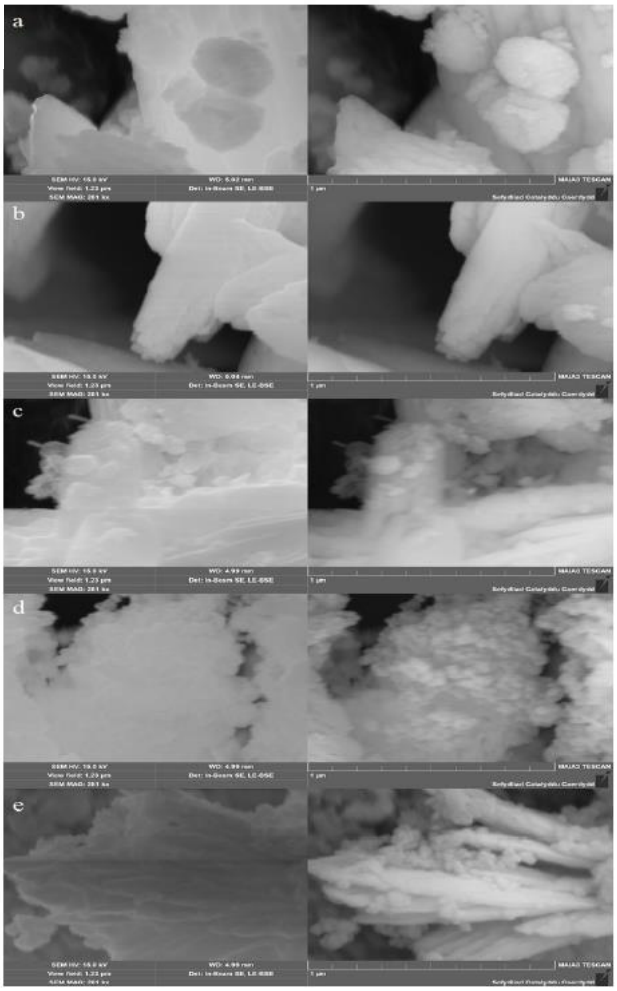
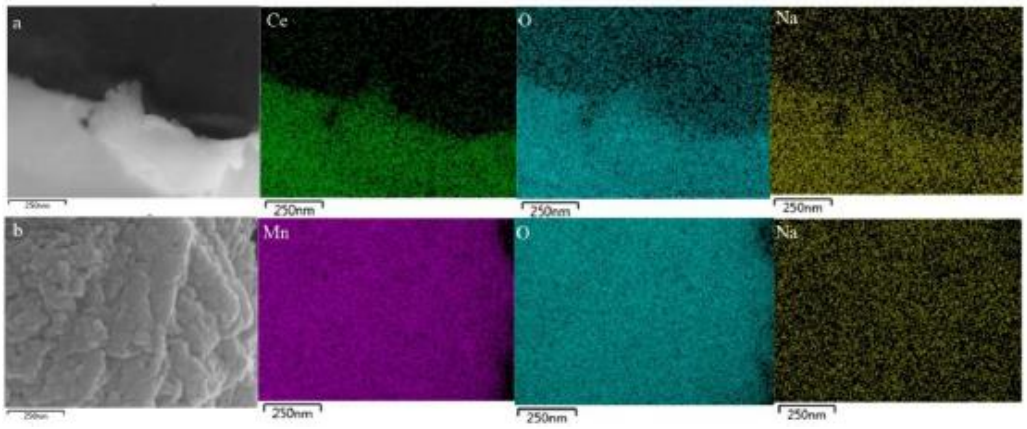


Figure S2: i. SEM images of (a.) CeO_2 and (b.) MnO_x prepared via sodium carbonate co-precipitation. ii. SEM images of (a.) $Ce_{0.95}Mn_{0.05}O_x$, (b.) $Ce_{0.9}Mn_{0.1}O_x$, (c.) $Ce_{0.75}Mn_{0.25}O_x$, (d.) $Ce_{0.5}Mn_{0.5}O_x$ and (e.) $Ce_{0.25}Mn_{0.75}O_x$. Left image obtained using secondary electrons, right image obtained using backscattered electrons

i.



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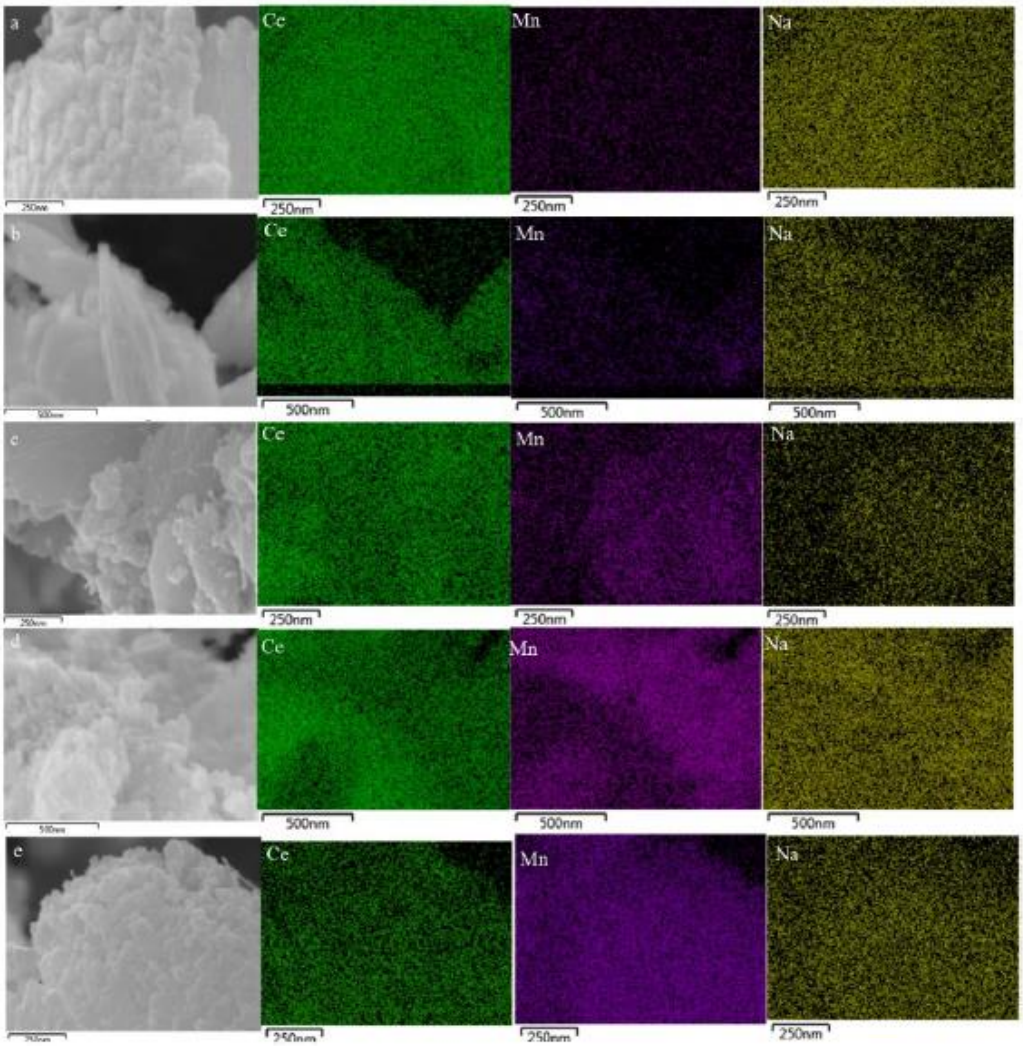

Figure S3: i. SEM-EDX images of (a.) CeO_2 and (b.) MnO_x prepared via sodium carbonate co-precipitation. ii. SEM-EDX images of (a.) $Ce_{0.95}Mn_{0.05}O_x$, (b.) $Ce_{0.9}Mn_{0.1}O_x$, (c.) $Ce_{0.75}Mn_{0.25}O_x$, (d.) $Ce_{0.5}Mn_{0.5}O_x$ and (e.) $Ce_{0.25}Mn_{0.75}O_x$. Left image obtained using secondary electrons, right image obtained using backscattered electrons

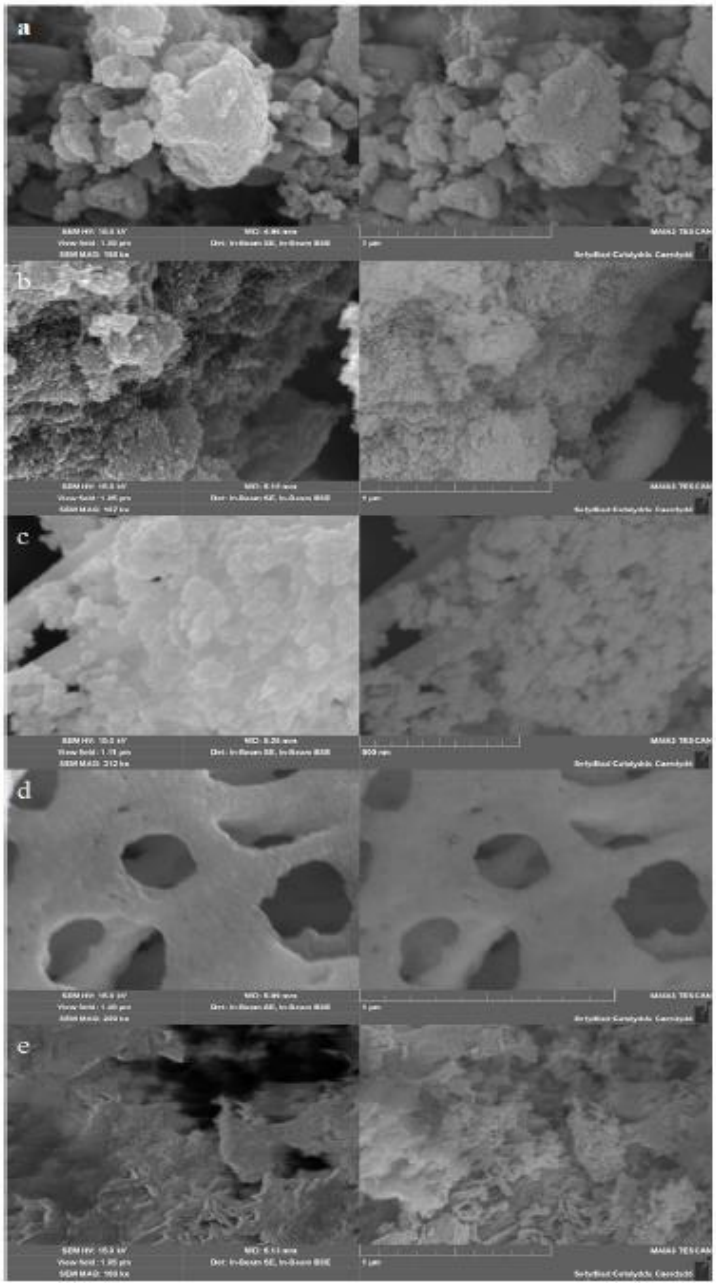

Figure S4: SEM images of $Ce_{0.25}Mn_{0.75}O_x$ prepared by (a) ball mill-CO_3, (b) ball mill- NO_3, (c) urea, (d) citric acid and (e) oxalic acid. Left image obtained using secondary electrons, right image obtained using backscattered electrons.

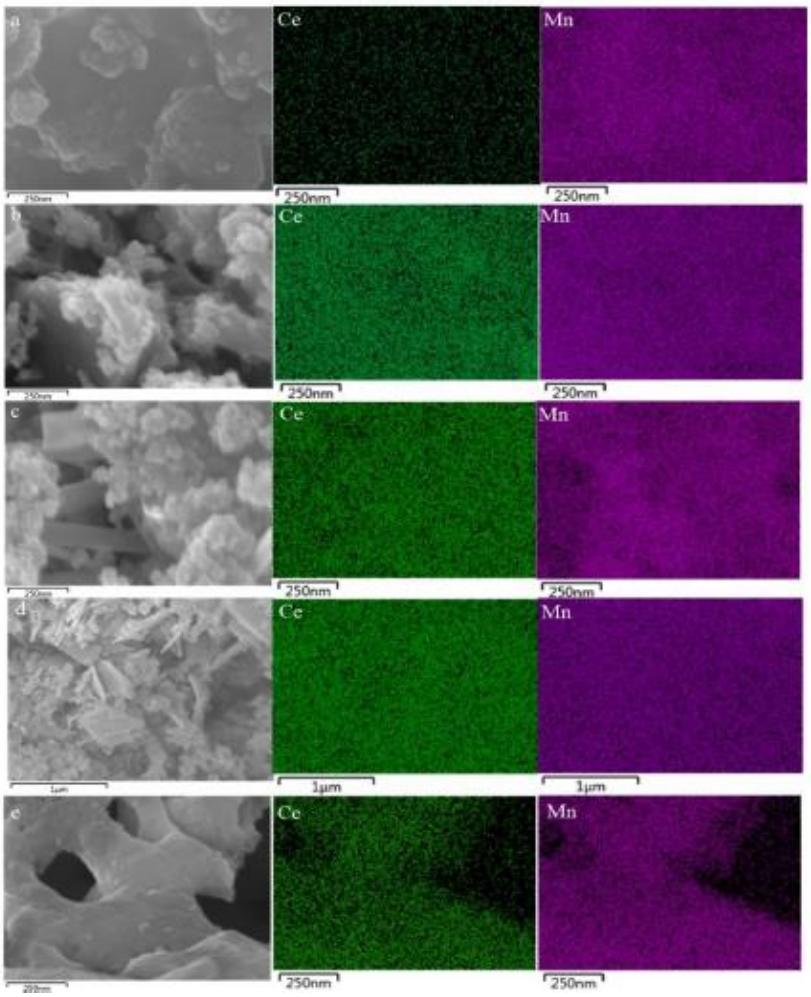

Figure S5: SEM-EDX mapping of $Ce_{0.25}Mn_{0.75}O_x$ prepared by (a) ball mill-CO_3, (b) ball mill- NO_3, (c) urea, (d) oxalic acid and (e) citric acid. Cerium (green) and manganese (pink).

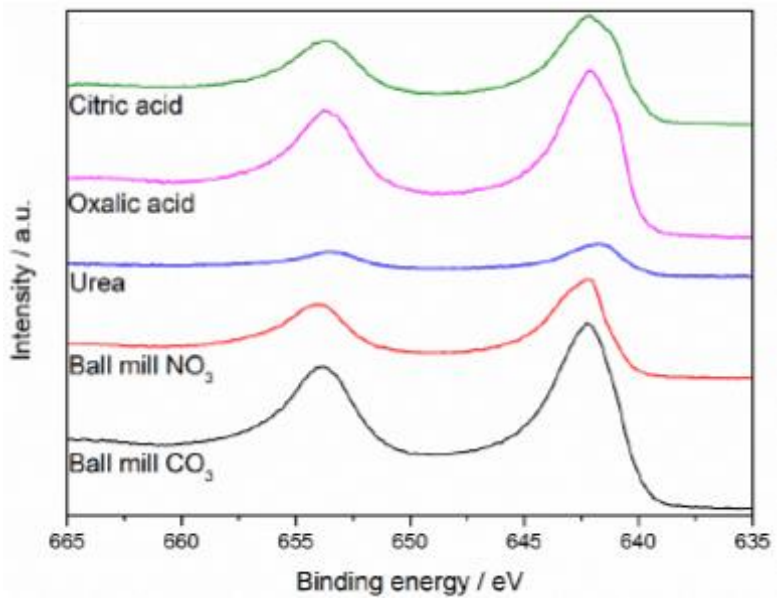

Figure S6: Mn 2p XPS spectra of the $Ce_{0.25}Mn_{0.75}O_x$ catalysts prepared by different methods.

Table S1: Rate of reaction normalised to surface area for ceria-manganese mixed metal oxides prepared by sodium carbonate coprecipitation

Catalyst	Surface area normalised propane total oxidation rate at 350 °C (10^{-7}) (mol s^{-1} m^{-2})	Surface area normalised naphthalene total oxidation rate at 175 °C (10^{-11}) (mol s^{-1} m^{-2})
CeO_2	0.06	0.45
$Ce_{0.95}Mn_{0.05}O_x$	0.09	0.31
$Ce_{0.9}Mn_{0.1}O_x$	0.16	0.40
$Ce_{0.75}Mn_{0.25}O_x$	0.47	0.59
$Ce_{0.5}Mn_{0.5}O_x$	0.41	1.07
$Ce_{0.25}Mn_{0.75}O_x$	0.74	1.93
MnO_x	1.03	3.44

Table S2: XPS derived surface elemental concentrations for ceria-manganese mixed metal oxide catalysts prepared by co-precipitation with sodium carbonate.

Catalyst	Relative surface Ce concentration (%)	Relative surface Mn concentration (%)	Surface Na concentration (%)
CeO_2	100.0	0.0	14.2
$Ce_{0.95}Mn_{0.05}O_x$	97.4	2.6	13.7
$Ce_{0.9}Mn_{0.1}O_x$	92.8	7.2	13.5
$Ce_{0.75}Mn_{0.25}O_x$	66.5	33.5	11.3
$Ce_{0.5}Mn_{0.5}O_x$	41.3	58.7	5.7
$Ce_{0.25}Mn_{0.75}O_x$	36.7	63.3	11.9
MnO_x	0	100.0	6.7

Table S3: Rate of reaction normalised to surface area for $Ce_{0.25}Mn_{0.75}Ox$ catalyst prepared by different techniques.

Catalyst	Surface area normalised propane total oxidation rate at 300 °C (10^{-8}) (mol s^{-1} m^{-2})	Surface area normalised naphthalene total oxidation rate at 225 °C (10^{-11}) (mol s^{-1} m^{-2})
Mechanochemical grinding – carbonates	2.59	0.90
Mechanochemical grinding – nitrates	2.72	1.09
Urea co-precipitation	3.40	1.25
Oxalic acid	0.92	0.86
Citric acid co-precipitation	9.07	3.15