# Temperature and pressure effects on the electrochemical CO2 reduction

Vos, R.E.

# II

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# List of publications

**Chapter 2**
R.E. Vos, M.T.M. Koper
The Effect of Temperature on the Cation-Promoted Electrochemical $CO_2$ Reduction on Gold
*ChemElectroChem* **9** e202200239 (2022)

**Chapter 3**
R.E. Vos, K.E. Kolmeijer, T.S. Jacobs, W van der Stam, B.M. Weckhuysen, M.T.M. Koper
How Temperature Affects the Selectivity of the Electrochemical $CO_2$ Reduction on Copper
*ACS Catalysis* **13** 8080-8091 (2023)

**Chapter 4**
R.E. Vos, J.S. Smaak, M.T.M. Koper
The Temperature Dependence of Electrochemical $CO_2$ Reduction on Ag and CuAg alloys
*Journal of Catalysis* 115613 (2024)

**Chapter 5**
R.E. Vos, M.T.M. Koper
Nickel as Electrocatalyst for $CO_{(2)}$ Reduction: Effect of Temperature, Potential, Partial Pressure, and Electrolyte Composition
*ACS Catalysis* **14** 4432-4440 (2024)

**Chapter 6**
A.H.M. da Silva, R.E. Vos, R.J.C. Schrama, M.T.M. Koper
Design of a Rotating Disk Electrode setup operating under high pressure and temperature: application to CO2 reduction on gold
*Electrochimica Acta* 144612 (2024)

**Chapter 7**
R.E. Vos, D. Schauermann, Pengfei Sun, Selwyn R. Hanselman, M.T.M. Koper
Change in the C-C coupling mechanism during $CO_2$ electroreduction on Cu at elevated temperature and pressure
In preparation

**Chapter 8**
R.E. Vos, M.T.M. Koper
Screening of Various Metal Catalysts for Electrochemical CO2 Reduction at Elevated Temperatures and Pressures
In preparation

**Other publications**

I.E.L. Stephens, et al.
2022 Roadmap on Low Temperature Electrochemical $CO_2$ reduction
*Journal of Physics: Energy* **4** 042003 (2022)

A. Shih, et al.
Water Electrolysis
*Nature Reviews Methods Primers* **2** 84 (2022)

A.H.M. da Silva, Q. Lenne, R.E. Vos, M.T.M. Koper
Competition of CO and Acetaldehyde Adsorption and Reduction on Copper Electrodes and Its Impact on n-Propanol Formation
*ACS Catalysis* **13** 4339-4347 (2023)

A.H.M. da Silva, G. Karaiskakis, R.E. Vos, M.T.M. Koper
Mechanistic Insights into the Formation of Hydroxyacetone, Acetone, and 1,2-Propanediol from Electrochemical CO2 Reduction on Copper
*Journal of the American Chemical Society* **145** 15343-15352 (2023)

O. van der Heijden, S. Park, R.E.Vos, J.J.J. Eggebeen, M.T.M. Koper
Tafel Slope Plot as a Tool to Analyze Electrocatalytic Reactions
*ACS Energy Letters* **9** 1871-1879 (2024)

M.R. Pinto, R.E. Vos, R. Nagao, M.T.M. Koper
Electrolyte Effects on Electrochemical $CO_2$ Reduction at Sn Metallic Electrode
*Journal of Physical Chemistry C,* in revision

O. van der Heijden, R.E. Vos, A.H.M da Silva, M.T.M. Koper
Determination of the Temperature Dependent Tafel Slope, Activation Energy and Transfer Coefficients for the Alkaline Oxygen Evolution Reaction on NiFeOOH
In preparation

O. van der Heijden, A.H.M da Silva, R.E. Vos, M.T.M. Koper
Effects of Pressure on the Oxygen Evolution Reaction
In preparation

# Curriculum vitae

Rafaël Vos was born on the 28th of November 1995 in Almere, the Netherlands, where he lived the first 18 years of his life. He went to high school at het Oostvaarders College (OVC) from 2008 to 2014 and graduated the gymnasium cum laude with a curriculum of both 'nature and health' and 'nature and technology' extended with economics and French. After high school he moved to Leiden to start his university education.

From 2014 to 2017, Rafaël followed the bachelor Molecular Science and Technology (MST), which is a joint degree of the TU Delft and Leiden University combining Chemistry and Chemical Engineering. He was always interested in sustainability and his first introduction with electrochemistry and with prof. Marc Koper was during an interview for a course in the extracurricular Honours Program. This sparked his interest for electrochemistry and resulted in a bachelor thesis in the CASC research group researching the effect of the carbon substrate on the electrochemical $CO_2$ reduction on indium protoporphyrins under supervision of Yuvraj Birdja.

After graduating his bachelor summa cum laude, Rafaël started the master Chemistry in Leiden. He chose the 'Energy and Sustainability' specialization and pursued both the Research and Business track. This entailed that besides 60 ECTS of Chemistry courses, which were mainly focused on physical and inorganic chemistry, he also followed business courses such as Finance and Strategy. Rafaël performed his master thesis again in the CASC research group. This time he studied the reduction and adsorption mode of acetylpyridine on Au under supervision of dr. Christoph Bondü. After his master thesis, he carried out a second research internship in the research group of prof. Alexis Bell in Berkeley, USA. Here he researched the electrochemical $CO_2$ reduction to C2+ products on Cu foils. Besides two research internships, Rafaël also performed a business internship at nlmtd, at that point a small consulting firm focusing on sustainability and specialized in the energy sector. Moreover, Rafaël participated in the Leiden Leadership Programme, an extracurricular programme focusing on self-development via seminars, workshops, group projects and much self-reflection. Due to these extra activities, Rafaël obtained his master cum laude in three years (2017-2020).

For his PhD, Rafaël stayed in Leiden and specifically the CASC research group under supervision of Prof. Marc Koper. He started during the COVID-19 epidemic in 2020 and his research was part of the TRANSCRIPT (Transforming carbon-rich industrial waste gases of metallurgical plants into valuable products) project. This project was cofunded by the Netherlands Organization for Scientific Research

(NWO), Materials Innovation Institute (M2i) and Tata Steel. Besides Rafaël, also one PhD candidate, two postdocs in Leiden and three PhD candidates in Utrecht were part of this project. The project of Rafaël focused on the effect of temperature on the electrochemical $CO_2$ reduction and he co-developed the high-pressure, high-temperature electrochemical cell. Besides research, Rafaël also supervised several bachelor and master students during their thesis or other internships in the group. Moreover, he supervised bachelor students during their first practical course (Basic Practical Skills) and small lab internships, and assisted during a seminar for chemistry bachelor students.

Furthermore, several courses where followed by Rafaël during his PhD. Besides 'Visualize your Science' (Visualize your science) and 'High Impact Writing' (HRSMC) also several courses from Leiden University were completed (PhD Introductory Meeting, Speed Reading, Manage your Brain, Basic Project Management, Negotiating, Storytelling Lab, Scientific Conduct). Additionally, he presented his work at several national and international conferences and summer schools, both via poster presentations (ECCM graduate school in 2021, HRSMC symposium in 2021, 2022 and 2023, Surfcat summer school in 2022, ISE topical meeting in 2022, NCCC in 2022, Amcel symposium in 2023, ISE 74$^{th}$ Annual Meeting in 2023, the M2I conference from 2020 till 2023) and via oral presentations (NCCC in 2023 in Noordwijkerhout, CHAINS-IUPAC in Den Haag in 2023, M2I conference in Apeldoorn in 2023, NanoGE in Keele in 2023, National Symposium on Electrochemical Conversion in Den Haag in 2024, ISE 75$^{th}$ Annual Conference in Montreal in 2024). Rafaël was also member of the PhD platform of the Holland Research School for Molecular Chemistry (HRSMC) and the PhD representative during the CASC staff meetings.

# Acknowledgements

With the end of my PhD also my time at Leiden University comes to an end after a decade long journey. This journey formed me both as a researcher and as a person, and I would like to take this opportunity to express my gratitude to the people who joined me on this journey and contributed to the realization of this thesis, may it be directly or indirectly.

First I would like to thank prof. dr. Marc Koper for his supervision during all these years. We first met in my first year as a bachelor student and during this interview my passion for electrochemistry was ignited. I want to thank Marc for providing me the opportunity to join the Catalysis and Surace Chemistry (CASC) group not once, but three times during all these years. Thank you for the freedom to explore my own ideas, for the impactful advises, for all the feedback on my work, for the opportunities to go on conferences both in the Netherlands and abroad, for providing an excellent work environment and creating such an amazing research group full of wonderful people.

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Yuvraj and Christoph, you got me acquainted with electrochemistry and paved the way for me to pursue a PhD. Thank you for laying the foundations and for your great supervision during my bachelor and master project in the group.

A PhD is not a journey you should do on your own and I'm grateful for all the wonderful people in the CASC research group that joined me on this journey, not only in the lab but also as wonderful friends outside of the university. Sergi, I'm grateful and happy I can call you my good friend. Even though in the lab we did not spend much time together, the more time we spend at the lunch table and outside of university. Thank you for all the laughter, stories, food and good times. Alisson, you have been the closest colleague I worked with. Thank you for all the wonderful scientific discussion we had, for the amazing collaboration and for all the fun, also outside of the lab. With Cássia, Marleen and Francesc, we had a lot of fun times. Thank you for the wonderful dinners, the great parties and your amazing friendship.

I'm thankful to all the other people I closely work with in our project. You were amazing colleagues in and outside of the lab; Xuan, Zhiqin and Quentin. I also want to express my gratitude to our collaborators from Utrecht. Angela, Joyce and Thimo, we had a great time during all the meetings and conferences we were together.

I want to thank Aleksandra for being a great companion, in and outside the $CO_2$ team. Together with Nicci you livened up our office. Nipon, we started our journey together and I'm thankful for all the time we spend in and outside the lab together. Too bad that our trip didn't take place yet. Onno, we shared a lot of experiences together. At the start as the minority of Dutch people in the lab and I'm happy you were always by my side in the office. We have had great conversations there, both scientific and not at all, such as about football. I could also always count on you if something needed to be organized for the lab. Sunghak, thank you for all the wonderful discussions, for the moments of distraction when we peaked at each other's setup when we were bored and for the wonderful food you made and the recipes you gave me. Mingchuan, I remember the times it was the standard that we were working in the spots next to each other in the lab. Thank you for all the good times and giving us always a reason to laugh.

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