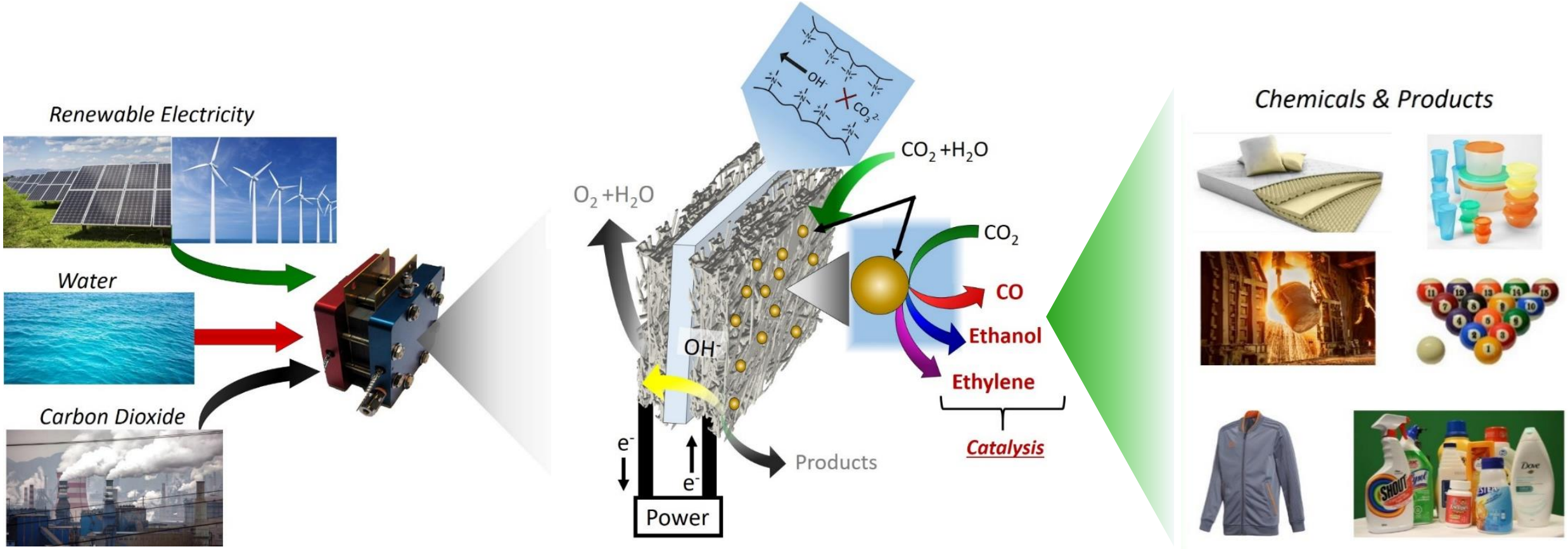
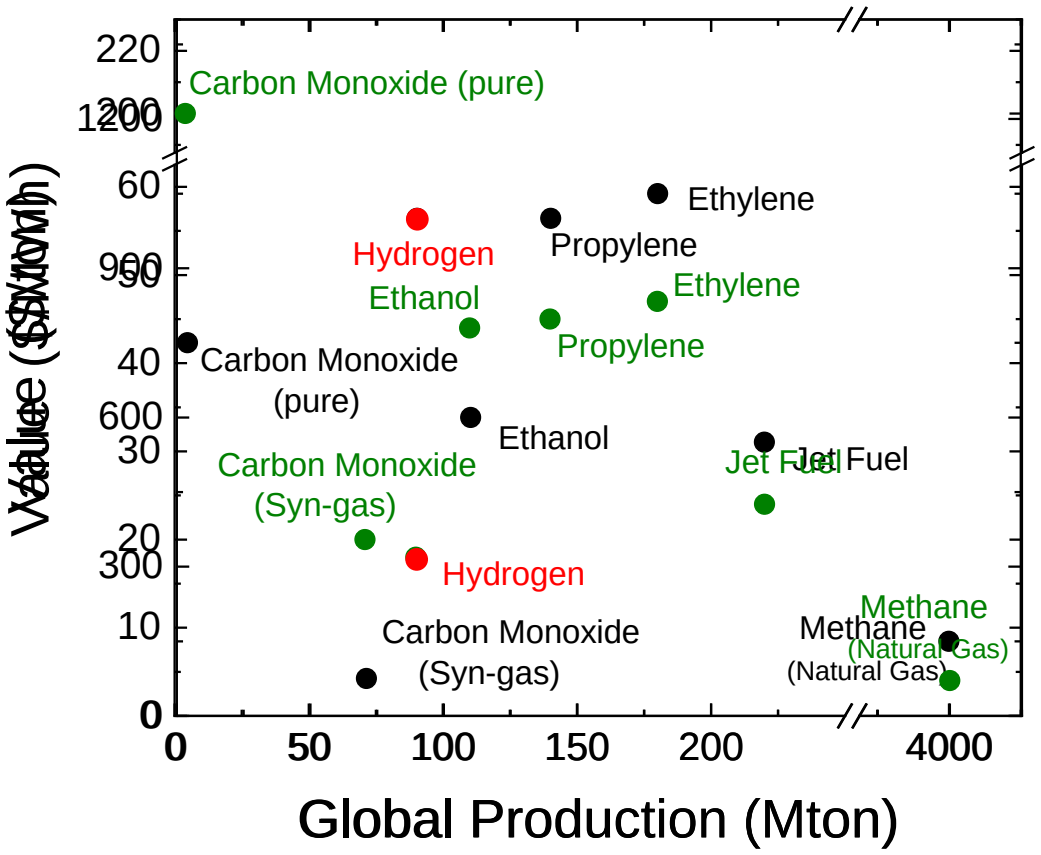
Using Deuterated Water to Analyze Reaction Mechanisms in CO_2 Electrolysis

2022 Spring ECS Vancouver
02-06-2022



What are we trying to do?

- Chemicals are 7% of EU's greenhouse gasses emissions



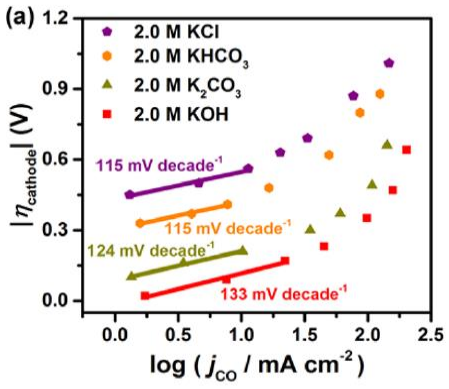
Applications of chemicals

Carbon monoxide → Chemical building block

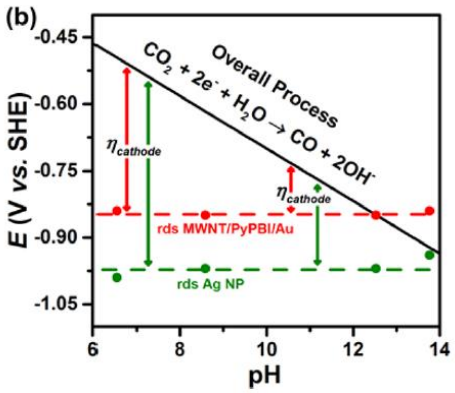
- Methanol (70 Mton/y)
- Reductant Iron/Steel (1900 Mton/y)
- Fischer-Tropsch Aviation Fuel (220 Mton/y)

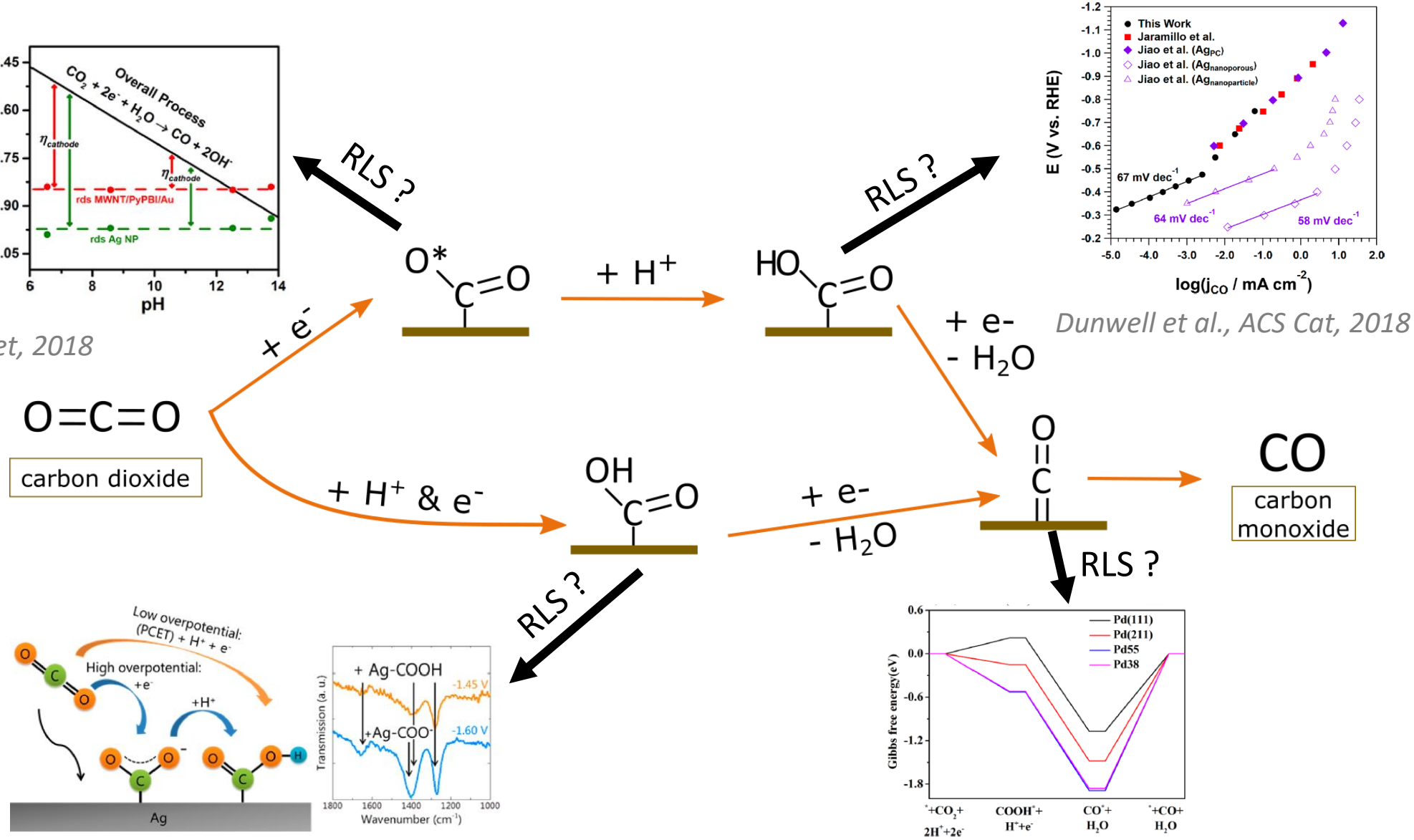
- *If all of USA's electricity went to CO production, we would only produce 4.3 times are need of world's carbon monoxide.*

What is the rate limiting step for CO (RLS)?



Verma et al., ACS Energy Let, 2018





Dunwell et al., ACS Cat, 2018

Nienke et al., ACS Cat., 2016

Gao et al., JACS, 2015

CO_2 to CO Rate limiting step

Different Pathways

H from H^+

H from H_2O

Step[b]	Possible RLS	Proposed Rate Expression	Type	Tafel slope (mV/dec)
A1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{CO} = 2Fk_{A1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118
A2	$*CO_2^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{A2}{}^0K_{A1}{}^\theta a[CO_2]\theta^*a[H^+]\exp(-fh)$	PT	59
A3	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{A3}{}^0K_{A2}{}^\theta K_{A1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$	ET	39
A4	$*COOH^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{A4}{}^0K_{A3}{}^\theta K_{A2}{}^\theta K_{A1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp(-2fh)$	PT	30
A5	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{A4}{}^0K_{A3}{}^\theta K_{A2}{}^\theta K_{A1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp(-2fh)/a(H_2O)$	D	30
a1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{CO} = 2Fk_{a1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118
a2	$*CO_2^- + H_2O \rightarrow *COOH + OH^-$	$j_{CO} = 2Fk_{a2}{}^0K_{a1}{}^\theta a[CO_2]\theta^*a[H_2O]\exp(-fh)$	PT	59
a3	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{a3}{}^0K_{a2}{}^\theta K_{a1}{}^\theta a[CO_2]\theta^*a[H^+]$		39
a4	$*COOH^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{a4}{}^0K_{a3}{}^\theta K_{a2}{}^\theta K_{a1}{}^\theta a[CO_2]\theta^*a$		30
a5	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{a5}{}^0K_{a4}{}^\theta K_{a3}{}^\theta K_{a2}{}^\theta K_{a1}{}^\theta a[CO_2]\theta^*a^2[H^+]a[H_2])\exp(-2fh)/K_W{}^2$	D	30
B1	$CO_2 + * + e^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{B1}{}^0a[CO_2]\theta^*a[H^+]\exp(-\alpha fE)$	PCET	118
B2	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{B2}{}^0K_{B1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$		
B3	$*COOH^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{B3}{}^0K_{B2}{}^\theta K_{B1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp(-2fE)$		
B4	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{B4}{}^0K_{B3}{}^\theta K_{B2}{}^\theta K_{B1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp(-2fh)/a[H_2O]$	D	30
b1	$CO_2 + * + e^- + H_2O \rightarrow *COOH + OH^-$	$j_{CO} = 2Fk_{b1}{}^0a[CO_2]\theta^*a[H_2O]\exp(-\alpha fh)$	PCET	118
b2	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{b2}{}^0K_{b1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_W$	ET	39
b3	$*COOH^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{b3}{}^0K_{b2}{}^\theta K_{b1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp(-2fh)/K_W$	PT	30
b4	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{b4}{}^0K_{b3}{}^\theta K_{b2}{}^\theta K_{b1}{}^\theta a[CO_2]\theta^*a[H_2O]a^2[H^+]\exp(-2fh)/K_W{}^2$	D	30
C1	$CO_2 + * + e^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{C1}{}^0a[CO_2]\theta^*a[H^+]\exp(-\alpha fh)$	PCET	119
C2	$*COOH + e^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{C2}{}^0K_{C1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp[-(1+\alpha)fh]$	PCET	39
C3	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{C3}{}^0K_{C2}{}^\theta K_{C1}{}^\theta a[CO_2]\theta^*a^2[H^+]\exp(-2fh)/a(H_2O)$	D	30
c1	$CO_2 + * + e^- + H_2O \rightarrow *COOH + OH^{-}$	$j_{CO} = 2Fk_{c1}{}^0a[CO_2]\theta^*a[H_2O]\exp(-\alpha fh)$	PCET	119
c2	$*COOH + e^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{c2}{}^0K_{c1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_W$	PCET	39
c3	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{c3}{}^0K_{c2}{}^\theta K_{c1}{}^\theta a[CO_2]\theta^*a[H_2O]a^2[H^+]\exp(-2fh)/K_W{}^2$	D	30

Others focus on this

We focus on this

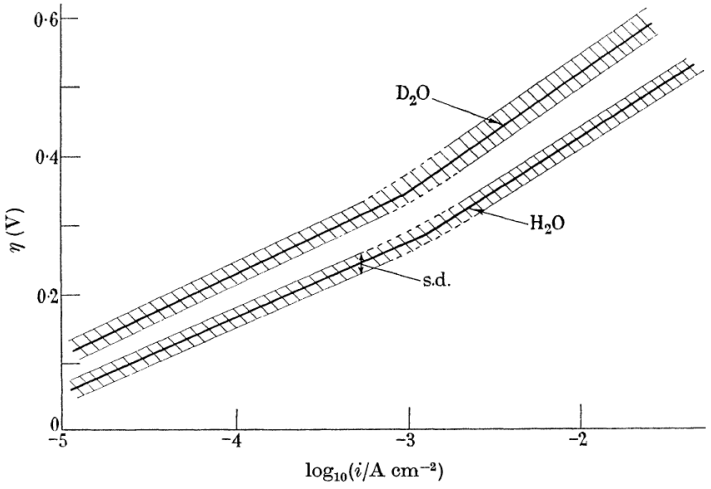
How do we test for rate order?

To investigate whether H^+ is part of reaction order

- Vary the electrolyte pH
- if H^+ is involved in the RLS, current sill vary versus potential on an absolute scale (i.e. vs. SHE)

To investigate whether H_2O is part of reaction order

- Use deuterated water (i.e D_2O versus H_2O)
- If water is involved in the RLS, current will vary versus potential on an absolute scale (i.e. vs. SHE)

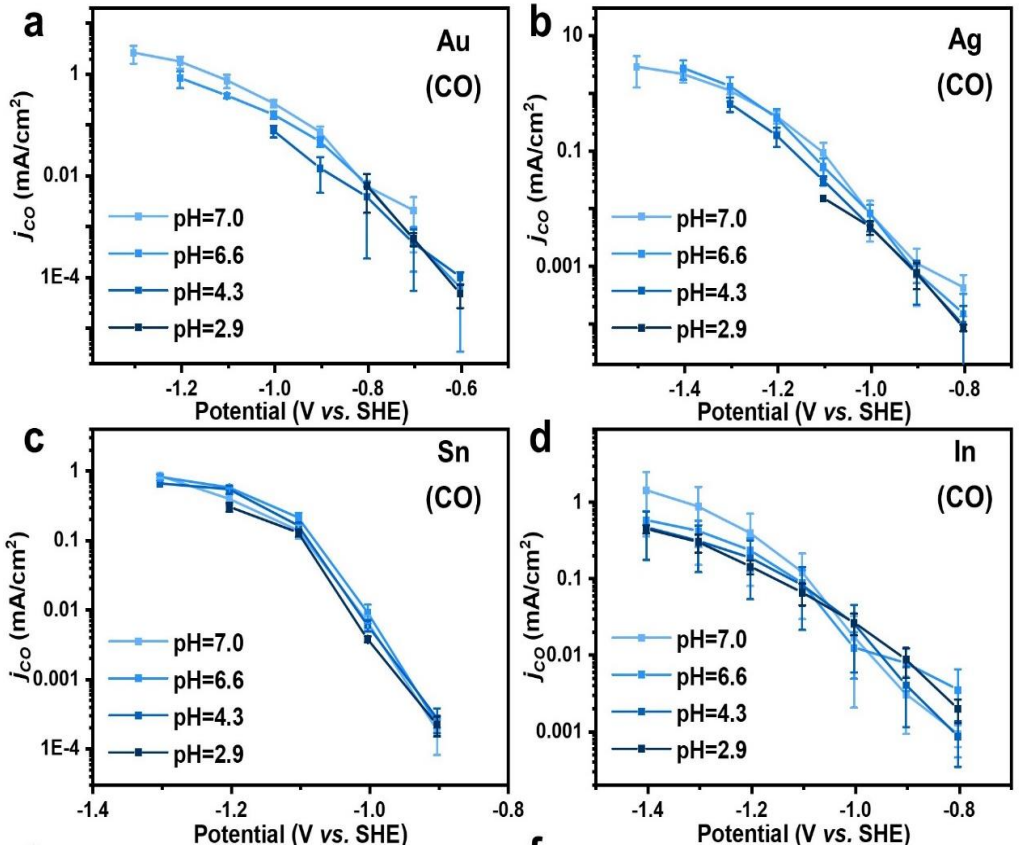


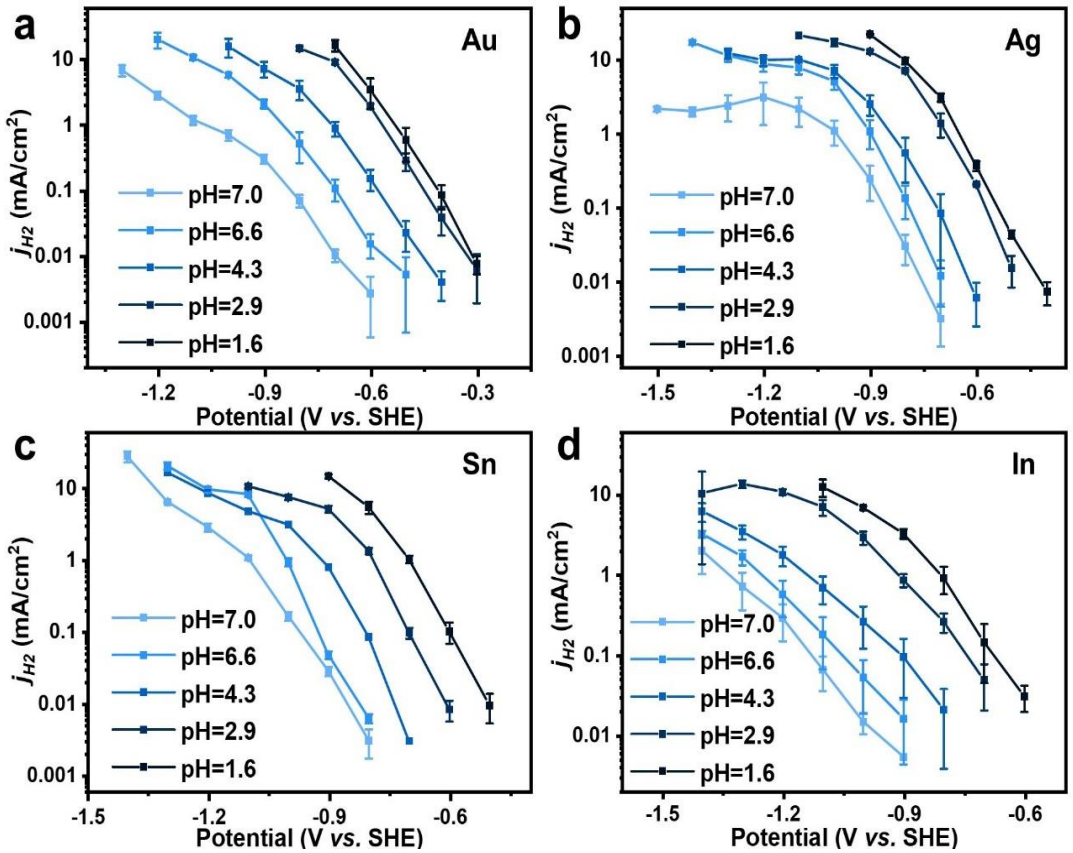
B. E. Conway, Proc. Roy. Soc. London, 1964

Testing with pH variations

pH has no effect on CO production for 4 catalysts.

pH has substantial effect on H_2 production for 4 catalysts.



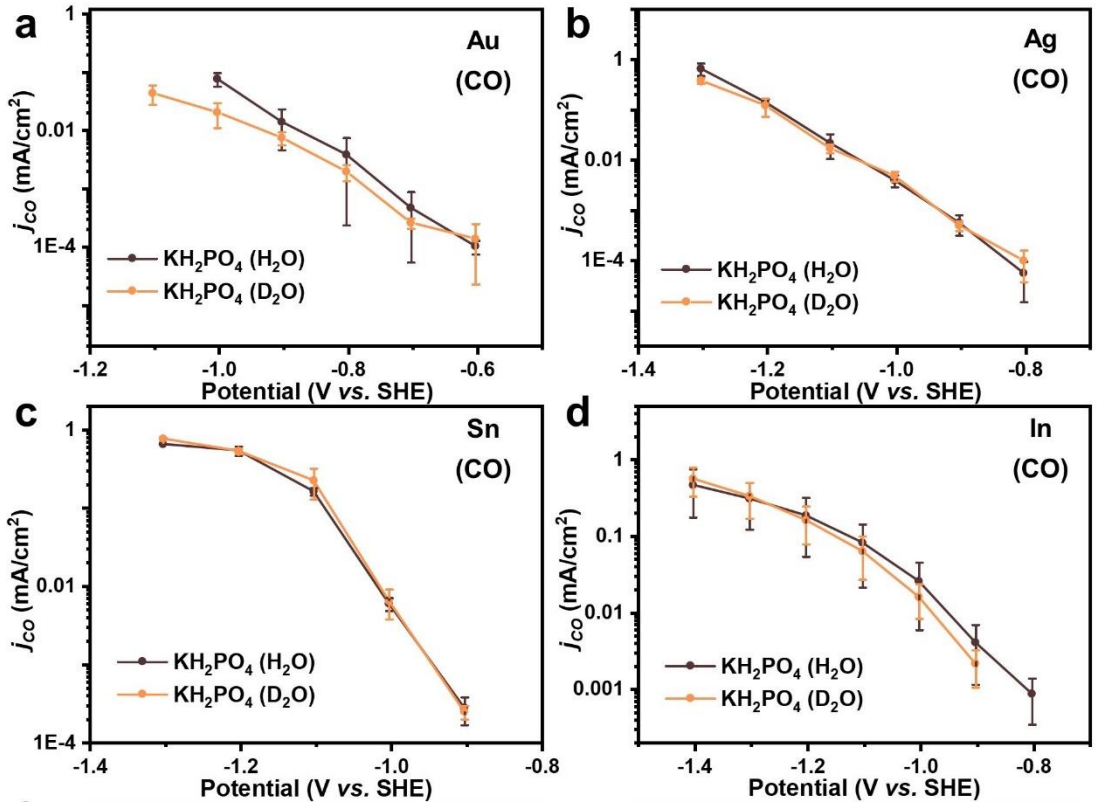


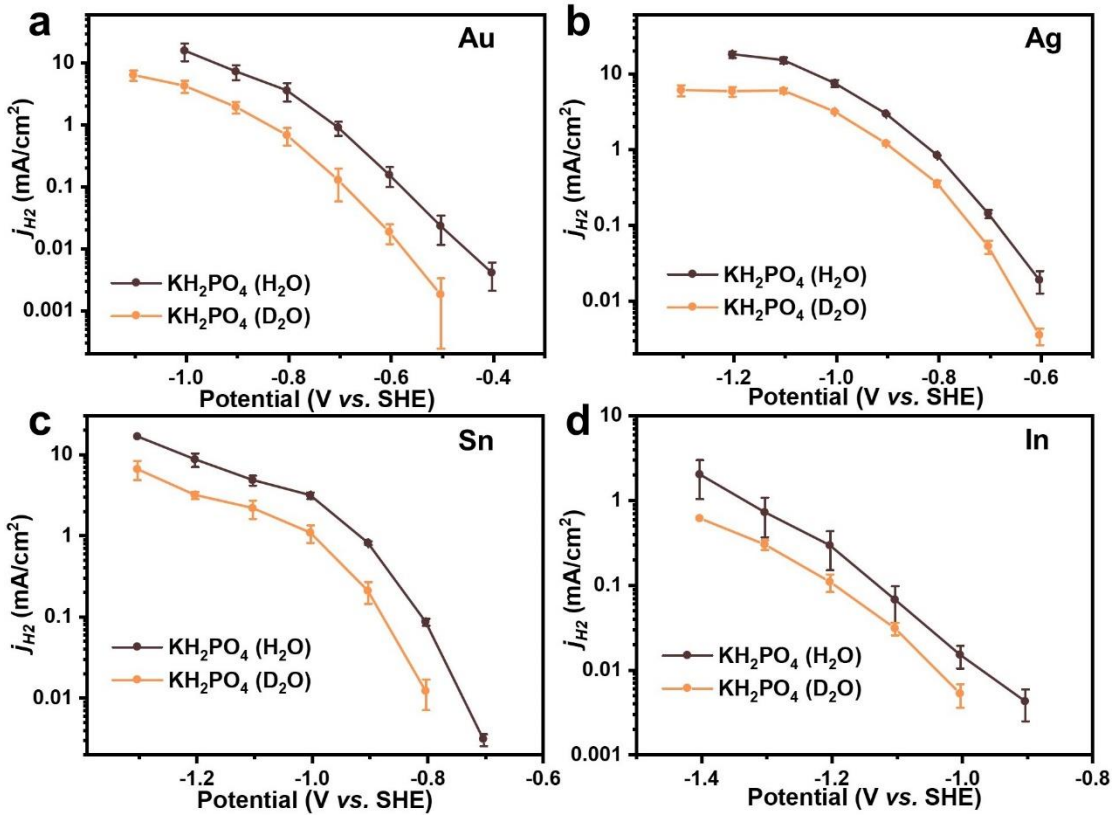
Deng, et. al., Nature Communications **volume 13**, Article number: 803 (2022)

Effects of Deutrated Water

D_2O shows no effect on CO production for 4 catalysts.

D_2O shows substantial effect on H_2 production for 4 catalysts.





Deng, et. al., Nature Communications **volume 13**, Article number: 803 (2022)

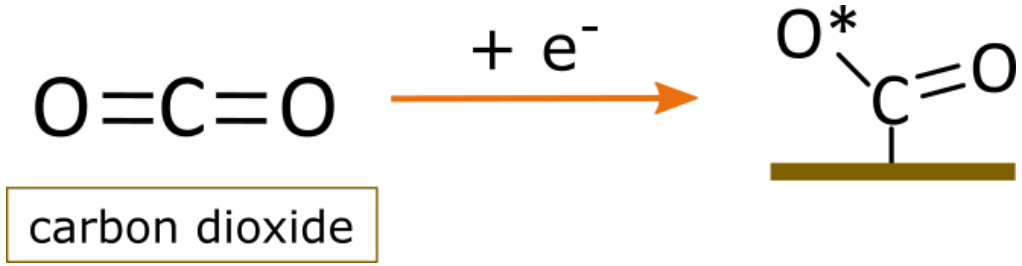
Analysis on rate limiting step for CO production

Technique	Species of Focus	Rate Order
pH Variation	H^+	0
Deutrated water	H_2O	0

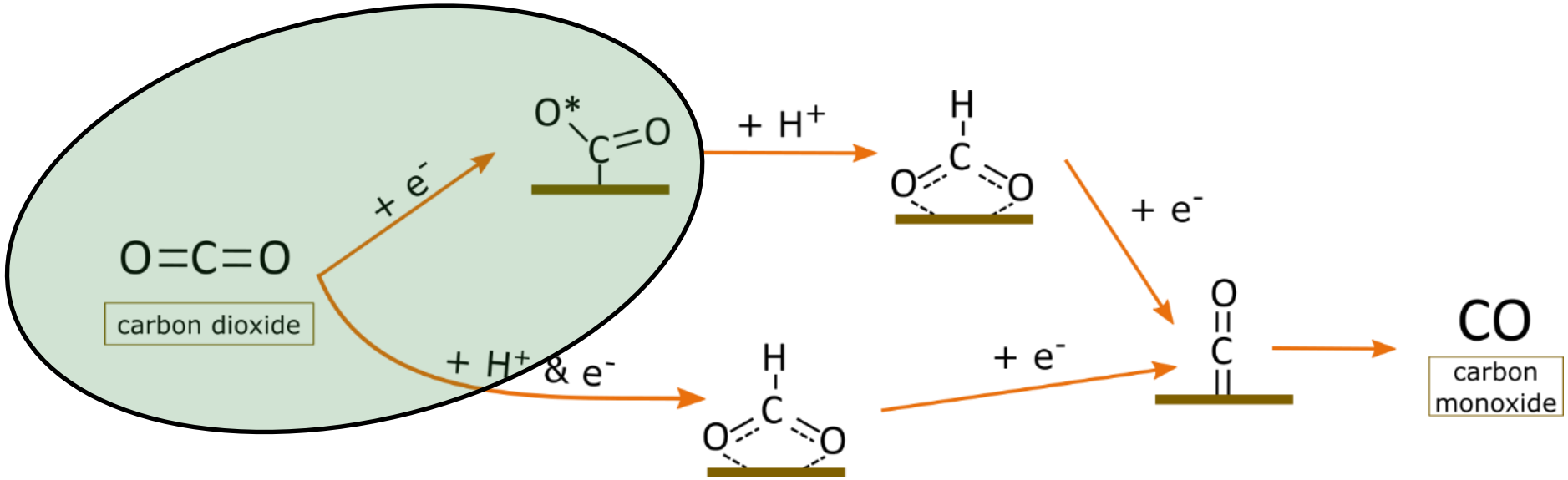
Reaction Kinetics

Step[b]	Possible RLS	Proposed Rate Expression	Type	Tafel slope (mV/dec)	H^+ order	H_2O order
A1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{CO} = 2Fk_{A1}{}^{0}a[CO_2]\theta^{*}\exp(-\alpha fh)$	ET	118	0	0
A2	$*CO_2^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{A2}{}^{0}K_{A2}{}^{0}a[CO_2]\theta^{*}a[H^+]\exp(-fh)$	PT	59	1	0
A3	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{A3}{}^{0}K_{A3}{}^{0}K_{A2}{}^{0}a[CO_2]\theta^{*}a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
A4	$*COOH^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{A4}{}^{0}K_{A4}{}^{0}K_{A3}{}^{0}K_{A2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp(-2fh)$	PT	30	2	0
A5	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{A5}{}^{0}K_{A5}{}^{0}K_{A4}{}^{0}K_{A3}{}^{0}K_{A2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp(-2fh)/a(H_2O)$	D	30	2	−1
a1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{CO} = 2Fk_{a1}{}^{0}a[CO_2]\theta^{*}\exp(-\alpha fh)$	ET	118	0	0
a2	$*CO_2^- + H_2O \rightarrow *COOH + OH^-$	$j_{CO} = 2Fk_{a2}{}^{0}K_{a2}{}^{0}a[CO_2]\theta^{*}a[H_2O]\exp(-fh)$	PT	59	0	1
a3	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{a3}{}^{0}K_{a3}{}^{0}K_{a2}{}^{0}a[CO_2]\theta^{*}a[H^+]a[H_2O]\exp[-(1+\alpha)fh]/K_w$	ET	39	1	1
a4	$*COOH^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{a4}{}^{0}K_{a4}{}^{0}K_{a3}{}^{0}K_{a2}{}^{0}a[CO_2]\theta^{*}a[H^+]a[H_2O]\exp[-2f(E)]/K_w$	PT	30	1	1
a5	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{a5}{}^{0}K_{a5}{}^{0}K_{a4}{}^{0}K_{a3}{}^{0}K_{a2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]a[H_2]\exp(-2fh)/K_w^2$	D	30	2	1
B1	$CO_2 + * + e^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{B1}{}^{0}a[CO_2]\theta^{*}a[H^+]\exp[-\alpha f(-)]$	PCET	118	1	0
B2	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{B2}{}^{0}K_{B2}{}^{0}a[CO_2]\theta^{*}a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
B3	$*COOH^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{B3}{}^{0}K_{B3}{}^{0}K_{B2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp[-2f(E)]$	PT	30	2	0
B4	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{B4}{}^{0}K_{B4}{}^{0}K_{B3}{}^{0}K_{B2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp(-2fh)/a[H_2O]$	D	30	2	−1
b1	$CO_2 + * + e^- + H_2O \rightarrow *COOH + OH^-$	$j_{CO} = 2Fk_{b1}{}^{0}a[CO_2]\theta^{*}a[H_2O]\exp(-\alpha fh)$	PCET	118	0	1
b2	$*COOH + e^- \rightarrow *COOH^-$	$j_{CO} = 2Fk_{b2}{}^{0}K_{b2}{}^{0}a[CO_2]\theta^{*}a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_w$	ET	39	1	1
b3	$*COOH^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{b3}{}^{0}K_{b3}{}^{0}K_{b2}{}^{0}a[CO_2]\theta^{*}a[H_2O]a[H^+]\exp[-2f(h)]/K_w$	PT	30	1	1
b4	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{b4}{}^{0}K_{b4}{}^{0}K_{b3}{}^{0}K_{b2}{}^{0}a[CO_2]\theta^{*}a[H_2O]a^2[H^+]\exp(-2fh)/K_w^2$	D	30	2	1
C1	$CO_2 + * + e^- + H^+ \rightarrow *COOH$	$j_{CO} = 2Fk_{c1}{}^{0}a[CO_2]\theta^{*}a[H^+]\exp(-\alpha fh)$	PCET	119	1	0
C2	$*COOH + e^- + H^+ \rightarrow *CO + H_2O$	$j_{CO} = 2Fk_{c2}{}^{0}K_{c2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp[-(1+\alpha)fh]$	PCET	39	2	0
C3	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{c3}{}^{0}K_{c3}{}^{0}K_{c2}{}^{0}a[CO_2]\theta^{*}a^2[H^+]\exp(-2fh)/a(H_2O)$	D	30	2	−1
c1	$CO_2 + * + e^- + H_2O \rightarrow *COOH + OH^-$	$j_{CO} = 2Fk_{c1}{}^{0}a[CO_2]\theta^{*}a[H_2O]\exp(-\alpha fh)$	PCET	119	0	1
c2	$*COOH + e^- \rightarrow *CO + OH^-$	$j_{CO} = 2Fk_{c2}{}^{0}K_{c2}{}^{0}a[CO_2]\theta^{*}a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_w$	PCET	39	1	1
c3	$*CO \rightarrow CO + *$	$j_{CO} = 2Fk_{c3}{}^{0}K_{c3}{}^{0}K_{c2}{}^{0}a[CO_2]\theta^{*}a[H_2O]a^2[H^+]\exp(-2fh)/K_w^2$	D	30	2	1

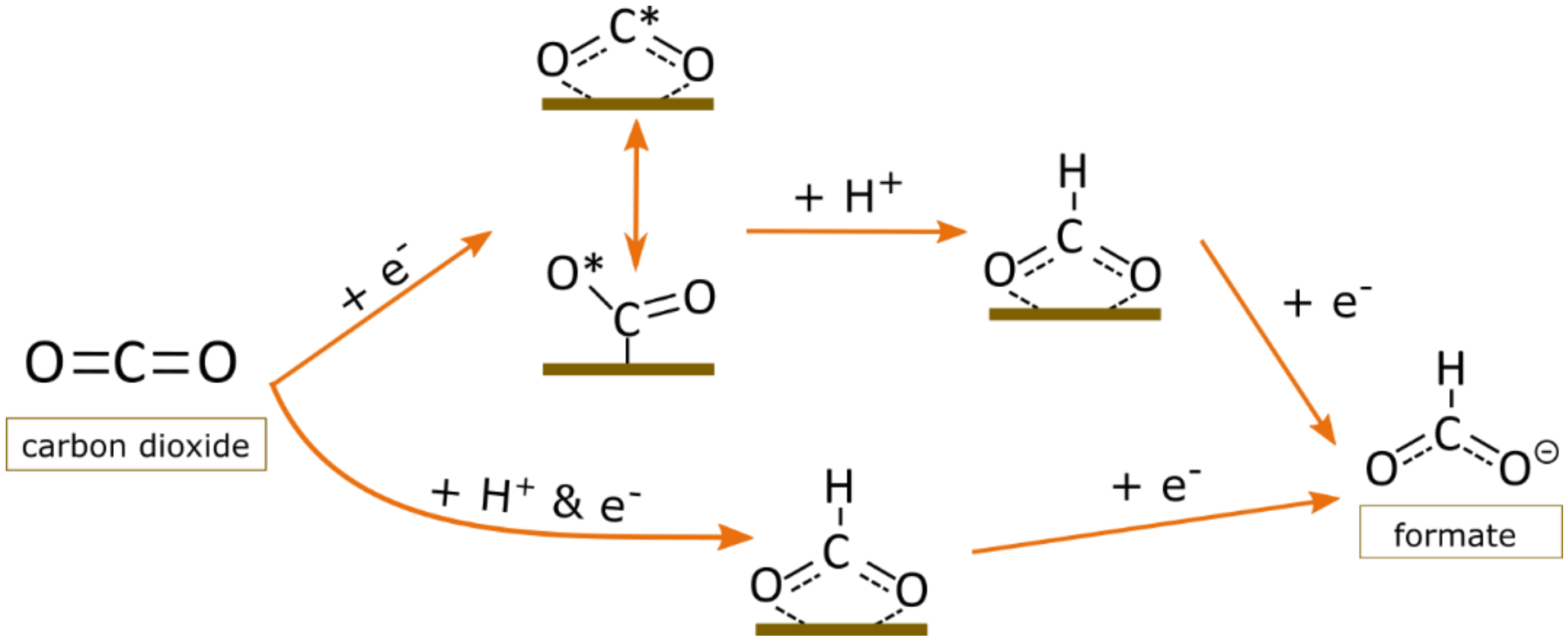
Only elementary step with 0,0 rate order



What is the rate limiting step (RLS)?



What is rate limiting step of CO_2 to formate?



Formate: Not a wanted product

- We never produce formate, but rather postassium formate
- Where does the K come from?
- $KHCO_3$ is produced commercially via bubbling CO_2 in KOH

$$KOH + CO_2 \rightarrow KCOOH + {}^{1}/_{2}\, O_2$$

Name	Value ($/ton)	Value ($/Mmole)
Potassium hydroxide	1800	16
Potassium formate	1000	5

What is the rate limiting step (RLS)?

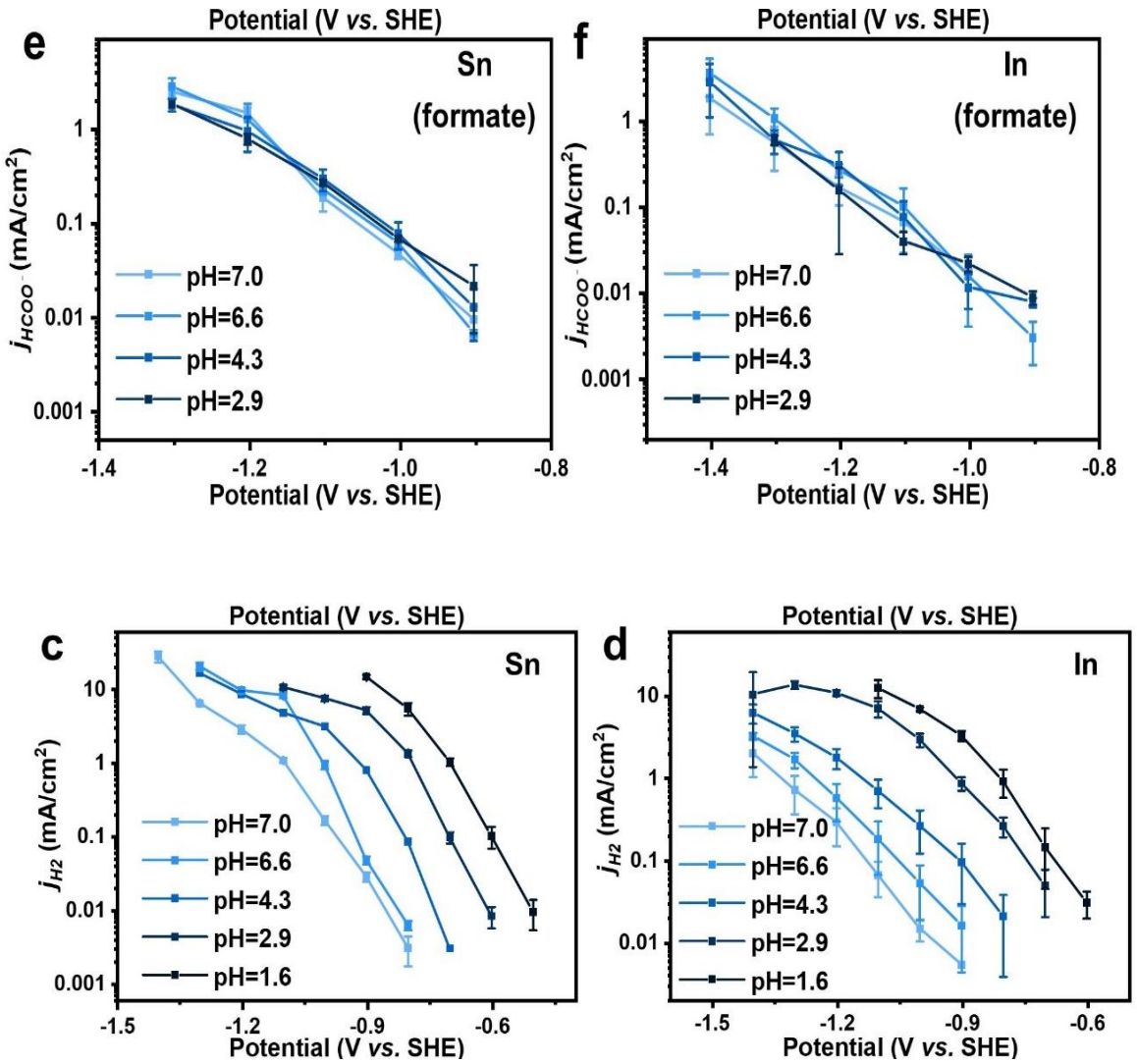
- Apply same analysis as $CO_2 \rightarrow CO$ for $CO_2 \rightarrow$ formate

Step	Possible RLS	Proposed Rate Expression	Type	Tafel slope (mV/dec)	H^+ order	H_2O order
D1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{HCOO^-} = 2Fk_{D1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118	0	0
D2	$*CO_2^- + H^+ \rightarrow *OOCH$	$j_{HCOO^-} = 2Fk_{D2}{}^0K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp(-fh)$	PT	59	1	0
D3	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{D3}{}^0K_{D2}{}^\theta K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
D4	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{D4}{}^0K_{D3}{}^\theta K_{D2}{}^\theta K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp(-2fh)$	PT	30	1	0
d1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{HCOO^-} = 2Fk_{d1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118	0	0
d2	$*CO_2^- + H_2O \rightarrow *OOCH + OH^-$	$j_{HCOO^-} = 2Fk_{d2}{}^0K_{d1}{}^\theta a[CO_2]\theta^*a[H_2O]\exp(-fh)$	PT	59	0	1
d3	$*OOCH + e^- \rightarrow *OCOH^-$	$j_{HCOO^-} = 2Fk_{d3}{}^0K_{d2}{}^\theta K_{d1}{}^\theta a[CO_2]\theta^*a[H^+]a[H_2O]\exp[-(1+\alpha)fh]/K_W$	ET	39	1	1
d4	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{d4}{}^0K_{d3}{}^\theta K_{d2}{}^\theta K_{d1}{}^\theta a[CO_2]\theta^*a[H^+]a[H_2O]\exp[-2fh]/K_W$	PT	30	1	1
E1	$CO_2 + * + e^- + H^+ \rightarrow *OOCH$	$j_{HCOO^-} = 2Fk_{E1}{}^0a[CO_2]\theta^*a[H^+]\exp(-\alpha fh)$			1	0
E2	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{E2}{}^0K_{E1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
E3	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{E3}{}^0K_{E2}{}^\theta K_{E1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-2fh]$	PT	30	1	0
e1	$CO_2 + * + e^- + H_2O \rightarrow *OOCH + OH^-$	$j_{HCOO^-} = 2Fk_{e1}{}^0a[CO_2]\theta^*a[H_2O]\exp(-\alpha fh)$	PCET	118	0	1
e2	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{e2}{}^0K_{e1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_W$	ET	39	1	1
e3	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{e3}{}^0K_{e2}{}^\theta K_{e1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp(-2fh)/K_W$	PT	30	1	1

We focus on this

Testing with pH variations

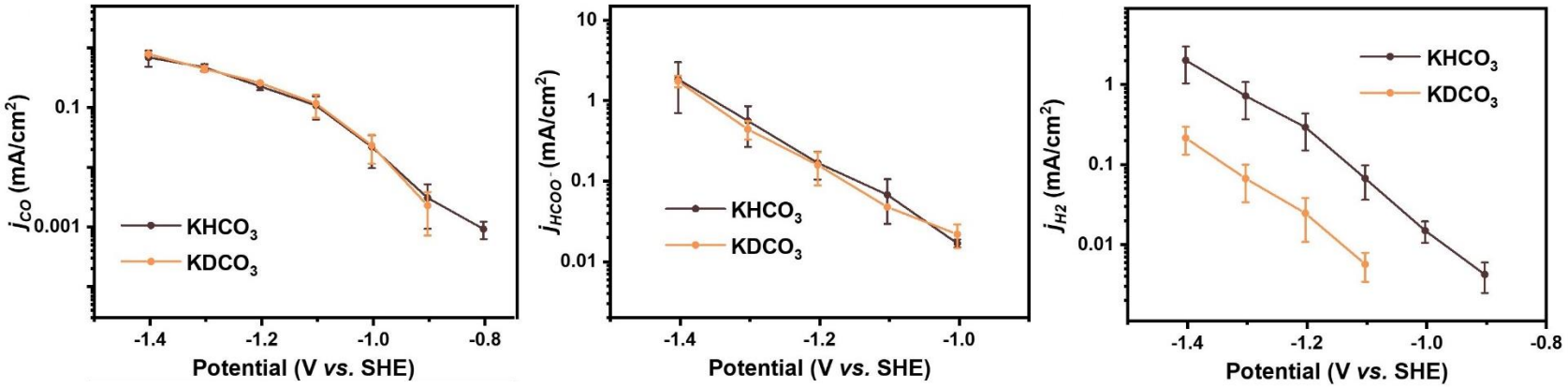
- Sn and In produce both CO and formate
- Formate does production is not a function of pH
- Testing for H_2 evolution validates that this technique can show a pH effect.

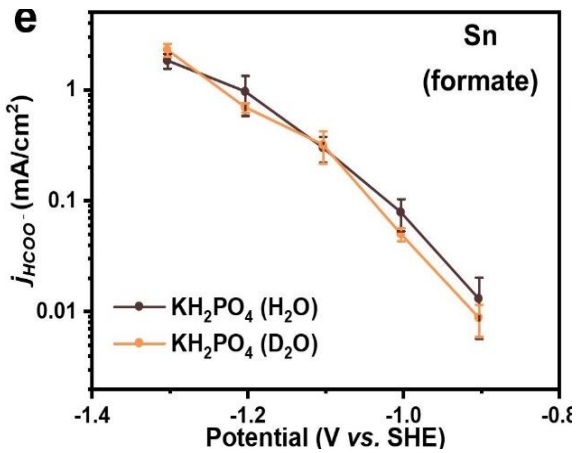


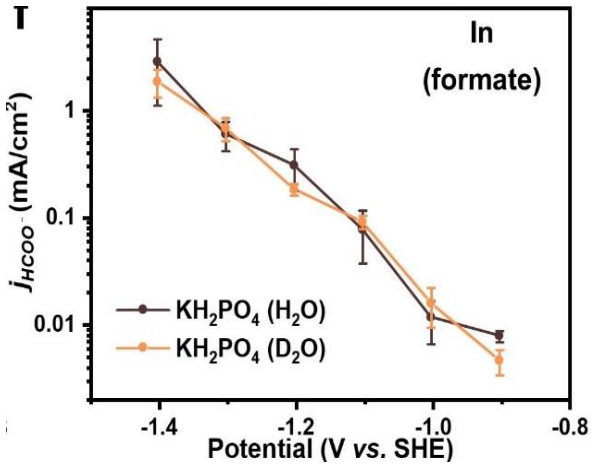
Deng, et. al., Nature Communications **volume 13**, Article number: 803 (2022)

Effects of Deutrated Water

- Deutrated water experiments did not show any change for formate production.
- We were worried the hydrogen in our phosphate could contaminate D_2O with a little H_2O
- Deutrated carbonate was hydrogen free and showed same results.







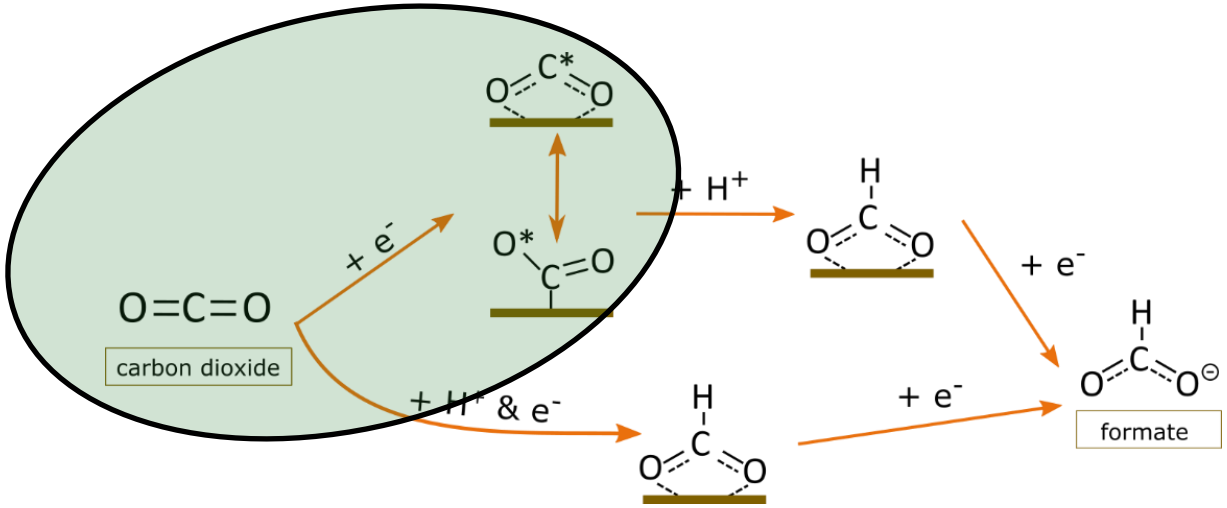
Analysis on rate limiting step for formate production

Technique	Species of Focus	Rate Order
pH Variation	H^+	0
Deutrated water	H_2O	0

Only elementary step with 0,0 rate order

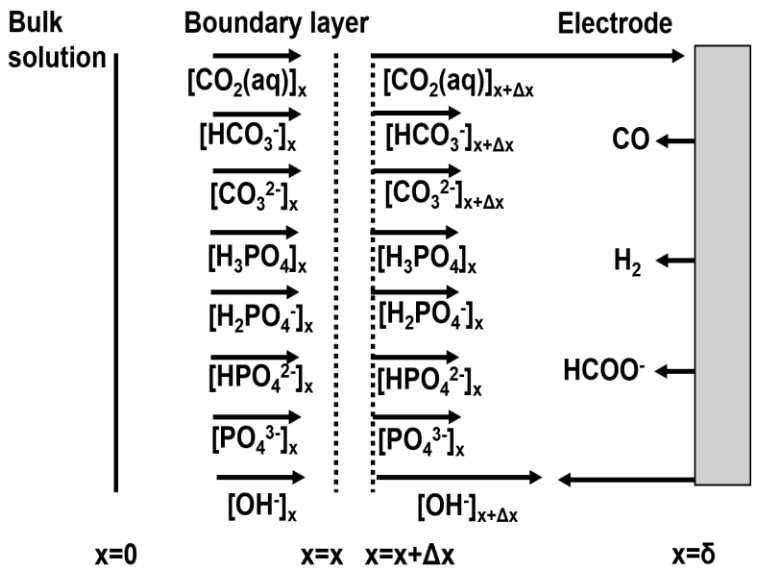
Reaction Kinetics

Step	Possible RLS	Proposed Rate Expression	Type	Tafel slope (mV/dec)	H^+ order	H_2O order
D1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{HCOO^-} = 2Fk_{D1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118	0	0
D2	$*CO_2^- + H^+ \rightarrow *OOCH$	$j_{HCOO^-} = 2Fk_{D2}{}^0K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp(-fh)$	PT	59	1	0
D3	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{D3}{}^0K_{D2}{}^\theta K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
D4	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{D4}{}^0K_{D3}{}^\theta K_{D2}{}^\theta K_{D1}{}^\theta a[CO_2]\theta^*a[H^+]\exp(-2fh)$	PT	30	1	0
d1	$CO_2 + * + e^- \rightarrow *CO_2^-$	$j_{HCOO^-} = 2Fk_{d1}{}^0a[CO_2]\theta^*\exp(-\alpha fh)$	ET	118	0	0
d2	$*CO_2^- + H_2O \rightarrow *OOCH + OH^-$	$j_{HCOO^-} = 2Fk_{d2}{}^0K_{d1}{}^\theta a[CO_2]\theta^*a[H_2O]\exp(-fh)$	PT	59	0	1
d3	$*OOCH + e^- \rightarrow *OCOH^-$	$j_{HCOO^-} = 2Fk_{d3}{}^0K_{d2}{}^\theta K_{d1}{}^\theta a[CO_2]\theta^*a[H^+]a[H_2O]\exp[-(1+\alpha)fh]/K_W$	ET	39	1	1
d4	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{d4}{}^0K_{d3}{}^\theta K_{d2}{}^\theta K_{d1}{}^\theta a[CO_2]\theta^*a[H^+]a[H_2O]\exp[-2fh]/K_W$	PT	30	1	1
E1	$CO_2 + * + e^- + H^+ \rightarrow *OOCH$	$j_{HCOO^-} = 2Fk_{E1}{}^0a[CO_2]\theta^*a[H^+]\exp(-\alpha fh)$	PCET	118	1	0
E2	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{E2}{}^0K_{E1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-(1+\alpha)fh]$	ET	39	1	0
E3	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{E3}{}^0K_{E2}{}^\theta K_{E1}{}^\theta a[CO_2]\theta^*a[H^+]\exp[-2fh]$	PT	30	1	0
e1	$CO_2 + * + e^- + H_2O \rightarrow *OOCH + OH^-$	$j_{HCOO^-} = 2Fk_{e1}{}^0a[CO_2]\theta^*a[H_2O]\exp(-\alpha fh)$	PCET	118	0	1
e2	$*OOCH + e^- \rightarrow *OOCH^-$	$j_{HCOO^-} = 2Fk_{e2}{}^0K_{e1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp[-(1+\alpha)fh]/K_W$	ET	39	1	1
e3	$*OOCH^- \rightarrow HCOO^- + *$	$j_{HCOO^-} = 2Fk_{e3}{}^0K_{e2}{}^\theta K_{e1}{}^\theta a[CO_2]\theta^*a[H_2O]a[H^+]\exp(-2fh)/K_W$	PT	30	1	1

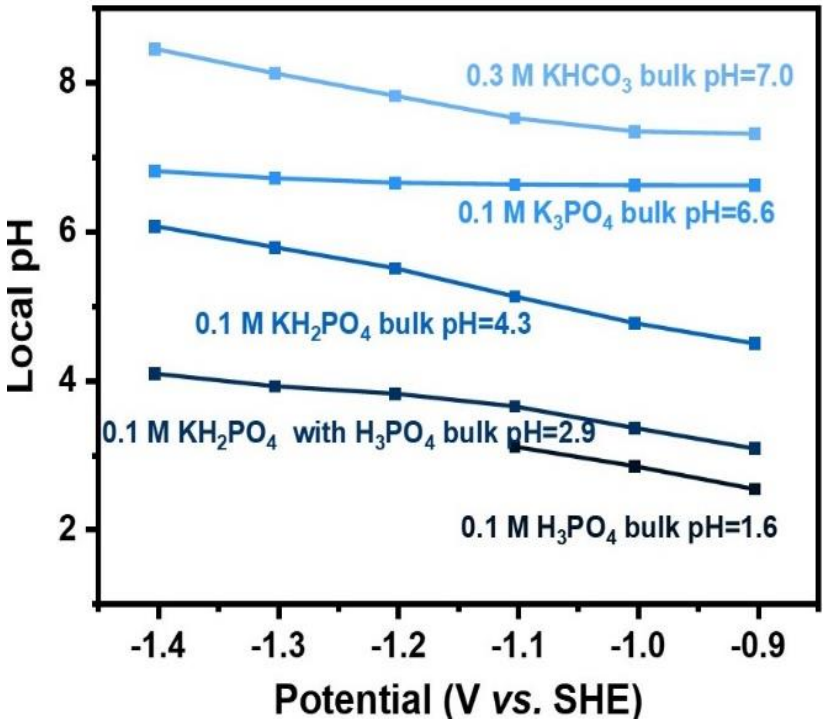


Local pH

- Local pH could have an effect on our results
- We measured a boundary layer of 8 μm using ferricyanide redox couple.
- We then modelled surface pH based off the Gatrell model.

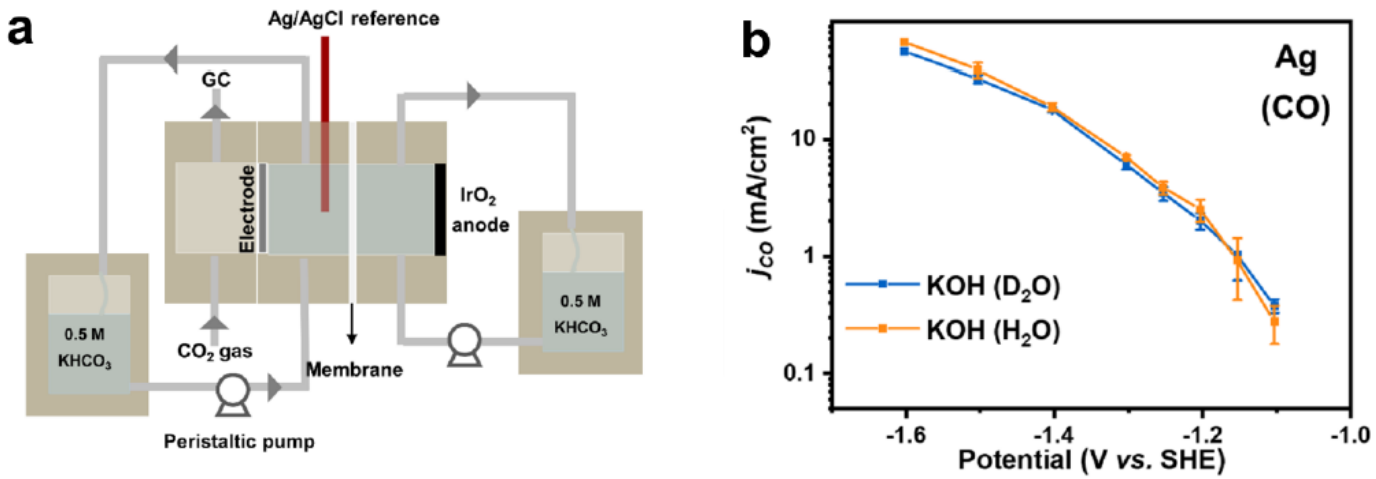


Model based off Gupta et al, J. Appl. Elec., 2006



Ensuring sufficient mass transfer

- 8 μm boundary layer thickness is quiet small
- Our reactor, designed by Ezra Clark, bubbles CO_2 in a separate chamber and the reactor itself only sees a very fast flow of saturated CO_2.



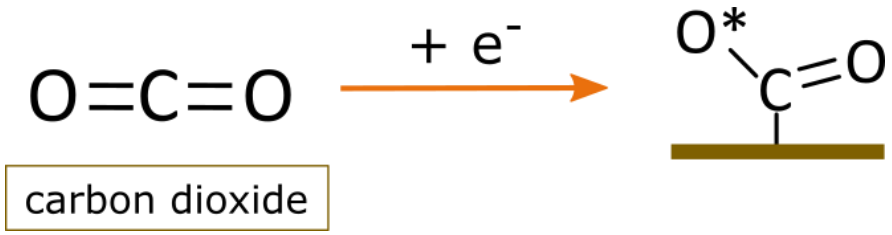
- This quick mass transfer may even allow us to measure CO_2 reduction in KOH in an H–cell design

Conclusions

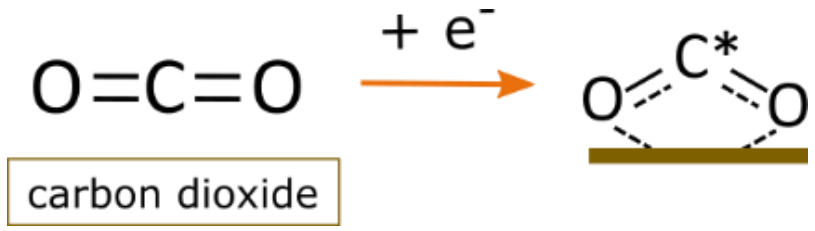
- Using pH & deutrated water gives us unique insight into reaction mechanisms
- pH variations and deutrated experiments are simple to do.
- We feel this provides clarity to determining rate limiting steps for CO_2 electrolysis.

Rate Limiting Step

For CO production



For formate production



Acknowledgements

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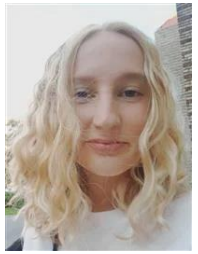

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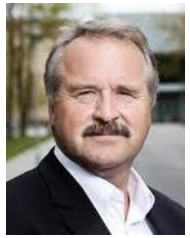

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