How membrane characteristics influence the performance of CO_2 and CO electrolysis

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Table S1. Performance of ion selective exchange membranes from data published for CO_2 electrolysis

Notation	Authors	Electrode	Anode	IEM Type	Membrane	Electrolyte	Current Density (mA/cm^2)	Cell Voltage (V)	Operation Conditions (P.T)	CO_2 Feeding Rate	Configuration	Main Product	FE (%)	CL (mg/cm^2)	EE (%)[1]	Ref.
a	Jhong et al.	Unsupported Ag air-brushed in GDE	Pt/C (50% wt.)	CEM	Nafion 117	1 M KCl	100	-0.7 V vs Ag/AgCl (E_{WE})	RT	7 sccm	Microfluidic fuel cell (flow cell)	CO	94% CO	8-10	N.A	**1**
b	Garcia de Arquer et al.	2D-Bi catalyst BiOBr	Pt Foil	CEM	N.S	2 M $KHCO_3$	200	-1.2 V vs. RHE (E_{WE})	RT	N.S	Flow Cell	$HCOO^-$	90% $HCOO^-$	Dilution Ink 250 μL cm^{-2}	N.A	**2**
c	Ju et al.	Sn/Cu Catalyst	IrO_2	AEM	Sustainion-PTFE Supported	0.1 M $KHCO_3$	100	-1.0 V vs. RHE (E_{WE})	N.S	N.S	MEA	CO	80% CO	N.S	N.A	**3**
d	Ma et al.	Ag/CF in SG35BC	IrO_2	AEM	N.S	0.5 M $KHCO_3$	200	-2.1 V vs Ag/AgCl (E_{WE})	RT	7 sccm	Flow Cell	CO	64% CO	1.0	N.A	**4**
e	Hori et al.	Ag SPE	Pt-plate	AEM	Selemion AMV	0.2 M K_2SO_4	100	-2.96	RT	100 mL/min	H-cell	CO	>50% CO	6.1	22.5	**5**
f	Obrien et al.	Cu Sputtered in PTFE filter	Ti mesh	AEM	Sustainion X37-50 RT	0.1 M $KHCO_3$	100	-4.0	RT	1-10 sccm	MEA	C_2H_4	40% C_2H_4	250 nm	11.5	**6**
g	Zheng et al.	Ni single-atom catalyst on GDE	IrO_2	CEM	PSMIM (Sustainion)	0.1 M $KHCO_3$	100	-2.8	N. S	50 sccm	MEA	CO	>95% CO	1.25	45.1	**7**
h	Lee et al.	Ag-GDE	IrO_2 in Ti Felt	AEM	Sustainion	10 mM $KHCO_3$	162	-3.0	N.S	50 sccm	MEA	CO	96.7% CO	1.0	42.9	**8**
i	Yang et al.	Sn/C GDE	IrO_2	AEM	Sustainion X37-50 RT	Deionized Water	140	-3.5	RT	20 mL/min	Flow Cell	$HCOO^-$	94% $HCOO^-$	5.0	36.3	**9**
j	Del Castillo et al.	Sn/C-GDE (Toray Paper)	Ir-MMO	CEM	Nafion 117	0.45 M $KHCO_3$+ 0.5 M KCl	150	-4.3	N.S	200 mL/min	Flow cell	$HCOO^-$	70% HCOO	0.75	22	**10**
k	Jeanty et al.	Ag in Covestro GDE	N.S	CEM	Nafion 117	0.4 M K_2SO_4	150	-5.84	RT	21 mL/min	Flow Cell	CO	65% CO	N.S	14.8	**11**
l	Liang et al.	SnO_2 nanoparticles (5 nm)	IrO_2	AEM	Fumatech	1 M $KHCO_3$	145	-1.21 V vs. RHE	N.S	N.S	Flow Cell	$HCOO^-$	64% $HCOO^-$	1.5	N.A	**12**
m	Gabardo et al.	Sputtered Cu (150 nm)	IrO_2	AEM	Sustainion X37-50 RT	0.1 M $KHCO_3$	150	-3.25	RT	80 sccm	MEA	C_2H_4	46% C_2H_4	2.0	16.3	**13**
n	Bhargava et al.	Ag NPs-GDE	IrO_2	AEM	N.S	3.0 M Cs_2CO_3	200	-3.3	RT	17 sccm	Flow Cell	CO	90% CO	2.0	36.3	**14**
o	Kutz et al.	Ag NPs	IrO_2	AEM	AMI-7001	0.01 M $KHCO_3$	200	-3	N.S	20 sccm	MEA	CO	95% CO	1.0	42.1	**15**
p	Sassenburg et al.	Ag-GDE	Pt-wire	CEM	Nafion 212	1 M $KHCO_3$	200	-3.6	RT	30 mL/min	Flow Cell	CO	90% CO	100 nm	33.3	**16**
q	Fan et al.	nBuLi-Bi in SG 35BC	IrO_2	AEM	Sustainion X37-50	1.0 M $KHCO_3$	200	-1.05 vs. RHE	RT	50 sccm	Flow Cell	$HCOO^-$	92% $HCOO^-$	0.7	N.A	**17**
r	Kopljar et al.	Sn NPs in SG 35 BC	Pt foil	CEM	Nafion 117	0.1 M $KHCO_3$	200	-1.57 vs SHE	RT	3 mL/min	MEA	$HCOO^-$	80-90% $HCOO^-$	5.0	N.A	**18**
s	Irtem et al.	Sn in Toray H-60	DSA SA Plate	CEM	Nafion 117	0.5 M $NaHCO_3$	200	-4.0	RT	50-200 mL/min	Micro Flow cell	HCOO	71% HCOO	2.6	24.0	**19**
t	Ozden et al.	Cu CTPI/PTFE	IrO_2 on Titanium Mesh	AEM	Sustainion X37-50	0.1 M $KHCO_3$	220	-3.7	RT	80 sccm	MEA	C_2H_4	69% C_2H_4	100-200 nm	21.4	**20**

Notation	Authors	Electrode	Anode	IEM Type	Membrane	Electrolyte	Current Density (mA/cm^2)	Cell Voltage (V)	Operation Conditions (P.T)	CO_2 Feeding Rate	Configuration	Main Product	FE (%)	CL (mg/cm^2)	EE (%)	Ref.
u	Patru et al.	Au-GDE	Pt/CN or IrO_2- TiO_2	BPM	Fumatech FBM (130 µm)	0.1 M $CsHCO_3$	200	-4.9	N.S	5 mL/min	MEA	CO	60% CO	3.0	16.3	21
v	Xie et al.	Cu NPs in GDL	IrO2 in Ti-felt	BPM	SC-BPM in Nafion 212 (65 µm)	0.5 M K_2SO_4/0.1 M $KHCO_3$	200	-4.05	308 K	10 $sccm/cm^2$	MEA	C_2H_4	34% C_2H_4	1.5	9.8	22
w	Siritanaratkul et al.	Ni molecular electrocatalyst	RuO_2	BPM	Fumatech	Pure Water	100	-5.0	N.S	20 sccm	MEA	CO	30% CO	1.0	6.8	23
x	Jing Lv et al.	Cu NPs in GDL	IrO_2 coated in GDE	AEM	Fumasep FAA-3	1 M $KHCO_3$	200	-0.8 vs RHE	N.S	10 sccm	Flow Cell	C_2H_4	30% C_{2+}	0.6	N.A	24
y	Thang Dinh et al.	Cu/Ag catalyst on expanded PTFE GDE	Ni mesh	AEM	N.S	1 M $KHCO_3$	200	-0.7 vs RHE (E_{WE})	RT	50 mL/min	MEA	CO	90% CO	500 nm	N.A	25
z	Jeong et al.	Single NNC	IrO_2	AEM	Sustainion X37-50	0.5 M $KHCO_3$	300	-2.6	RT	N.S	MEA	CO	99% CO	0.2	50.6	26
aa	Yin et al.	CoPc	IrO_2	AEM	QPAAT-based AEM	Pure Water	200	-2.85	333 K	100 sccm	Flow Cell	CO	90% CO	0.4	42.0	27
ab	Jiang et al.	Ni-NG catalyst	IrO_2	AEM	PSMIM (DM)	0.5 M $KHCO_3$	200	-2.78	N.S	50 sccm	MEA	CO	90% CO	0.5-1	43.1	28
ac	Corral et al.	Sputtered Cu in PTFE	IrO2	AEM	Sustainion	1 M $KHCO_3$	300	-3.8	RT	40 sccm	MEA	EtOH	34% EtOH	275 nm	10.2	29
ad	Dufek et al.	Ag-GDE	IrO_2 supported on Ni mesh	CEM	Nafion 115	0.5 M K_2SO_4	275	-3.0	15 atm and 363 K	85 mL/min	Flow Cell	CO	>80% CO	N.S	35.5	30
ae	Sen et al.	SnO_2 NPs	Pt-GDE	CEM	Nafion 112	0.5 M Na_2CO_3	220	-2.27	N.S	10 mL/min	Flow Cell	$HCOO^-$	74% $HCOO^-$	0.35±0.07	44.0	31
af	Li et al.	Sn particles	Ti Mesh	CEM	Nafion 117	0.5 M $KHCO_3$+ 2 M KCl	310	-3.9	314 K and 600 Kpa	400-1600 mL/min	Flow Cell	$HCOO^-$	61% $HCOO^-$	Commercial AEE SN 131	21.1	32
ag	Li et al.	Bimetallic Ag/Cu	IrO_2	AEM	Fumasep FAA-3-PK-150	1 M $KHCO_3$	250	-0.67 vs RHE	RT	N.S	Flow Cell	EtOH	41% EtOH	300 nm	N.A	33
ah	Hashiba et al.	Cu Plates	Pt Wire	CEM	Nafion 424	0.5 M ($KCl+KHCO_3$)	200	-2.4 V vs Ag/AgCl	273 K. 3 atm and 500 rpm	125 sccm	Flow Cell	CH_4	73.3% CH_4	Commercial Cu Plates (Nilaco.99%)	N.A	34
ai	Wang et al.	Sputtered Cu in PTFE membrane	Ni Foam	AEM	Fumasep FAB-PK-130	1 M $KHCO_3$	225	-1.4 V vs RHE	RT	90 mL/min	Flow Cell	CH_4	48% CH_4	100 nm	N.A	35
aj	Li et al.	FeTPPCl/Cu (Molecular catalyst)	Ni Foam	AEM	Fumasep FAA-PK 130	3 M $KHCO_3$	300	-3.7	RT	50 sccm	MEA	EtOH	41% EtOH	200 nm	12.6	36
ak	Huq et al.	Cu-coated in PTFE Membranes	Ni foam	AEM	Fumasep FAB-PK-75	1 M $KHCO_3$	347	-0.6 V vs RHE	RT	20.2 mL/min	Flow cell	C_2H_4	30% C_2H_4	0.15	N.A	37
al	Kohjiro and Tadayoshi	Ag	Pt Foil	CEM	Nafion 115	0.5 M $KHCO_3$	300	-4	20 atm and 333 K	50 sccm	MEA	CO	>85% CO	N.S	26.1	38
am	Zhang et al.	NiPc–OMe MDE	Pt Foil	AEM	Selemion DSV	0.5 M $KHCO_3$	400	-0.6 V vs RHE	RT	5 sccm	Flow Cell	CO	99% CO	1	N.A	39

Notation	Authors	Electrode	Anode	IEM Type	Membrane	Electrolyte	Current Density (mA/cm²)	Cell Voltage (V)	Operation Conditions (P.T)	CO_2 Feeding Rate	Configuration	Main Product	FE (%)	CL (mg/cm²)	EE (%)	Ref.
an	Kibria et al.	CuCl-derived catalyst (electropolished Cu)	Ni Foam	AEM	N.S	1.0 M $KHCO_3$	450	-2.5	N.S	30 mL/min	Flow Cell	C_2H_4	50% C_2H_4	300 nm	23	**40**
ao	De Luna et al.	ERD-Cu	Pt Foil	AEM	N.S	0.1 M $KHCO_3$	450	-1.2 V vs RHE.	RT	25 mL/min	Flow Cell	C_2H_4	35.8% C_2H_4	N.S	N.A	**41**
ap	Yin et al.	Au GDE	IrO_2	AEM	APE Membrane	Pure Water	500	-3	333 K	100 sccm	Flow Cell	CO	85% CO	0.4	24.7	**27**
aq	Shafaque et al.	Ag in SG 29BC GDE	IrO_2 NPs	CEM	Nafion 115	0.1 M $KHCO_3$	575	-3.6	333 K	20 sccm	MEA	CO	4.3% CO	1.10±0.01	1.6	**42**
ar	Môller et al.	Ni-N-C Catalyst	IrO_2	AEM	Selemion AMV	1 M $KHCO_3$	700	-1.2 V vs RHE	RT	50 mL/min	Micro Flow Cell	CO	85% CO	0.75	N.A	**43**
as	Luo et al.	Porous Zn-electrocatalyst	Pt Foil	CEM	Nafion 212	0.1 M $KHCO_3$	200	-0.9 V vs RHE	N.S	40 mL/min	Flow Cell	CO	70% CO	6.5	N.A	**44**

N.S stands from the data not specified **N.A stands when a value/calculation for a specific parameter doesn't apply.**

[1.] Energy Efficiency was calculated from the provided data using the expression $EE = \frac{E^0}{E_{cell}} * FE.$ E^0 corresponds to the difference between the standard half reaction potentials from cathodic and anodic reactions ($E^0 = E^0_{cat\,(CO2RR)} - E^0_{an\,(OER)}$). E_{cell} is the applied cell voltage and FE represents the faradaic efficiency of the main product.

Table S2. Performance of ion selective-exchange membranes from data published for CO electrolysis

Notation	Authors	Electrode	Anode	IEM Type	Membrane	Electrolyte	Current Density (mA/cm²)	Cell Voltage (V)	Operation Conditions (P.T)	CO Feeding Rate	Configuration	Main Product	FE (%)	CL (mg/cm²)	EE (%)[1]	Ref.
a	Ripatti et al.	Cu NPs in AVCarb 2230	Ni-foam	CEM	Nafion 117	1 M NaOH	100	-2.41	RT	0.5 sccm	Flow Cell	C_2H_4	‘50% C_2H_4	0.25	22.0	45
b	Ripatti et al.	Cu NPs in AVCarb 2230	Ni-foam	CEM	Nafion 117	1 M NaOH	100	-2.41	RT	0.5 sccm	Flow Cell	EtOH	12% EtOH	0.25	5.2	
c	Ripatti et al.	Cu NPs in AVCarb 2230	Ni-foam	CEM	Nafion 117	1 M NaOH	100	-2.41	RT	0.5 sccm	Flow Cell	AcO^-	10% AcO^-	0.25	4.5	
d	Ni et al.	N-doped Cu catalyst	Ni-foam	AEM	Fumasep FAB-PK-130	2 M KOH	180	-1.2 V vs RHE (E_{WE})	RT	20 sccm	Flow Cell	AcO^-	42% AcO^-	0.5	N.A	46
e	Li et al.	Cu_2O NPs	Nickel foam	AEM	Fumasep FAB-PK-130	1 M KOH	250	-1.76 V vs RHE (E_{WE})	RT	10 mL/min	Flow Cell	PrOH	21% PrOH	1.0	N.A	47
f	Han et al.	Cu NPs in GDE	Ni coal	AEM	AHO Selemion	10 M KOH	250	-0.74 vs. RHE (E_{WE})	258 K	20 sccm	Flow Cell	C_2H_4	17.8% C_2H_4	7	N.A	48
g	Luc et al.	Cu NPs in 29BC	IrO_2	AEM	Fumatech FAA-3	2.0 M KOH	450	-0.75 V vs. RHE (E_{WE})	RT	15 sccm	Flow Cell	AcO^-	48% AcO^-	0.5	N.A	49
h	Jouny et al.	Commercial Cu(99%) in 29 BC GDE	IrO_2	AEM	Fumatech FAA-3	2.0 M KOH	630	-0.65 vs. RHE(E_{WE})	RT	10 sccm	Flow Cell	C_2H_4	41.8% C_2H_4	1.0	N.A	50
i	Jouny et al.	Commercial Cu (99%) in 29 BC GDE	IrO_2	AEM	Fumatech FAA-3	2.0 M KOH	630	-0.65 vs. RHE (E_{WE})	RT	10 sccm	Flow Cell	EtOH	26.7% EtOH	1.0	N.A	
j	Jouny et al.	Commercial Cu (99%) in 29 BC GDE	IrO_2	AEM	Fumatech FAA-3	2.0 M KOH	630	-0.65 vs. RHE (E_{WE})	RT	10 sccm	Flow Cell	AcO^-	91% C_{2+} (AcO^- 13%)	1.0	N.A	
k	Zhao et al.	Cu3N-HDD in 35 BC	IrO_2	AEM	Sustainion X37-50	1 M KOH	500	-3.5	RT	N.S	MEA	C_2H_4	70% C_{2+} (C_2H_4 33%)	N.S	10	51
l	Wang et al.	Ag-Ru-Cu in PTFE Membrane Sp Cu	IrOx	AEM	FAB-PK-130	1 M KOH	300	-2.75	RT	47 mL/min	MEA	PrOH	37% PrOH	6	13.6	52
m	Xia et al.	Cu NPs in 39 BC	IrO_2	AEM	Fumatech FAA-3	1M KOH	200	0.59 V vs RHE	RT	5 mL/min	Flow Cell	C_2H_4	40% C_2H_4	0.6	N.A	53
n	Ren et al.	CuPc Catalys	Ni Foam	AEM	Sustainion X37-50	2 M KOH	200	1.6 V vs RHE	RT	10 sccm	Micro Flow Cell	AcO^-	70% C_{2+} (AcO 36%)	0.6	N.A	54
o	Tran et al.	Cu dendrite in GDE	Ni/Fe	AEM	Sustainion AEM	0.1 M KOH	125	-4	RT	60 mL/min	MEA	C_2H_4	68% C_2H_4	1	18.0	55

Notation	Authors	Electrode	Anode	IEM Type	Membrane	Electrolyte	Current Density (mA/cm^2)	Cell Voltage (V)	Operation Conditions (P.T)	CO Feeding Rate	Configuration	Main Product	FE (%)	CL (mg/cm^2)	EE (%)[1]	Ref.
p	Ozden et al.	Cu Py-based catalyst on PTFE	Ni Foam	AEM	Sustainion 37-50 grade 60	3 M KOH	150	-2.5	RT	N.A	MEA	C_2H_4	68% C2H4	N.S	25.4	56
q	Doung et al.	D-Cu Deposited in GDE	Ni Foam	AEM	Sustainion X37-50 Grade T	3 M KOH	100	-3	RT	40 mL/min	Flow cell	C_2H_4	70% C2H4	150 nm	24.7	57

N.S stands from the data not specified **N.A stands when a value/calculation for a specific parameter doesn't apply.**

1. Energy Efficiency was calculated from the provided data using the expression $EE = \frac{E^0}{E_{cell}} * FE$. E^0 corresponds to the difference between the standard half reaction potentials from cathodic and anodic reactions ($E^0 = E^0_{cat\ (CORR)} - E^0_{an\ (OER)}$). E_{cell} is the applied cell voltage and FE represents the faradaic efficiency of the main product.

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