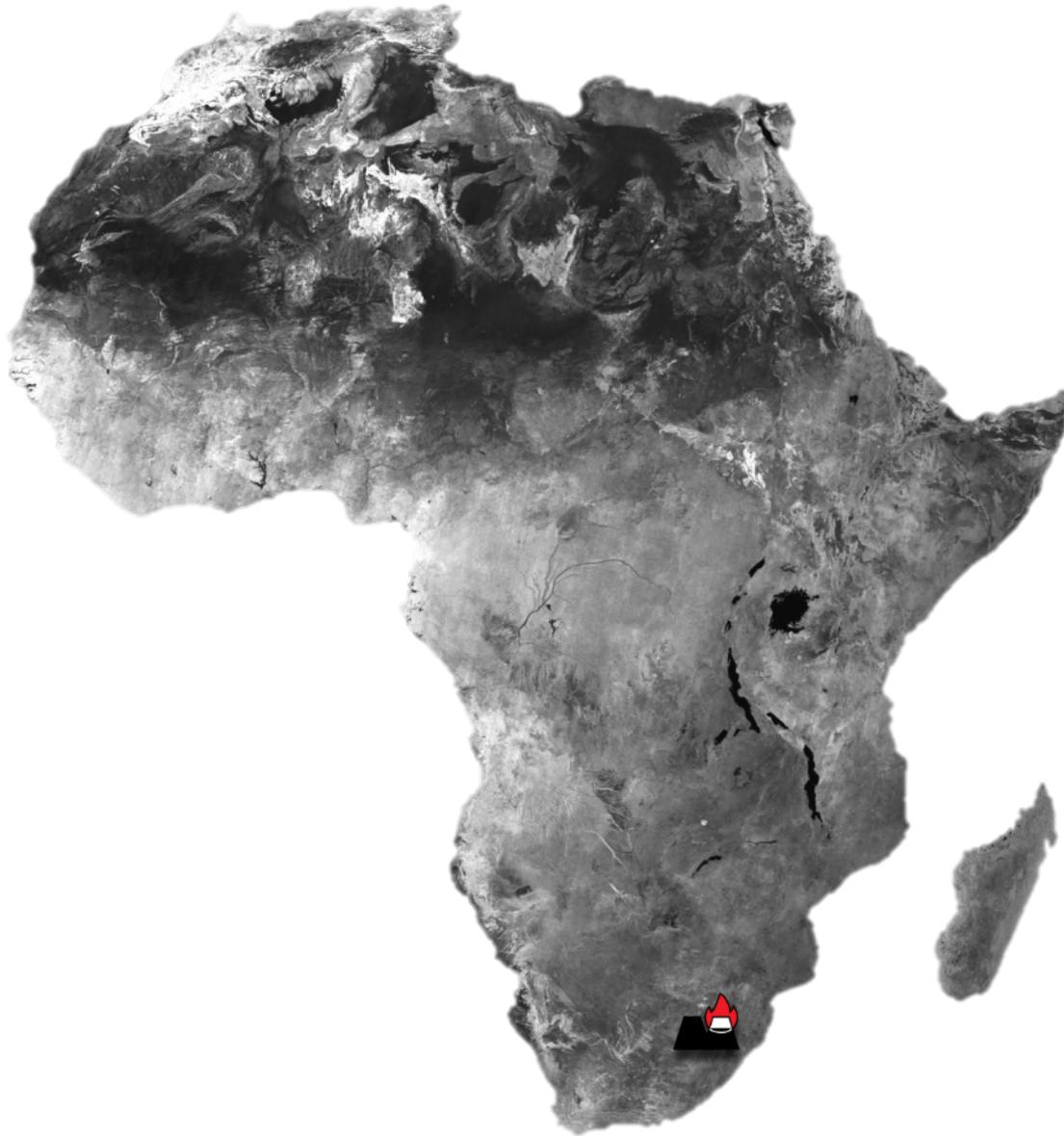


Metal Recovery using DC arc furnaces

Mintek – Pyrometallurgy Division
Isabel Geldenhuys

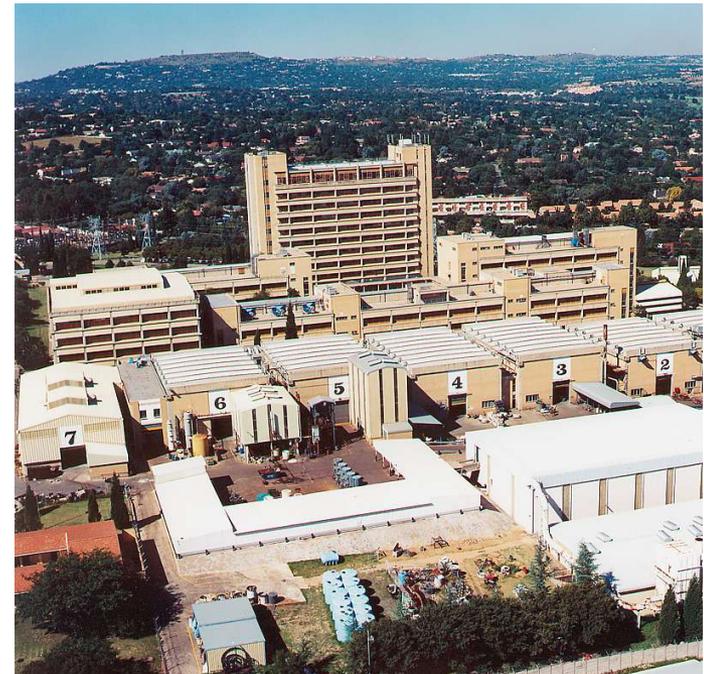


Mintek – Johannesburg, South Africa



Mintek

- Minerals R & D organization with market focus (established in 1934)
- Based in Randburg, South Africa
- Substantial capabilities in all metallurgical disciplines
- Celebrated 82 years of R&D in metallurgy



Art or Science?

- Pyro is from the Greek word for fire (πυρα)
- Pyrometallurgy is the oldest extractive process
- Definition of Pyrometallurgy?
- The art and science of extracting metals by thermal methods



The exact ART and subtle SCIENCE

I am quoting from Harry Potter to set the scene

Professor Snape introduces the subject of Potion Making to the first year students:

“You are here to learn the subtle science and exact art of potion-making. As there is little foolish wand-waving here, many of you will hardly believe this is magic. I don't expect you will really understand the beauty of the softly simmering cauldron with its shimmering fumes, the delicate power of liquids that creep through human veins, bewitching the mind, ensnaring the senses...” © J.K. Rowling

Pyrometallurgy is indeed a bewitching art and those of us ensnared by the beauty of the simmering cauldron are tirelessly working to unlock the magic, with very little wand-waving (usually).

For the ensnared...

- A (true) **Pyrometallurgist** will admit that operating a process at extreme high temperature is akin to madness. We are after all trying to tame chaos.
- A (true) **Pyrometallurgist** will also understand the passion and the misery that brings with it challenges that goes beyond just extracting the metal from ore
- We are living in an era where true sustainability is sought (cradle-to-cradle principle of true eco-efficiency)
- We live in an era where the selection of the appropriate technology are fraught with challenges

A brief history of time (electric furnaces)

“Only time (whatever that may be) will tell.”

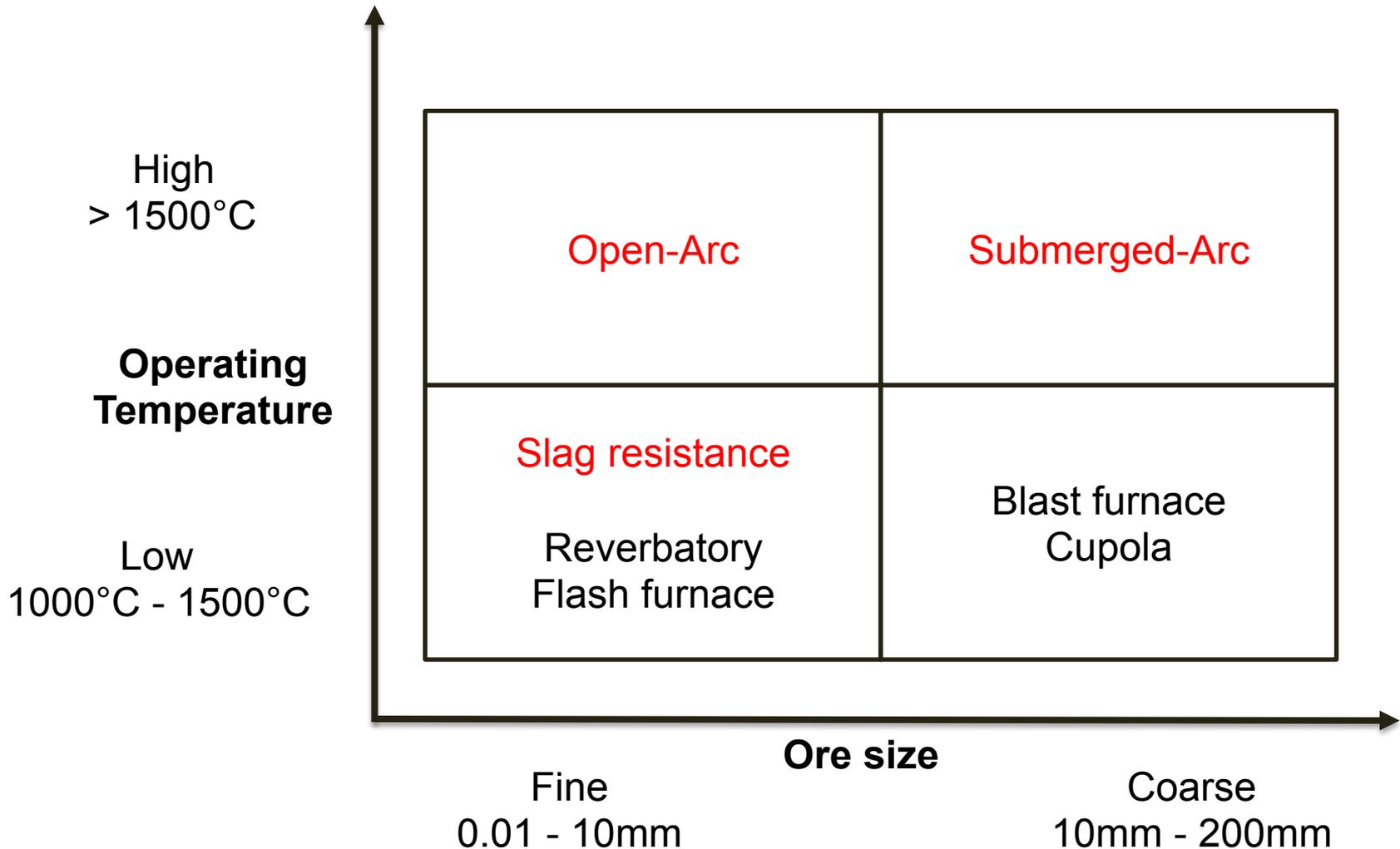
from “A brief history of time by Stephen Hawking

Let’s look at history...

- Electric furnaces evolved from the late 1880s
- By early 1970’s there were three basic types
 - Slag resistance
 - Open-arc
 - Submerged-arc
- All using graphite electrodes

Note: induction and muffle furnaces excluded

A smelting furnace classification



1970s Classification...

Slag Resistance Furnaces

- Usually six-in-line electrodes, rectangular shell
 - Non-ferrous industry Cu, Ni, PGMs
 - Self-baking electrodes dipped into molten slag
 - Ohmic heating from 3 single phase AC transformers

Submerged-Arc Furnaces

- 3 AC-electrodes in circular shell
 - Ferroalloy industry (FeCr, FeMn, FeSi)
 - Self-baking electrodes, choke-fed lumpy feed
 - Arcs submerged, typically >3m deep in feed

1970s Classification...

In the 70s Open-Arc furnaces were:

- 3 AC-electrodes in a circular shell
 - Steel scrap melting
 - Pre-baked electrode sections
 - Open-arc into solid scrap or molten slag

Up to this point electric furnaces meant AC furnaces (circular or rectangular); the bread and butter of the industry.

To understand how DC furnaces evolved a brief look at history next...

The DC furnace – a footnote in history (1)

- Early 1800s: earliest known written description of a man-made electric arc emanated from Humphry Davy's work

“I have found that this substance [well burned charcoal] possesses the same properties as metallic bodies in producing the shock and spark when made a medium of communication between the ends of the galvanic pile of Signor Volta. The spark is most vivid when the charcoal is hot.”

- The idea behind the (direct current) DC arc furnace has been around for a very long time however. Its use for the bulk melting of metals dates back at least to 1878 via an English Patent (Sir William Siemens)

Sir William Siemens described a DC arc furnace with a vertical graphite cathode, with the arc transferred to the melt in contact with a water-cooled bottom anode

The DC furnace – a footnote in history (2)

- About two decades after this, the first AC (alternating current) electric arc furnace was patented and first operated in France, in 1900.
- Electric furnace technology became almost entirely AC based thereafter (because of the use of AC for efficient power transmission from large central power stations and the use of local step-down transformers to supply the high currents required in the furnaces)
- Following the development of high power solid-state rectifiers DC furnaces became popular in the steel-scrap industry. Coinciding with the development work Mintek was conducting to solve the FeCr problem in SA

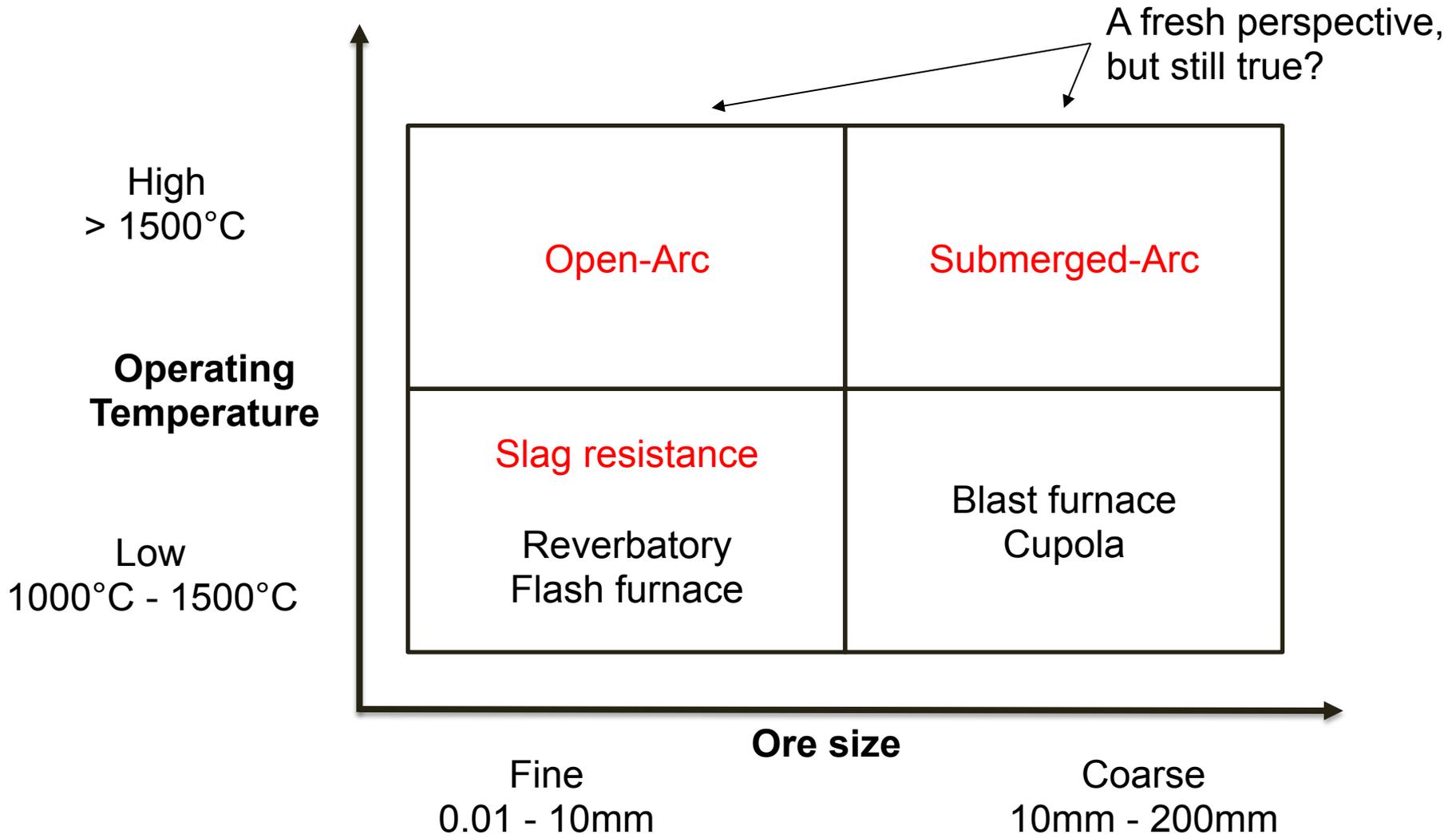
Open Arc Furnaces

- The DC open-arc reductive smelting concept really evolved from the plasma torch (which could process fines directly), but could not be scaled up – referred to as a non-transferred arc (originating in the space race)
- Mintek's work in the mid-80s: Applied the original idea of the cathode (graphite) and anode in contact with molten metal to reductive smelting of fines - resulting in what is today a mature technology

Big footnote:

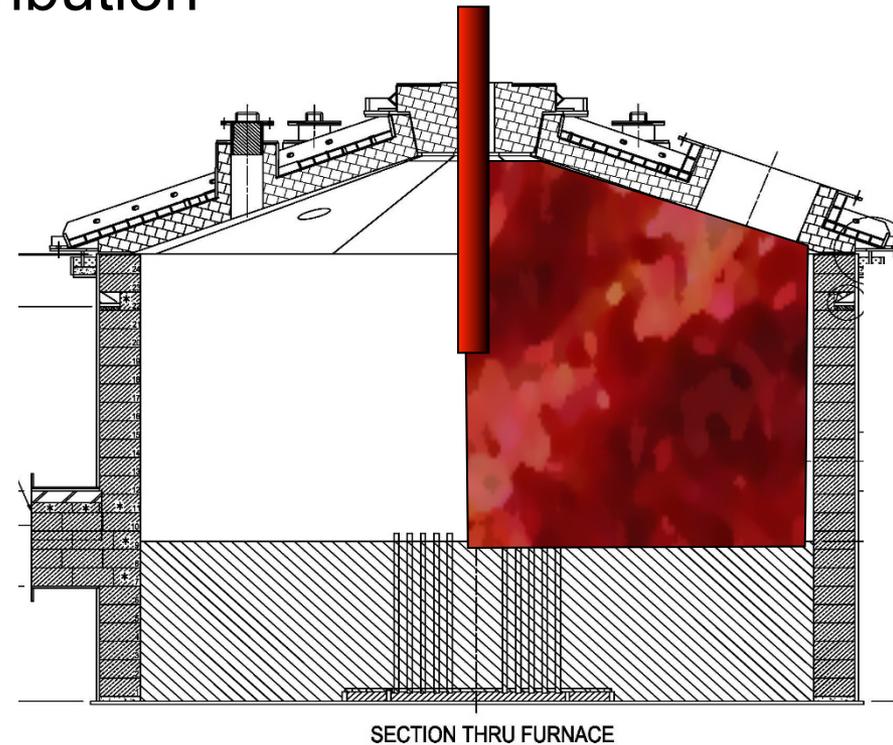
In principle one could use either DC or AC for smelting ore in an open-arc furnace. For that matter! A DC furnace could also operate in submerged mode. Nothing new just a perspective

Simplified smelting furnace classification



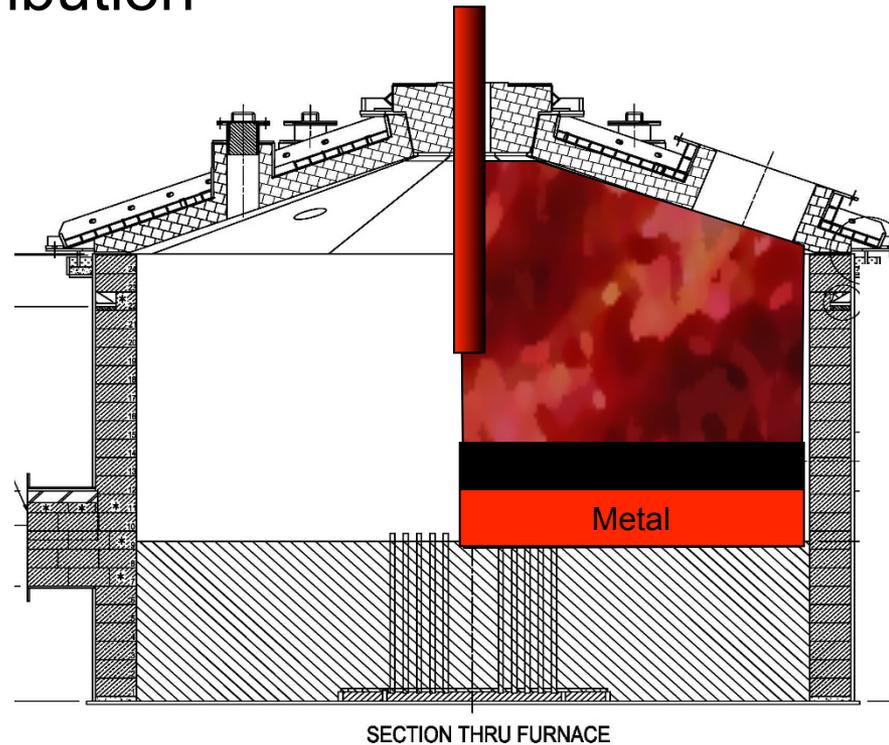
The Basics of a DC arc furnace

- **Cylindrical, refractory lined steel shell**
- **Central graphite electrode (cathode)**
- **Anode imbedded in hearth**
- Metal layer in electrical contact with anode
- Energy supplied by open plasma arc
- Fairly uniform temperature distribution



The Basics of a DC arc furnace

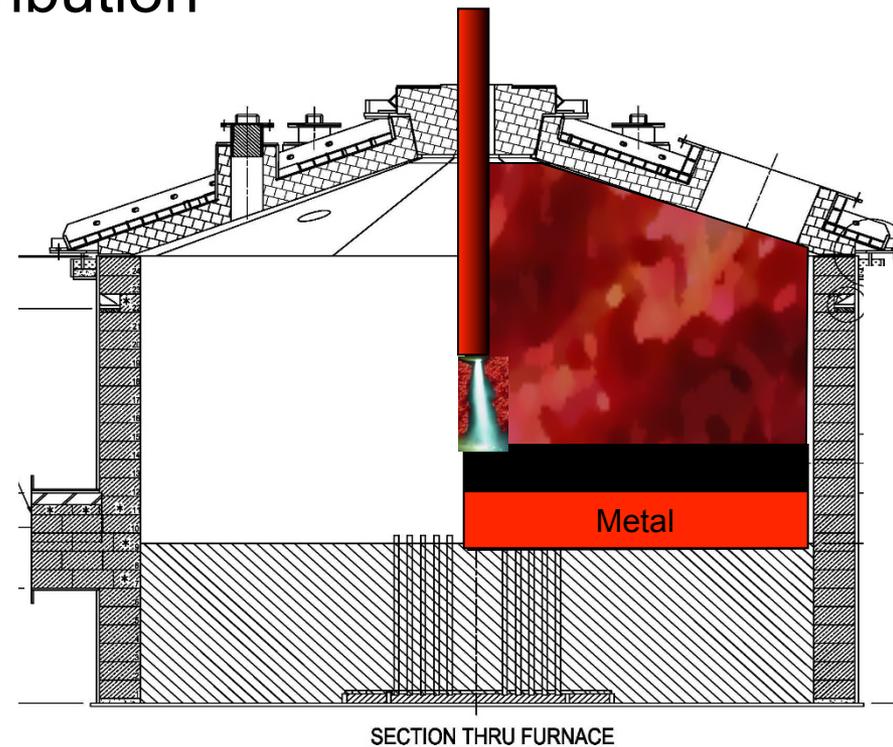
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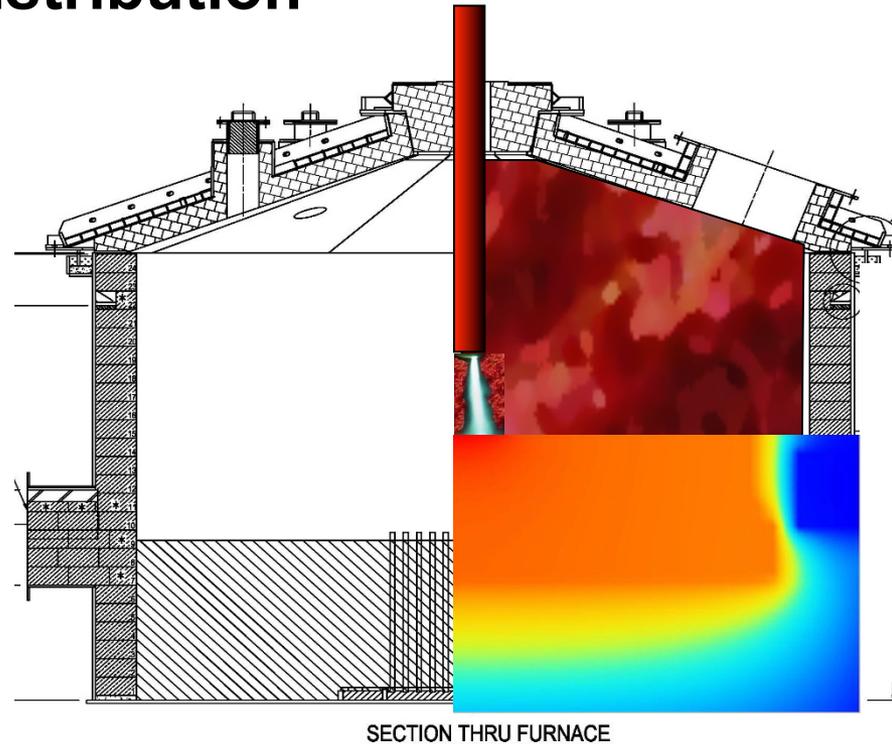
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The power of lightning



The Basics of a DC arc furnace

- Cylindrical, refractory lined steel shell
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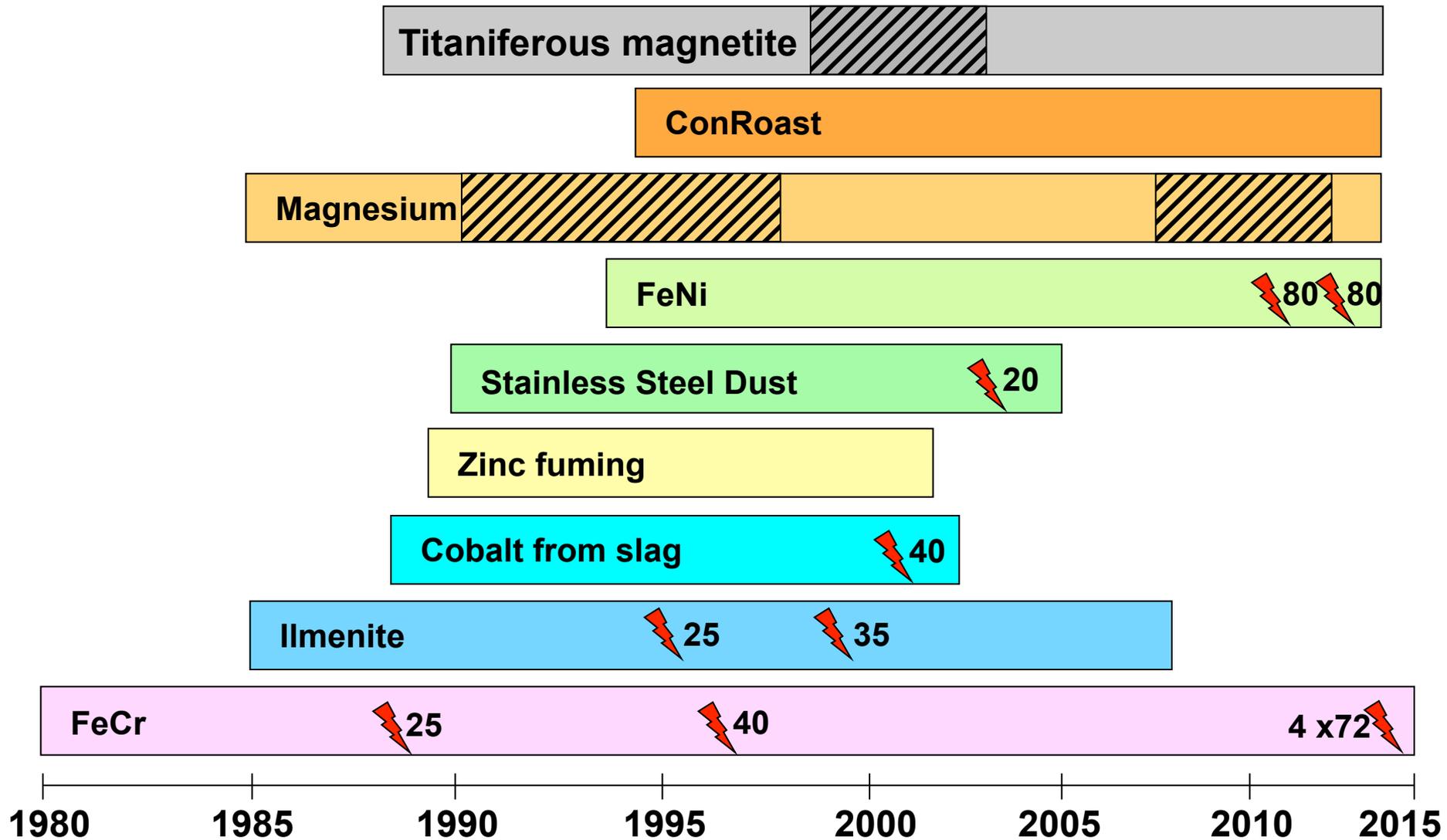
Properties of DC arc furnaces

- **Metallurgically flexible**
 - *Can treat feed materials with a wide range of composition (because of extra degree of freedom coming from power being supplied by an open arc); this allows choice of chemistry for metallurgical benefit*
- **Virtual independent power supply; Temperature control**
 - *good temperature distribution; not self-limiting; very clean slags; tolerant of high temperature operation*
- **Stable operation**
 - *no short-circuiting by coke between electrodes; don't have three hot spots (single arc to balance); wealth of knowledge equipment design from steel scrap furnaces (mega-scale possible); multiple electrodes;*
- **Electrode consumption and maintenance**
 - *no 'skin' effect allows smaller electrodes; only one electrode; controlled arc length to suit the process; don't require slag immersion to generate heat; can use either pre-baked or paste*

Properties of DC arc furnaces

- **Structural benefits**
 - *simpler with one electrode; better gas sealing, Geometrically simple and elegant, reducing uneven wear on side-walls, and lower cost*
- **Electrical power supply**
 - *less harmonics and flicker*
- **Good at handling fines (open-arc mode)**
- *It is important to note that the benefits stated are often linked to “open-arc” and “open-bath” mode*
- *As highlighted earlier however, the basic principles apply via the classification – a lot of the benefit is via the independence of power supply but some are due to the use of DC current*
- **1 electrode versus 3 or 6, simpler structurally and control is “exclusively a DC benefit (simple power to feed balance)**
- **Metallurgically found additional benefits (uniform temperature distribution – operating closer to equilibrium, stirring); Excellent at transferring heat to the bath**

DC arc furnace processes



Installed furnace power listed in MW

Metal recovery using DC arc furnaces

- FeCr and ilmenite smelting - the success stories in South Africa for DC furnaces. Well suited to reductive smelting processes (especially high-temperatures).
- Most of the MINTEK research and pilot testing is currently focussed on unlocking complex ores, recycling, recovery of metals from wastes, low-grade or urban ores
- New era: mega-companies focussing internally. Finance for smelters are scarce; mega-projects few and far between. Not a lot of profit in smelter operations and it is high risk. Many “walking away from smelting” as their main business.



1980



1985



1990



1995



2000



2005

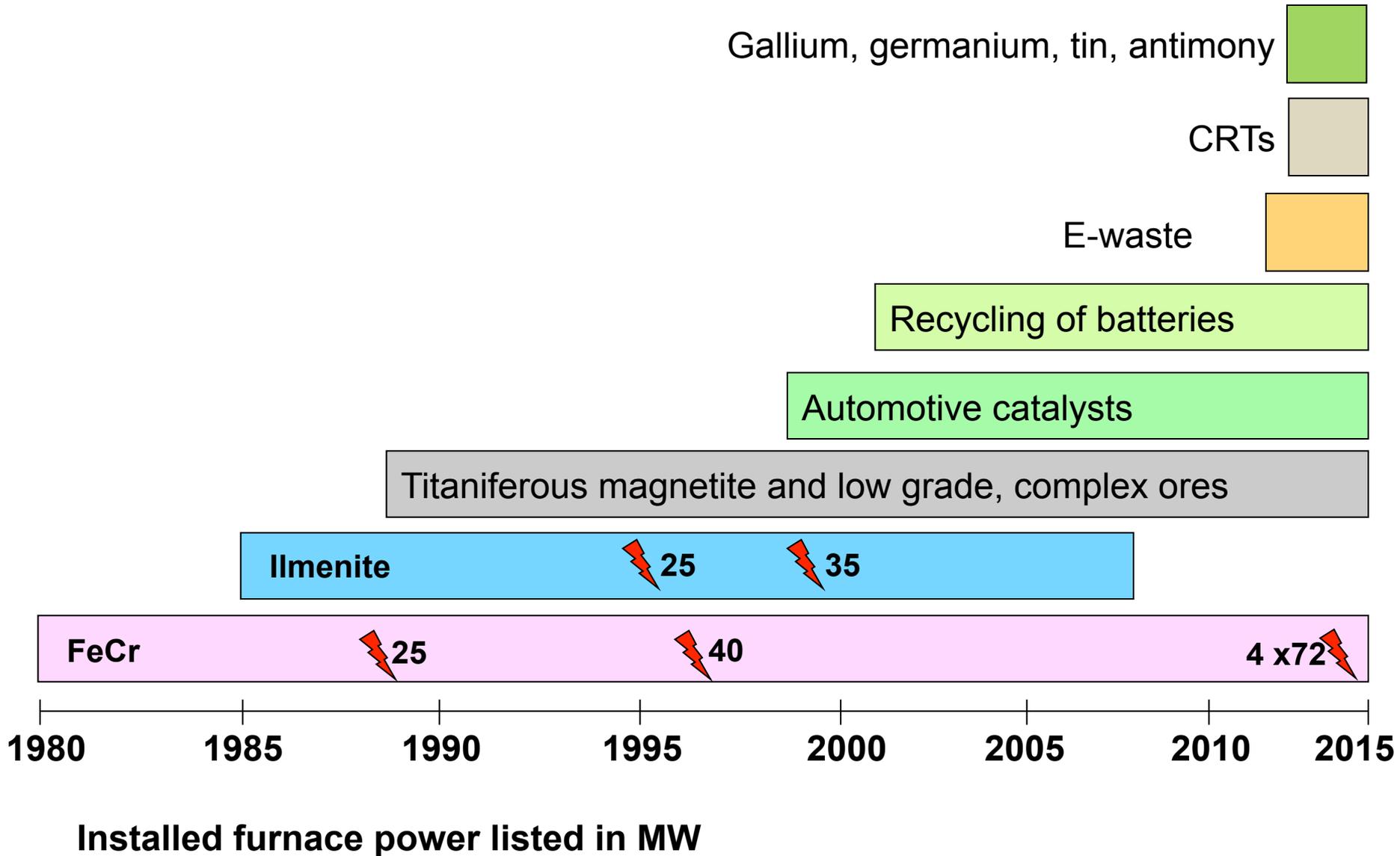


2010



2015

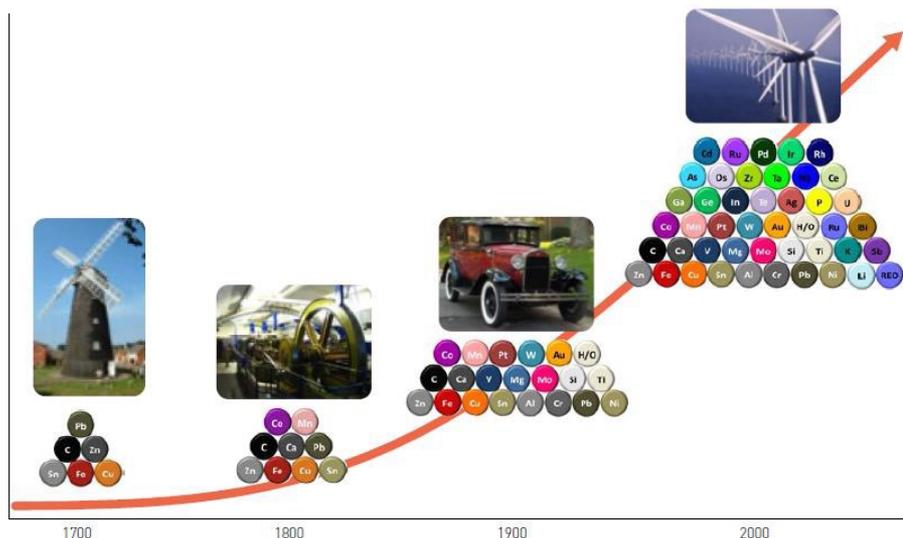
Other applications for DC arc furnaces?



Urban mining

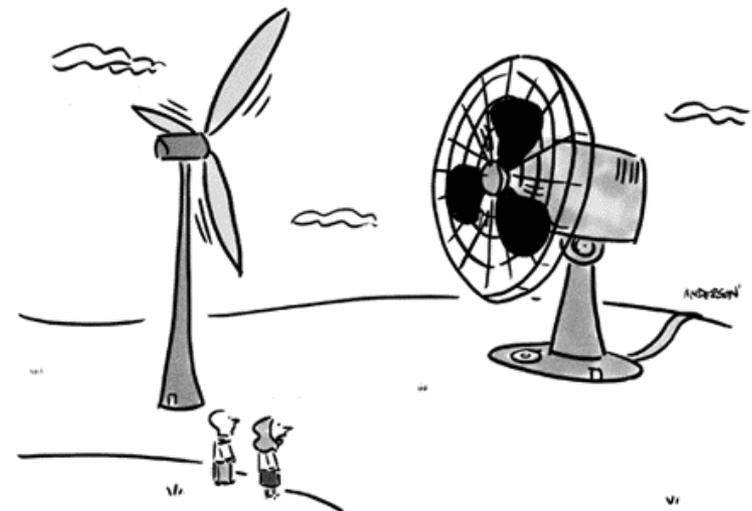
- Increasing complexity of products impacts recyclability & cost of recycling
- Whilst we are continuing to research eco-efficient processes the Urban Mine is growing around the world.
- Legacy of complex, low-grade urban mine requires creative solutions (especially in developing countries), treat at source, modular approaches
- South African example: complex economical challenges adds to the mix, but users have access to technology (phones, computers, TVs etc), however scale of recycling industry small and not economical
- Often e-wastes are stripped of value leaving a more complex, or lower-grade waste behind

Metal/Element Use Intensity in Products



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"I dunno, kind of defeats the purpose, doesn't it?"

Metal recovery using DC arc furnace

Why are we talking about DC furnaces?

- Sustainable smelting requires **technology that can process metallurgically complex, low-grade, ultra-fine materials, as well as the more desirable ores.**
- The multi-phase multi-component systems involved in these “new” complex smelting processes have many variables
- New models or criteria for business success; demands flexibility (switching between products e.g.)
- DC arc furnaces are one tool that may provide the needed flexibility and is worth considering when addressing the complexities we face towards zero waste processing



Towards sustainability

- Urban mine complex and thus most likely will require several clever Pyrometallurgical solutions to really address the problems we face around the world.
- The challenges of the urban mine is as complex as the “ores” itself and requires more than just “smelting solutions” (often collecting or sorting is a greater challenge than the extractive metallurgy bit)
- DC furnaces may offer exciting creative solutions due to the inherent properties:
 - Flexibility key, scale key (mega or mini plants possible), exquisite temperature and metallurgical control possible in a DC furnace, elegant geometry and control

In conclusion

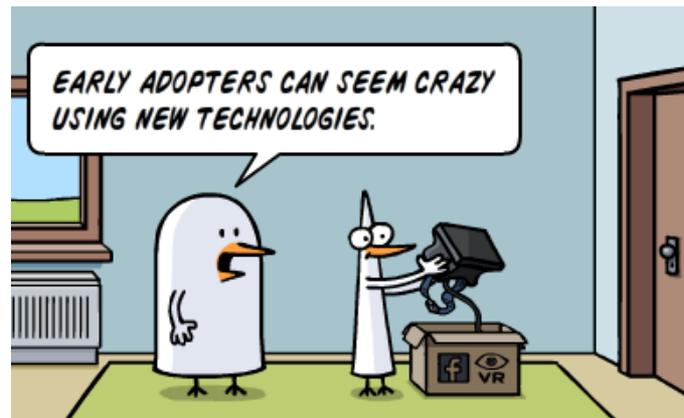
- DC operation achieves phenomenal results in terms of recovery and throughput and it appears to be beyond the mere “open arc” benefit.
- DC arc furnaces have been used for smelting processes, where the feed materials are predominantly non-metallic and significant chemical reactions are involved.
- Waste treatment, automotive catalysts recycling, batteries, subsidised high-temperature “cleaning up” operations are just some of the applications for which DC has demonstrated success at MINTEK.



Pyrometallurgy is indeed bewitching and those of us ensnared by the beauty of the simmering DC cauldron are tirelessly working to unlock the magic, with very little wand-waving (usually).

DC arc furnaces, despite it's reputation for being a challenging new technology, in fact is not that new, nor that different.

DC furnaces offer great power control, and with great power comes responsibility. No free ride in pyrometallurgy. High temperatures are not forgiving.



From : <http://www.pidjin.net/2014/03/27/early-adopters/>

A final pop culture reference

Author Arthur C. Clarke's third law is often quoted as:

Any sufficiently advanced technology is indistinguishable from magic.

- DC arc furnaces are not magic, nor is DC technology the answer to all problems. Like any smelting furnace it requires exquisite control and a lot of hard work to manage well.
- Understanding the tools we have available to us however is the first step in really addressing the challenges we have to face with regards to complexities of ores and wastes.
- MINTEK continues to test and develop new technology to address the challenges

Pyrometallurgy at Mintek

Back then...



...the 80s



...now



Thank You
www.mintek.co.za

