Addressing the sustainability challenge in materials extraction

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ILP Conference - Tokyo - January 2017

Messages

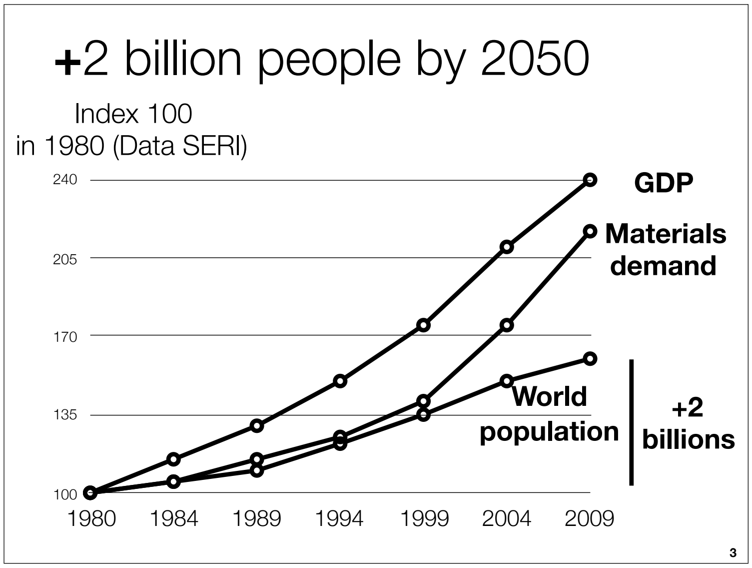
Metals are key materials, at the basis of modern economy. Their sustainability is becoming a global and strategic challenge

Materials extraction and processing have large impact on environment, with practices inherited from a time of limited awareness

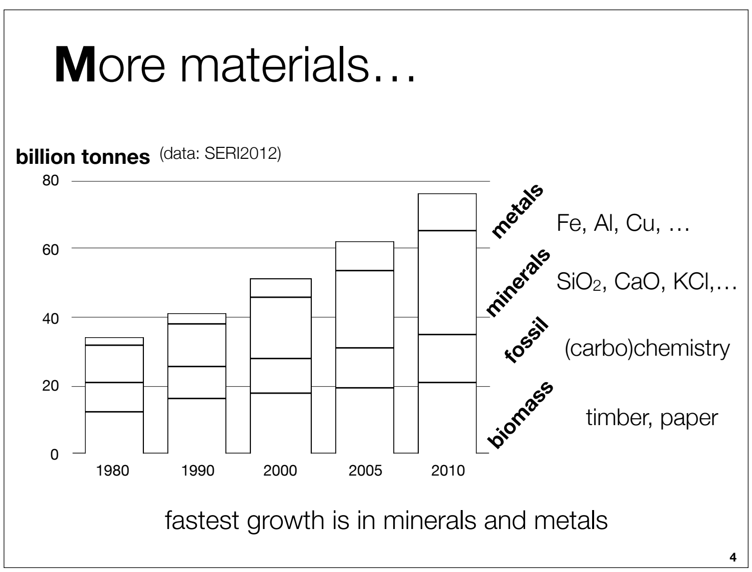
Novel paradigms are possible, taking benefit of decarbonized electricity and multidisciplinary approaches

New technologies are invented, developed and commercialized at MIT

Join the Metals and Minerals Program (MME) at MIT, May 2017



as population increases on the planet, it gets wealthier, in a non linear way… and in an even more non linear, maybe exponential way, as population increase the materials demand is drastically increasing.



looking at the same time frame, on finds that it is not any materials…the fastest growing demand is for metals and minerals. Minerals for construction, fertilizers, and metals for infrastructure (see aluminium Al and and Iron Fe) and modern technologies linked to electricity, see Copper (Cu) and Aluminium

Metals facts

Globally,

in last 35 years, double steel production
(now around 1,500 000 000 tonnes)
in last 35 years, quadruple aluminum production
(now around 50,000,000 tonnes)

Nationally,

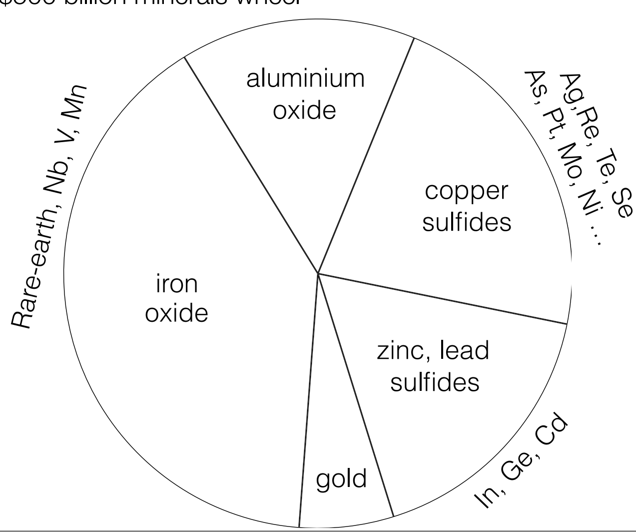
leadership of China
in any developed economy, 10 to 15% of the value added tied to 'metals', largest share of any materials

Strategically,

important metals and compounds are derived from primary metals supply-chain

the $500 billion minerals wheel

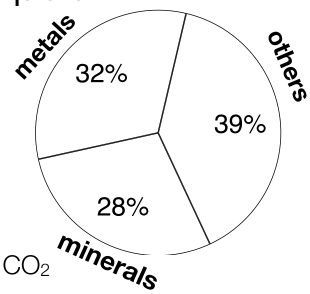
the $500 billion minerals wheel



rare-earth, Nb is niobium, V is vanadium, Mn is manganese, In is indium, Ge is germanium, Cd is cadmium, Ag is silver, Re is rhenium, Te is tellurium, Se is selenium, As is arsenic, Pt is platinum, Mo is molybdenum, Ni is nickel, Al is aluminium, Fe is iron, Cu is copper

Environmental impact

Greenhouse gas emissions for materials in 2013 in USA (EPA)



1 tonne of steel ~ 2 tonnes of CO_2

1 tonne of copper ~ 2 to 4 tonnes of CO_2

1 tonne of aluminium ~ 4 to 10 tonnes of CO_2

CO2 is carbon dioxide. EPA is environmental protection agency

Nations requests

PARIS2015
CONFÉRENCE DES NATIONS UNIES SUR LES CHANGEMENTS CLIMATIQUES
COP21·CMP11

legally binding text

target at warming temperature (as opposed to emissions)

5-year timescale for countries to propose a plan

no constraints on a time for « phase out» of fossil

COP is Conference of Parties - name is “COP 21”

Government requests

China ?

The 12th Five-Year Plan (FYP)

-16% in energy intensity

+11% of renewable energy

-17% in carbon intensity

MIT News, February 2016

"Using carbon pricing in combination with energy price reforms and renewable energy support, China could reach significant levels of emissions reduction without undermining economic growth," says Valerie Karplus, an assistant professor at the MIT Sloan School of Management. Details in *Energy Economics*

Consumers?

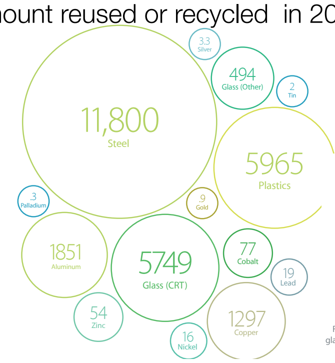
ONTARIO'S
CLIMATE CHANGE
STRATEGY

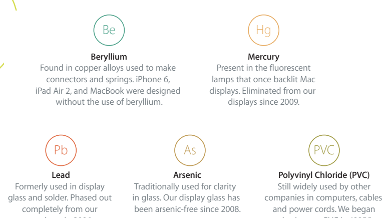
Ontario

Consumer products company?

Consumer products company?

amount reused or recycled in 2014

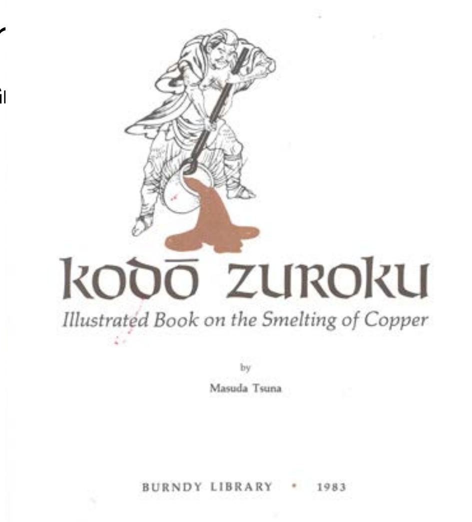




materials banned from product

Envir

G



Origin of impact: smelting

6000BC

$$Cu_2S + O_2 = 2Cu(l) + SO_2(g)$$

S^{2-} as a fuel

S^{2-} as a reductant

☛ smelting

Cu2S is copper sulfide, O2 is oxygen, Cu is copper, SO2 is sulfur dioxide. S2- is sulfur

Technological framework

free combustible — abundant & free

in Cu_2S — O_2 from air
in FeS
in PbS

process basic principle

Cu — SO_2

product
and co-products
(Te, Se, Ag, Mo, Re, Pb,…)

waste

FeS is iron sulfide, also called pyrite, PbS is lead sulfide, O2 is oxygen, see slide 6 for other names

process basic principle

ore purification

gas
treatment

SO_x, As, Zn(g)
Pb(g
H_2SO_4

process
basic
principle

excess S, O
noble impurity
recovery

product
purification

waste
retreatment

CuO

additional engineering
steps to cope with inefficiencies

SOx reads SOex, As is arsenic, S is sulfur, O is oxygen, CuO is copper oxide

process
basic
principle

additional engineering
steps to cope with inefficiencies

mining realities

variation in energy cost

process
basic
principle

environmental awareness

additional engineering
steps to cope with inefficiencies

recycled materials

markets and
society

Existing
paradigm

process
basic
principle

incremental
engineering

markets and society

Sustainable Materials Processing

Existing paradigm

process basic principle

incremental engineering

markets and society

Sustainable Materials Processing

Existing paradigm

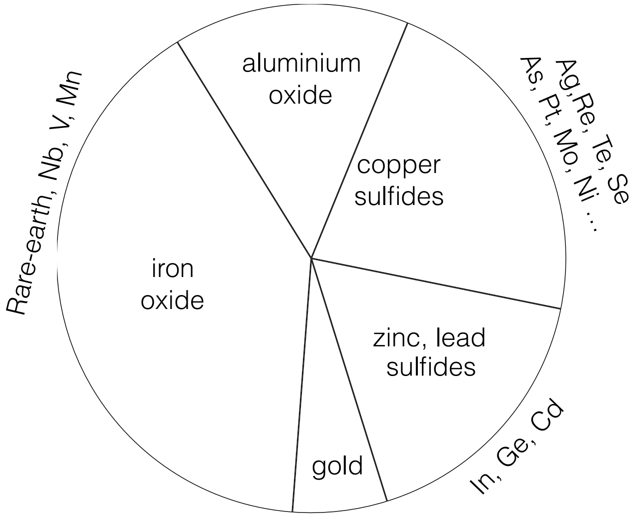
process basic principle

incremental engineering

markets and society

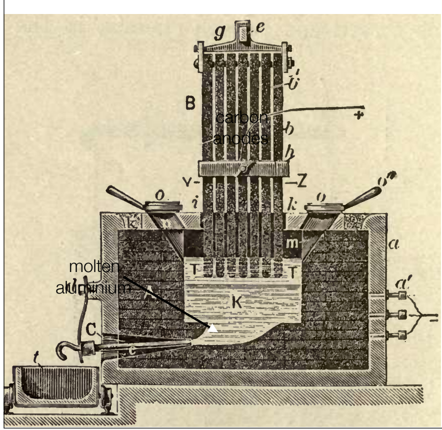
21st century processing

higher selectivity



Aluminium oxide electrolysis

Using electricity and carbon since 1886



$2Al_2O_3 + 3C = 4Al(l)+3CO_2(g)$

C as a fuel

e^- as a reductant

☛ Hall-Héroult

What Aluminium is doing…


EUROPEAN ALUMINIUM

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Innovation

A revolutionary project towards low-carbon aluminium production

Rio Tinto's H2020 AGRAL (Advanced Green Aluminium) Inert anode Project

This project was prepared in 2014, accepted in the framework of the H2020-SILC-II-2014 programme and launched the 1st May 2015 (duration 36 months). The project will aim at developing the manufacturing technologies of a specific anodic material that has shown previously at lab scale outstanding properties in high temperature and corrosive media of the aluminium electrolysis.

This new material will be tested for two applications: in aluminium production for the manufacturing of an inert anode up to industrial scale, and in hydrogen and fuel cell application.

This will allow Rio Tinto, leader of this project, to consider the replacement of the current carbon anode by inert anode, therefore achieving a major technology breakthrough. The use of inert anode in the aluminium production is expected to decrease by a minimum of 50% the CO2 emissions as compared to the current process with carbon anode.

Besides the technology development, the economic viability and the environmental impact of both the inert anode and its manufacturing process will be monitored.

Industrials, laboratories and state organizations of 4 European countries - France, Germany, Italy and the Netherlands - participate to the project.

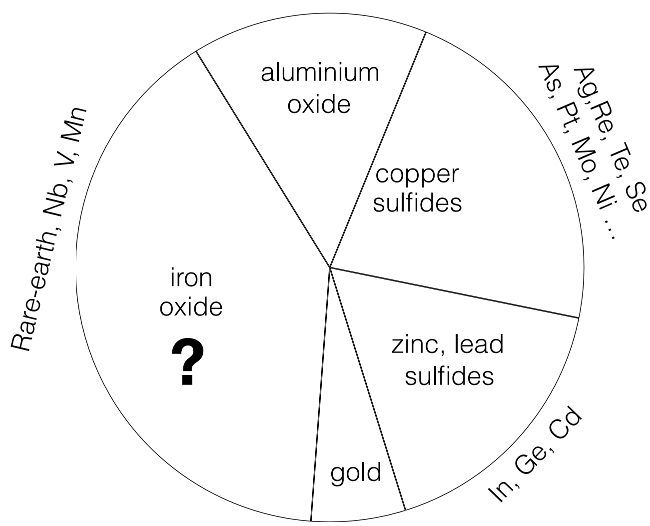
Visit Rio Tinto website

$2Al_2O_3 = 4Al(l) + 3/2\ O_2(g)$

cost reduction

eliminates CFC & GHG emissions

allows higher productivity



Electricity & steelmaking

1901, Emile Zola, *Work*

Mr. Smelt *had already felt that he was threatened. He was aware of the researches which* Mr. Coulomb *was making with the view of replacing the old, slow, barbarous smeltery by batteries of electrical furnaces. The idea that one might extinguish and demolish the giant pile which flamed during seven or eight years at a stretch, quite distracted the master smelter […] However, as the cost price still remained too high for electricity to be employed for smelting ore*, Mr. Smelt *was able to rejoice over the futility of* Mr Coulombs'*s victory.*

Electric Arc Furnace

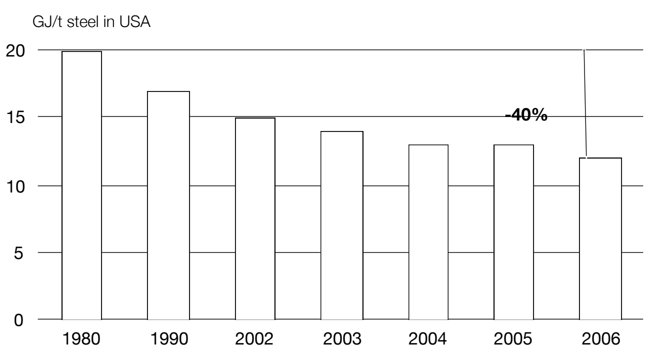
AISI

Heroult 1906 (CA)

27

Emile Zola, french writer of the end of the 19th century, famous for his writings about coal miners also wrote about his vision for metal extraction

Electricity & steelmaking



electricity for recycling… source: AISI

but how about for metal extraction from ore?

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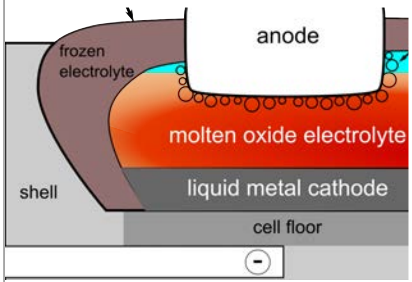
Electrochemical processing

Principle: solid oxide feed, liquid product



$MO \rightarrow M(l) + 1/2O_2(g)$

periodic feed of oxide

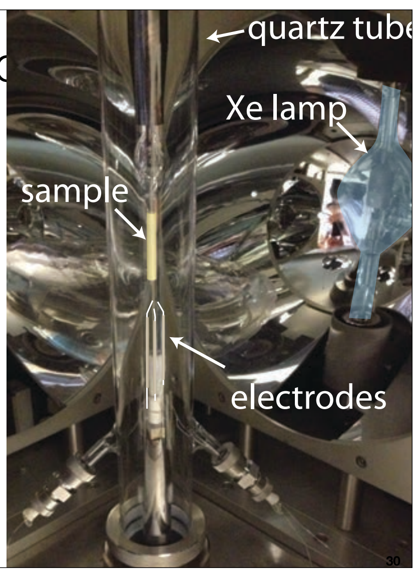
operating temperature above metal melting point

carbon-free

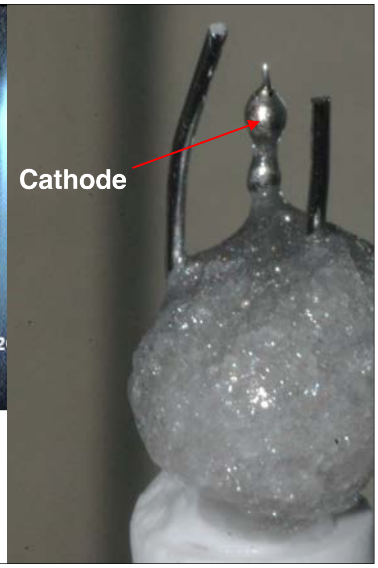
liquid metal product

Electrochemic

in the laboratory

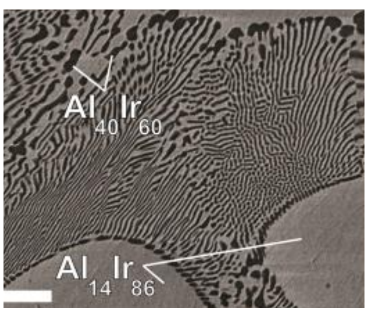


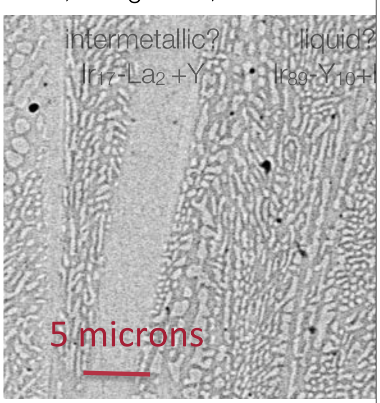
Floating zone furnace, Xe is Xenon



Metal oxide processing

Aluminium, Rare-earth, Titanium, Manganese, Nickel…





Metal oxide processing

Discovery of an inert anode material to make oxygen at MIT in 2011


nature International weekly journal of science

NEWS & VIEWS

METALLURGY

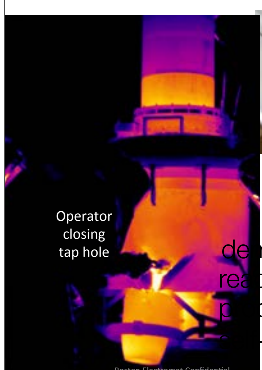
Iron production electrified

Scientists have long dreamt of converting molten iron oxide to iron and oxygen using electricity. An anode material that withstands the high temperatures and corrosive chemicals involved brings the dream closer to reality.

A. Allanore et al., *Nature*, 2013

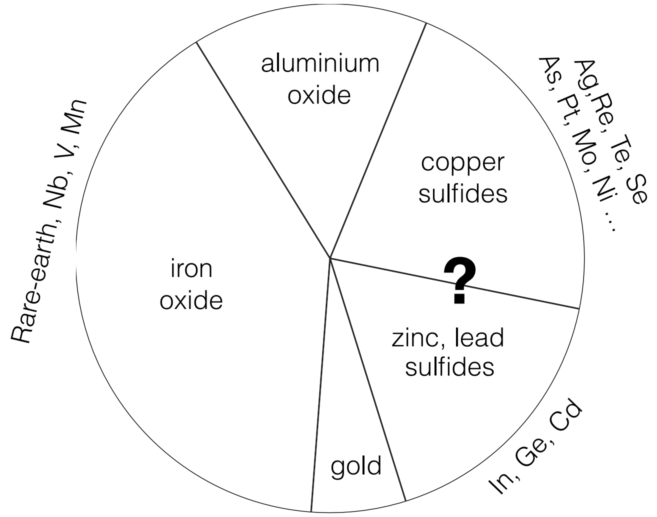
Metal oxide processing

Boston ElectroMETallurgical Corporation (BEMC)



more than 1 tonne of processed metal

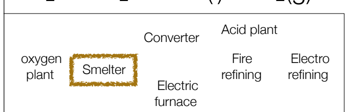
demonstrated up scalability by 1000x
reactor design allows operation up to 2000°C
producing liquid metal from oxide feed
-heated thanks to electricity

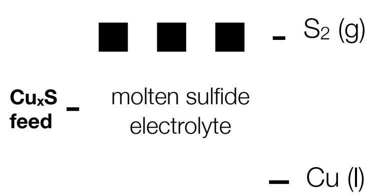


Currently…

Copper, since 6000BC

$Cu_2S + O_2 = 2Cu(l) + SO_2(g)$





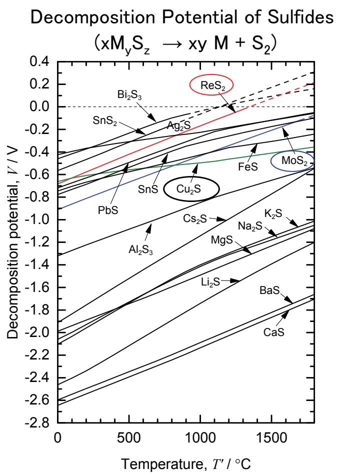
process basic principle

higher selectivity

incremental engineering

markets and society

Sulfides?

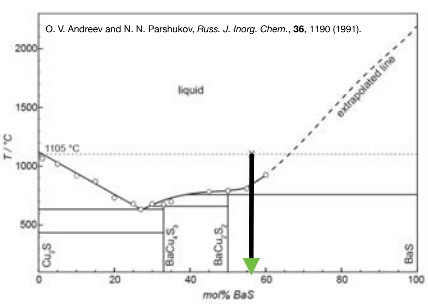


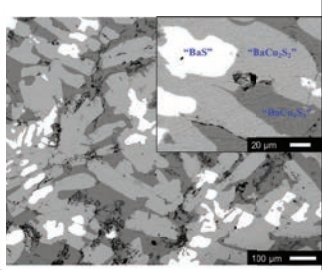
different 'electrochemical serie'

Molten sulfide electrolyte?

Molten BaS - Cu_2S electrolyte

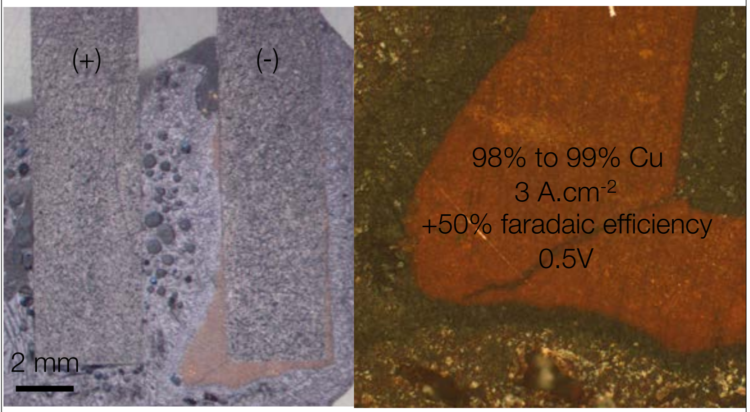
It is possible to use alkaline-earth sulfides (BaS) as an additional component to "solvate" Cu_2S at 1105°C

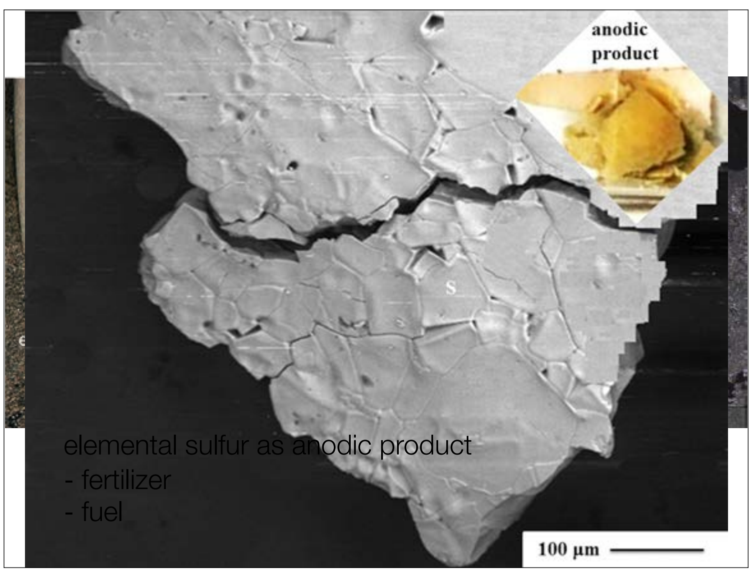




Sokhanvaran et al., *J. Electrochem. Soc.*, 2016

Copper production





Summary

There is a need to reshape the metals and minerals industry to allow **materials to meet global challenges**

Electrochemical techniques are one possible path

There is a need for **novel electrolytes** compatible with the ore feedstocks and molten metal production for high productivity

Two examples, **molten sulfides and molten oxides**, with their own materials science & engineering challenges

Funding agencies

Metals & Minerals
for the Environment

Framing out the vision of this collaboration to transform the minerals and metals industry and your role in facilitating it (1 minute)

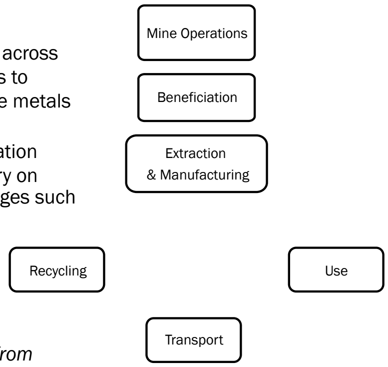
The kinds of opportunities that have been unearthed - new way of metal extraction and the phosphate extraction idea – as example of scalable better practices (2 mins)

The dilemmas and barriers that have been discovered along the way and your thoughts re: how this kind of enterprise needs to be supported going forward (2 minutes)

Any connection to course participants or content that you are already thinking might be of value in your work ahead (1 min)

Metals & Minerals for the Environment

- Team of 20+ researchers from across MIT finding innovative solutions to sustainability challenges for the metals and minerals sector
- MME is a platform for collaboration between academia and industry on environmental & social challenges such as
  - Climate and energy
  - Wastes and tailings
  - Supply chain



Launched in 2015 with support from

ENVIRONMENTAL SOLUTIONS INITIATIVE

Metals & Minerals for the Environment

Examples of Ongoing Research

MOLTEN OXIDE AND SULFIDE ELECTROLYSIS

- Novel technique for extracting value from oxide waste
- Energy efficient & renewable-friendly
- Eliminates sulfuric acid as byproduct

POTASH FERTILIZER FROM FELDSPAR

- New approach to produce potash for local mineral resource, feldspar
- Better fertilizer for tropical soils

CONFLICT MINERALS IN IT SUPPLY CHAINS

- Improved tracing of conflict minerals in IT products like phones, servers and laptops
- Focus on tungsten, gold and tantalum

CARBON CAPTURE

- More efficient and cheaper techniques for carbon capture
- Diverse application, such as power plants, steel mills, mobile transportation

Metals & Minerals for the Environment

Copper, potash, tungsten

Metals & Minerals for the Environment

SYMPOSIUM

- Presentations from researchers showcasing ongoing research on metals and minerals at MIT
- Keynote speakers from industry
- Opportunities for discussion and information sharing

May 11 – 12, 2017

Visit metalsandminerals.mit.edu for more info.

Metals & Minerals for the Environment