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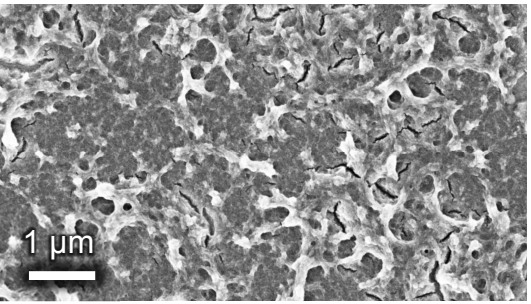

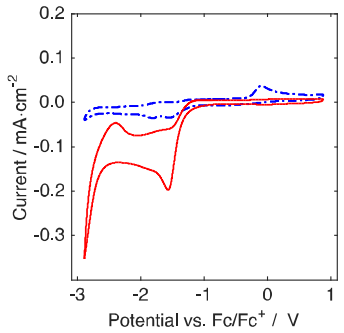

Electrochemical REcycling of Erbium using Ionic Liquids

Leo J. Small,

Timothy N. Lambert, Julian A. Vigil, Maria Kelly, Timothy J. Boyle, Jeremiah Sears, Ryan F. Hess

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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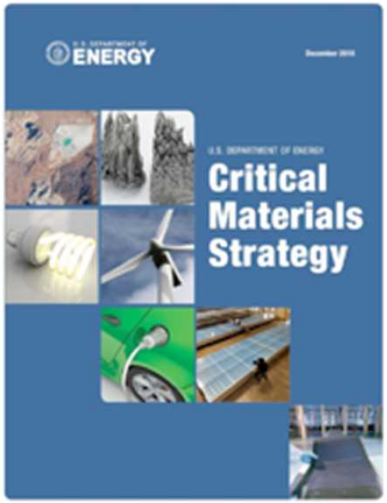
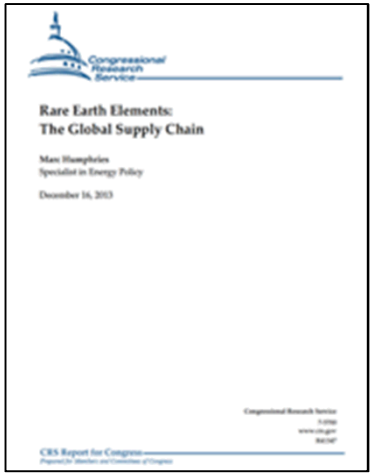
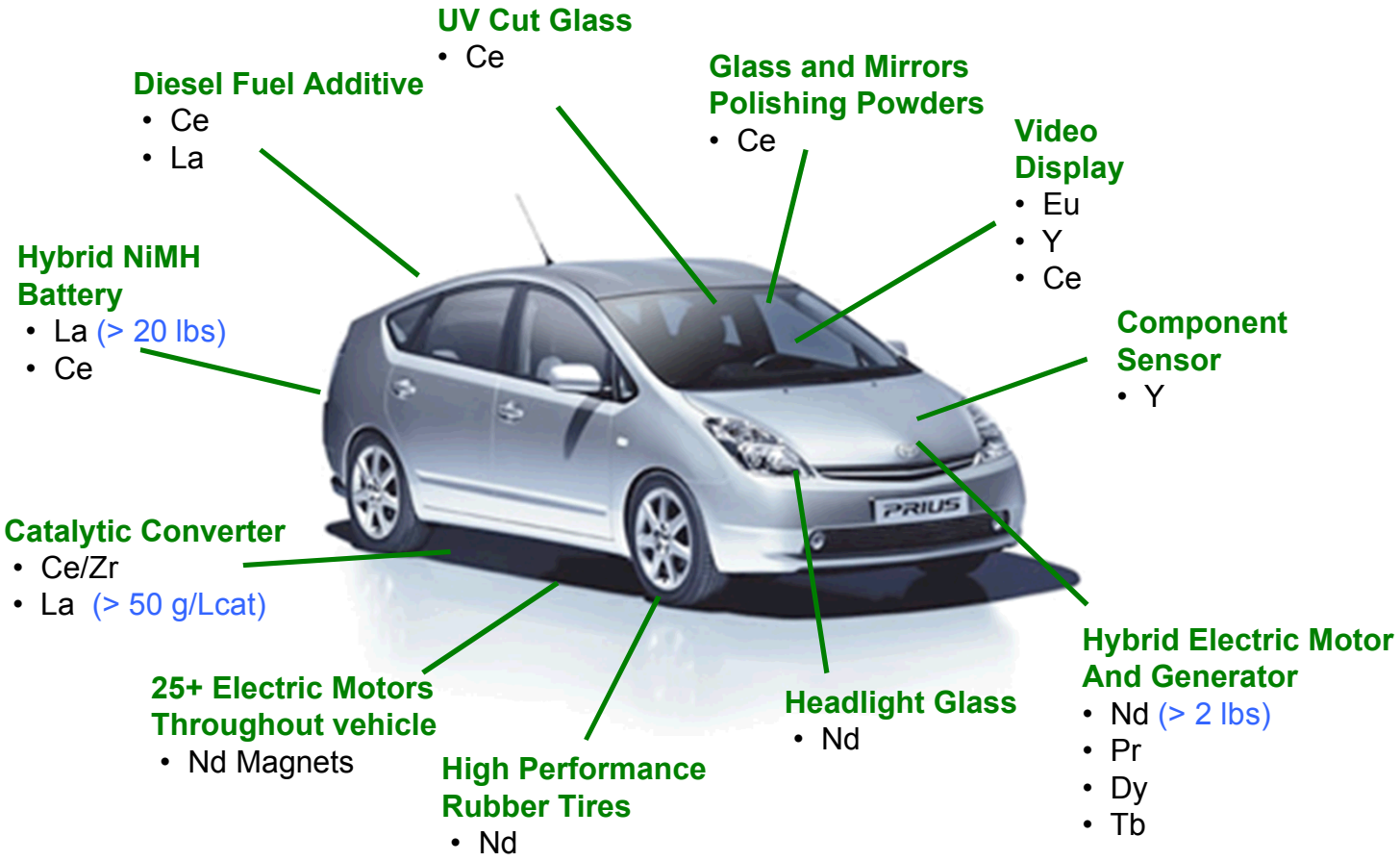
Overview

- Motivation
- REcycling scheme
- REcycling in molten salts
- REcycling in ionic liquids
  - Influence of cation
  - Influence of anion
  - Influence of electrode material





RE Are Ubiquitous in Modern Society



"Analysts have called the Prius™ one the most rare-earth intensive consumer product ever made."

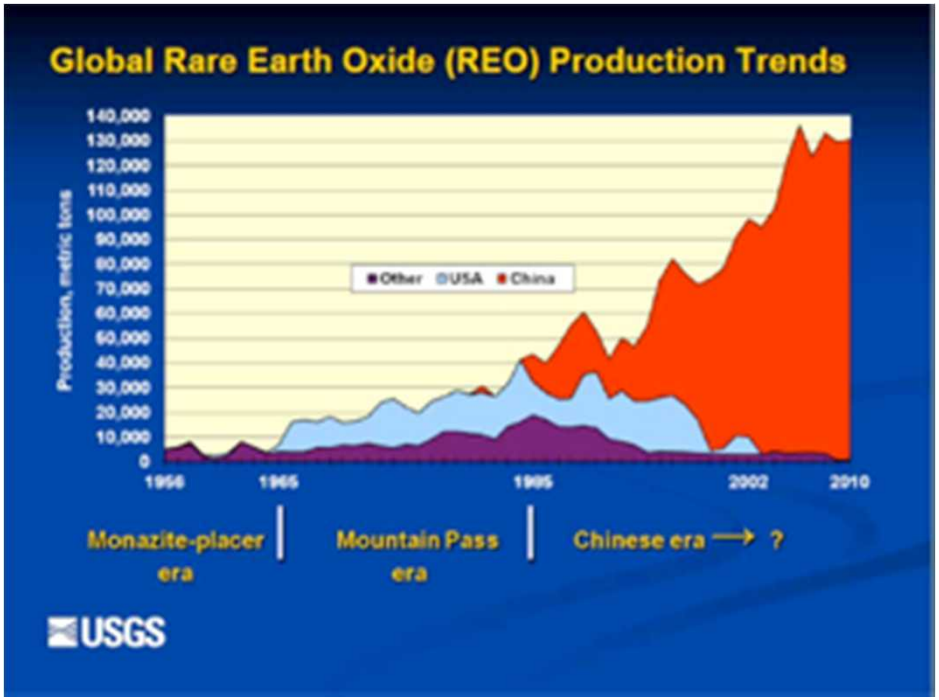
Power Hungry – The myths of 'green' energy and the real fuels of the future
-Robert Bryce (2011) *PublicAffaris*

Les Terres Rares Uniques, Incontournables, strategiuqes
-J. Lucas *Universite de Rennes*

Over the past few decades China has taken over production of RE materials.

RE Historically Produced:

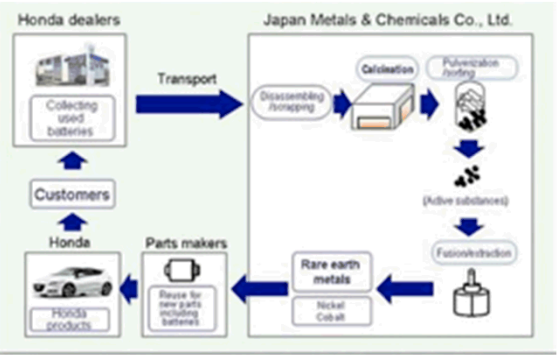
- 1950s: South Africa (monazite)
- 1960-1980: Mountain Pass (CA)
- 2000: Inner Mongolia, China
- 2011: MolyCorp resurrects Mountain Pass (CA)



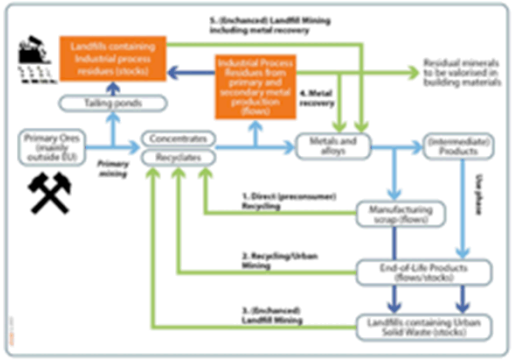
Molycorp filed for bankruptcy in June 2015.
In August 2015, it was reported that the mine was to be shutdown.

REcycle: A Route to Reduced Dependency

Sandia National Laboratories

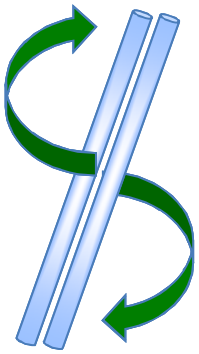


Honda recently announced that key materials for their hybrid automobiles will be recycled.



Rhodia (France) has begun to recover Tb and other RE elements from magnets, windmill components, electric vehicles and hard disks.

Hitachi, Ltd. announced plans for recycling RE-magnets from hard disk drive motors, air conditioners, and other compressors.



Sandia 8700 kg of fluorescent waste, a loss $900,000 in RE material (per 2 yrs).

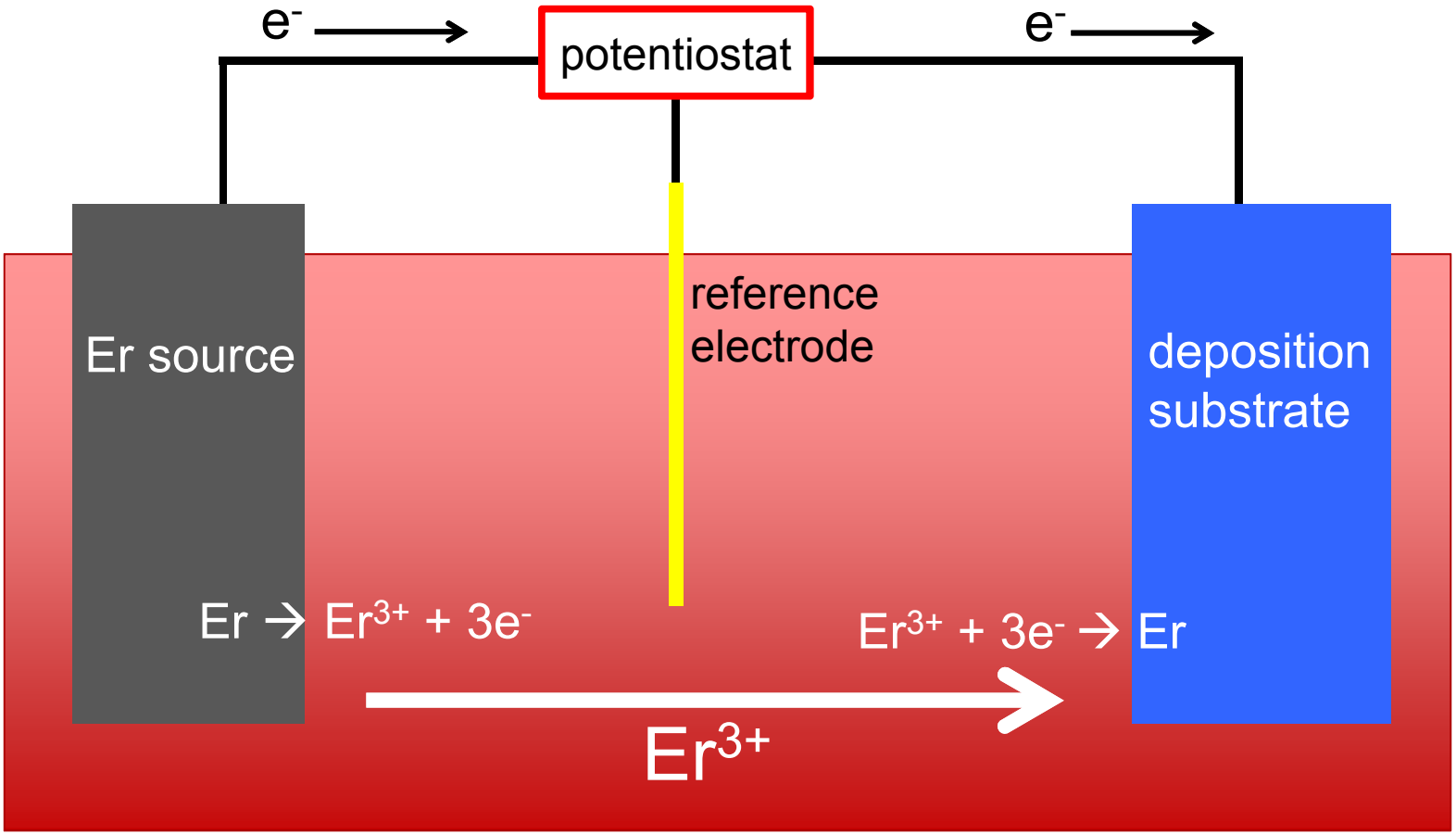
New extraction methods are necessary to aid in the RE-utilization of other 'waste' RE-materials

- REEcycle (U. Houston) has a patented method to extract Dy/Nd from magnets.
- Ames Laboratory and Critical Materials Institute has an imidazolium BF_4^- ionic liquid to dissolve lanthanide oxides.

REEcycle

The Ames Laboratory
Creating Materials & Energy Solutions
U.S. DEPARTMENT OF ENERGY

Electrorefining Erbium

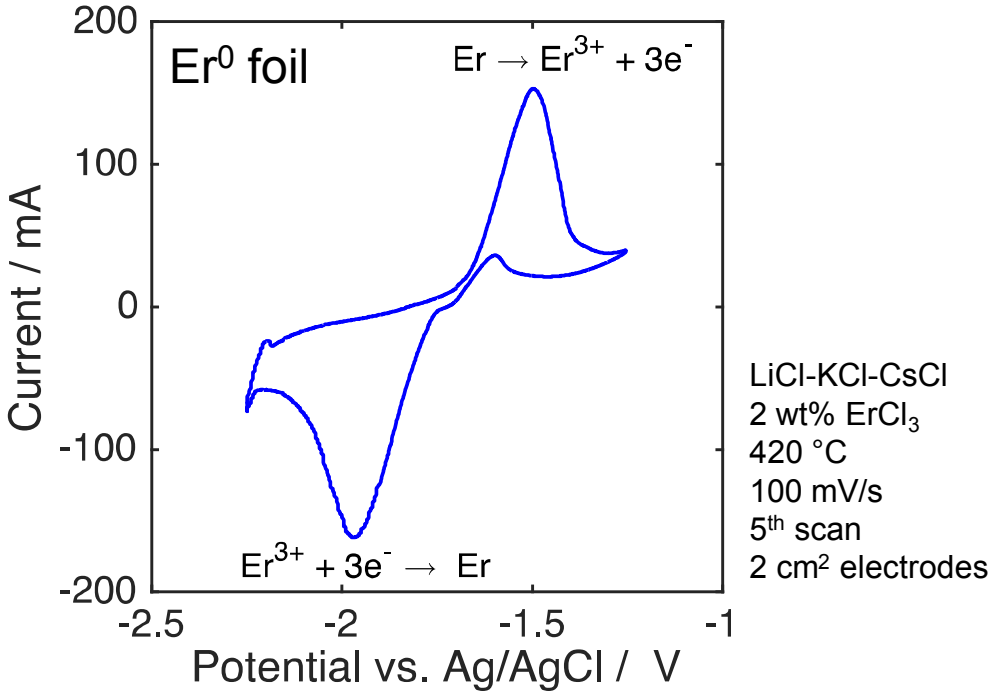


Electrochemically move erbium from source to target substrate.

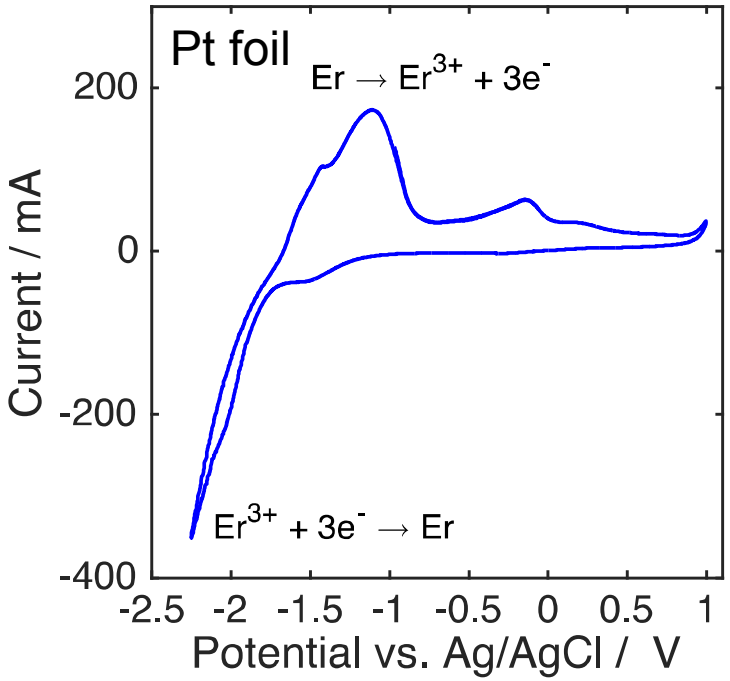
Electrorefining in Molten Salts

Sandia National Laboratories

Erbium is easily oxidized into solution…



…and reduced onto platinum.



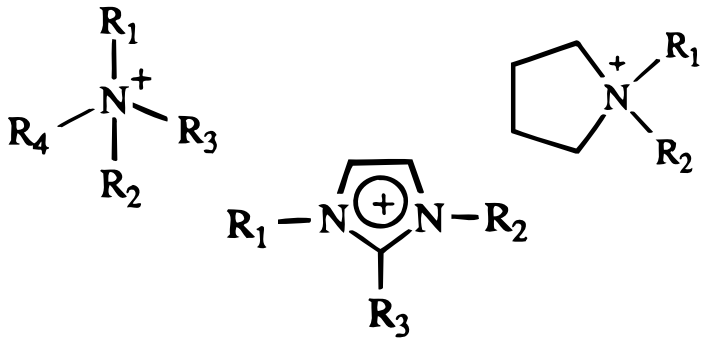
>90% Coulombic efficiency on 250 mg scale at ***420 °C***

Inert environment with heat-tolerant materials required!

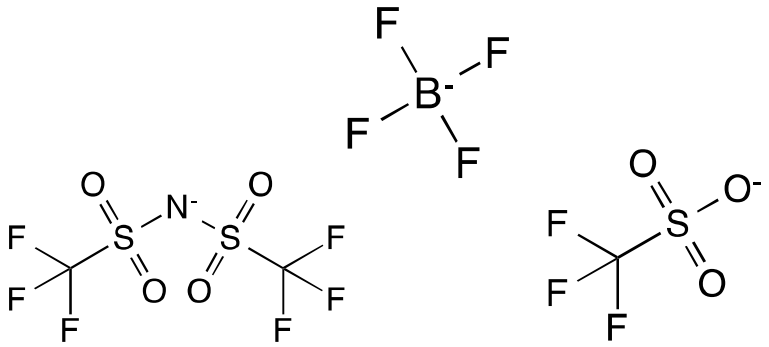
Ionic Liquids

- Room temperature liquids with negligible vapor pressure
- Bulky non-coordinating ions
- Versatile, highly tunable
- Large (>4 V) electrochemical windows common

Example Cations



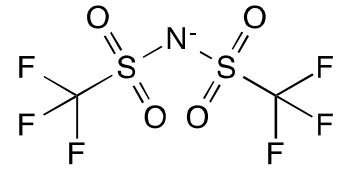
Example Anions

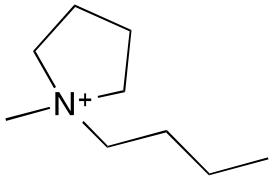


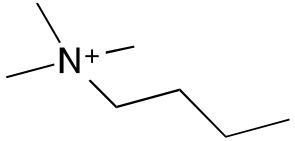
Ionic Liquids may be tuned to have a wide range (electro)chemical properties.

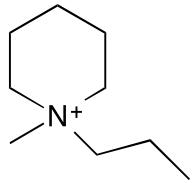
Variation of Ionic Liquid Cation

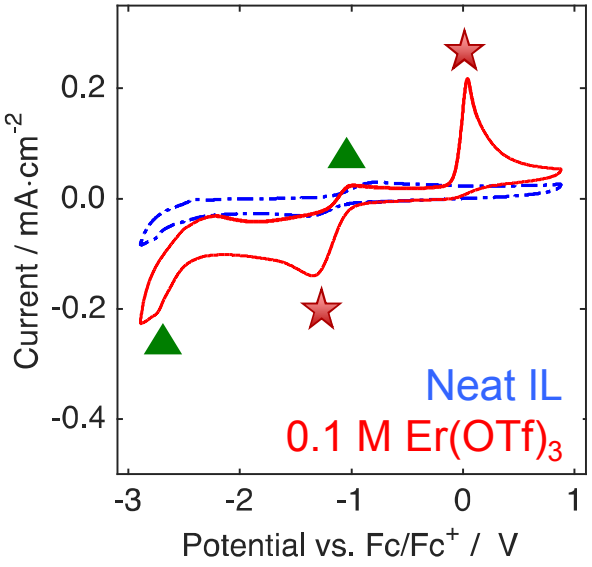
0.1 M $Er(OTf)_3$ in NTf_2 ionic liquids at a platinum surface

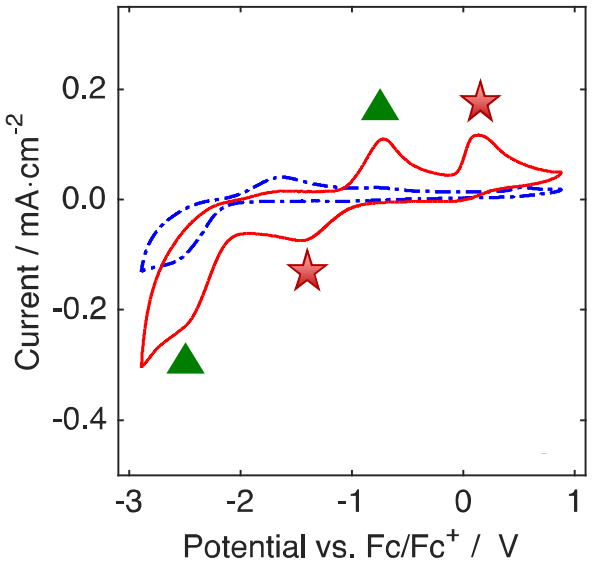


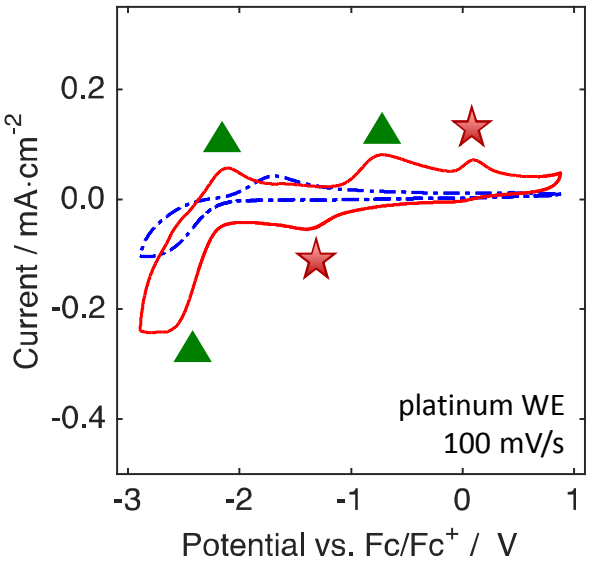












Redox active intermediates formed during Er^{3+} reduction

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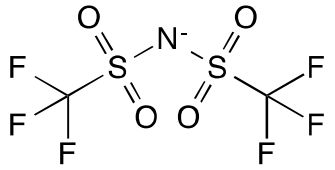
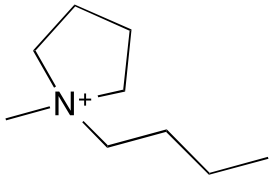
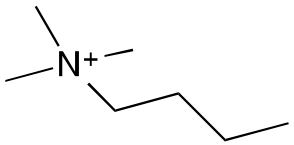
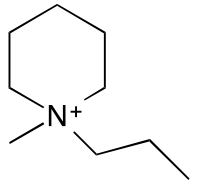
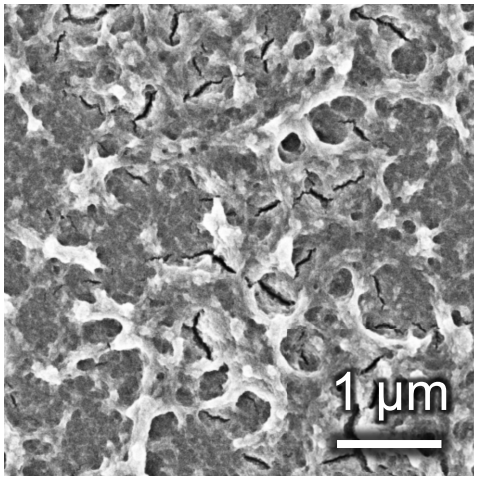


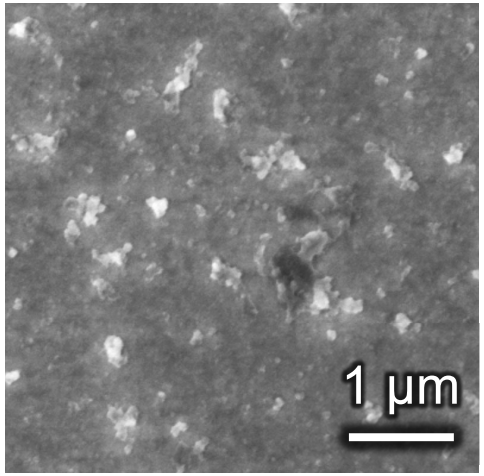


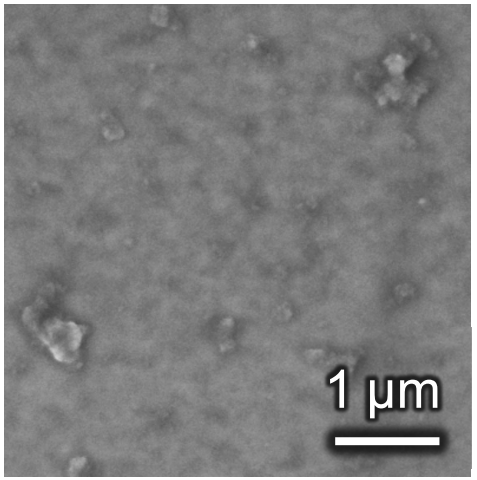




Deposit at -2.9 V for 2 hours







Amorphous, anion-contaminated ErO_x deposited onto Pt.

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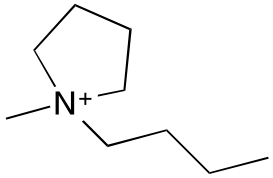

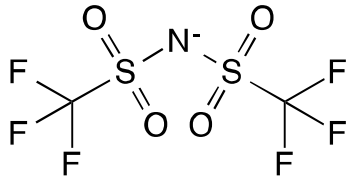

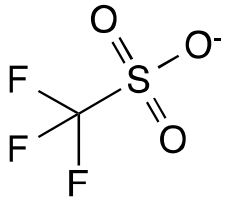

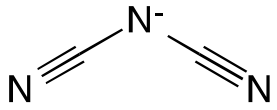

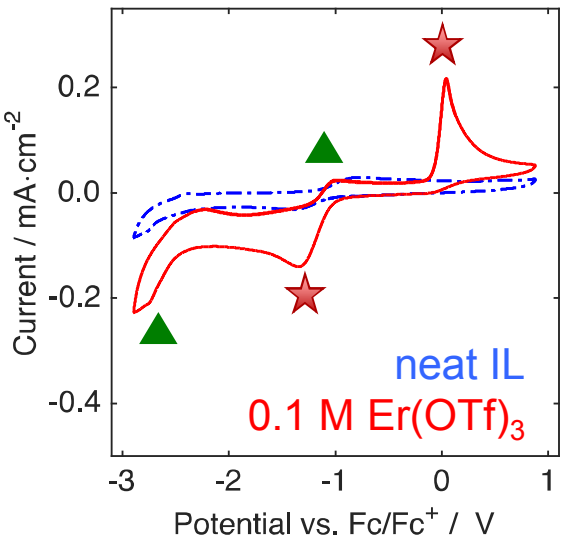

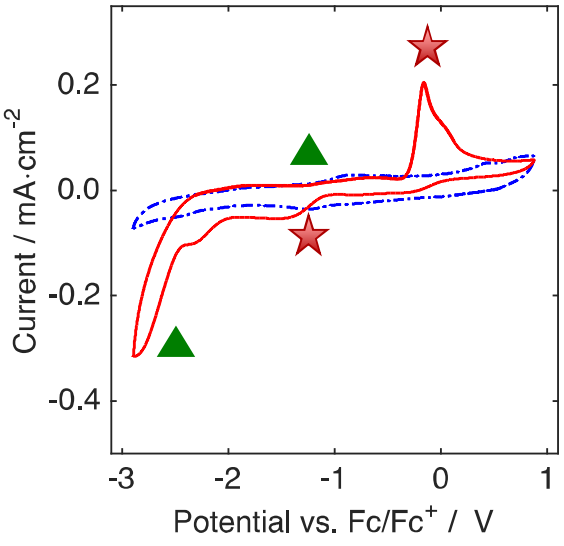

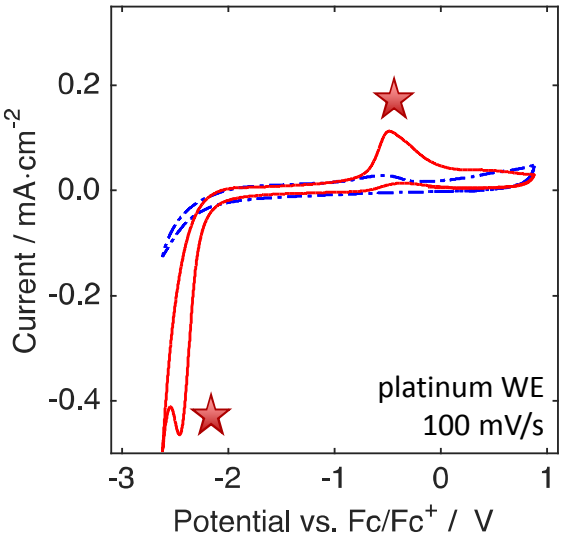

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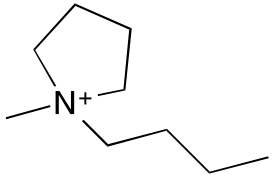
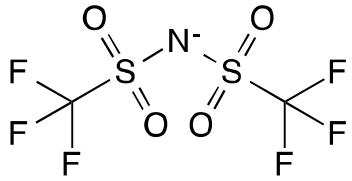
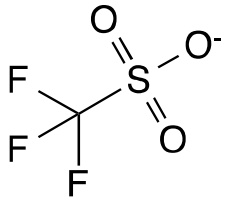
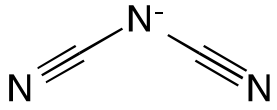
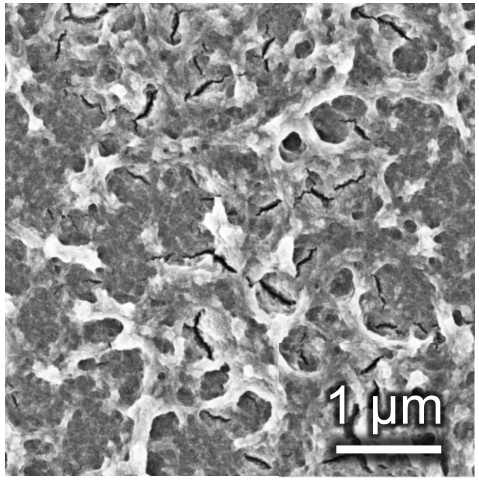
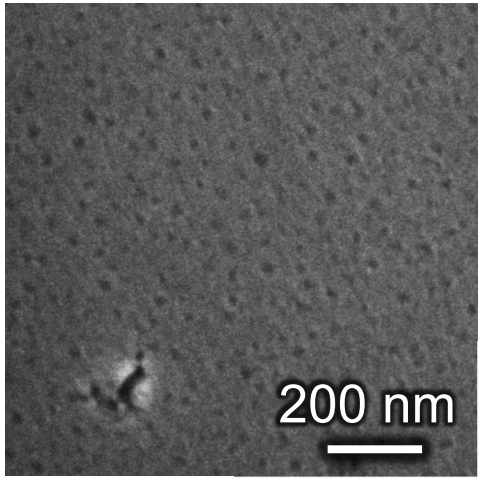


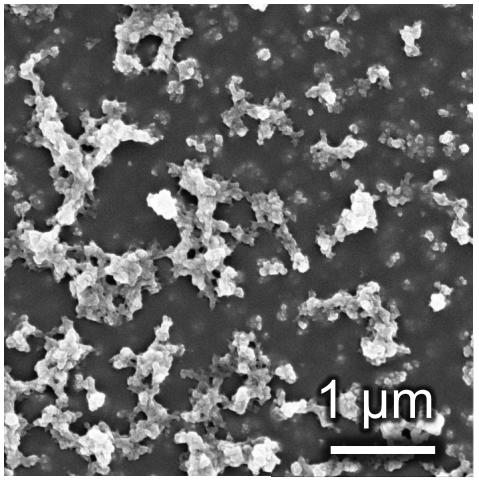






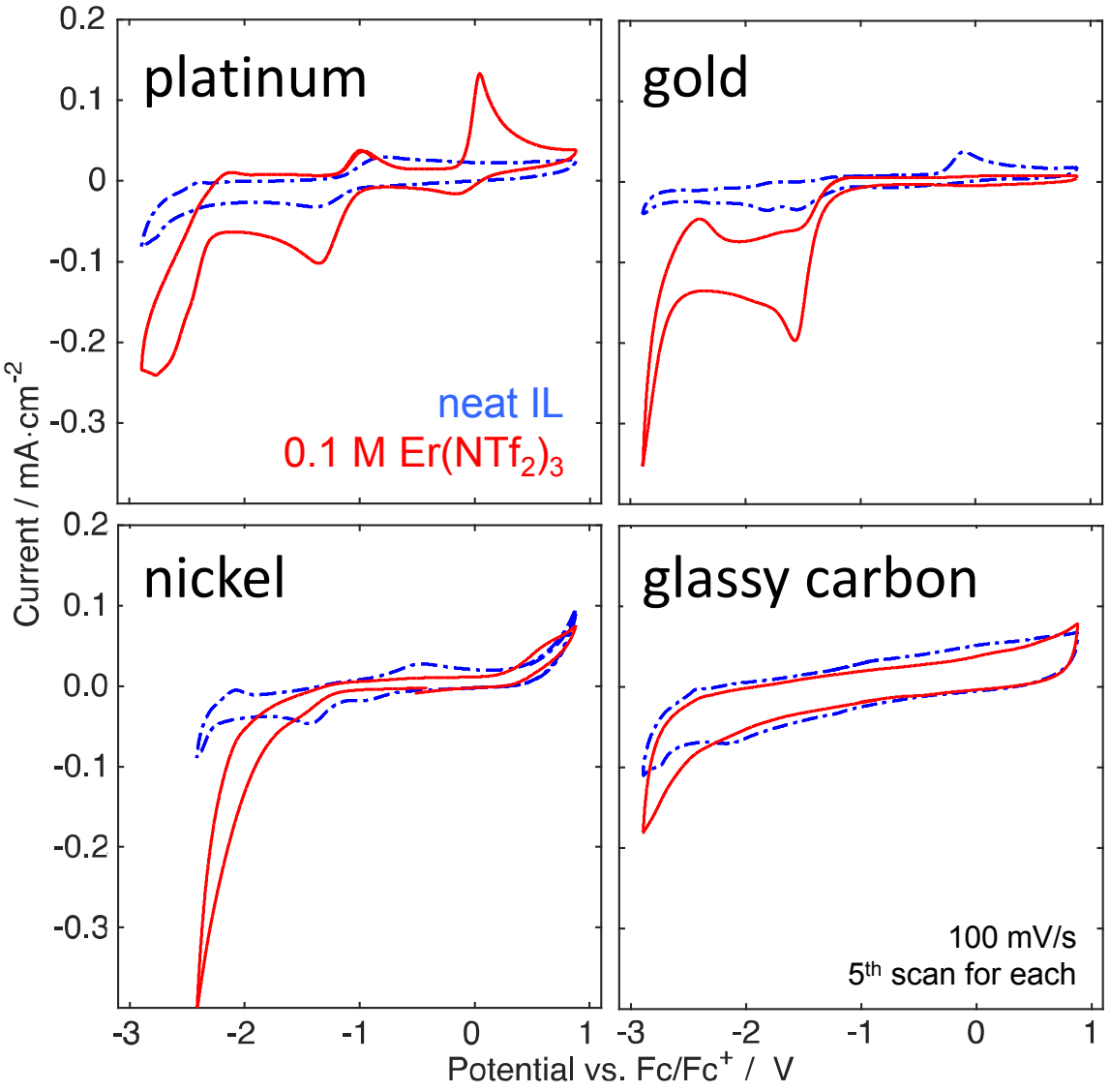






Amorphous, anion-contaminated ErO_x deposited onto Pt.

Er Deposition onto Different Materials



- No deposition on glassy carbon
- Oxidizable species only on platinum
- No intermediate on nickel

Electrode material greatly influences deposition electrochemistry.

Summary

- REcyling of “nationally critical” erbium needed to provide alternative to foreign sources.
- Molten salts offer facile erbium redox, but severely limit processing flexibility.
- Ionic liquids offer a versatile medium for electroreduction.
- Investigation of processing space to improve Er^{3+} solubility, ionic liquid stability, deposition rate, and Er^{0} film purity.

Acknowledgments

- Drs. D. Kammler and L. Appelhans for materials and discussions

- Dr. Timothy N. Lambert, Julian A. Vigil, Maria Kelly, Dr. Timothy J. Boyle, Jeremiah Sears, Dr. Ryan F. Hess

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