Electronic Supporting Information

Low-temperature deep oxidation of N, N-dimethylformamide (DMF) over CeCu binary oxides

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Section 1: Preparation method

The powders were fabricated by Sol-gel method.

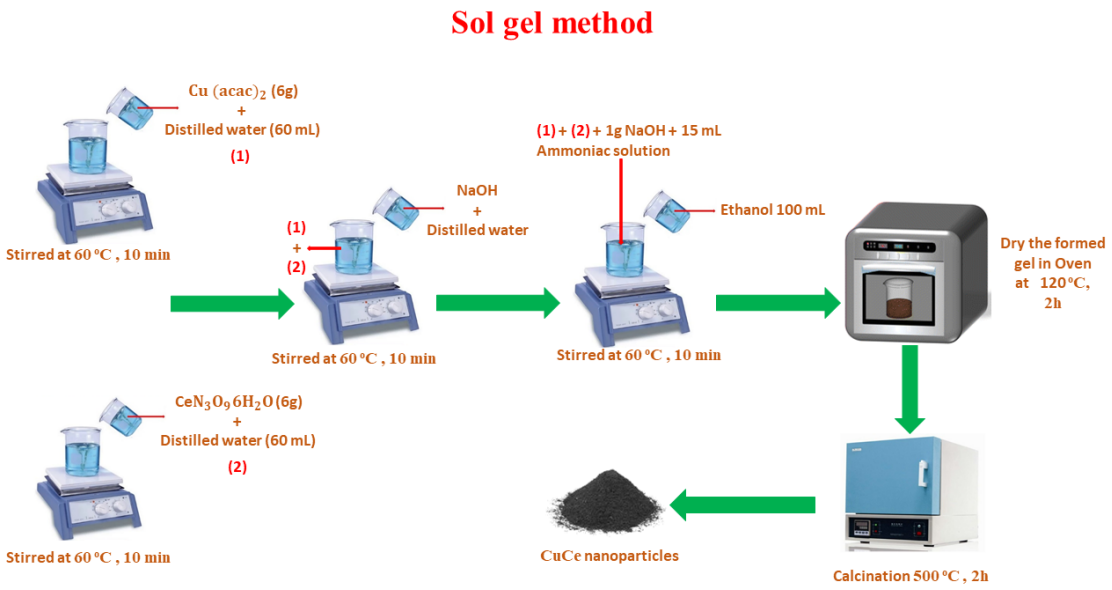

Figure S1. Sol-gel setup for the nanoparticles catalyst preparation [1, 2].

Section 2: Catalytic test experimental setup

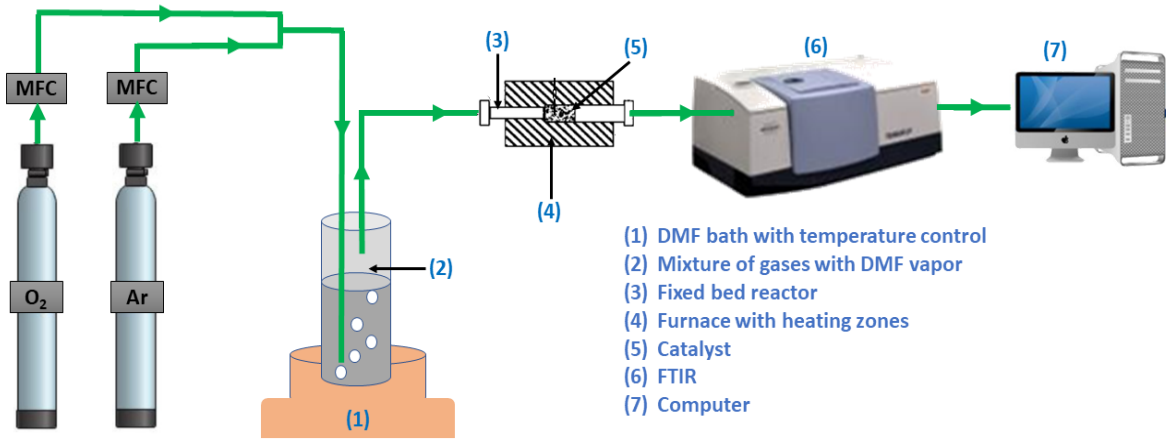

Figure S2. The catalytic test system connected to the FTIR equipment.

Section 3: Structural properties

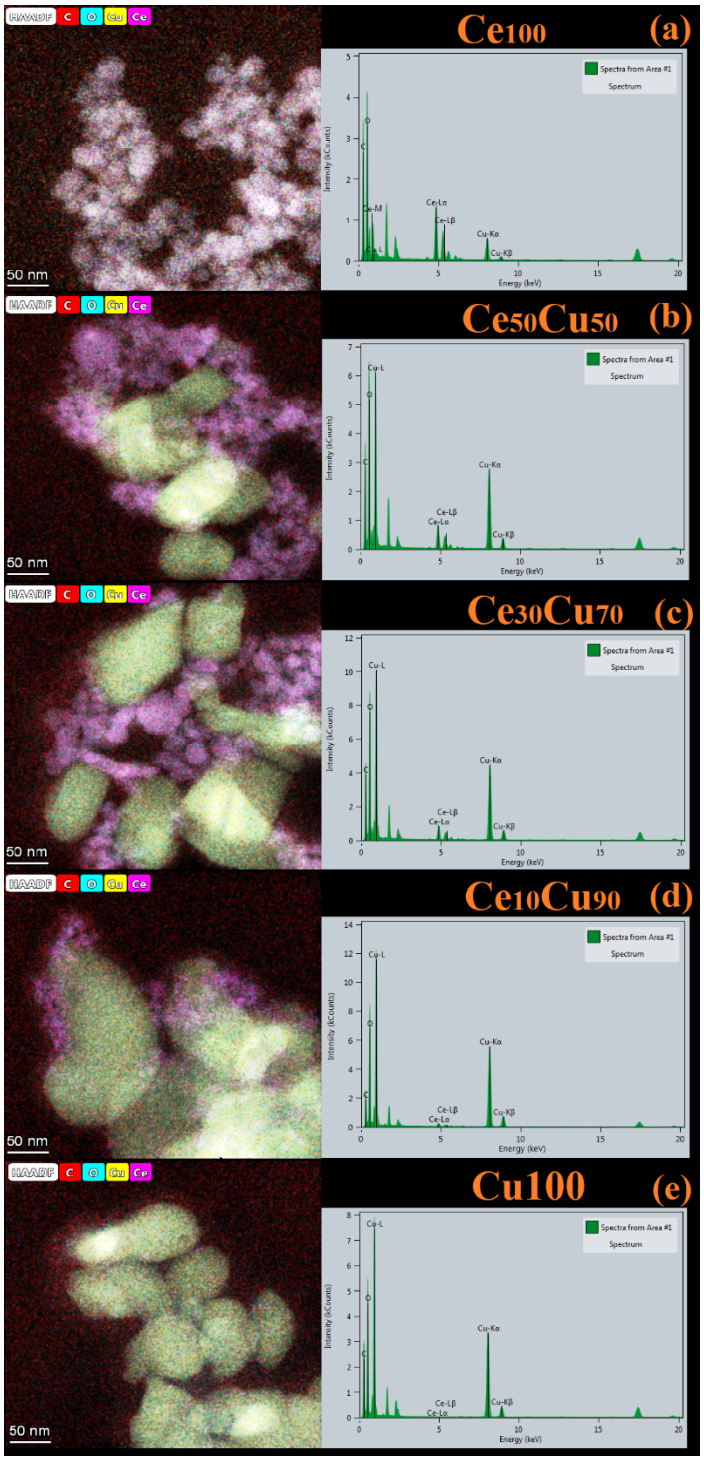

Figure S3. EDS-HAADF images of CuCe samples; Ce_{100}(a), $Ce_{50}Cu_{50}$(b), $Ce_{30}Cu_{70}$(c), $Ce_{10}Cu_{90}$(d), Cu_{100}.

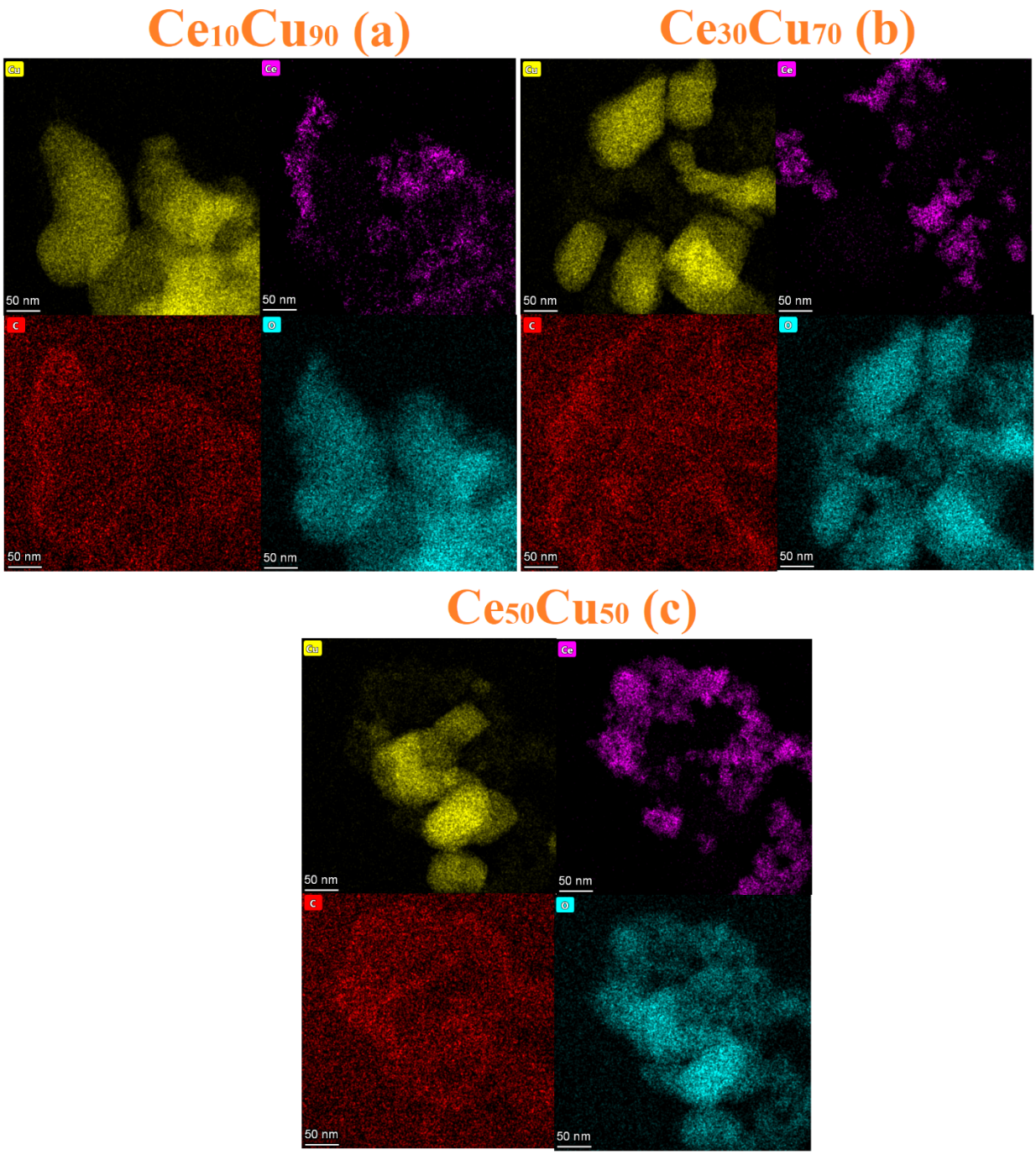

Figure S4. Fine-Element mapping images of CuCe samples; $Ce_{10}Cu_{90}$ (a), $Ce_{30}Cu_{70}$ (b), and $Ce_{50}Cu_{50}$(c).

Table S1 Crystallite size and micro-strain of thin-films samples.

Samples	hkl	FWHM (β) (º)	2θ (º)	Crystallite size D (nm)	D average (nm)	Micro-strain ε (%)	ε average (%)
Ce_{100}	110	0.41	35.47	20.34	20.20	0.11	0.12
	111	0.42	38.69	20.05		0.13	
$Ce_{50}Cu_{50}$	110	0.46	35.47	18.13	18.42	0.13	0.13
	111	0.45	38.69	18.71		0.14	
$Ce_{30}Cu_{70}$	110	0.49	35.47	17.02	17.28	0.14	0.14
	111	0.48	38.69	17.54		0.15	
$Ce_{10}Cu_{90}$	110	0.59	35.47	14.14	14.87	0.16	0.16
	111	0.54	38.69	15.59		0.16	
Cu_{100}	110	0.63	35.47	13.24	13.52	0.17	0.18
	111	0.61	38.69	13.80		0.19	

Note: hkl refers to Miller indicies, θ refers to Bragg's angle, and FWHM refers to the full width at half maximum of the peak.

Table S2 CeCu materials specific surface area.

Samples	Surface area (m^2/g)	Pore volume (cm^3/g)	Pore size (nm)
Ce_{100}[3]	3.775	0.009	25.703
$Ce_{50}Cu_{50}$	4.962	0.027	28.660
$Ce_{30}Cu_{70}$	5.319	0.031	39.382
$Ce_{10}Cu_{90}$	6.146	0.034	41.689
Cu_{100}	7.739	0.044	42.645

Section 4: Ionic states configuration

Table S3 Comparison of the relative contents of CeCu binary oxides using EDS and XPS.

Samples	Type	Ce	Cu	C	O	Ce/O	Cu/O	Cu/Ce
$\mathbf{Ce_{100}}$	XPS	5.77	0.00	29.11	65.12	0.09	0.00	0.00
	EDS	12.50	0.00	35.70	51.80	0.24	0.00	0.00
$\mathbf{Ce_{50}Cu_{50}}$	XPS	4.05	5.86	36.47	53.62	0.08	0.11	1.45
	EDS	3.40	17.30	39.40	39.90	0.08	0.43	5.09
$\mathbf{Ce_{30}Cu_{70}}$	XPS	3.34	6.87	39.66	50.13	0.07	0.14	2.06
	EDS	2.50	19.40	40.70	39.40	0.06	0.49	7.76
$\mathbf{Ce_{10}Cu_{90}}$	XPS	1.05	8.83	40.45	49.67	0.02	0.18	8.41
	EDS	0.20	22.80	46.00	30.50	0.01	0.75	114
$\mathbf{Cu_{100}}$	XPS	0.00	9.03	52.21	38.76	0.00	0.23	-
	EDS	0.00	23.90	49.90	26.20	0.00	0.91	-

Table S4 Results of curve-fitting on the Ce 3*d* binding energies and relative atomic percentage for the five sets of catalysts.

Catalysts	Parameters	Ce 3*d*5/2			Ce 3*d*3/2		
	Species	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}
Ce_{100}	BE (eV)	884.04	882.23	0.34	900.70	898.14	0.36
	RA (%)	25.36	74.64		26.46	73.54	
	Species	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}
$Ce_{50}Cu_{50}$	BE (eV)	884.33	882.16	0.39	900.61	898.06	0.40
	RA (%)	27.84	72.16		28.35	71.65	
	Species	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}
$Ce_{30}Cu_{70}$	BE (eV)	883.76	882.29	0.79	900.95	898.24	0.70
	RA (%)	44.24	55.76		41.30	58.70	
	Species	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}	Ce^{3+}	Ce^{4+}	Ce^{3+}/Ce^{4+}
$Ce_{10}Cu_{90}$	BE (eV)	883.79	882.30	1.13	900.92	898.26	0.93
	RA (%)	53.07	46.93		48.27	51.73	
Cu_{100}	-	-	-	-	-	-	-

Note: BE refers to binding energy, and RA refers to the relative area of the peak.

Table S5 Results of curve-fittings on the O 1*s* binding energies and relative atomic percentage for the four sets of catalysts

Catalysts	**Parameters**	**O 1*s***					
	Species	**O^{2-}**	**CO_3^{2-}**	**OH^-**	**H_2O**	**O_{Lat}/O_{Ads}**	**CO_3^{2-}/OH^-**
Ce_{100}	BE (eV)	529.20	531.17	532.74	535.86	0.22	0.32
	RA (%)	17.88	16.27	50.60	15.20		
	Species	**O^{2-}**	**CO_3^{2-}**	**OH^-**	**H_2O**	**O_{Lat}/O_{Ads}**	**CO_3^{2-}/OH^-**
$Ce_{50}Cu_{50}$	BE (eV)	529.43	531.13	532.32	535.13	0.32	1.90
	RA (%)	24.51	42.16	22.23	11.10		
	Species	**O^{2-}**	**CO_3^{2-}**	**OH^-**	**H_2O**	**O_{Lat}/O_{Ads}**	**CO_3^{2-}/OH^-**
$Ce_{30}Cu_{70}$	BE (eV)	529.35	531.22	532.61	535.38	0.34	2.60
	RA (%)	25.92	45.72	17.56	10.80		
	Species	**O^{2-}**	**CO_3^{2-}**	**OH^-**	**H_2O**	**O_{Lat}/O_{Ads}**	**CO_3^{2-}/OH^-**
$Ce_{10}Cu_{90}$	BE (eV)	529.58	531.17	533.01	535.51	0.38	3.24
	RA (%)	27.63	48.75	15.05	8.57		
	Species	**O^{2-}**	**CO_3^{2-}**	**OH^-**	**H_2O**	**O_{Lat}/O_{Ads}**	**CO_3^{2-}/OH^-**
Cu_{100}	BE (eV)	529.57	531.36	532.65	535.37	0.43	3.40
	RA (%)	29.92	49.13	14.44	6.51		

Note: BE refers to the binding energy; O_{Lat} refers to the lattice oxygen; O_{Ads} refers to the adsorption oxygen; RA refers to the relative area of the peak.

Table S6 Results of curve-fitting on the Cu 2*p* binding energies and relative atomic percentage for the five sets of catalysts.

Catalysts	Parameters	Cu 2*p*3/2			Cu 2*p*1/2		
Ce_{100}	-	-	-	-	-	-	-
	Species	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**
$Ce_{50}Cu_{50}$	BE (eV)	934.74	933.52	0.60	954.45	952.98	0.56
	RA (%)	37.42	62.58		35.98	64.02	
	Species	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**
$Ce_{30}Cu_{70}$	BE (eV)	934.67	933.10	0.66	954.43	952.84	0.66
	RA (%)	39.69	60.31		39.72	60.28	
	Species	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**
$Ce_{10}Cu_{90}$	BE (eV)	935.03	933.26	0.80	954.86	953.09	0.80
	RA (%)	44.42	55.58		43.80	56.20	
	Species	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**	Cu^{2+}	Cu^{+}	**Cu^{2+}/Cu^{+}**
Cu_{100}	BE (eV)	935.08	933.57	0.92	954.88	953.03	0.87
	RA (%)	47.94	52.06		46.50	53.50	

Note: BE refers to binding energy, and RA refers to the relative area of the peak.

Section 5: Redox properties

Table S7 Results of the H_2-TPR analysis for the CeCu catalysts.

Cat.		H_2 consumptions (mmol/g)		
		Peak 1	**Peak 2**	**Peak 3**
Ce_{100}	Temperature (°C)	575.60	589.94	641.77
	Area	4.03	1.31	6.52
$Ce_{50}Cu_{50}$	Temperature (°C)	339.58	392.46	520.55
	Area	1.74	1.68	0.38
$Ce_{30}Cu_{70}$	Temperature (°C)	305.51	0.00	0.00
	Area	6.65	0.00	0.00
$Ce_{10}Cu_{90}$	Temperature (°C)	255.39	0.00	0.00
	Area	5.59	0.00	0.00
Cu_{100}	Temperature (°C)	249.28	0.00	0.00
	Area	5.02	0.00	0.00

Table S8 Results of the O_2-TPO analysis for the CeCu catalysts.

Cat.		O_2 consumptions (mmol/g)		
		Peak 1	**Peak 2**	**Peak 3**
Ce_{100}	Temperature (°C)	693.42	0.00	0.00
	Area	7.09	0.00	0.00
$Ce_{50}Cu_{50}$	Temperature (°C)	180.24	536.26	694.14
	Area	0.09	0.64	0.71
$Ce_{30}Cu_{70}$	Temperature (°C)	130.66	438.95	693.84
	Area	0.02	0.23	0.68
$Ce_{10}Cu_{90}$	Temperature (°C)	85.69	399.26	599.29
	Area	0.03	0.18	0.50
Cu_{100}	Temperature (°C)	84.09	187.15	573.07
	Area	0.02	0.06	0.67

Section 6: Catalytic activity

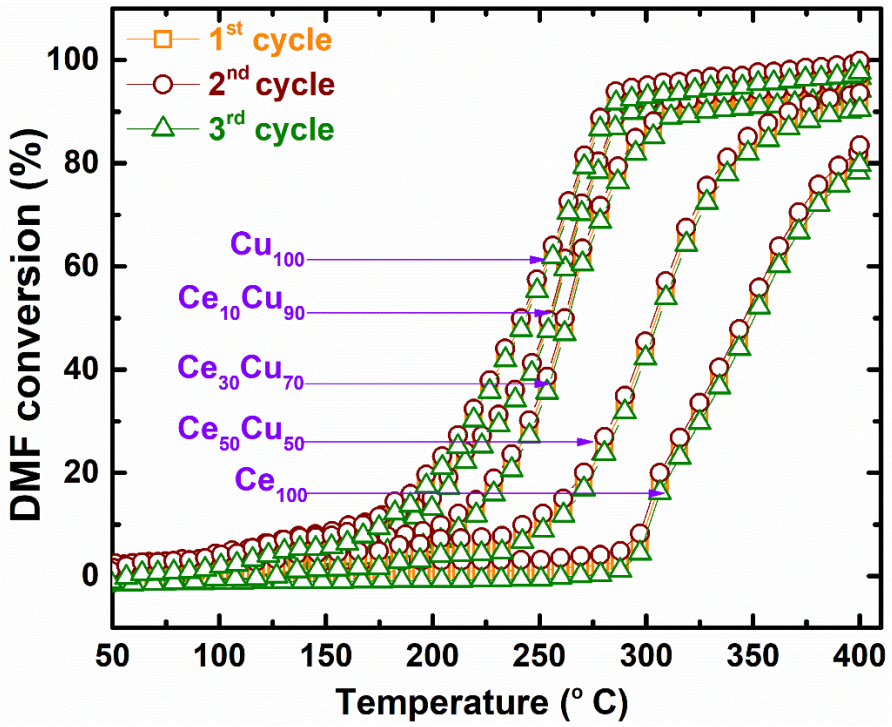

Figure S5. Reproducibility of DMF oxidation over CeCu binary oxides catalysts.

Table S9 Results of DMF conversion and selectivity of products obtained for CeCu binary oxides catalysts.

Catalysts	DMF	CO_2	NO_2
Ce_{100}	81.48	66.29	33.71
$Ce_{50}Cu_{50}$	91.99	62.48	37.52
$Ce_{30}Cu_{70}$	95.61	56.81	43.19
$Ce_{10}Cu_{90}$	97.55	56.33	43.67
Cu_{100}	98.72	56.27	43.73

References

1. C. K. Fonzeu Monguen, A. El Kasmi, M. F. Arshad, P. M. Kouotou, S. Daniel and Z.-Y. Tian, *Ind. Eng. Chem. Res.*, 2022, **61**, 4546-4560.
2. S. Daniel, C. K. F. Monguen, A. El Kasmi, M. F. Arshad and Z.-Y. Tian, *Catal. Lett.*, 2022, DOI: 10.1007/s10562-022-03977-6.
3. C. K. Fonzeu Monguen, E.-J. Ding, S. Daniel, J.-Y. Jia, X.-H. Gui and Z.-Y. Tian, *Catalysts*, 2023, **16**, 865.