Sustainable Metal Production

Presentation to Engineers Australia

MINERAL RESOURCES FLAGSHIP
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Outline

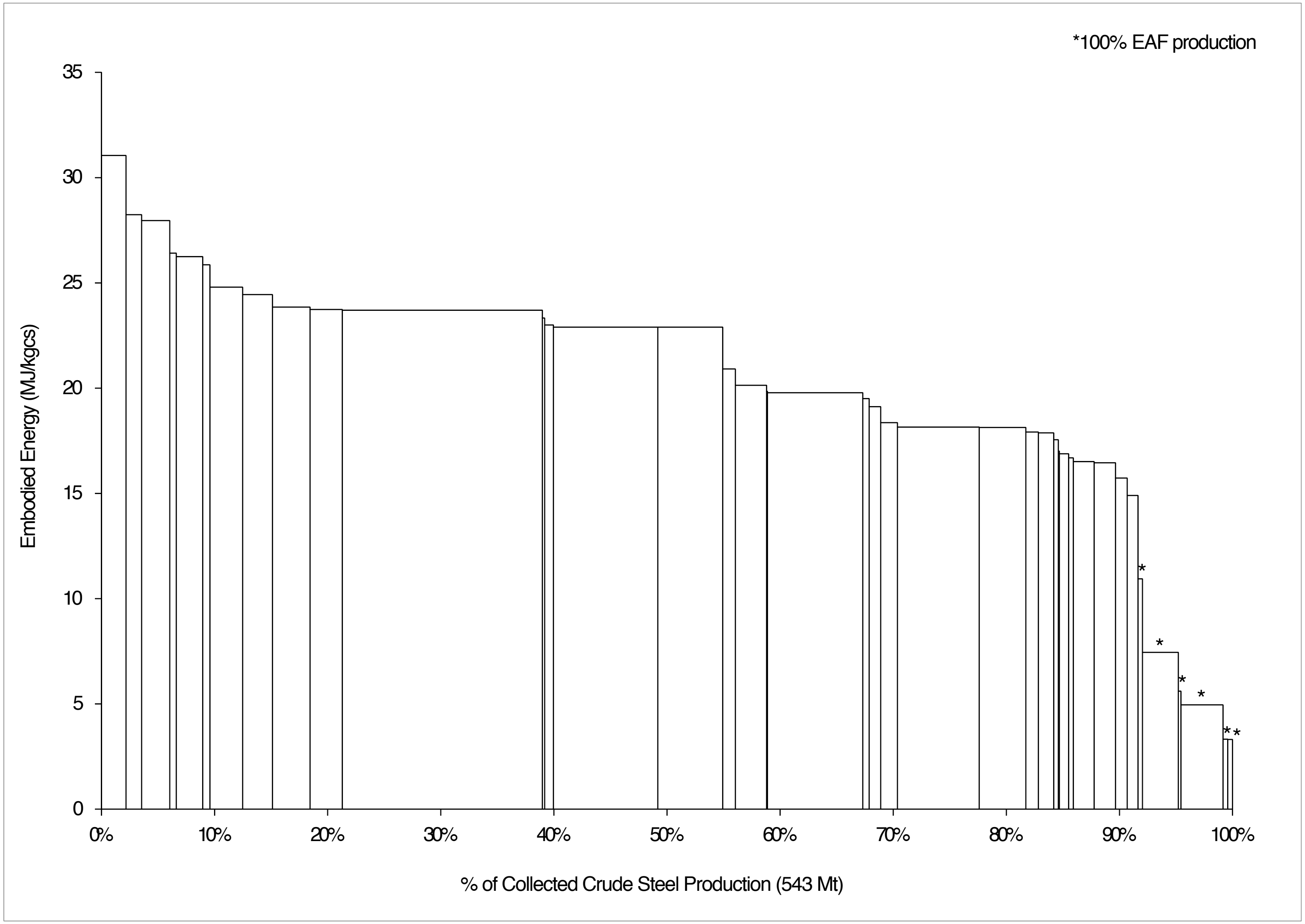
- Environmental Impacts of Metal Production
- New Technologies
  - Steelmaking
    - Dry Slag Granulation
    - Biomass
  - Aluminium
    - Bauxite Chlorination

ENVIRONMENTAL IMPACTS OF METAL PRODUCTION

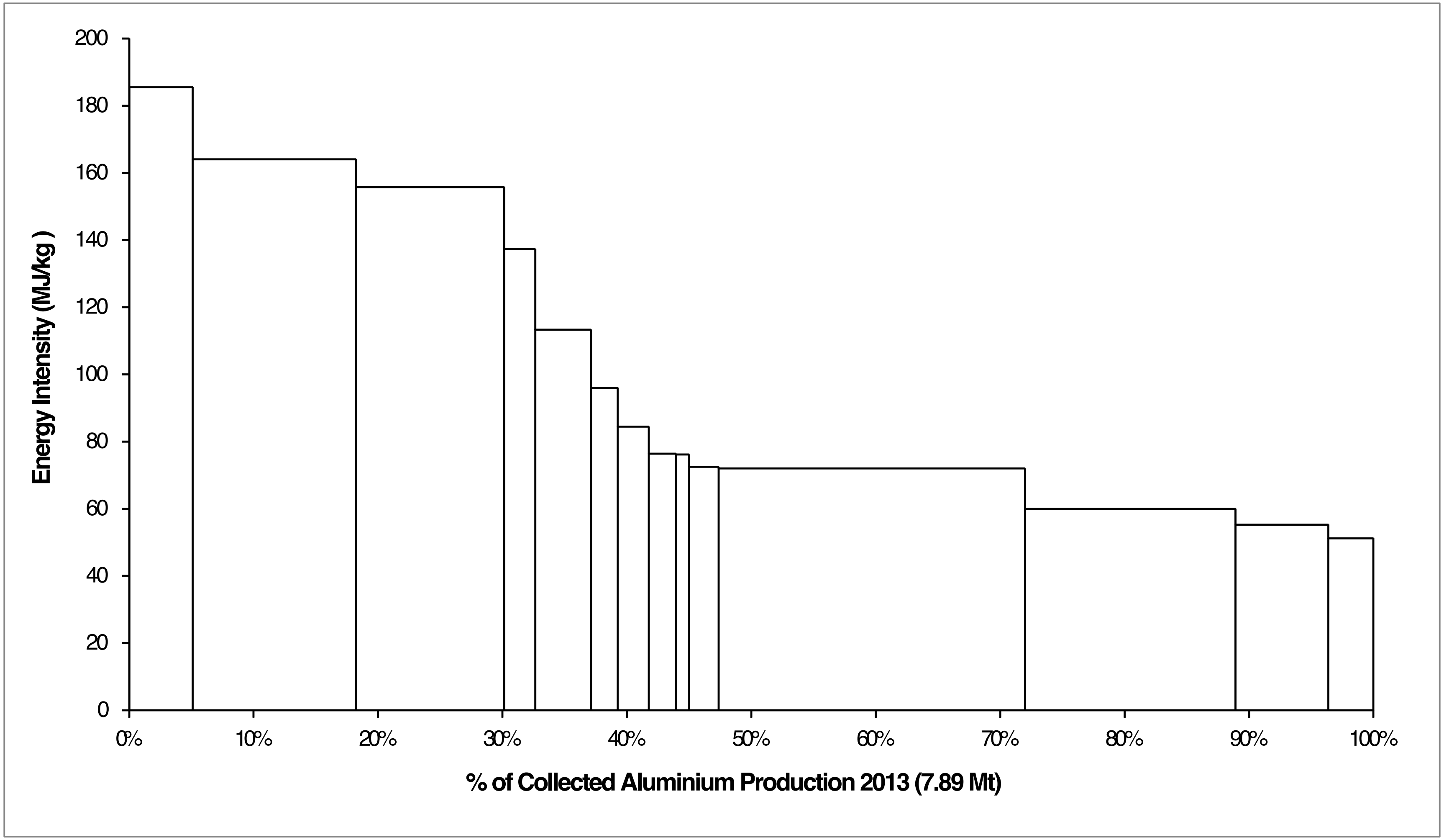
Environmental Metrics

Metrics	Unit (per tonne of ore, concentrate or metal)	Changes compared with conventional
Embodied energy	*MJ or GJ*	*Close to theoretical, Practical minimum*
Carbon footprint	*kg-equivalent CO_2*	*Minimum through best combination of technology*
Water footprint	*kL or ML of water*	*Minimum with recycling and reuse*
Waste footprint	*Tonne*	*Approaching zero by means of reducing or adding value as input*
Other environmental impact	*Depending on impact*	*Minimise*

How much energy does it take to produce steel?



How much energy does it take to produce aluminium?



Steel Production

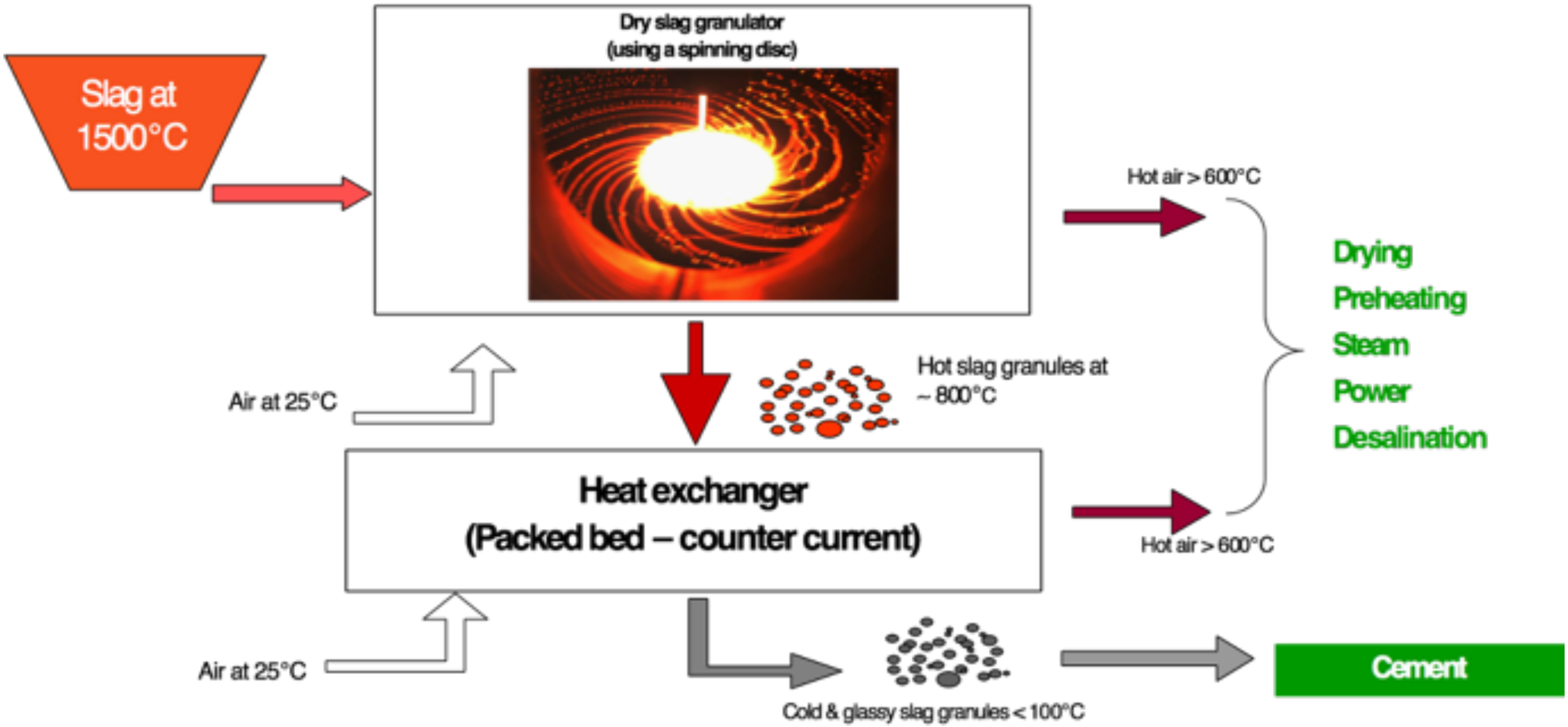
NEW TECHNOLOGIES

Iron Blast Furnace Slag
Current Treatment

Slag dumping at Arrium (OneSteel Whyalla)

Water Granulation at Blue Scope Steel Port Kembla

Dry Slag Granulation



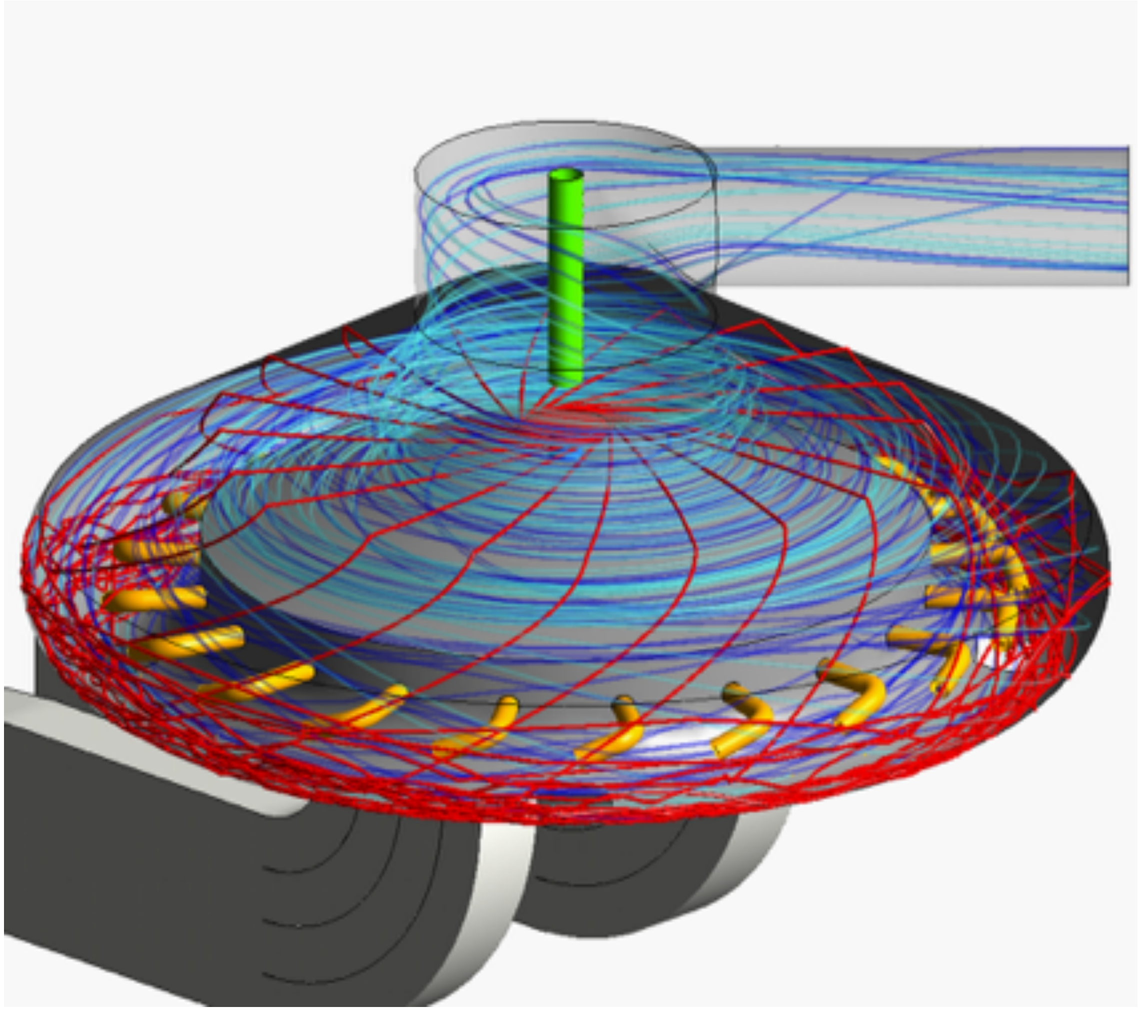
Dry Slag Granulation
CSIRO testing

Prototype scale DSG rig (ϕ1.2 m &10 kg/min)

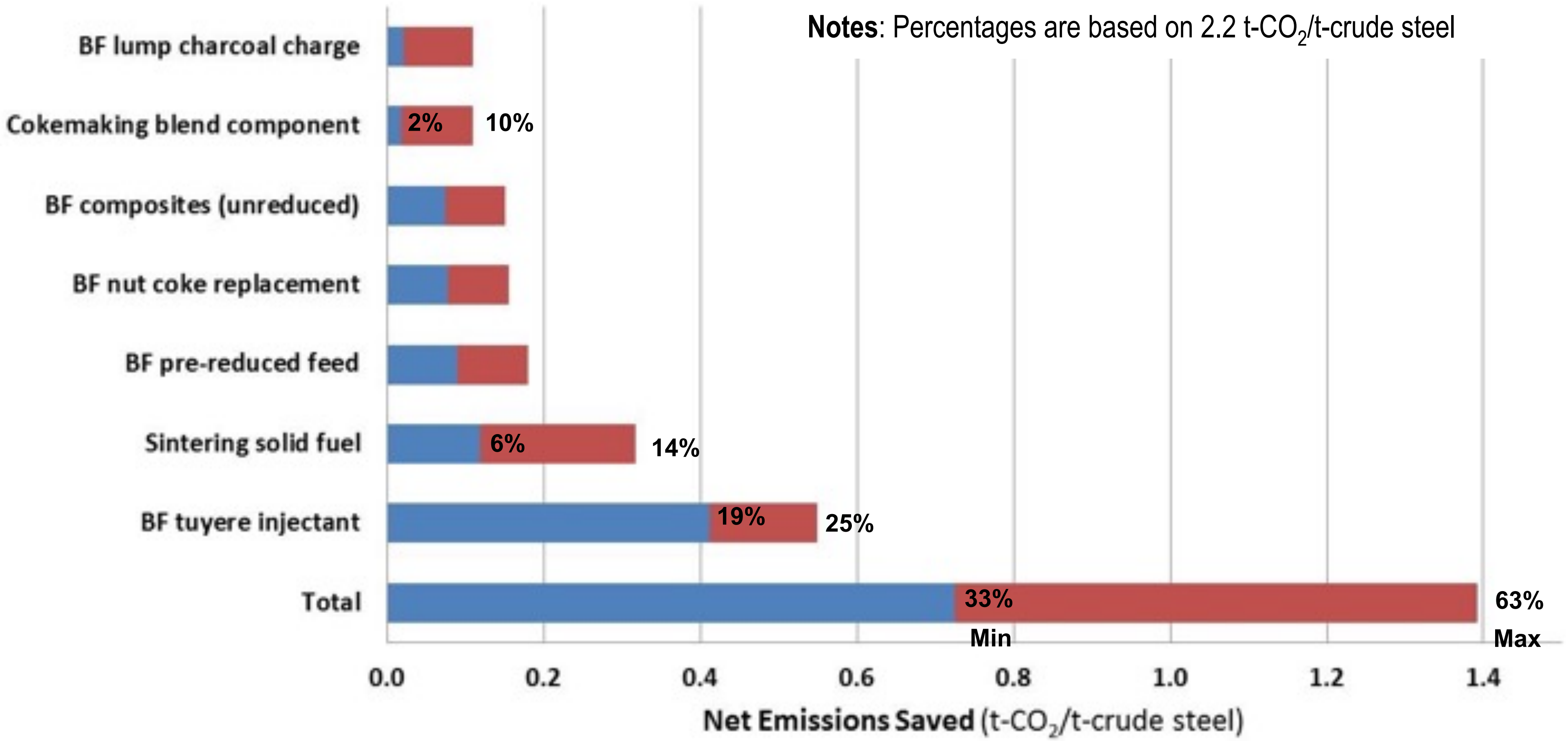
Semi-industrial scale DSG pilot plant (ϕ3 m &100 kg/min).

Dry Slag Granulation

Process Development



Biomass Applications in Integrated Ironmaking



Reference: J G Mathieson, M A Somerville, A Deev and S Jahanshahi, *Utilisation of Biomass as a Alternative Fuel in Ironmaking*, Chapter 25 in "Iron Ore: Mineralogy, Processing and Environmental Issues", Editor: Dr L Lu, Woodhead Publishing (in press).

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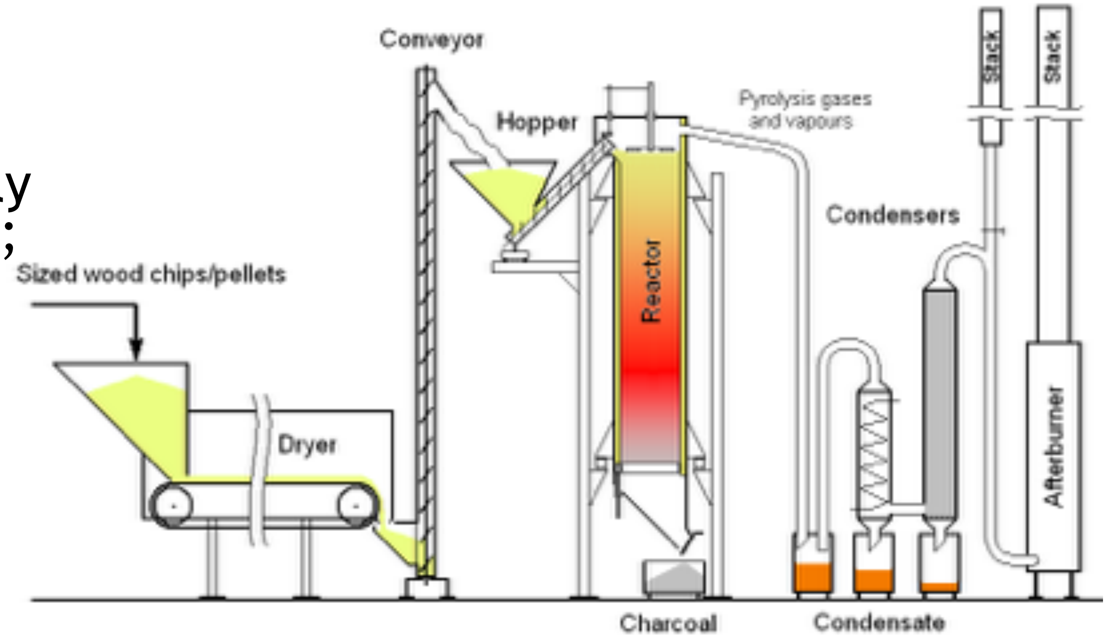
Pyrolysis

Challenges in process and reactor design

- Currently, there is no scientific approach to design and scaling-up of a biomass pyrolysis reactor.
- The application of "formal kinetics" to pyrolysis reactor design and scale-up is not possible:
  - Pyrolysis of biomass (wood) has not been characterized to the level of individual chemical reactions
  - Exhibits autocatalytic behaviour, but catalysts have not been identified; reaction rate constants "k" depend on scale
  - Heat of pyrolysis determined at small scale cannot be applied to large scale: ΔH_{pyro} is small, is **proportional to the yield of charcoal** and depends on scale
- Pyrolysis rector design is largely "an art"
- No systematic study of the effect of main process variables has been reported

Autothermal* Pyrolysis Technology

- Patented technology
- Wood is heated spontaneously with no supply of heat or air to the reactor;
- Can process small-sized wood, i.e. wood wastes or forest residues
- High charcoal yield
- Consumes only low-grade heat for drying the feed material



- Generates by-products of wood pyrolysis (bio-oil and bio-gas) with high calorific value
- Capable of continuous operation and a high degree of automation
- Reactors are very simple mechanically and can work in a broad range of sizes: from 1,000 to 50,000 t/year for a single reactor

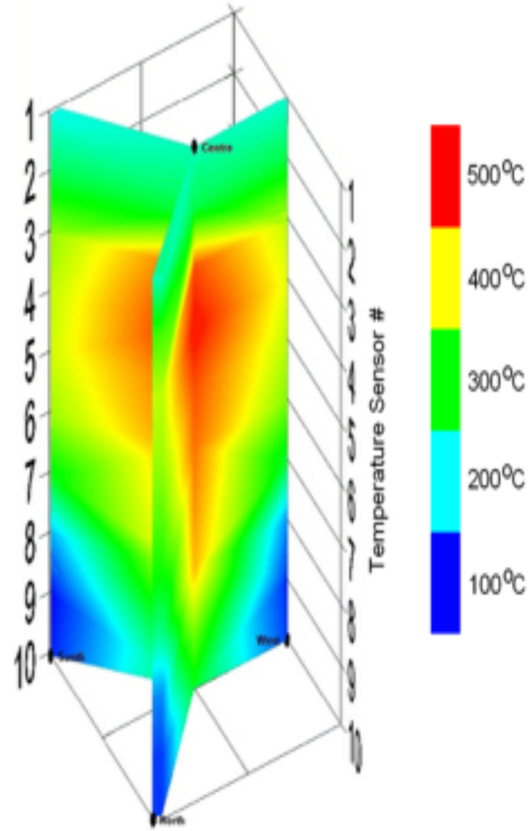
**) Autothermal pyrolysis: heating of material inside the reactor occurs spontaneously by the heat of exothermic pyrolysis reactions with no supply of oxygen/air to the reactor*

Autothermal Pyrolysis
CSIRO Continuous Pilot Plant

Autothermal Pyrolysis

CSIRO continuous pilot plant

- Reactor: ID 600 mm; shaft height 2750 mm, volume 800 L; feed rate 100 kg/h (chips) to 300 kg/h (pellets)
- Plant commenced continuous operation in 2014
- Maximum temperature reached spontaneously (no heating): 527 ºC
- Dry biomass throughput attained so far – 280 kg/h
- Production of dense charcoal from dense wood pellets achieved
- Residual volatile matter in charcoal – 15 to 19%
- Techno-Economic Assessment based on the data collected in 2014:
  - With the carbon price of >\$12/t_{CO2} the production of charcoal to replace pulverised coal injection can be profitable, if value of all the pyrolysis by-products (including pyroligneous acid) is captured



Temperature distribution inside the reactor (experimental data)

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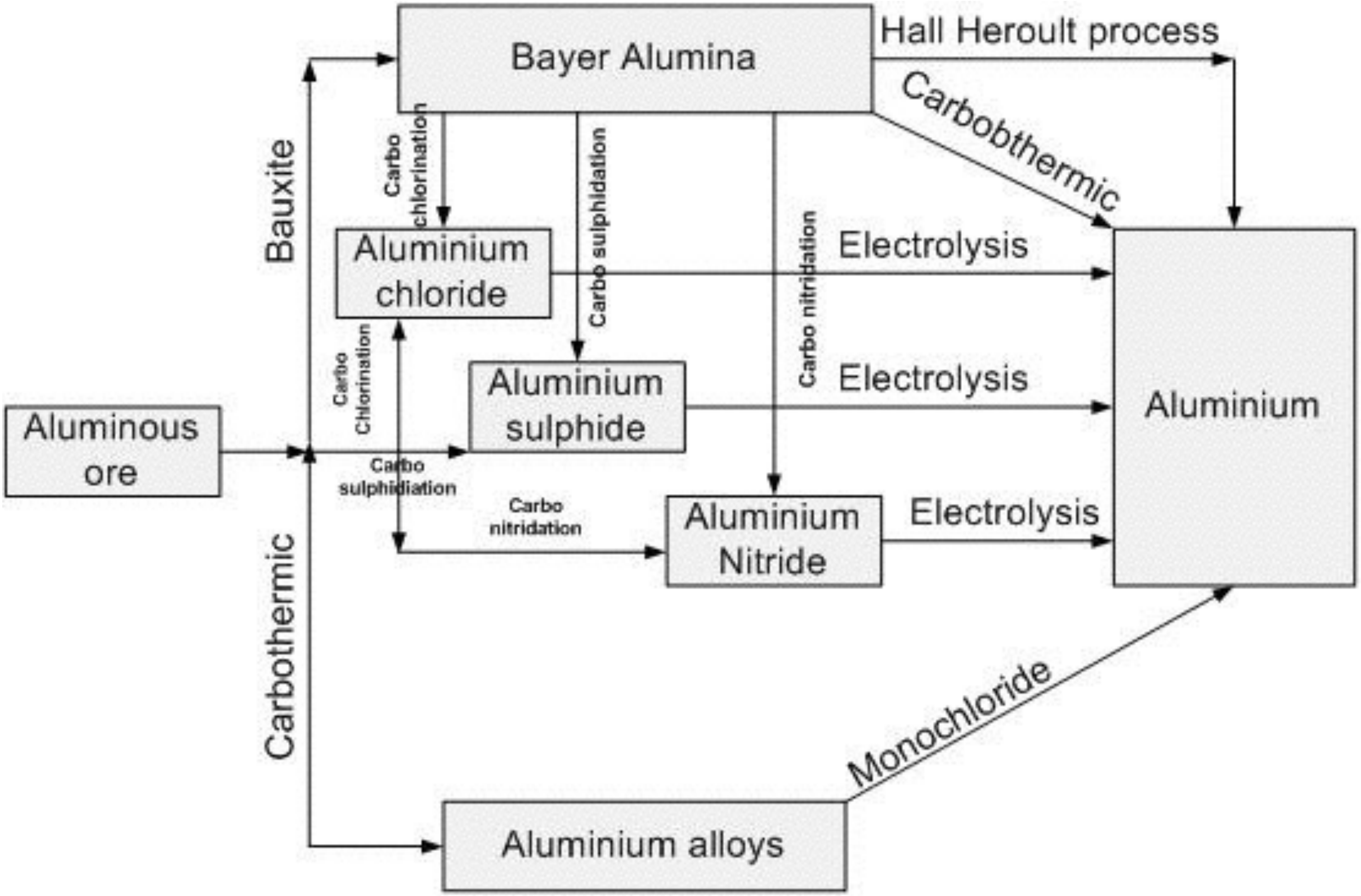
Aluminium Production

NEW TECHNOLOGIES

Bayer Process

Red Mud Dam

Aluminium Process Routes

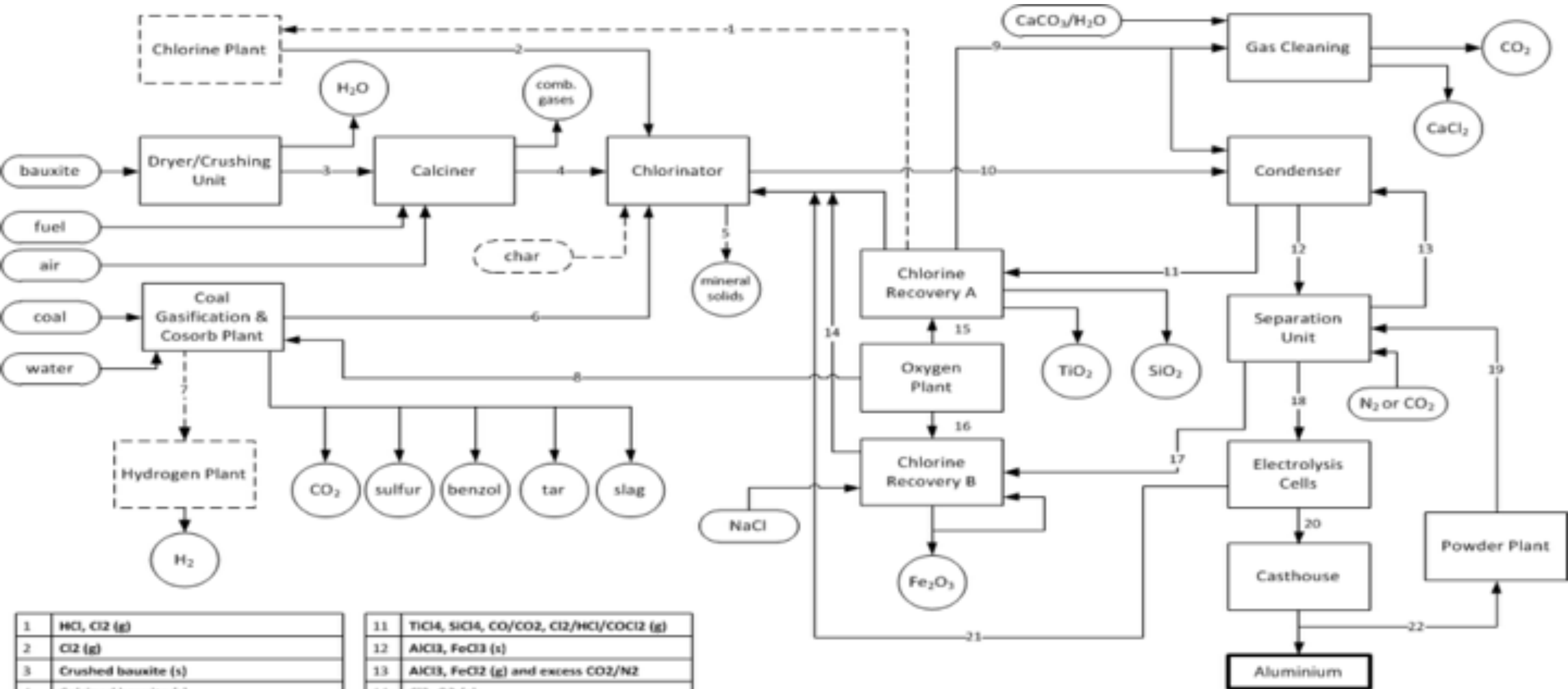


Aluminium Chloride Electrolysis

Alcoa Smelting Process

- 1962, goal of commercialising an alternative to Hall-Heroult.
- Reporting in 1981, Alcoa “didn’t regret their choice, after 19 years of development”.
- In 1976, a development plant was commissioned in Texas.
- The bipolar cells reportedly produced Al at <9.5 kWh/kg, with volumes in excess of 13 t/d.
- Stopped in 1981
  - Hall-Heroult had continued to improve
  - Technical
  - Economic

Bauxite Chlorination



1	HCl, Cl2 (g)
2	Cl2 (g)
3	Crushed bauxite (s)
4	Calcined bauxite (s)
5	Spent char, unreactive alumina and silica
6	CO2 (g)
7	H2 and N2 (g)
8	O2 (g)
9	CO2, trace chlorides and Cl2 (g)
10	Chlorides, CO/CO2, Cl2/HCl/COCl2 (g)

11	TiCl4, SiCl4, CO/CO2, Cl2/HCl/COCl2 (g)
12	AlCl3, FeCl3 (s)
13	AlCl3, FeCl2 (g) and excess CO2/N2
14	Cl2, O2 (g)
15	O2 (g)
16	O2 (g)
17	FeCl2, AlCl3 (s)
18	AlCl3 (g)
19	Al powder (s)
20	Al (l)

21	Cl2 (g)
22	Al (s)

Summary

- Metal production is energy intensive, and variable
- New technologies that can deliver substantial less environmental improvements are under development

Thank you

CSIRO Mineral Resources Flagship

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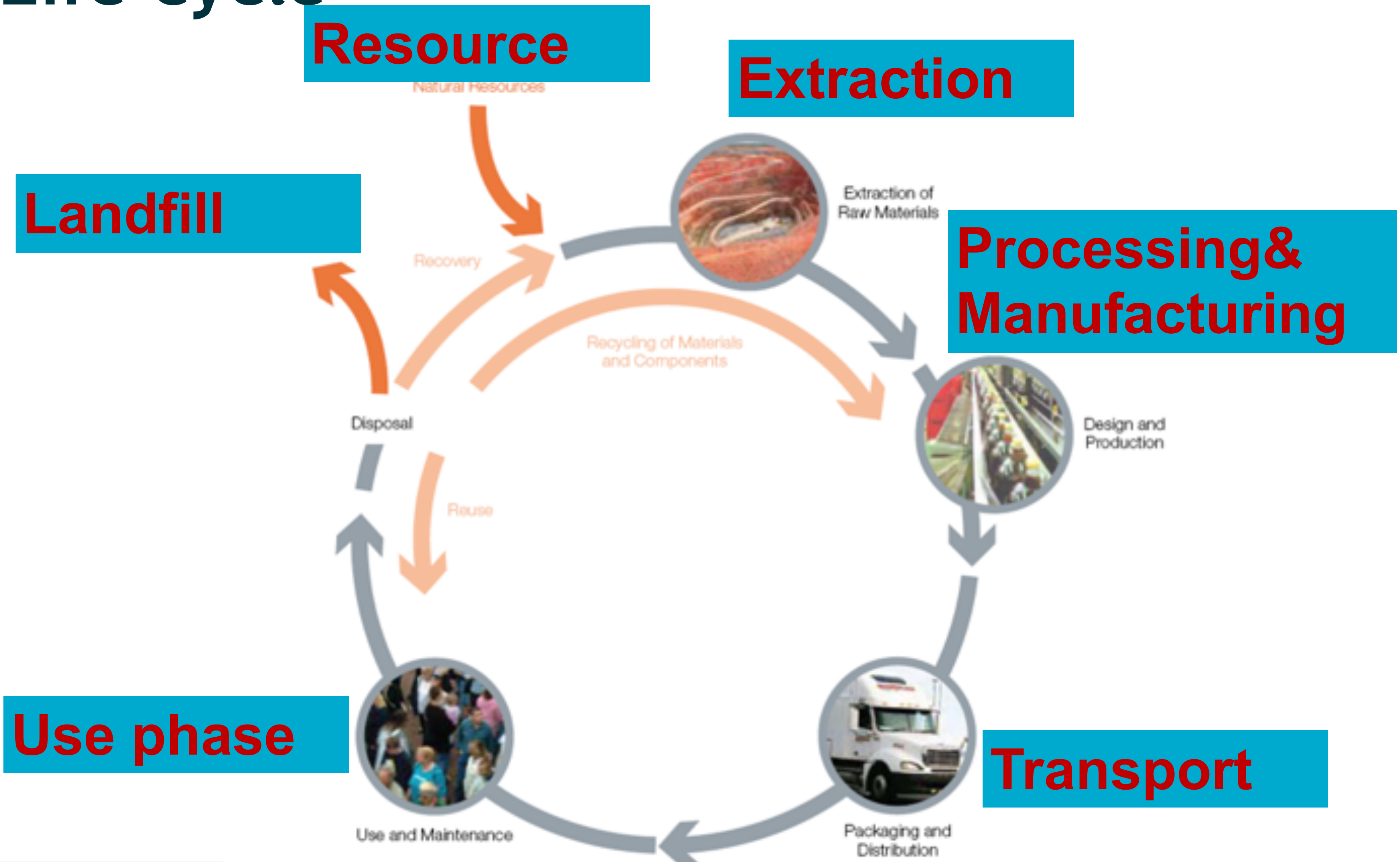
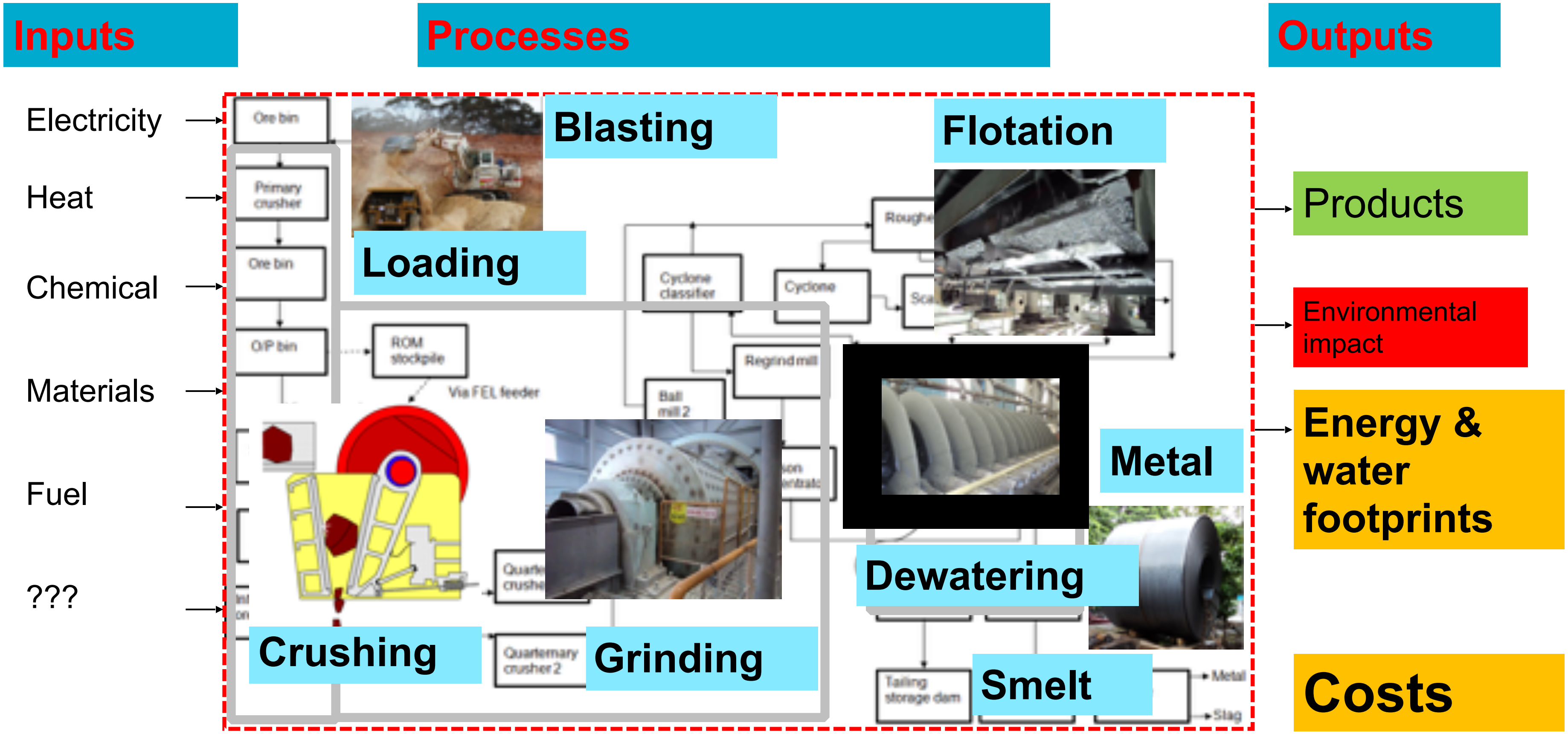
Life cycle


Resource
Natural Resources
Extraction
Extraction of Raw Materials
Landfill
Recovery
Processing&
Manufacturing
Recycling of Materials and Components
Disposal
Design and Production
Reuse
Use phase
Transport
Use and Maintenance
Packaging and Distribution

Process Evaluation- Techno-economic & Life cycle assessment



- CSIRO Tool for Life Cycle Based Environmental Impact Evaluation for mining, minerals and metal industries

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Pyrolysis
Approach

1. Small-scale systematic experimental characterisation. Novel methodology.
2. Key process variables determining the process kinetics and charcoal yield:
   - Heating Rate (HR)
   - Flow Rate of purging gas (FR)
   - Particle Size (PS)
   - Bed Depth of material in the reactor (BD)

   Residence time and partial pressures of pyrolysis vapours

3. Conditions for maximum yield of charcoal and exothermic heat generation: no gas through flow, reasonably slow heating, independent from the particle size (if no gas flow)
4. Judicious choice of technology:
   - self energy sufficient process without any external supply of heat or **air** to the reactor
   - maximum energy efficiency and scalability
5. Construction of the reactor plant and process characterisation