Understanding Catalysis Through the Construction and Study of an Artificial Enzyme

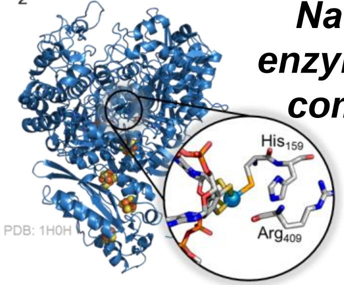
Regina E. Treviño, Joseph A. Laureanti, Bojana Ginovska, Gregory K. Schenter, Wendy J. Shaw
regina.trevino@pnnl.gov, Pacific Northwest National Laboratory

Nature's Exemplary Enzymes as Inspiration

Nature has championed clean energy conversion reactions with high degree of selectivity and activity all while operating in water and utilizing earth abundant metals

Formate Dehydrogenase (FDH)

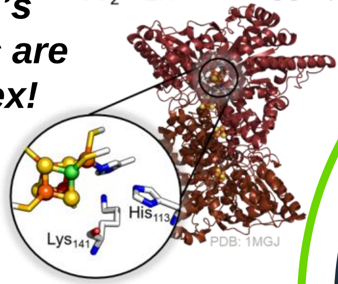
$CO_2 + H^+ \underset{}{\overset{2e^-}{\rightleftharpoons}} HCOO^-$



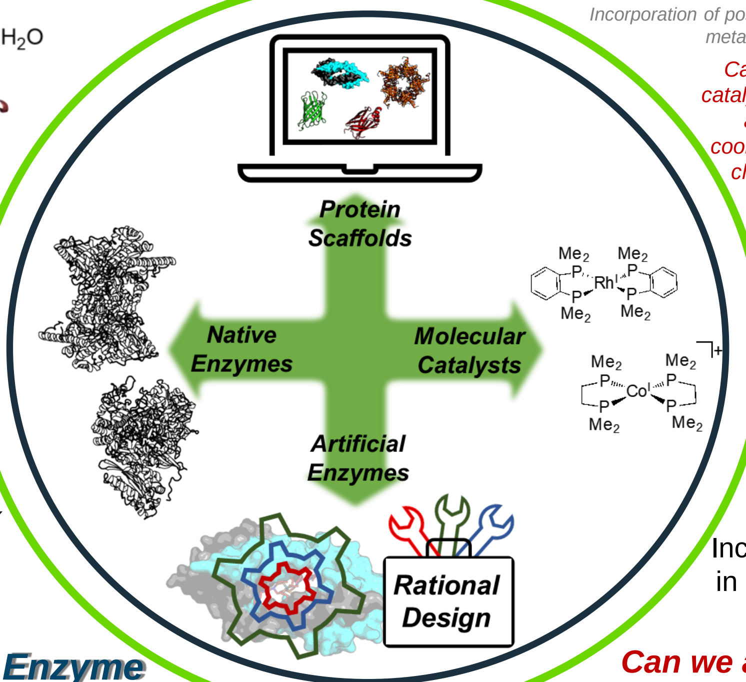
Nature's enzymes are complex!

Carbon Monoxide Dehydrogenase (CODH)

$CO_2 + 2H^+ \overset{2e^-}{\rightleftharpoons} CO + H_2O$



Can we identify the building blocks needed to achieve similar reactivity? What is the role of each complex element?



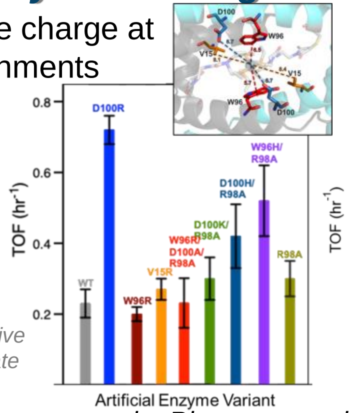
Tuning Catalysis by Modulating Protein Scaffold

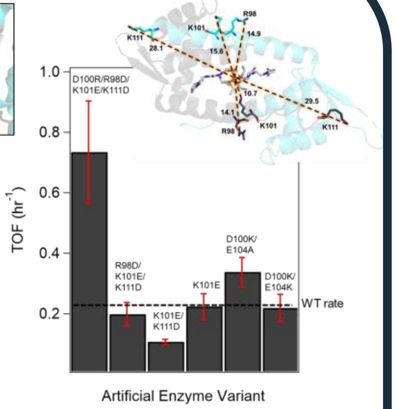
Introducing positive and negative charge at different coordination environments

Incorporation of positive charge near the metal center

Can we span the catalytic range? What are the outer coordination sphere charge effects?

Incorporate negative charge to modulate catalysis





Positive charge near the Rh center results in increased activity while negative charge in the outer coordination sphere has little effect on catalytic activity

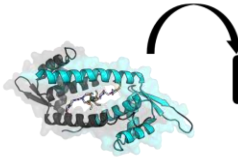
Building an Artificial Enzyme

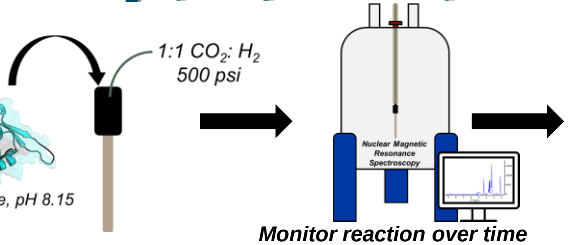
Taking a top-down approach to build an artificial enzyme by utilizing a well-structured *protein scaffold* and a *molecular complex*

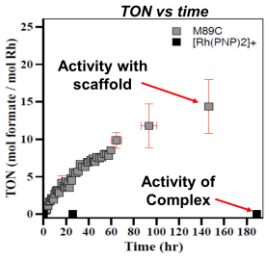
Structured Protein Scaffold + **Bio-inspired Molecular Complex** = **Artificial Enzyme**

Structured Protein Scaffold	Bio-inspired Molecular Complex	Artificial Enzyme
Well characterized	Well studied and characterized	Controlling outer-coordination sphere
High yield expression	Inactive in water	Rational design
Stable to mutagenesis		Tune catalysis?
Binding of exogenous molecules		

CO_2 Hydrogenation by an Artificial Enzyme







Protein scaffold turns on activity!

Can we incorporate design principles conserved in native enzymes to modulate catalysis?

Conclusions and Future Directions

Artificial enzyme demonstrate catalytic competence for hydrogenation of CO_2 to formate, *but what is the role of the scaffold?*

Incorporation of positively charged residues near the Rh center results in increased activity while global negative charges have little effect on catalytic activity. *Can we further define the mechanism?*

Can we apply these design principles across different scaffolds?

Acknowledgements and References

Wendy Shaw, Neeraj Kumar, Qiwen Su, Garry Buchko, Aaron Appel, Sriram Katipamula, Molly O'Hagan, Bojana Ginovska, John Linehan, Eric Weidner, Joe Laureanti, Greg Schenter, Jack Fuller, Aaron Walsh

U.S. DEPARTMENT OF ENERGY · EMSL

This work was supported by Office of Science, DOE-BES Chemical Sciences, Geosciences & Biosciences

Raaijmakers, H. *et al. Structure* **2002**, *10* (9), 1261–1272.; Boyington, J. C. *et al. Science* **1997**, *275* (5304), 1305–1308.; Doukov, T. I. *et al. Science* **2002**, *298* (5593), 567–572.; Schwizer, F.; Ward, T.R. *Chemical Reviews* 2018 *118* (1), 142-231.; Laureanti, J.A. *et al. Sustainable Energy Fuels*, 2019,3, 3260-3278.; Agustiandari, H. *et al. J Bacteriol* **2008**, *190* (2), 759–763.; Roelfes, G. *Acc. Chem. Res.* 2019, 52 (3), 545–556.; Laureanti, J. A. *et al. ACS Catal.* **2019**, *9* (1), 620–625.; Bays, J. T. *et al. ACS Catal.* **4**, 3663–3670 (2014).; Laureanti, J. A. *et al. Organometallics* **2020**, *39* (9), 1532–1544.