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Supplementary material: Investigations into the conversion of ethanol to butadiene-1,3 using $CuO/La_2O_3/ZrO_2/SiO_2$ catalyst systems

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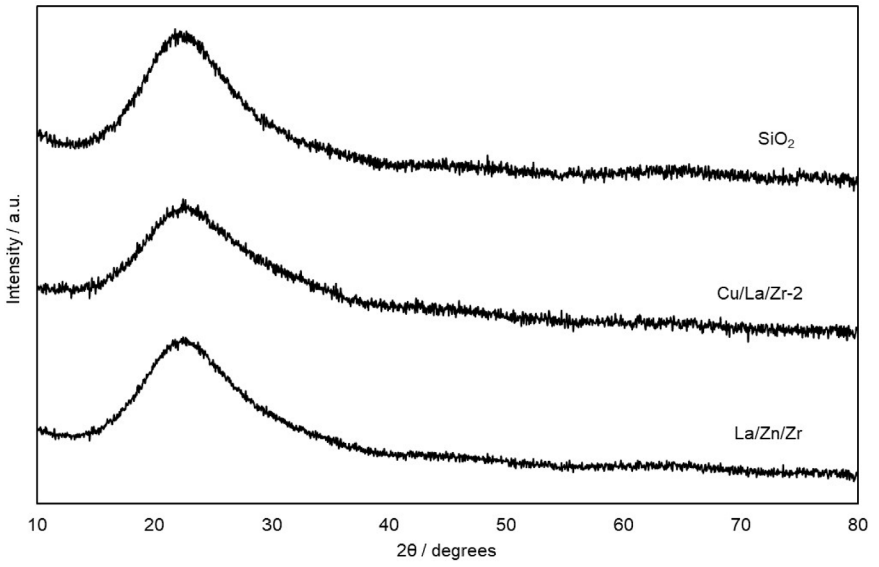
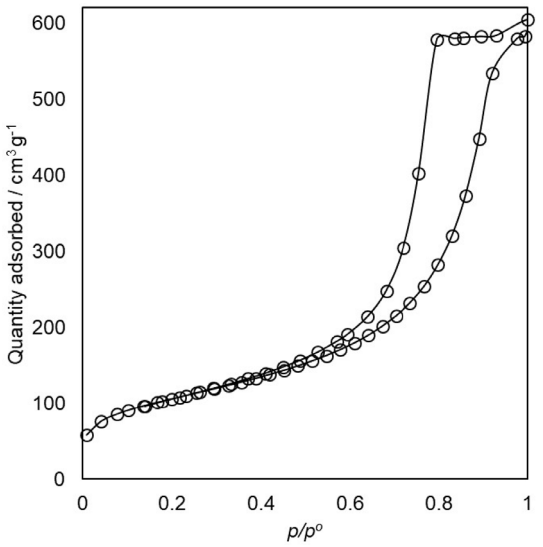
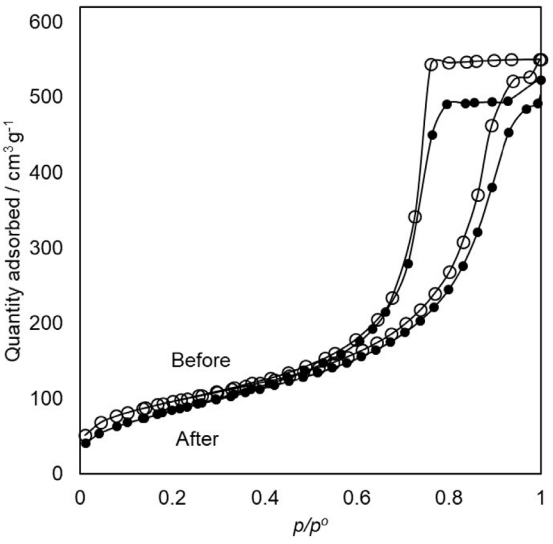


Supplementary Figure S1. XRD patterns of SiO_2, La/Zn/Zr and Cu/La/Zr-2.

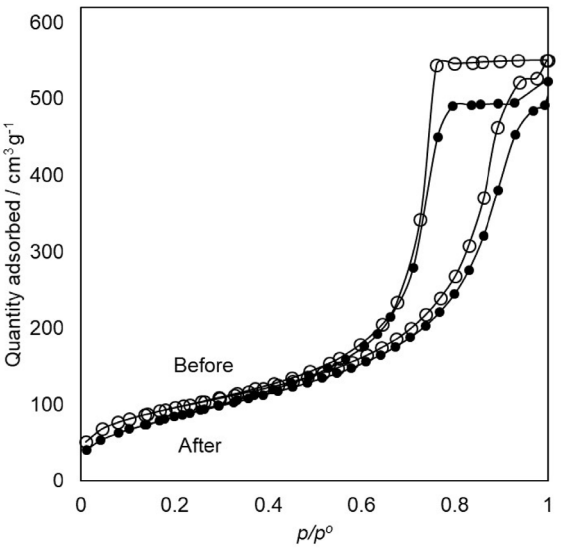
* Corresponding author.



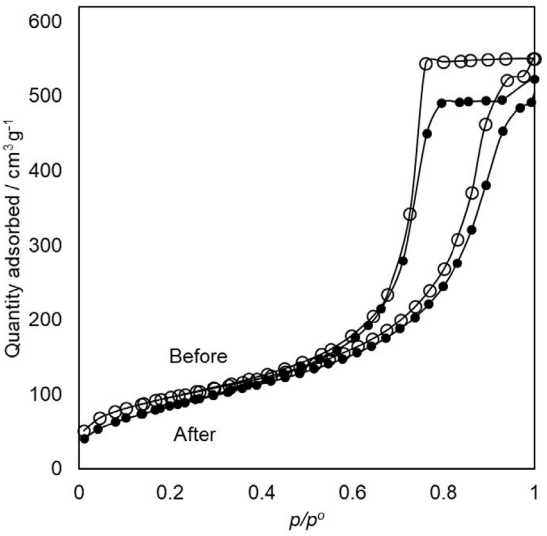
Supplementary Figure S2. Isotherm of nitrogen physisorption on SiO_2.



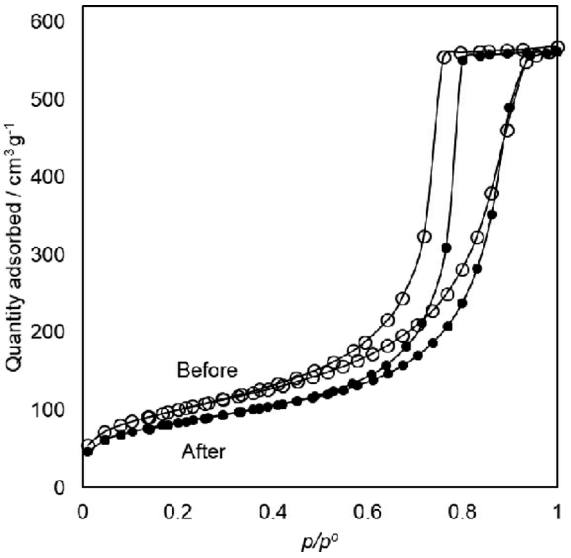
Supplementary Figure S4. Isotherm of nitrogen physisorption on Cu/Zn/Zr before and after the experiment.



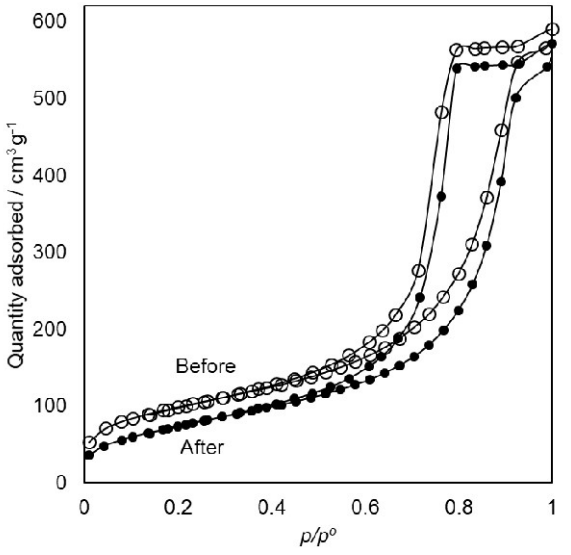
Supplementary Figure S3. Isotherm of nitrogen physisorption on Zn/Zr before and after the experiment.



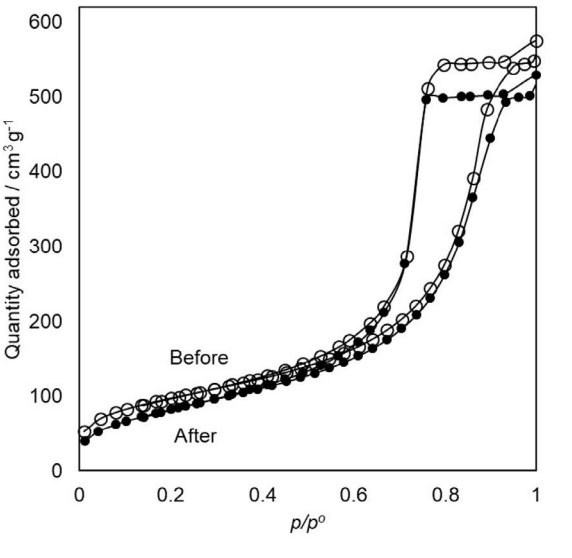
Supplementary Figure S5. Isotherm of nitrogen physisorption on La/Zn/Zr before and after the experiment.



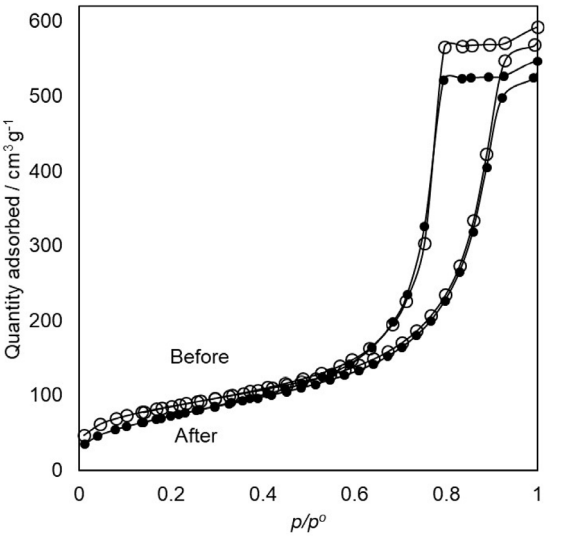
Supplementary Figure S6. Isotherm of nitrogen physisorption on Cu/La/Zr-1 before and after the experiment.



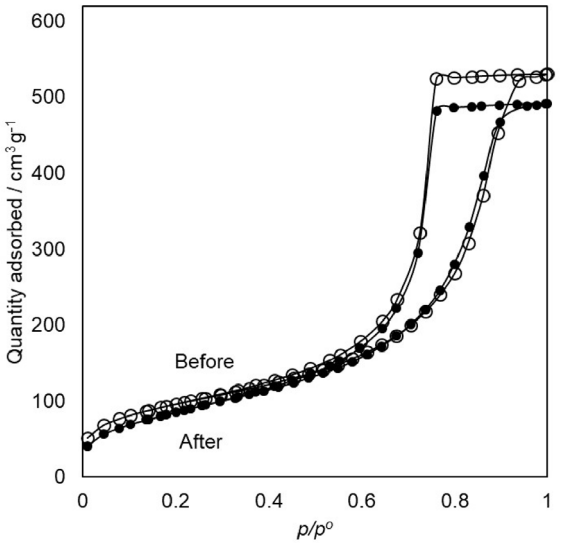
Supplementary Figure S7. Isotherm of nitrogen physisorption on Cu/La/Zr-2 before and after the experiment.



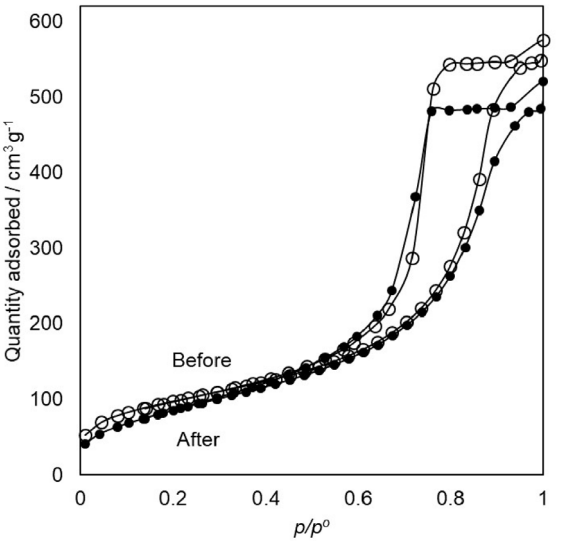
Supplementary Figure S8. Isotherm of nitrogen physisorption on Cu/La/Zr-3 before and after the experiment.



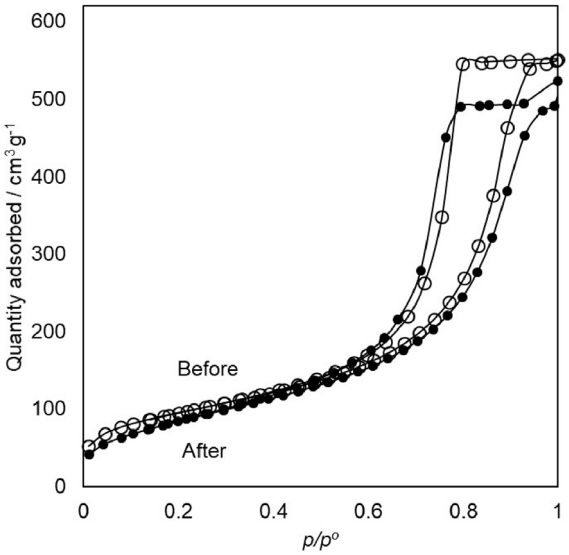
Supplementary Figure S9. Isotherm of nitrogen physisorption on Cu/La/Zr-4 before and after the experiment.



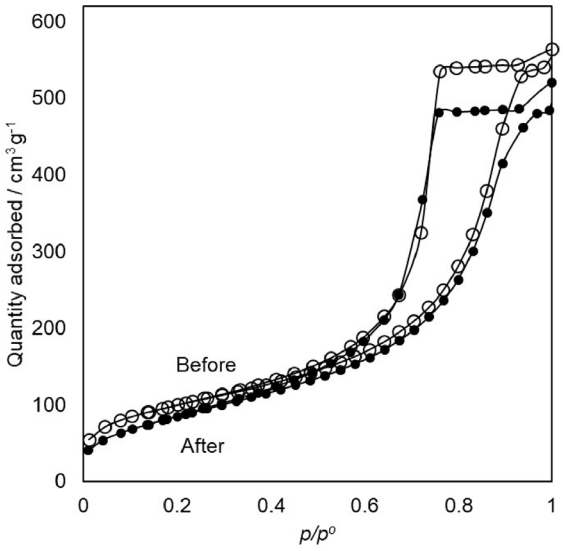
Supplementary Figure S10. Isotherm of nitrogen physisorption on Cu/La/Zr-5 before and after the experiment.



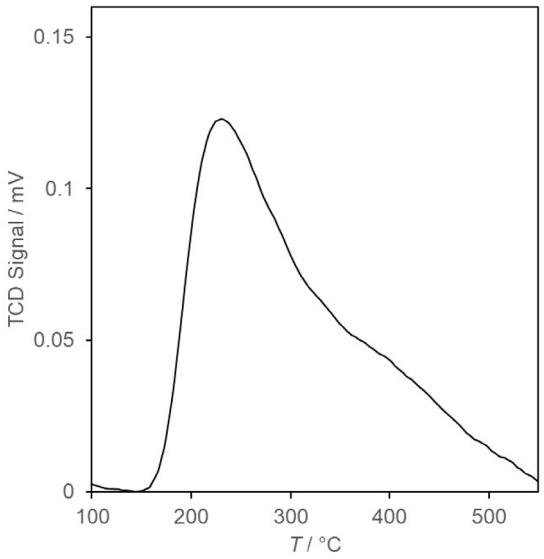
Supplementary Figure S11. Isotherm of nitrogen physisorption on Cu/La/Zr-6 before and after the experiment.



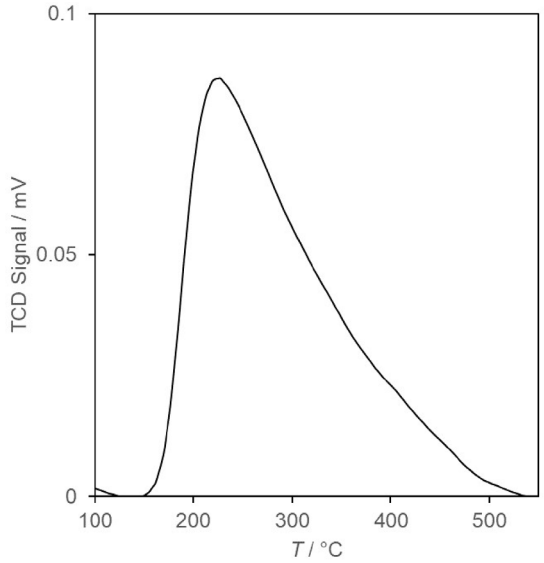
Supplementary Figure S12. Isotherm of nitrogen physisorption on Cu/La/Zr-7 before and after the experiment.



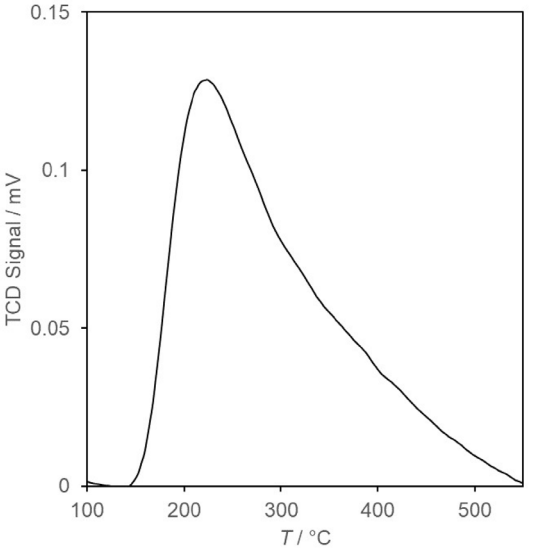
Supplementary Figure S13. Isotherm of nitrogen physisorption on Cu/La/Zr-8 before and after the experiment.



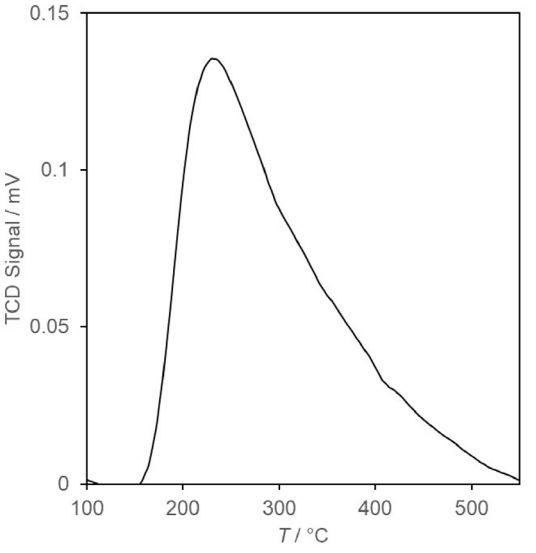
Supplementary Figure S14. The TPD-NH_3 curve (SiO_2).



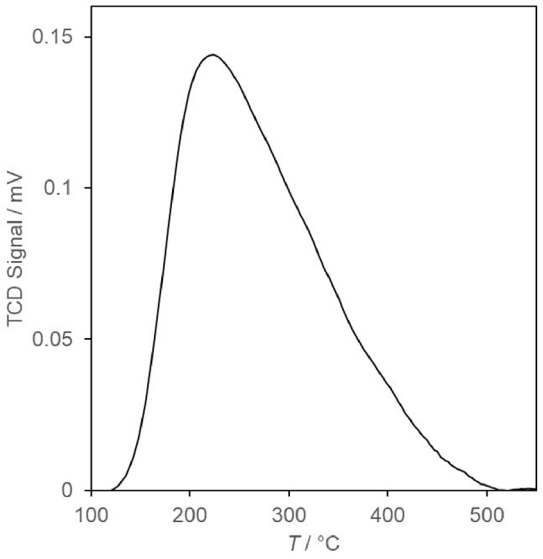
Supplementary Figure S15. The TPD-NH_3 curve (Zn/Zr).



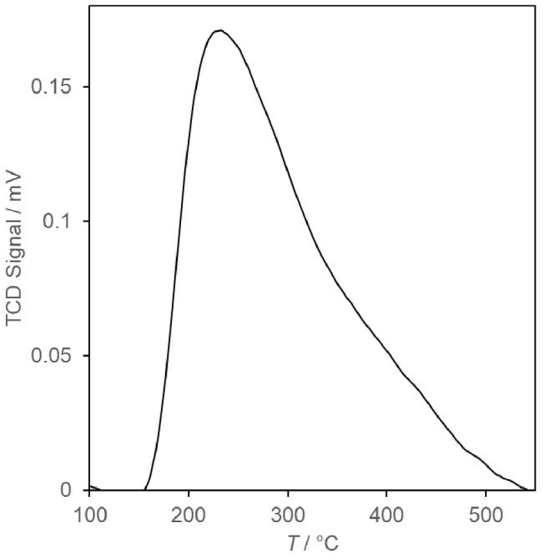
Supplementary Figure S16. The TPD-NH_3 curve (Cu/Zn/Zr).



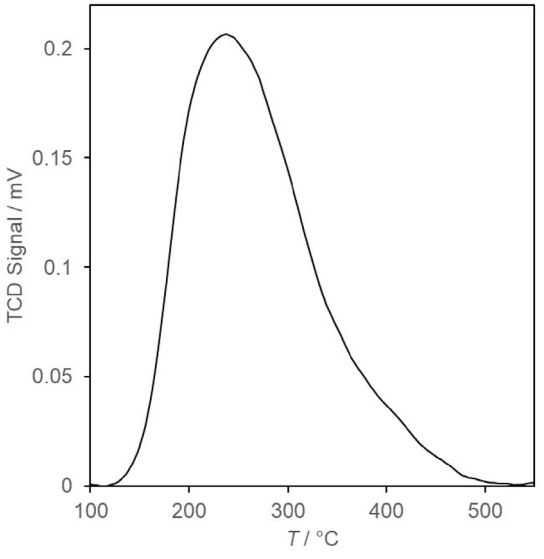
Supplementary Figure S17. The TPD-NH_3 curve (La/Zn/Zr).



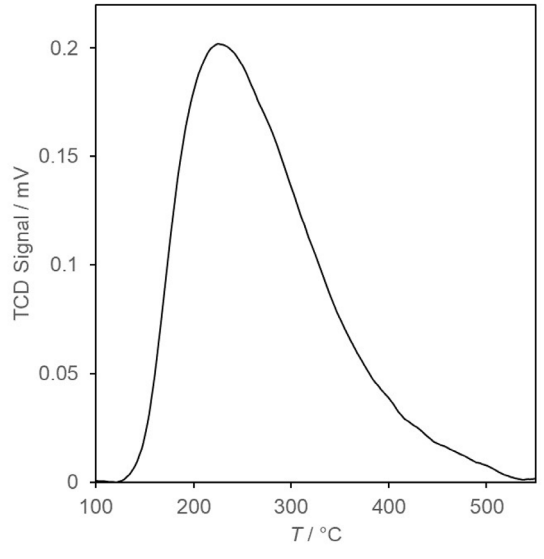
Supplementary Figure S18. The TPD-NH_3 curve (Cu/La/Zr-1).



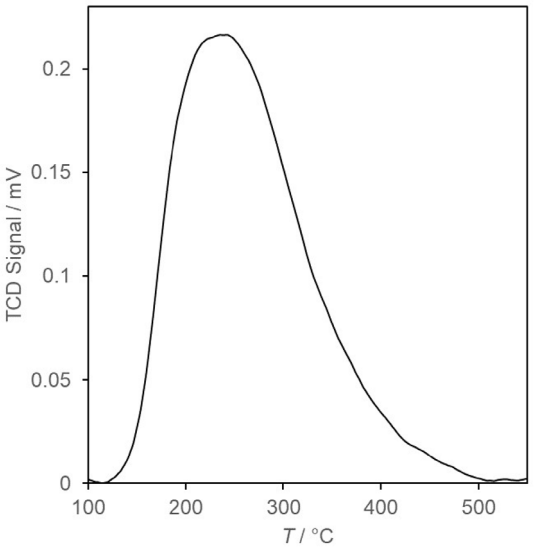
Supplementary Figure S19. The TPD-NH_3 curve (Cu/La/Zr-2).



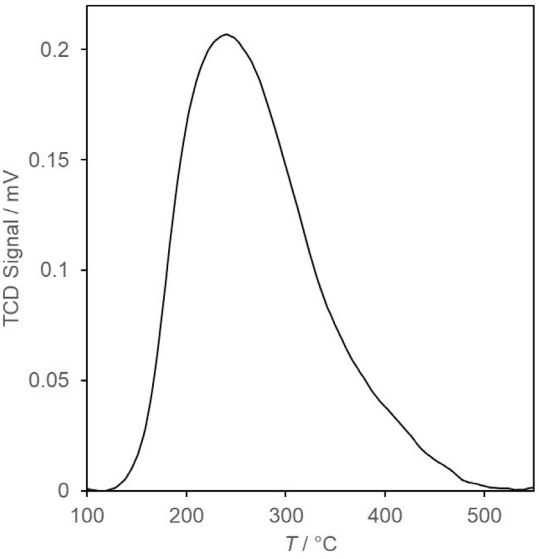
Supplementary Figure S20. The TPD-NH_3 curve (Cu/La/Zr-3).



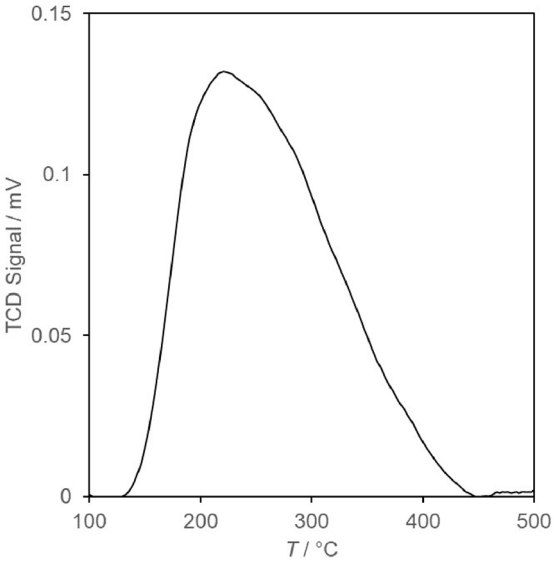
Supplementary Figure S21. The TPD-NH_3 curve (Cu/La/Zr-4).



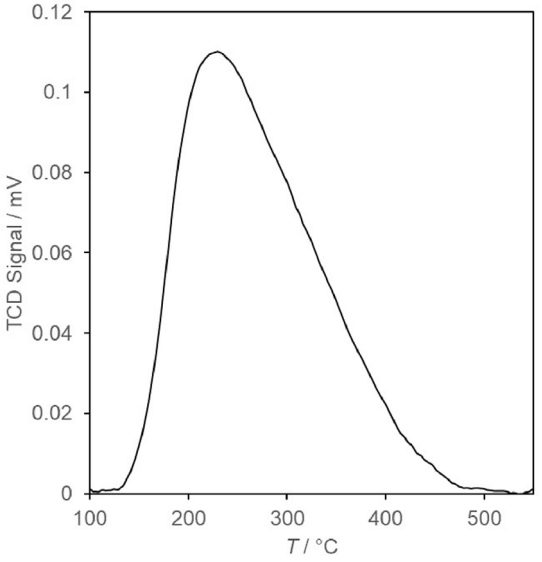
Supplementary Figure S22. The TPD-NH_3 curve (Cu/La/Zr-5).



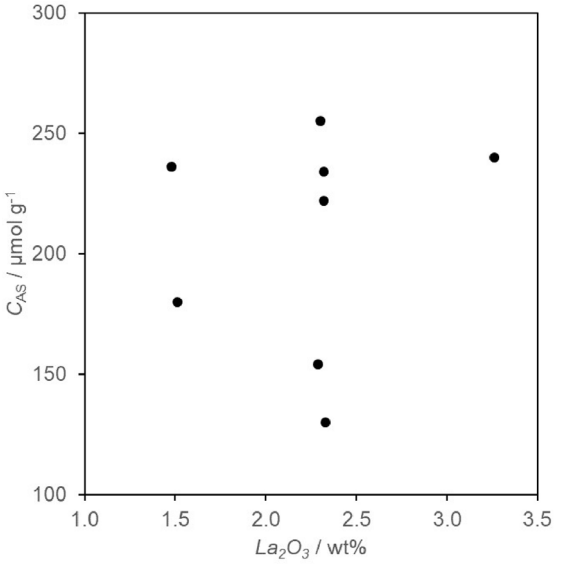
Supplementary Figure S23. The TPD-NH_3 curve (Cu/La/Zr-6).



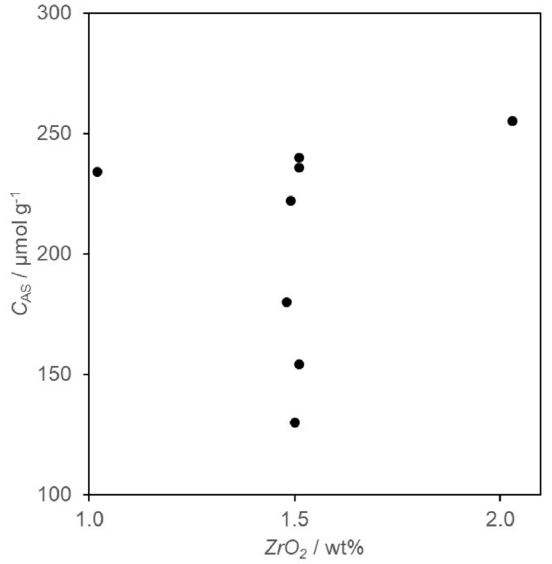
Supplementary Figure S24. The TPD-NH_3 curve (Cu/La/Zr-7).



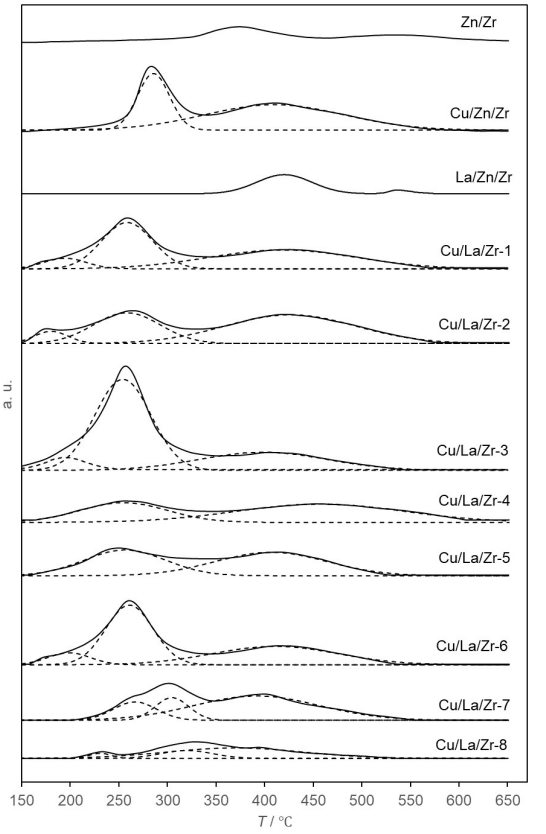
Supplementary Figure S25. The TPD-NH_3 curve (Cu/La/Zr-8).



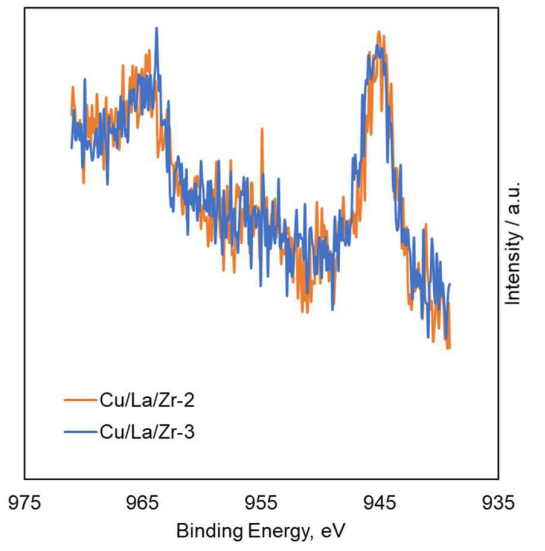
Supplementary Figure S26. Acid site concentration as a function of lanthanum content in Cu/La/Zr catalysts.



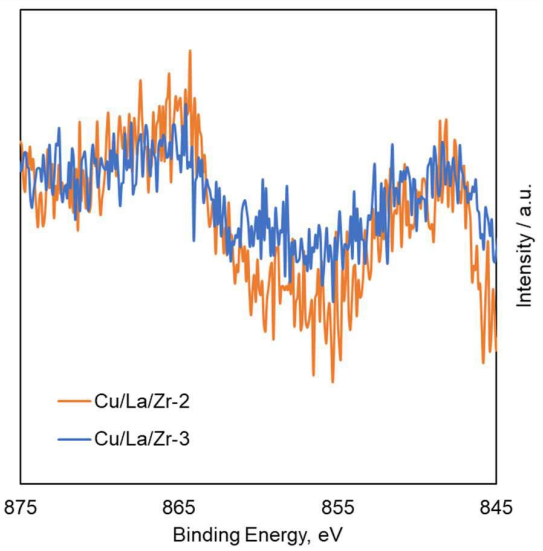
Supplementary Figure S27. Acid site concentration as a function of zirconium content in Cu/La/Zr catalysts.



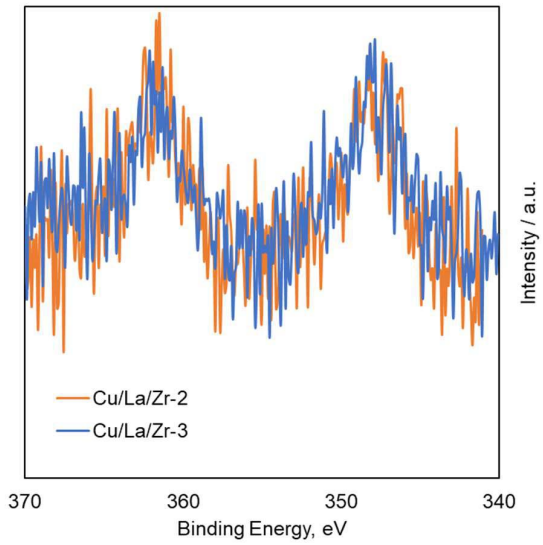
Supplementary Figure S28. The TPR curve for catalyst samples.



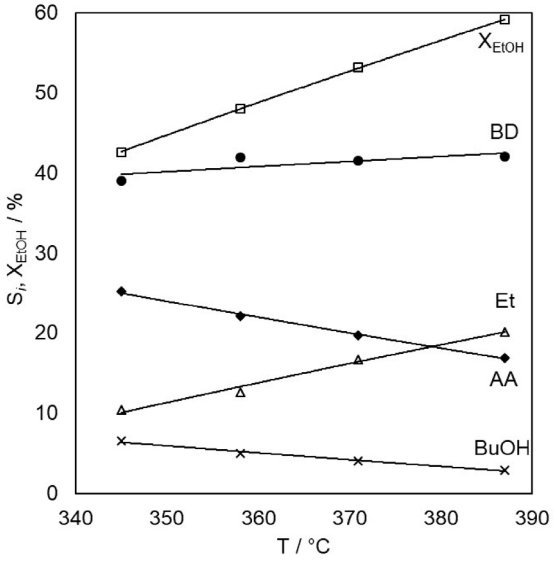
Supplementary Figure S29. XPS analysis of samples Cu/La/Zr-2 and Cu/La/Zr-3 (narrow scan of Cu).



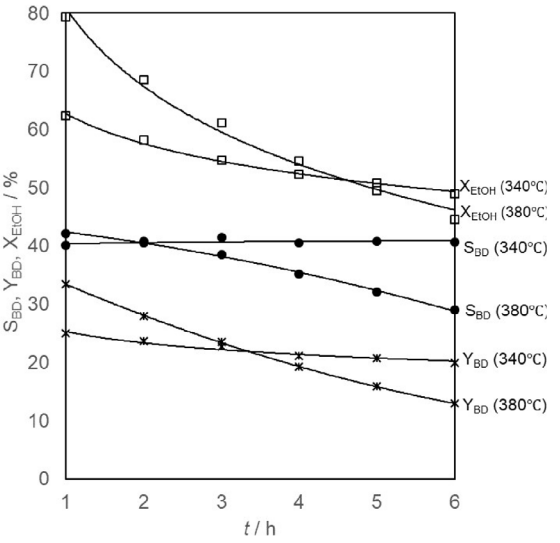
Supplementary Figure S30. XPS analysis of samples Cu/La/Zr-2 and Cu/La/Zr-3 (narrow scan of La).



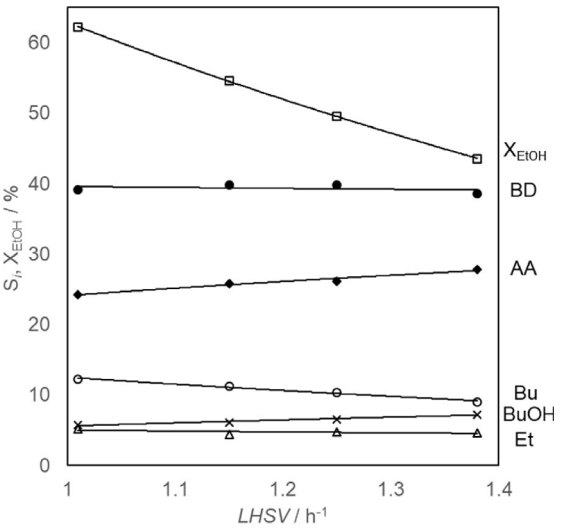
Supplementary Figure S31. XPS analysis of samples Cu/La/Zr-2 and Cu/La/Zr-3 (narrow scan of Zr).



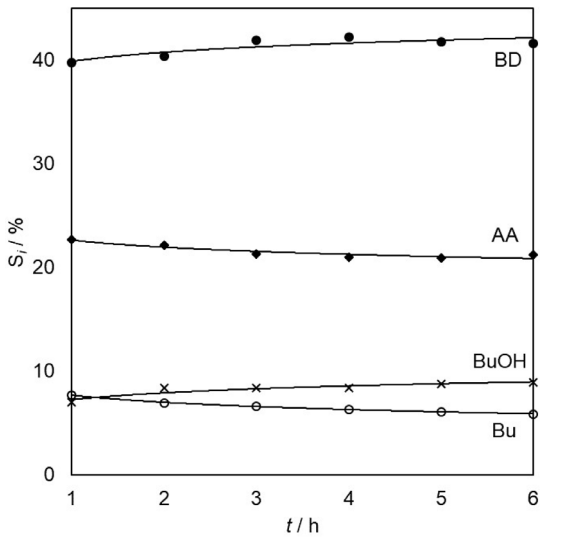
Supplementary Figure S32. Ethanol conversion and selectivity of the main reaction products as a function of temperature (100 cm^3 Cu/La/Zr-1, 340 °C, $LHSV = 1.15\ h^{-1}$, $t = 1$ h).



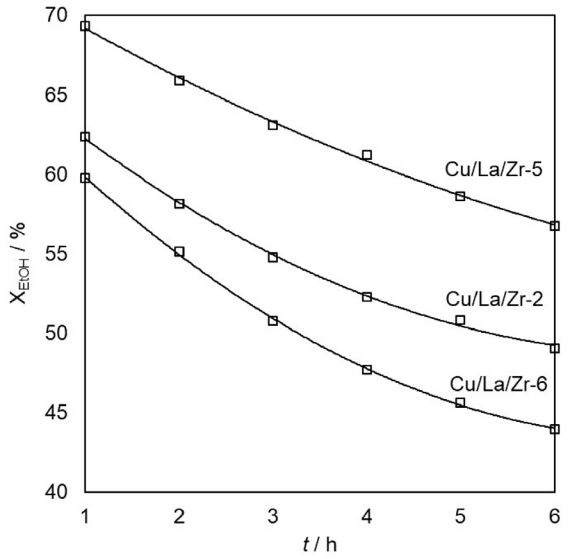
Supplementary Figure S33. Ethanol conversion, yield and selectivity butadiene as a function of time-on-stream at temperature 340 and 380 °C (100 cm^3 Cu/La/Zr-2, $LHSV = 1\ h^{-1}$).



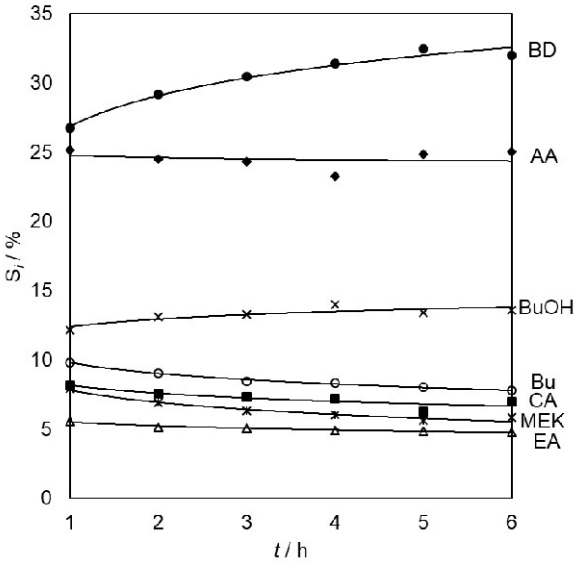
Supplementary Figure S34. Ethanol conversion and selectivity of the main reaction products as a function of *LHSV* (100 cm^3 Cu/La/Zr-2, 340 °C, t = 1 h).



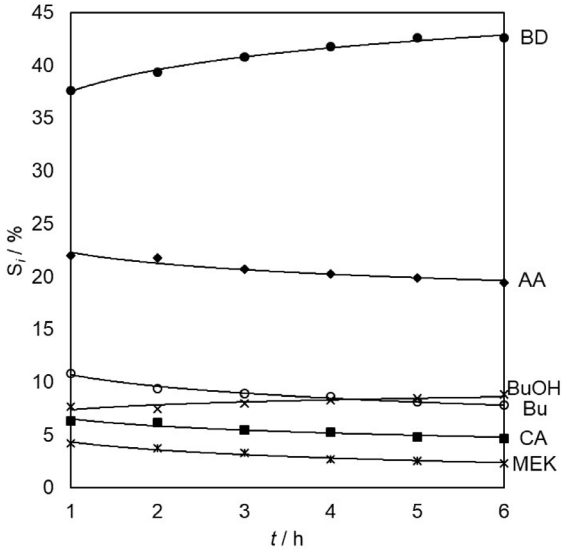
Supplementary Figure S35. Selectivity of the main reaction products as a function of time-on-stream (100 cm^3 Cu/La/Zr-6, 340 °C, *LHSV* = 1 h^{-1}).



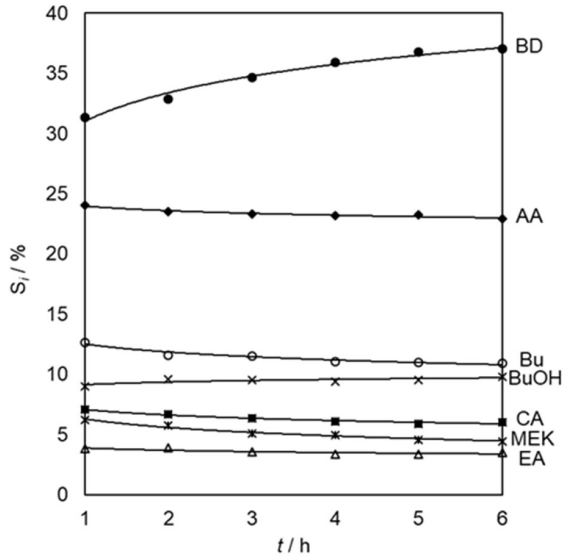
Supplementary Figure S36. Ethanol conversion as a function of time-on-stream over the Cu/La/Zr catalysts with different content Zr (100 cm^3 catalyst, 340 °C, *LHSV* = 1 h^{-1}).



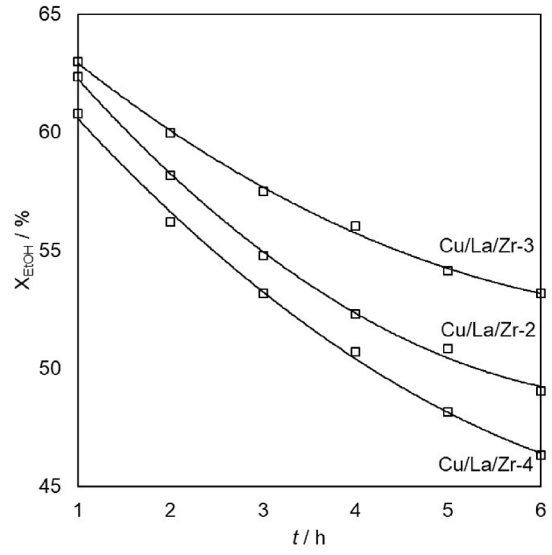
Supplementary Figure S37. Selectivity of the main reaction products as a function of time-on-stream (100 cm^3 Cu/La/Zr-5, 340 °C, *LHSV* = 1 h^{-1}).



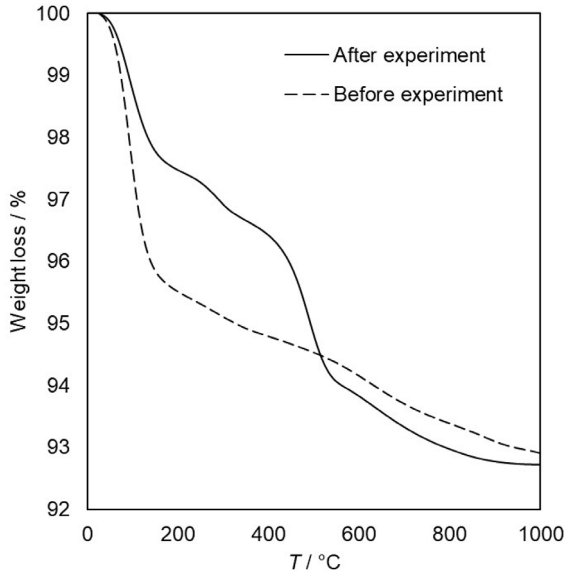
Supplementary Figure S38. Selectivity of the main reaction products as a function of time-on-stream (100 cm^3 Cu/La/Zr-4, 340 °C, $LHSV = 1\ h^{-1}$).



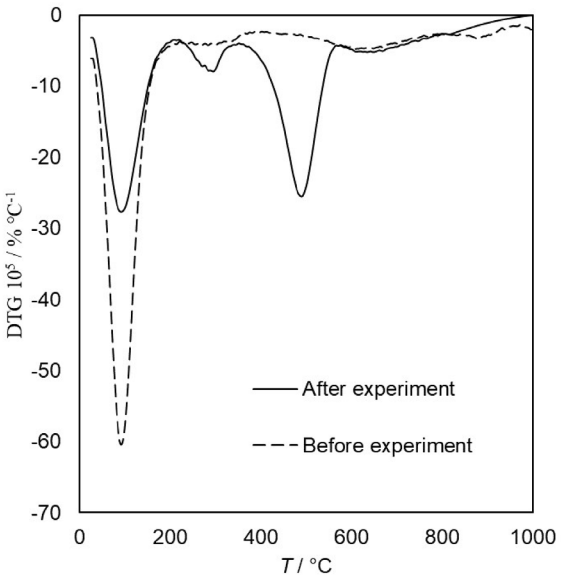
Supplementary Figure S40. Selectivity of the main reaction products as a function of time-on-stream (100 cm^3 Cu/La/Zr-3, 340 °C, $LHSV = 1\ h^{-1}$).



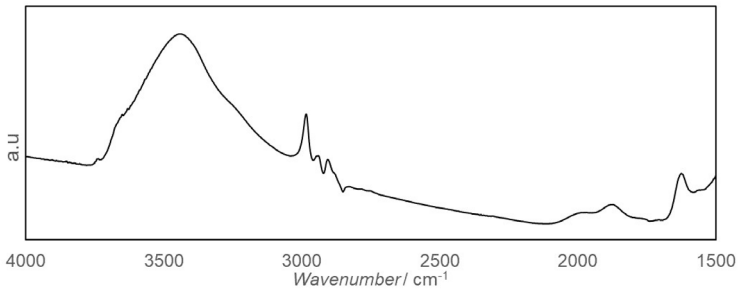
Supplementary Figure S39. Ethanol conversion as a function of time-on-stream over the Cu/La/Zr catalysts with different content La. (100 cm^3 catalyst, 340 °C, $LHSV = 1\ h^{-1}$).



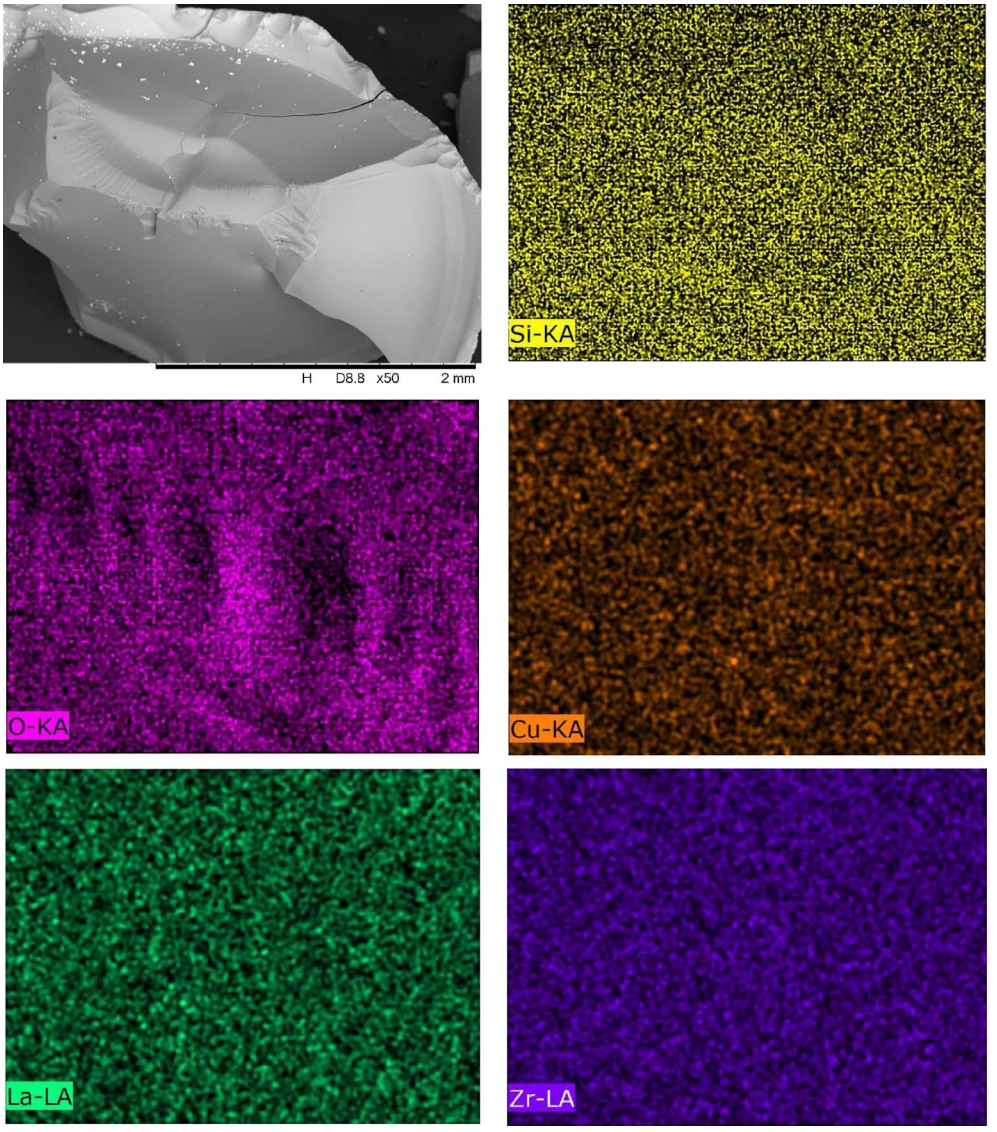
Supplementary Figure S41. TGA curves in air atmosphere for the Cu/La/Zr-2 before and after the experiment.



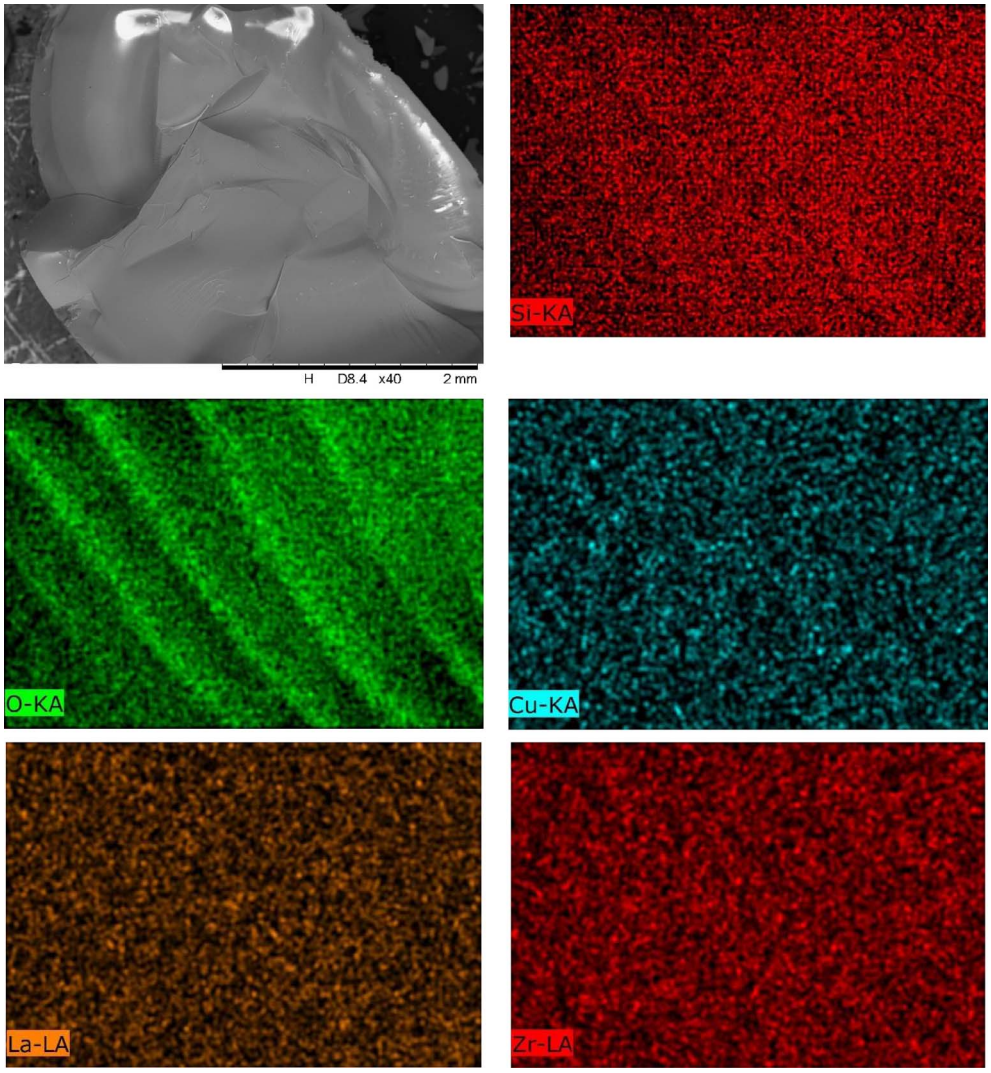
Supplementary Figure S42. DTG curves in air atmosphere for the Cu/La/Zr-2 before and after the experiment.



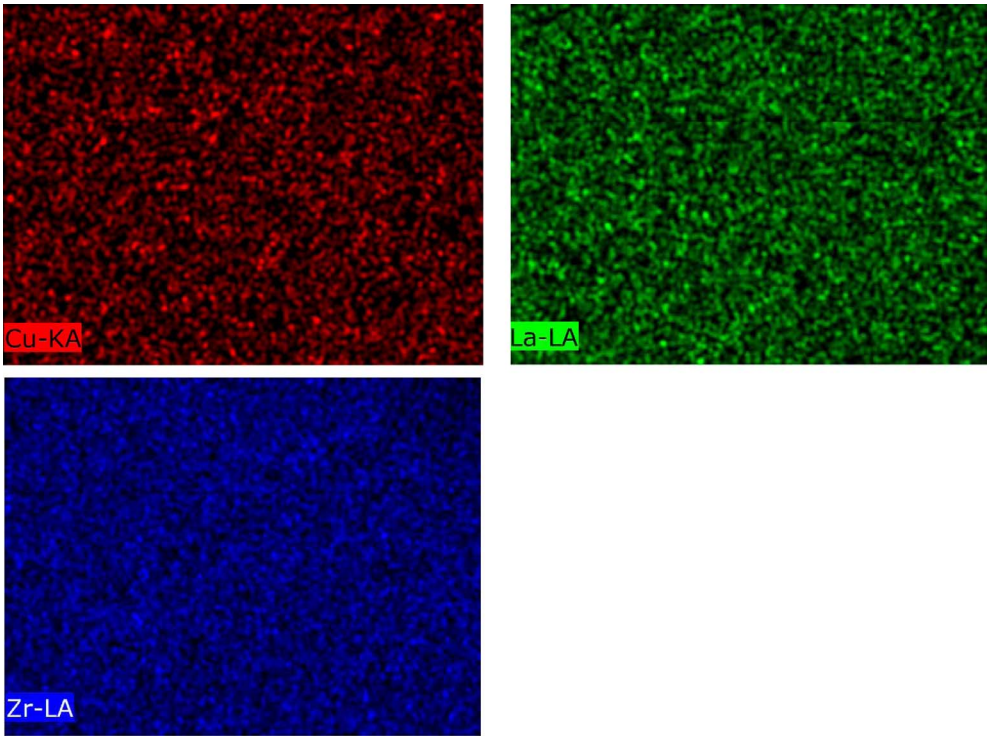
Supplementary Figure S43. FTIR result of coke deposit on the Cu/La/Zr-2.



Supplementary Figure S44. Representative SEM image and element (Si, O, Cu, La, Zr) EDX mapping for the fresh Cu/La/Zr-2.



Supplementary Figure S45. Representative SEM image and element (Si, O, Cu, La, Zr) EDX mapping for the regenerated Cu/La/Zr-2.



Supplementary Figure S46. Element (Cu, La, Zr) EDX mapping for the fresh Cu/La/Zr-3.