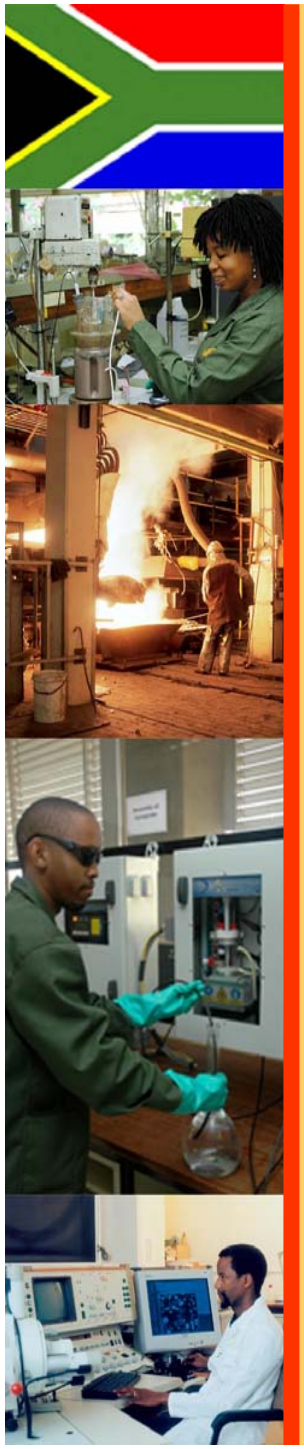

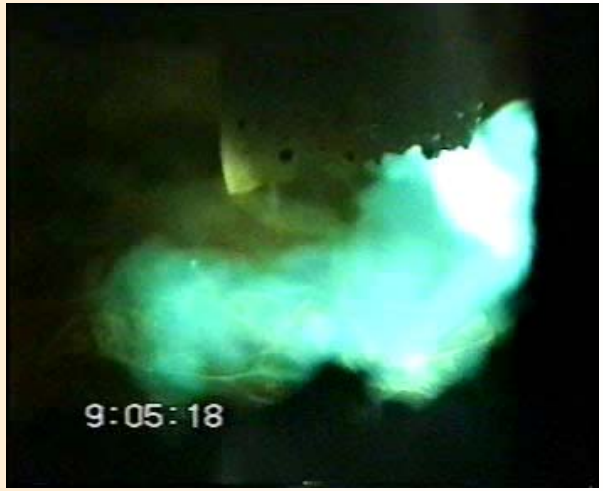

DC arc furnaces – The story of a successful South African technology

Rodney Jones

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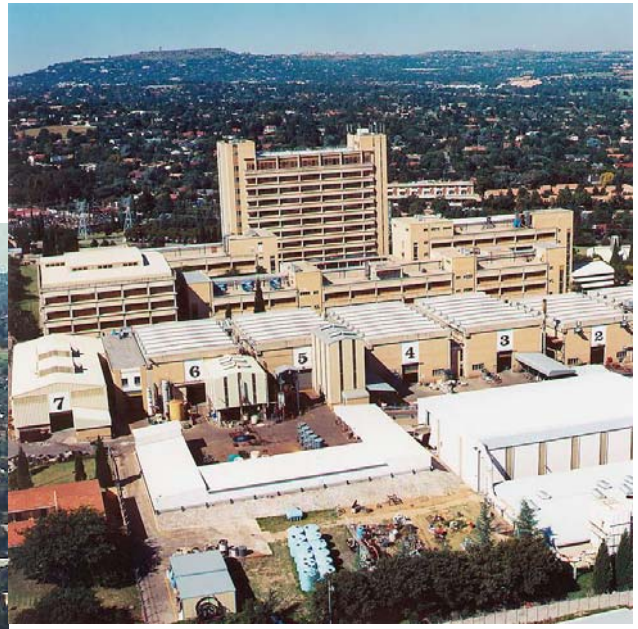
Mintek (Established 1934)

- Government-owned minerals research organization
- Employs ~800 people (300 professionals)
- Annual budget of ~R420m (US $40m)
- State & corporate funding (50:50)



Celebrating 80 years of excellence in mineral and metallurgical innovation

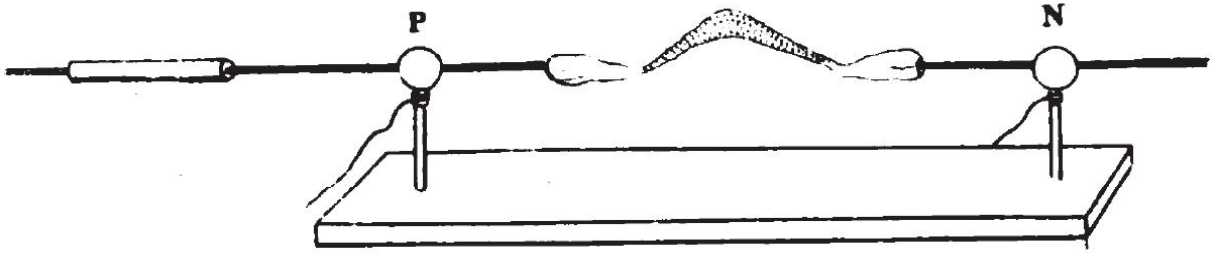
DC arc furnaces at Mintek

1.5 MW furnace

3 MW furnace

Early description of an arc by Humphry Davy

- Humphry Davy was first to describe a man-made electric arc in the early 1800s. His early experiments were only a few months after Volta's introduction of the electric battery.



- Humphry Davy's "Elements of Chemical Philosophy" in 1812 depicted a long horizontal arch of flame that gives the arc its name.

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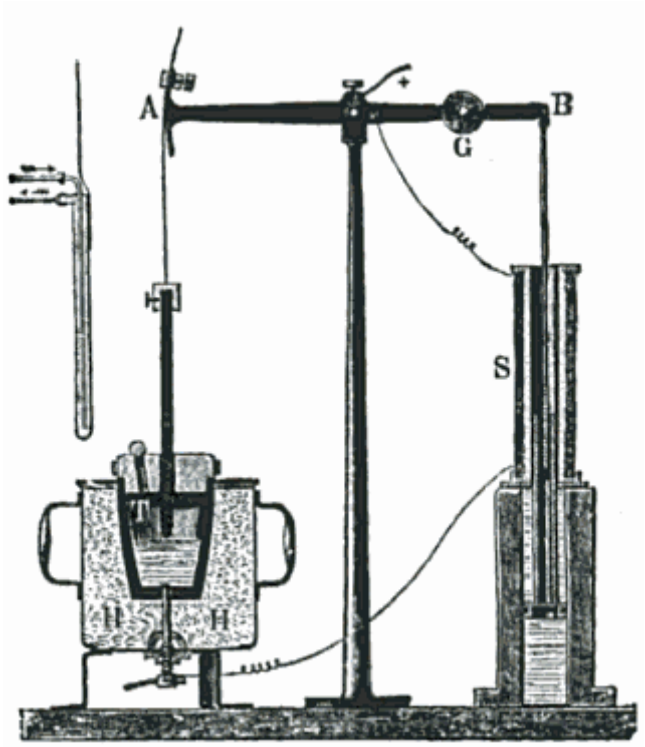
DC arc furnaces for melting metals date back to 1878

- Sir William Siemens used a DC arc furnace in 1878 with a vertical graphite cathode, with the arc transferred to the melt in contact with a water-cooled bottom anode



AC furnaces are more recent than DC furnaces

- The AC electric furnace was patented in 1900 by Paul Héroult, and operated in La Praz, France in 1900

First AC electric arc furnace in USA, 1906 (Philadelphia)

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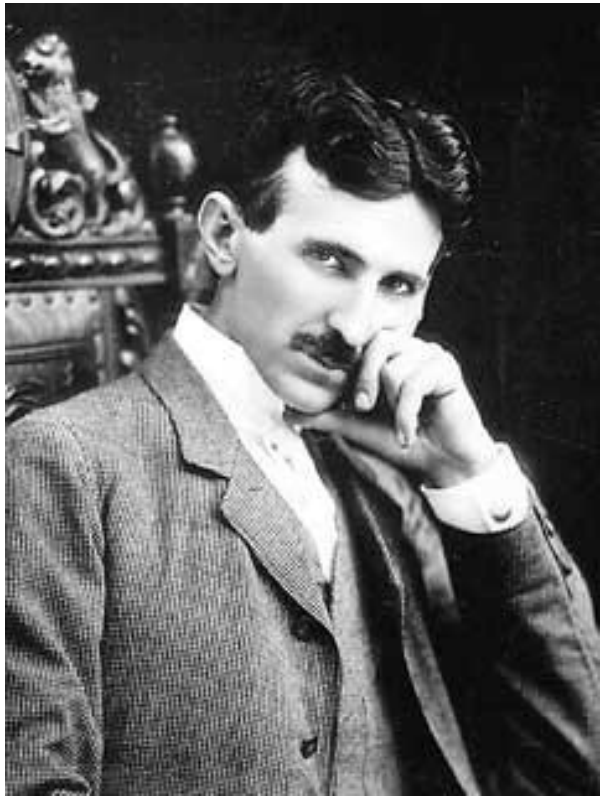
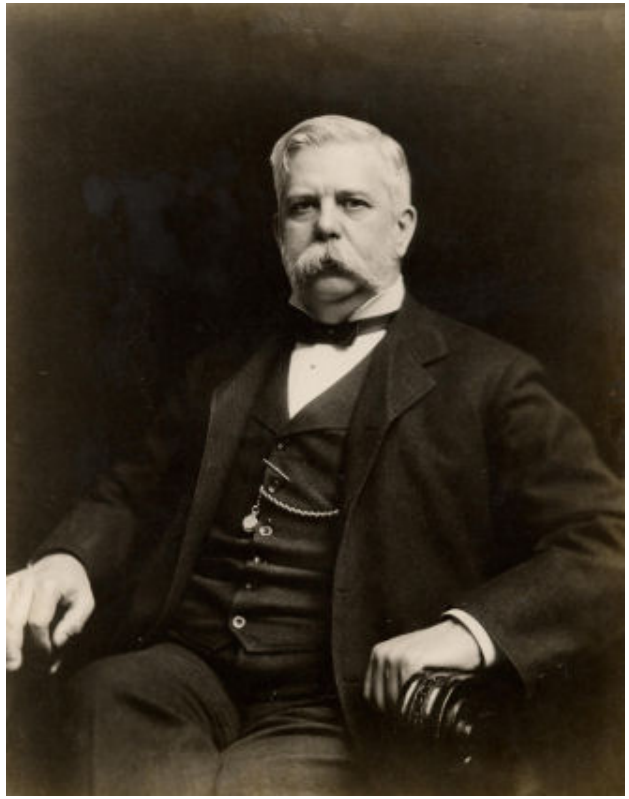
However, AC furnaces were widely used for a long time

- AC power was widely used, for reasons of effective power transmission from large central power stations, following developments by Nikola Tesla and George Westinghouse in 1887 and 1888





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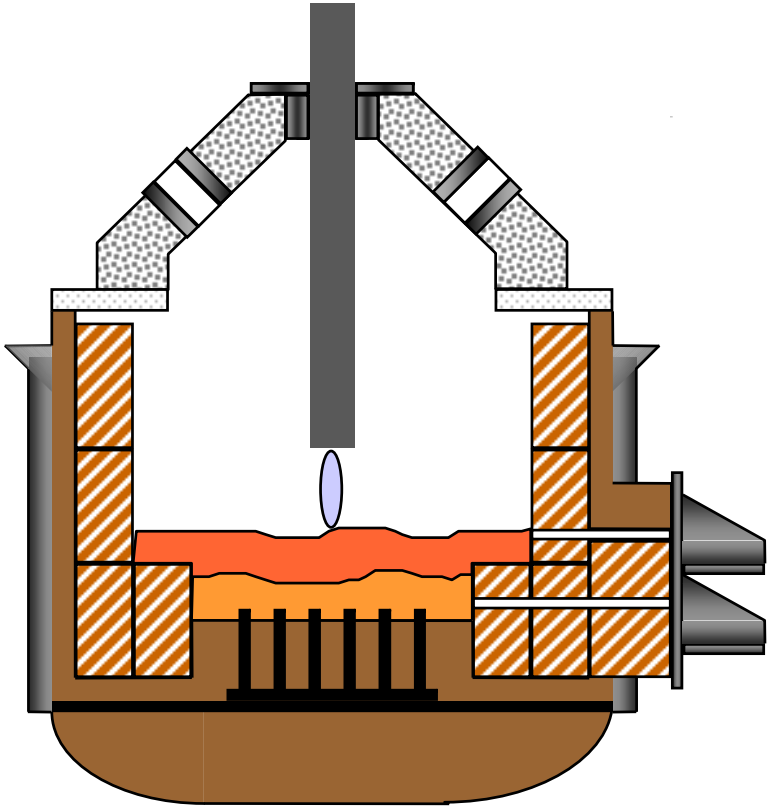
Features of DC arc furnaces



- Can achieve high temperatures (> 1500°C)
- Can accept fine feed materials (< 10 mm)
- Energy supplied by open plasma arc, so less sensitive to electrical properties of slag
- Lower electrode consumption
- No arc repulsion (and resulting hot spots)
- DC furnaces carry higher currents per electrode (no ‘skin effect’)

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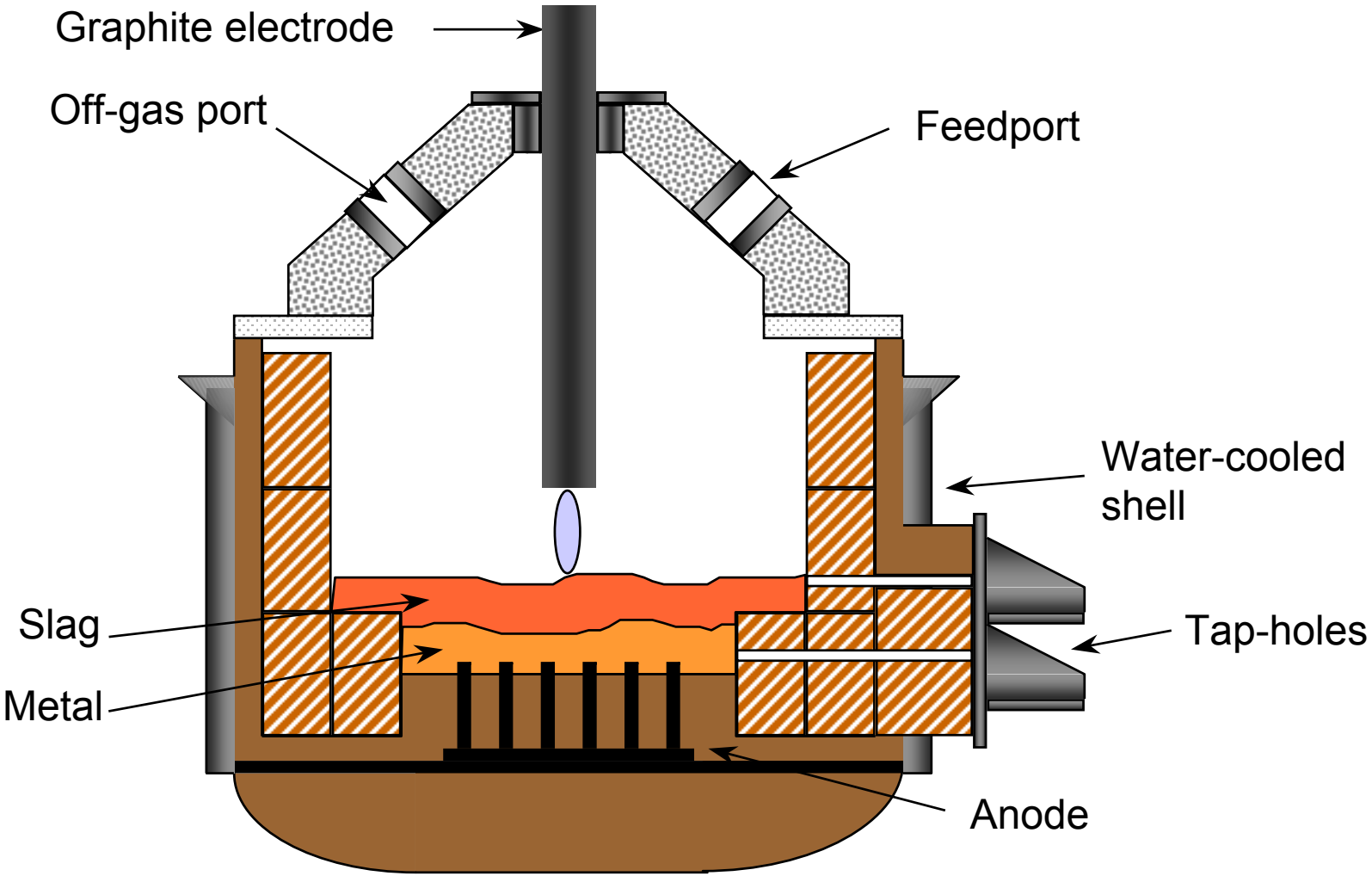
Schematic view of DC arc furnace



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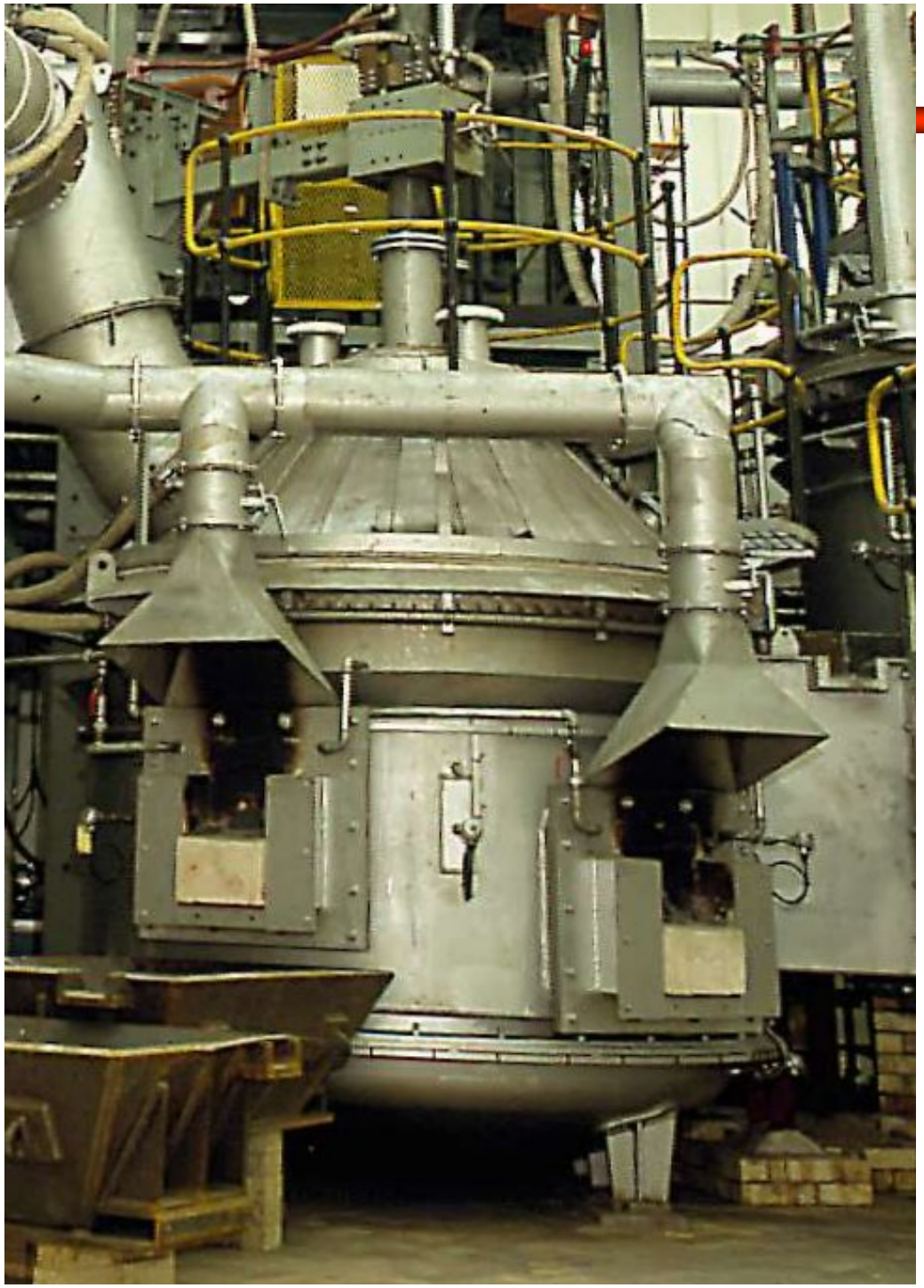

DC arc furnace

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

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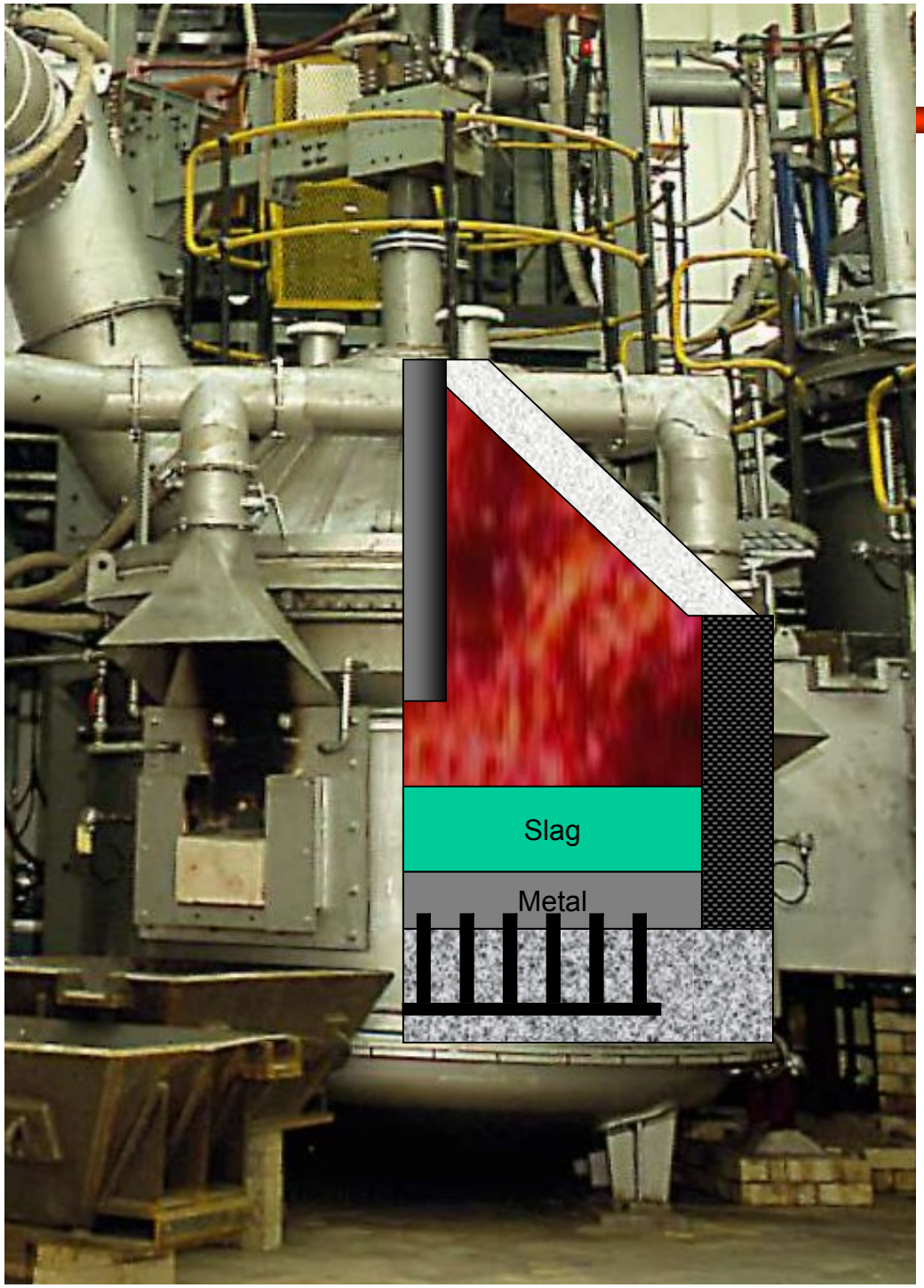

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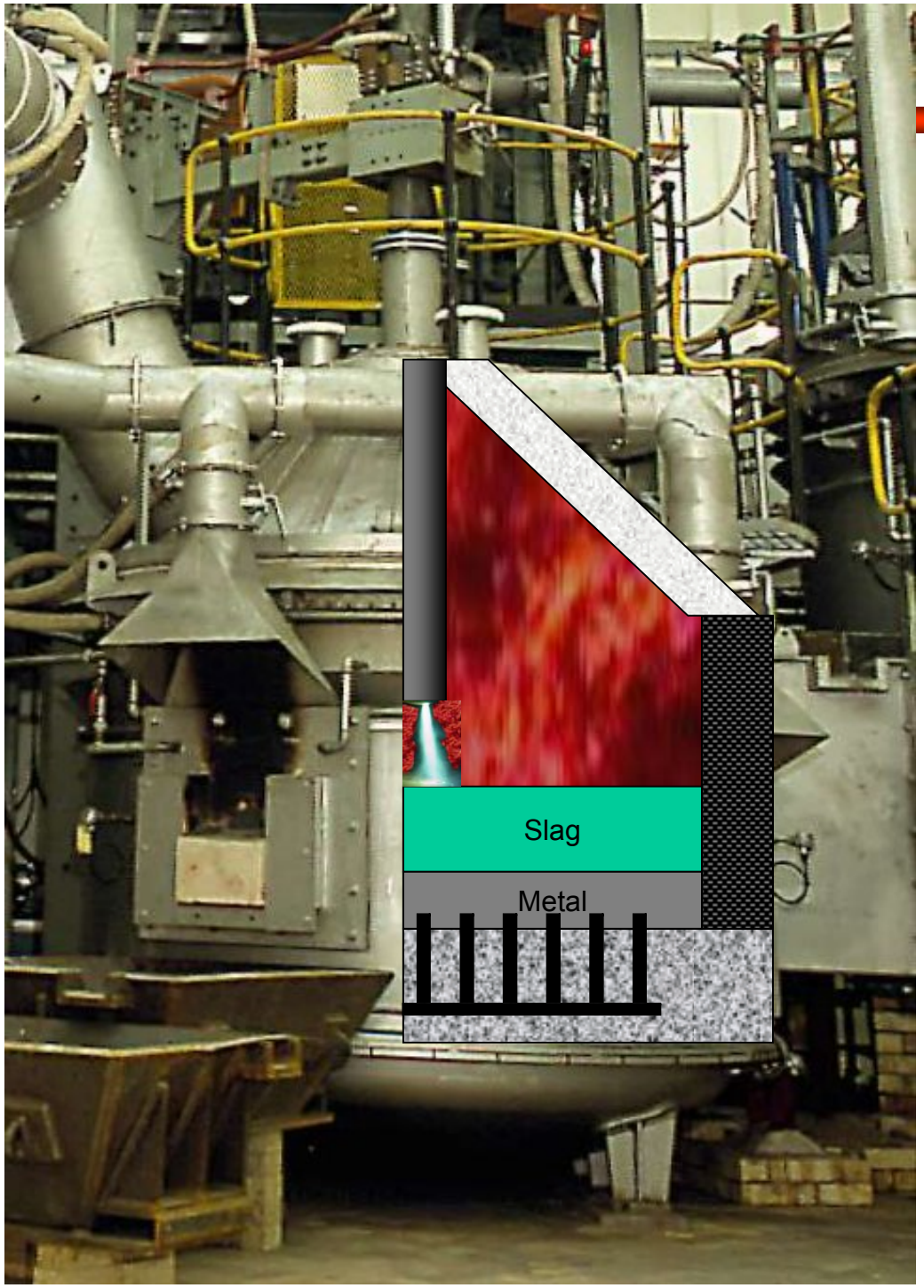

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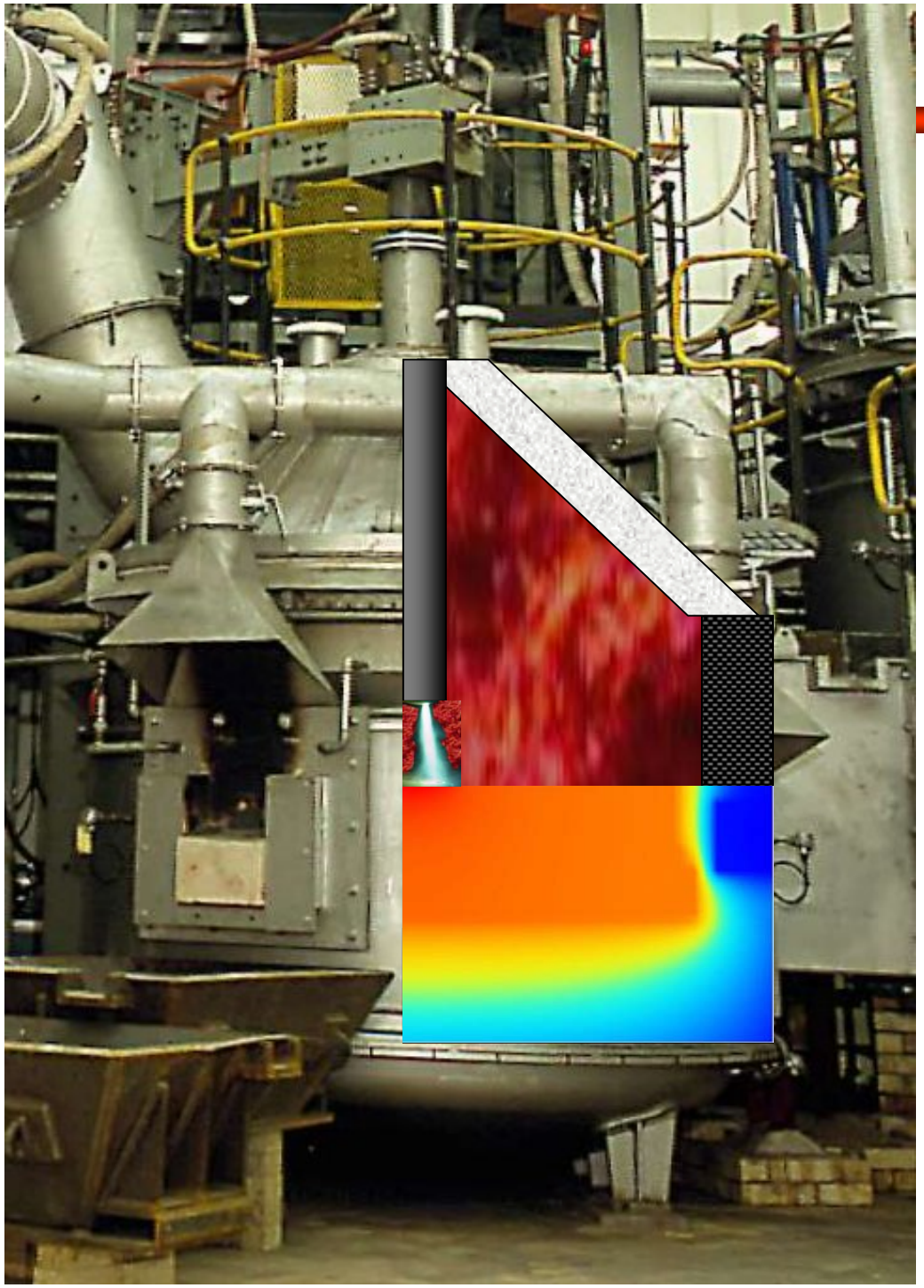

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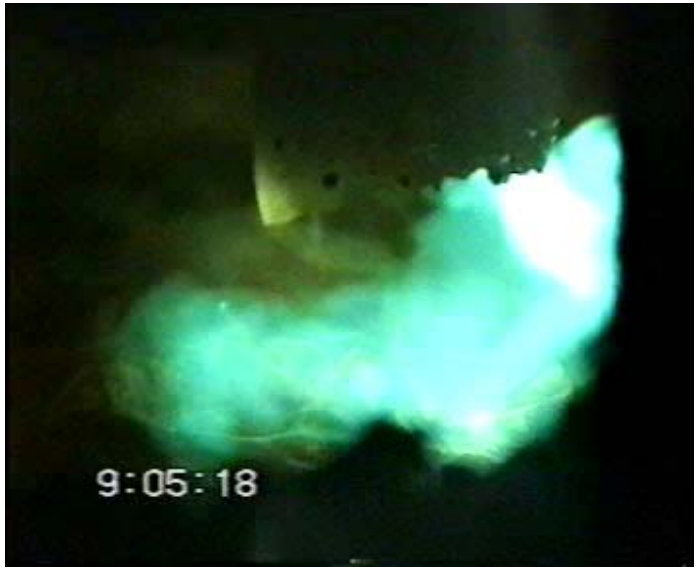
Inside the DC arc furnace





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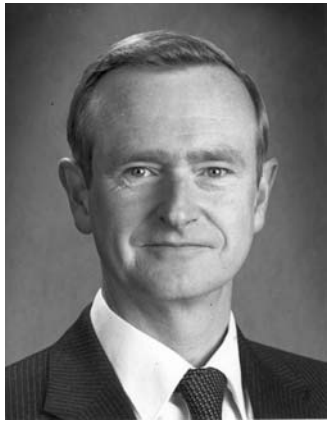
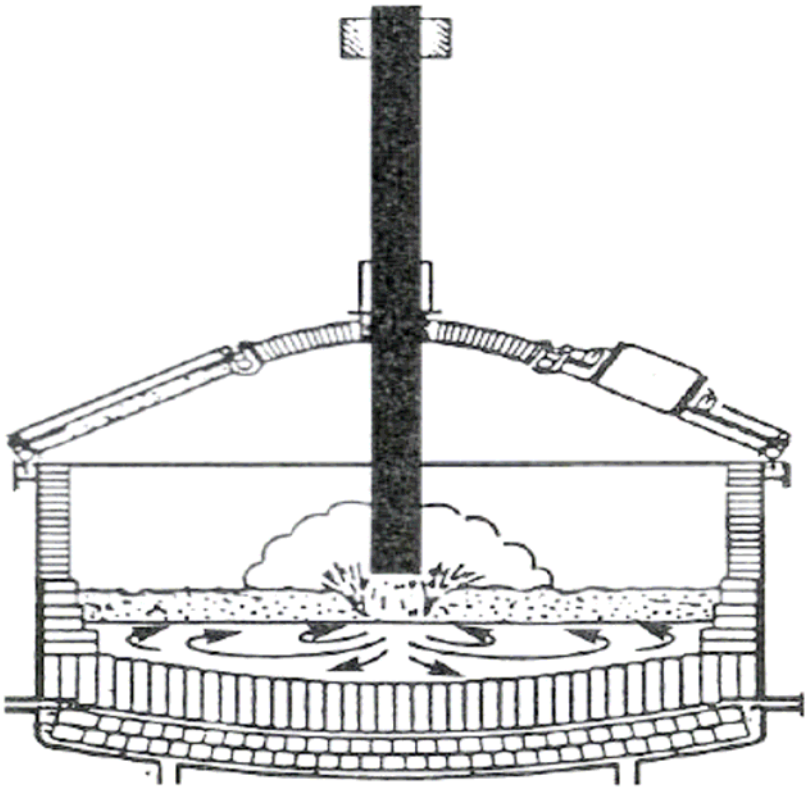
Mintek's initial work on 'plasma furnaces'



- Peter Jochens identified 'plasma furnaces' as a possible solution to the 'chromite fines' problem
- Mintek and Middelburg Steel & Alloys (now part of Samancor Chrome) conducted smelting trials on Tetronics' pilot transferred-arc plasma furnaces in the UK in 1979/80
- Metallurgically successful, but difficult to scale up to very large furnaces

ASEA's DC arc furnace



- ASEA in Sweden developed high-power thyristor rectifiers in the 1970s
- Sven-Einar Stenkvist investigated the conversion of AC open arc furnaces to DC, principally for steelmaking
- Identified a graphite cathode electrode arcing onto a slag/metal bath as the anode
- Devised an electrically conductive hearth and a hollow graphite electrode for finely sized iron ore smelting

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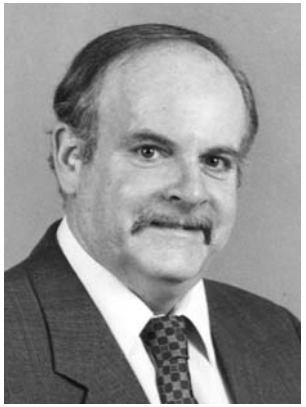
Mintek's early work with DC graphite electrodes



- Nic Barcza recognised the synergy between the metallurgy proven at Tetronics, and the scale-up potential of ASEA's DC arc furnace
- Mintek built a 1.2MW DC arc furnace in 1983 to support this development
- MS&A converted an existing AC furnace at Palmiet Ferrochrome (now Mogale Alloys) in Krugersdorp to a 12MW DC arc furnace of ASEA design in 1984

1. Chromite smelting

- Chromite is smelted to produce ferrochromium
- $FeO.Cr_2O_3 + 4C \rightarrow Fe + 2Cr + 4CO$
- Problem to be solved:
  Devise a process to treat fine chromite ore
- The DC arc furnace
  - Operates with open arc, open bath
  - Does not require coke
  - Power supplied to furnace is independent of slag composition, so slag can be changed to one that allows higher Cr recovery
  - Has lower electrode consumption

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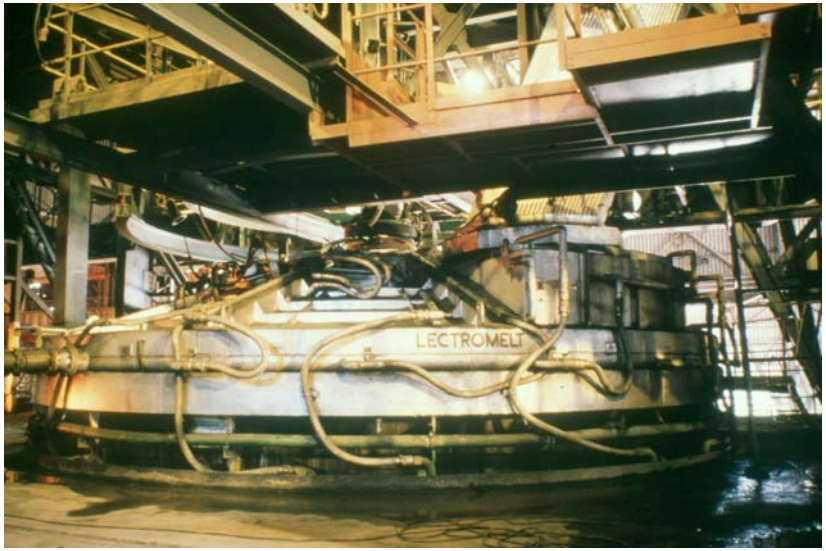
1. Chromite smelting (Mintek)

- DC arc furnace studies commenced in 1976 as a means of smelting chromite fines (< 6 mm)
- First ferrochromium was produced in a bench-scale DC furnace in 1979
- 1 t/h DC arc furnace pilot plant commissioned in 1984
- Patented process – jointly owned initially

1. Chromite smelting (Palmiet Ferrochrome)



- Tested at 0.3 - 0.5 MW, 1 – 2 m
- A 12MW (16MVA) furnace was built initially in 1984, then upgraded to 40 MVA (25 - 30 MW) in 1988
- An additional 10MW furnace was later built on the same site (for Mogale Alloys)

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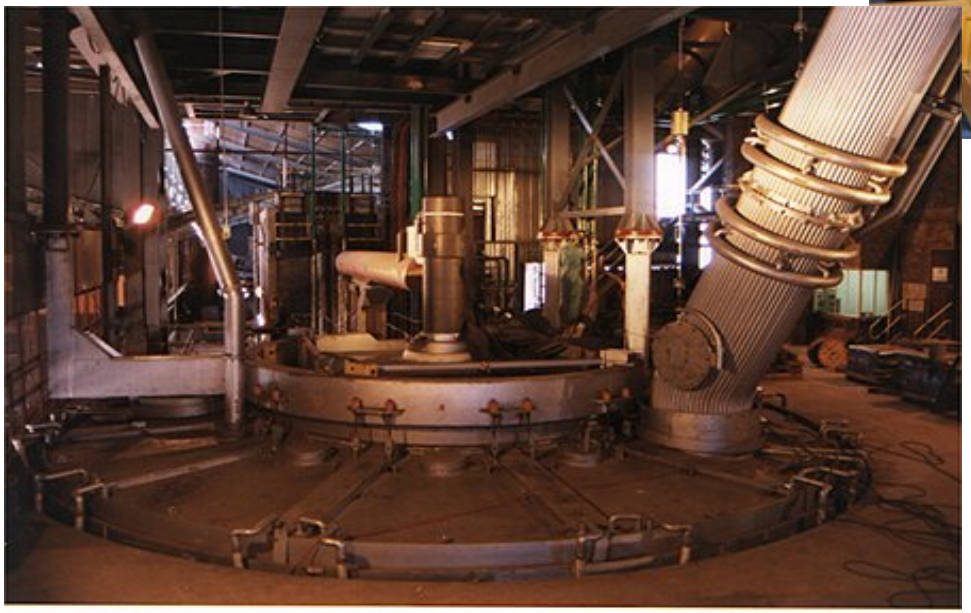
1. Chromite smelting (Samancor Cr, Middelburg)

- 44 MW (62 MVA) in 1997



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1. Chromite smelting (largest furnaces)

- Samancor Chrome's 60 MW furnace, built in Middelburg in 2009, is currently the largest DC arc furnace in South Africa

- The 44 MW furnace was recently upgraded to 60 MW as well
- Use of technology grew after patent expired

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1. Chromite smelting (Kazchrome)

- However, another four 72MW furnaces have recently been built in Kazakhstan

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- However, another four 72MW furnaces have recently been built in Kazakhstan

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2. Ilmenite smelting

- Ilmenite is smelted to produce titania slag and pig iron
- Problem to be solved:
  Find alternative equipment in which to produce a very conductive slag (needs an open arc)
- Piloted at Mintek in 1990 (0.5 MW, 1.8 m)

2. DC arc furnace for ilmenite smelting

- Same DC arc furnace equipment can be used for very different reasons
- Titania slag is highly conductive, therefore an open arc is required
- Slag is a valuable product; contamination must be avoided
- Degree of reduction must be carefully controlled, therefore no electrode immersion

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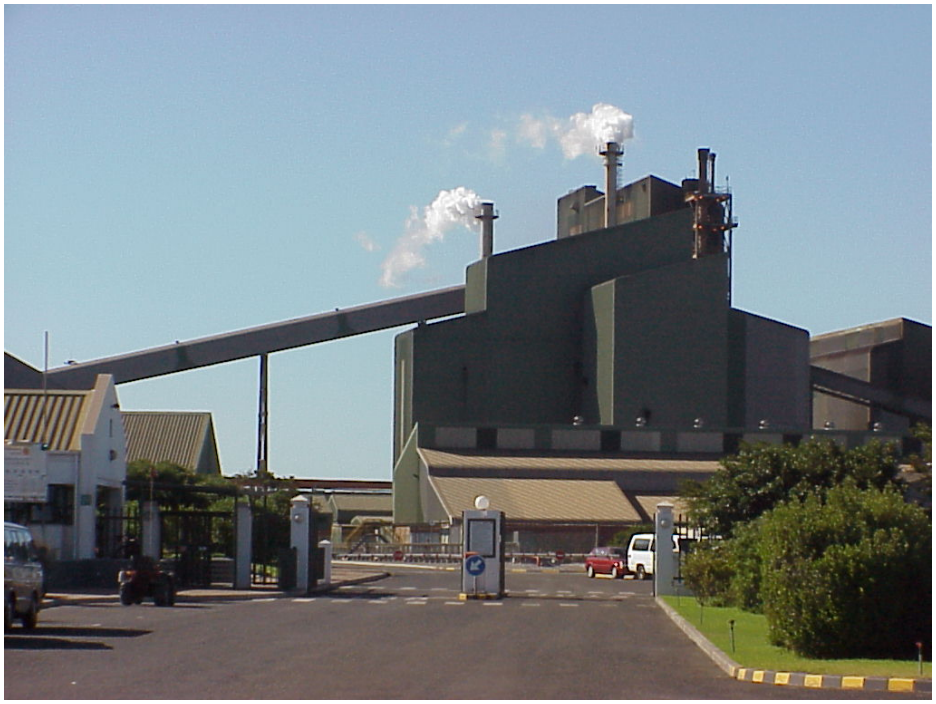
2. Ilmenite smelting (Namakwa Sands)

- 25MW DC furnace at Namakwa Sands in 1994
- 35MW DC furnace followed in 1998



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2. Ilmenite smelting (Ticor and CYMG)

- Two further 36MW DC furnaces at Ticor near Empangeni were commissioned in 2003

- Many other enquiries from around the world
- Constrained by licence agreements
- A 30MW furnace was commissioned for CYMG in China in 2009

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3. Cobalt recovery from non-ferrous slags

- The recovery of cobalt from copper discard slags was investigated from the 1980s
- Problem to be solved:
  Recover cobalt from its oxidized form in slag
- Piloted at Mintek at 2MW in 1999
- 40MW DC furnace in operation at Chambishi in Zambia in 2001
- First commercial DC smelting furnace to use solid electrodes with side-feeding
- (A number of furnaces have now changed away from hollow electrodes)

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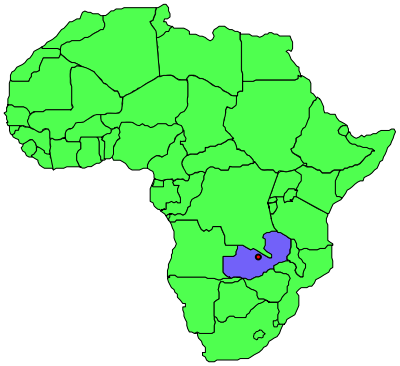
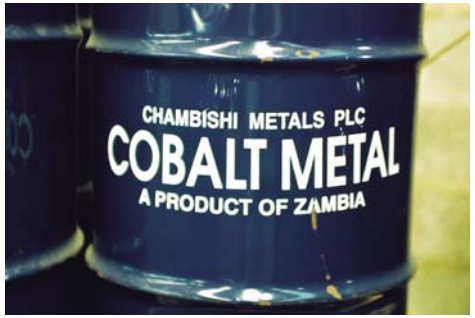


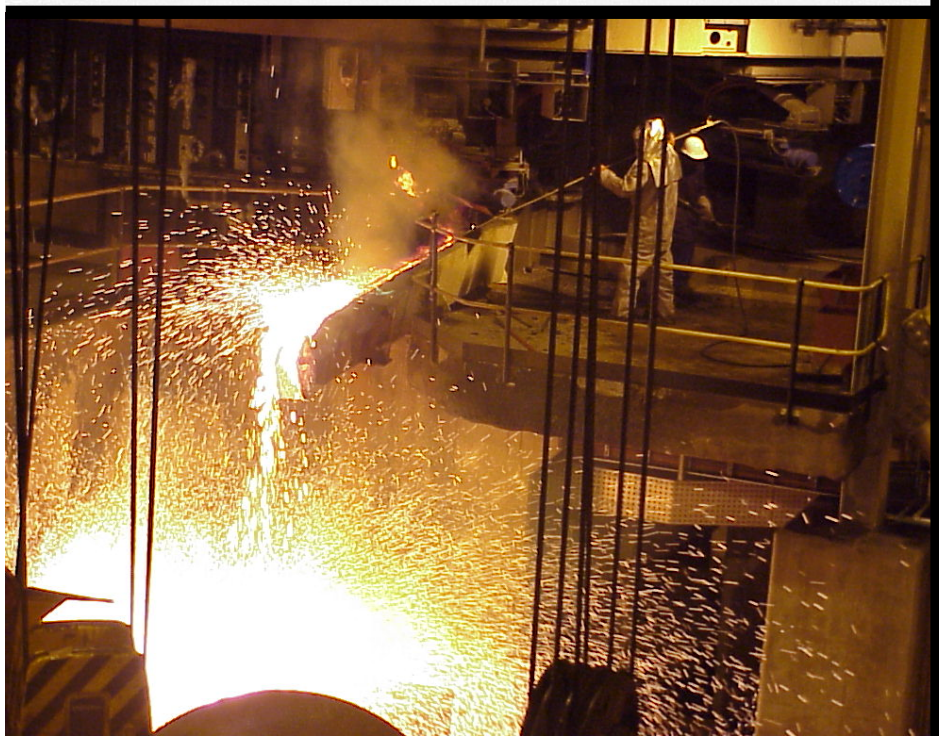
Chambishi

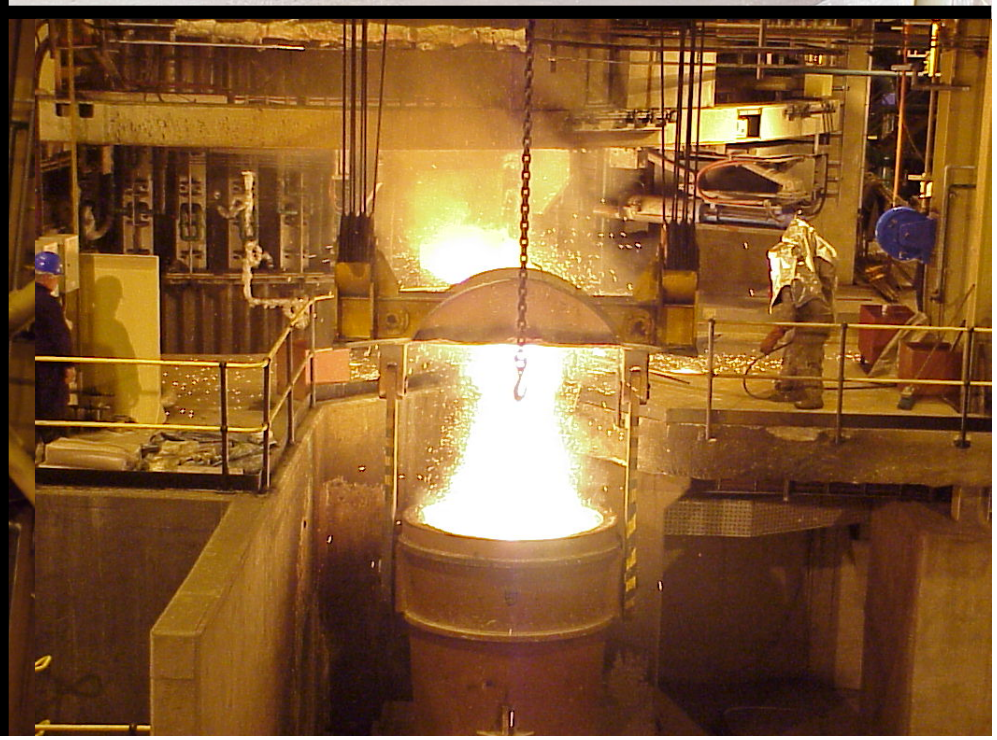
Tested at 2.0 MW, 2.5 m

Cobalt from slag 40 MW 2001




Chambishi Metals, Zambia





4. Battery recycling

- Batrec, Switzerland
- 2.5MW furnace in 2008 treats 5000 t/a and produces Zn and FeMn

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5. Stainless steel dust smelting

- Steel-plant dusts contain hazardous heavy metals
- DC arc furnace recovers Cr and Ni and produces a slag that can be safely disposed of
- Process operated at Mogale Alloys on a 32MW furnace

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6. Nickel laterite smelting

- Piloted at Mintek from 1998 to 2006

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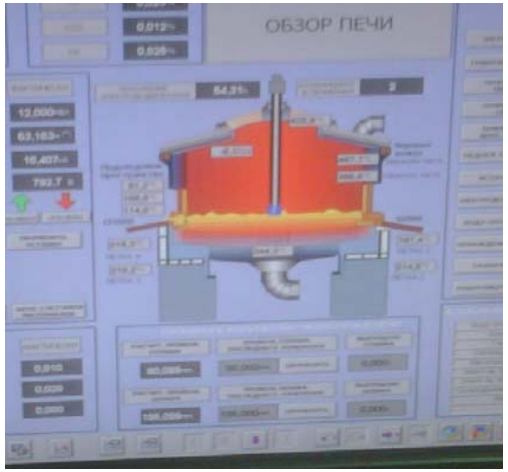
6. Nickel laterite smelting (Russia)

- 12MW furnace in Southern Urals, Orsk, Russia commissioned in 2011



6. Nickel laterite smelting (New Caledonia)

- Two 80MW twin-electrode DC furnaces constructed by Xstrata Nickel for the Koniambo FeNi smelter in New Caledonia, were started up in 2013 and 2014

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Summary of DC arc furnace smelting installations

Process	Year	Furnaces
Steel		> 80 DC furnaces, up to 175 MW
FeCr	1985	10MW, 30MW, 60MW, 60MW, (4 x 72MW)
TiO2	1994	25MW, 30MW, 35MW, 36MW, 36MW
Co	2001	40MW
Stainless steel dust	2004	32MW
Battery recycling	2008	2.5MW
FeNi	2011	12MW, (2 x 80MW)

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Conclusions

- DC arc furnaces – an interesting past, a productive present, and a promising future
- DC arc furnaces are not a panacea for all metallurgical problems, but are very well suited to a number of reductive smelting processes where they have been applied successfully in a number of industrial contexts, and many further applications are expected

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Mintek's DC furnaces

http://www.mintek.co.za/Pyromet/