

# Direct Iron Reduction in Acidic Systems

# Motivation Behind the Research

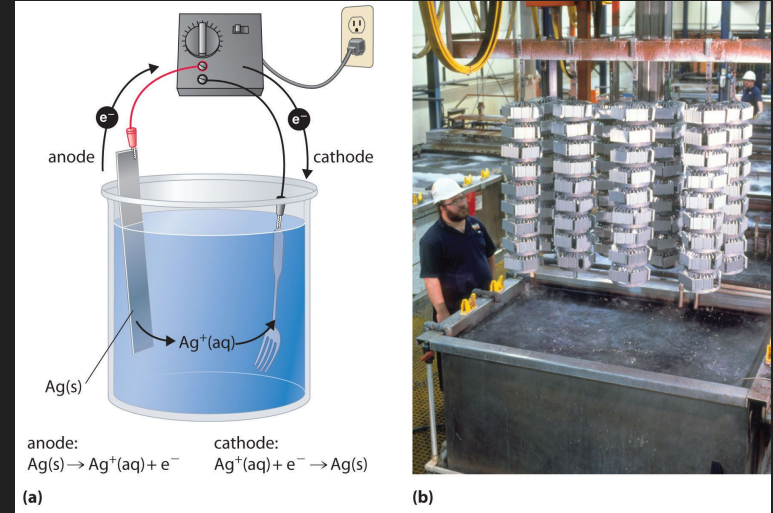
- Steel production is an important sector that accounts for 8% of global carbon emissions [1].
- These emissions come primarily from the smelting of Iron Ore in a blast furnace [1].
- Iron production remains an important component of industrialization, and the demand for iron grows higher every year in developing and developed countries [1].



Image from <https://www.kohlercastings.com/our-foundry>

# Proposed Solution

- It's possible this process could be replaced by using electrochemical methods. Using electrolysis to refine pure metal from composite ores is already used in industry for metals such as copper, aluminum, gold, and silver.
- There are two methods of refining that could be applied here. Direct reduction or a two step reduction.
- In previous research, I've helped work on two step reduction. I've conducted preliminary research proving direct reduction possible, but I'm now trying to identify the mechanics of the reaction.



# Initial Hurdles

- Iron has an abnormally high melting point even for a metal (~2,500 [F]), and will be difficult to decarbonize while using traditional methods
- Approaching this problem electrochemically has problems as well, due to the standard electromotive force of Iron
- Electrodes for direct reduction need to be composed of the iron ore itself, which is non-conductive.

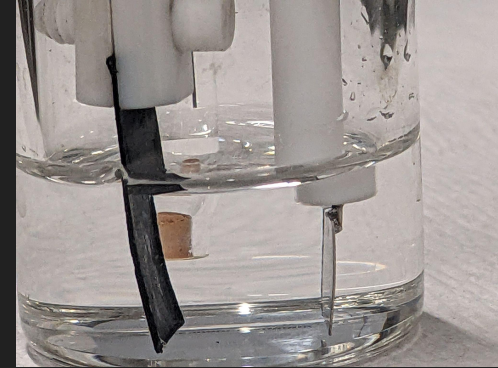
TABLE 20-1 The electromotive force (emf) series for selected elements

	Metal	Electrode Potential (V)
Anodic	$\text{Li} \rightarrow \text{Li}^+ + \text{e}^-$	-3.05
	$\text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-$	-2.37
	$\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^-$	-1.66
	$\text{Ti} \rightarrow \text{Ti}^{2+} + 2\text{e}^-$	-1.63
	$\text{Mn} \rightarrow \text{Mn}^{2+} + 2\text{e}^-$	-1.63
	$\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$	-0.76
	$\text{Cr} \rightarrow \text{Cr}^{3+} + 3\text{e}^-$	-0.74
	$\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$	-0.44
	$\text{Ni} \rightarrow \text{Ni}^{2+} + 2\text{e}^-$	-0.25
	$\text{Sn} \rightarrow \text{Sn}^{2+} + 2\text{e}^-$	-0.14
	$\text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^-$	-0.13
	$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	0.00
	$\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$	+0.34
	$4(\text{OH})^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$	+0.40
	$\text{Ag} \rightarrow \text{Ag}^+ + \text{e}^-$	+0.80
	$\text{Pt} \rightarrow \text{Pt}^{4+} + 4\text{e}^-$	+1.20
	$2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$	+1.23
Cathodic	$\text{Au} \rightarrow \text{Au}^{3+} + 3\text{e}^-$	+1.5

Image from  
[https://www.researchgate.net/figure/Electromotive-series-of-metals\\_tbl2\\_252322564](https://www.researchgate.net/figure/Electromotive-series-of-metals_tbl2_252322564)

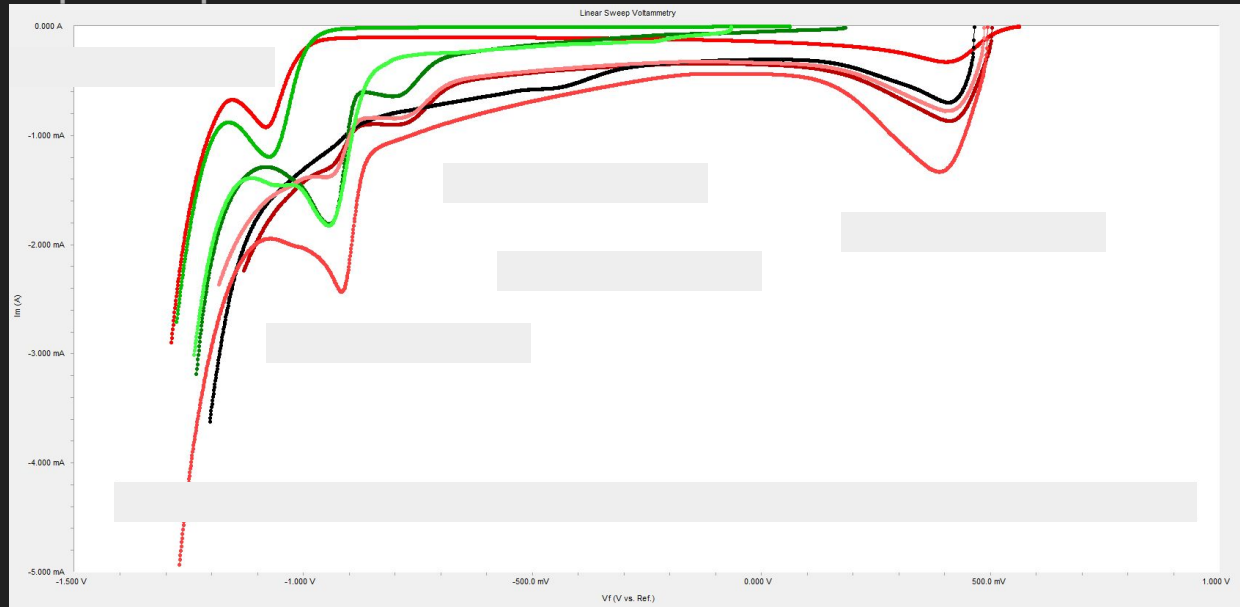
# Beginning Research

- The work began by creating electrodes that were a balance between 3 things. Stable form, conductivity, and material production.
- A system to suppress water activity was developed.
- The electrodes pictured at the right are attempt 1. Creating an electrode took roughly 24 hours, and the electrode that finally worked was electrode composition 27. But further optimization was conducted, and the one currently used is electrode 35.



# Results

- Ten reactions (and/or side reactions) involved in this process have been identified and characterized. Through this process, the path in which hematite turns into iron metal has been identified as two parallel series of reactions, each of which taking multiple steps.
- As I am currently working on publication with my PI, we felt it unwise to share too many details relating to my findings.



## Works Cited

[1] X. Zheng et al., “Correlating chemistry and mass transport in sustainable iron production,” *Proc. Natl. Acad. Sci. U.S.A.*, vol. 120, no. 43, p. e2305097120, Oct. 2023, doi: 10.1073/pnas.2305097120.