Magnesium: Current and Alternative Production Routes

27 September 2010

Winny Wulandari, Geoff Brooks, Akbar Rhamdhani, Brian Monaghan*

Faculty of Engineering and Industrial Sciences

Swinburne University of Technology

*Faculty of Engineering, University of Wollongong

SWINBURNE UNIVERSITY OF TECHNOLOGY

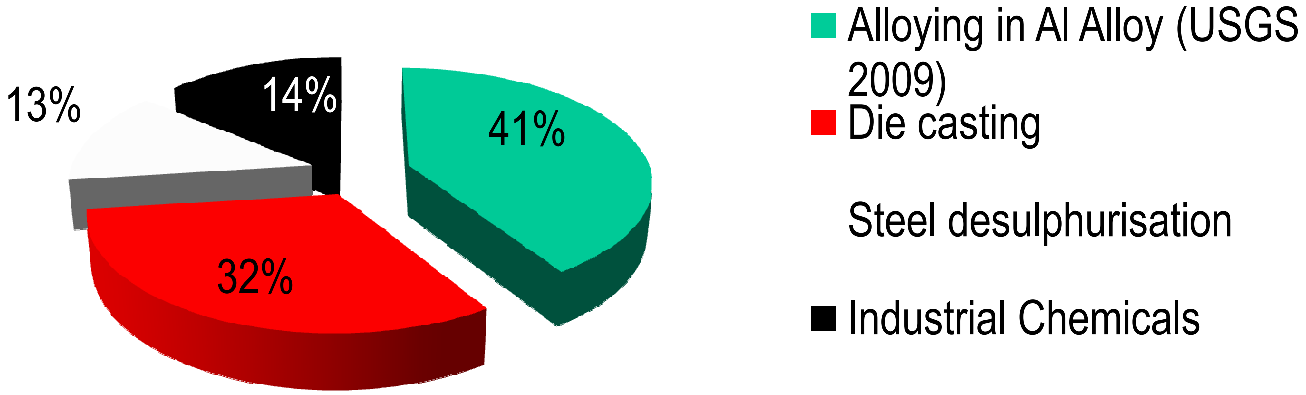
Outline

- Introduction
- Magnesium Technologies
  - Current Routes
  - Alternative Routes
- Magnesium in Australia
- Discussion and Insight
- Conclusion

SWINBURNE UNIVERSITY OF TECHNOLOGY

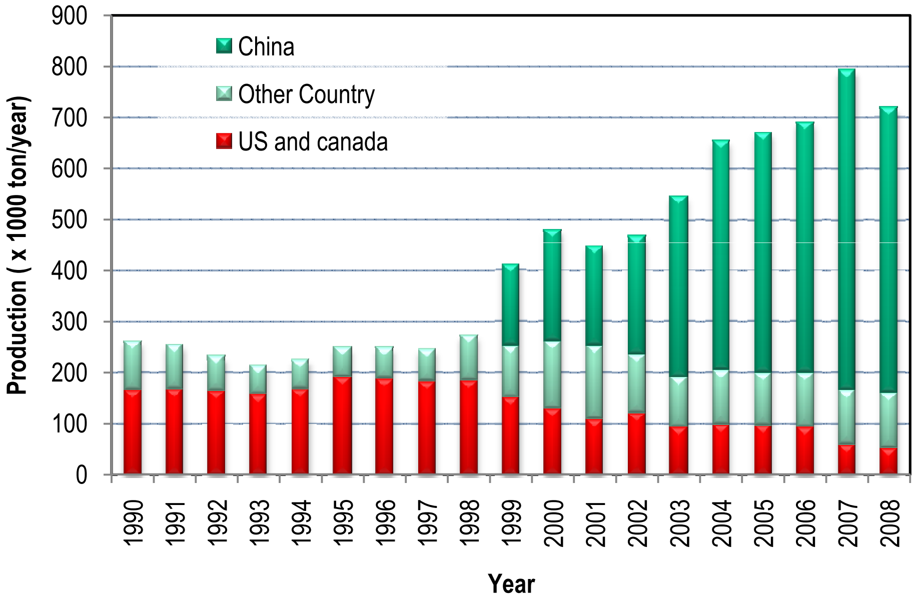
Introduction

- Magnesium
  - Best strength to weight ratio of structural metal
- Applications
  - Growth in automotive applications



Magnesium Production

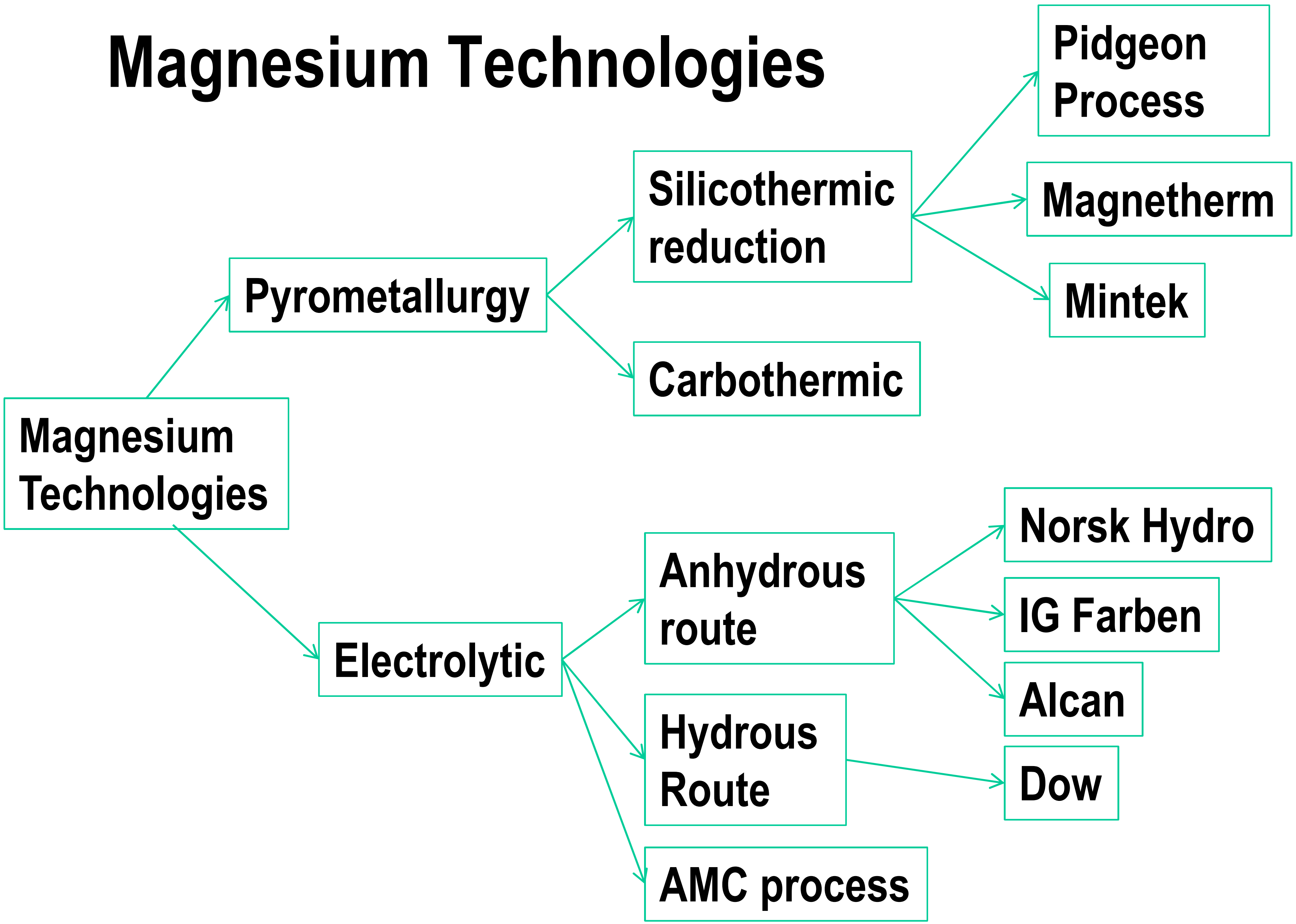
- 10% growth of Mg production
- Dominant technology is Pidgeon process



Magnesium Production (IMA)

image from csiro.au

Magnesium Technologies

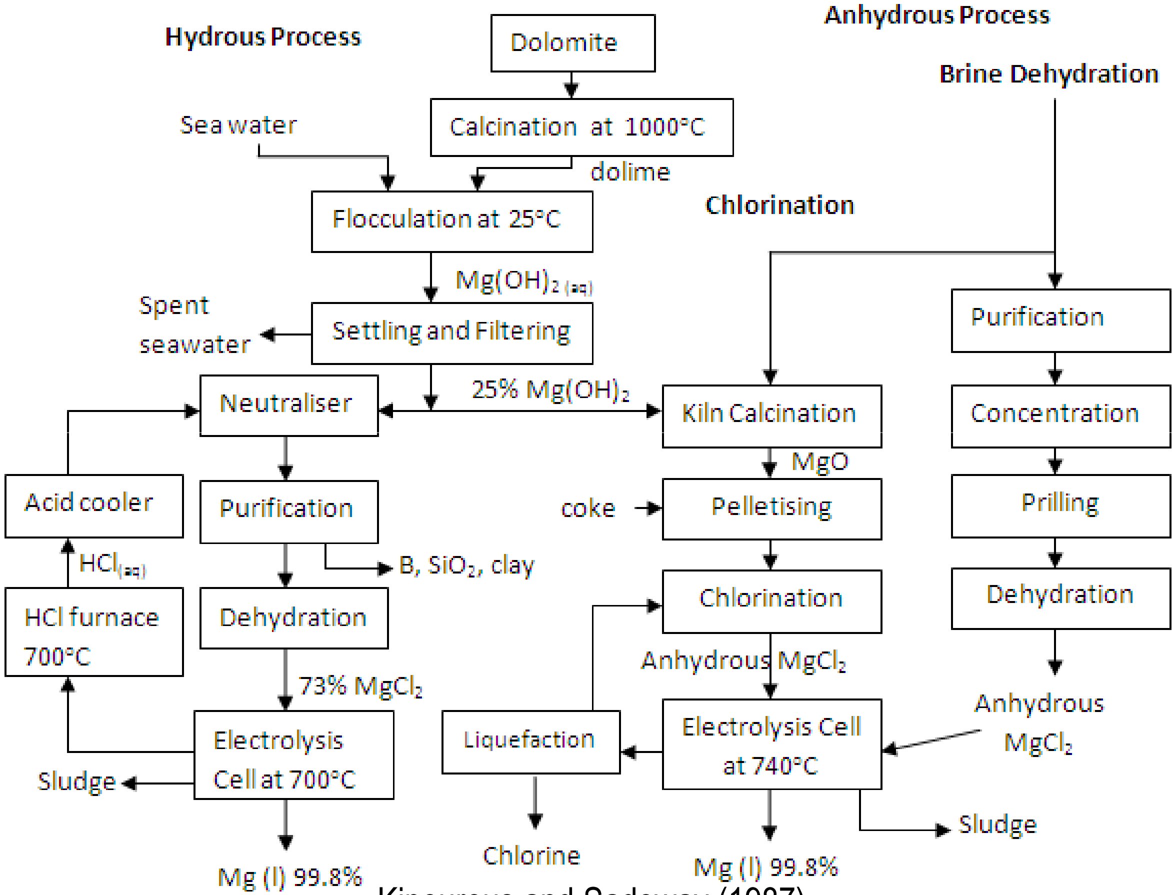


Current Routes

-Electrolytic Route

-Pidgeon Process

Electrolytic Routes



Kipourous and Sadoway (1987)

Electrolytic routes:

- Feed preparations process stage
- Electrolysis (700-800^{o}C, $MgCl_2$ 10-25%, 1 atm)

$$MgCl_2 \rightarrow Mg_{(l)} + Cl_{2(g)}$$

Electrolytic Routes

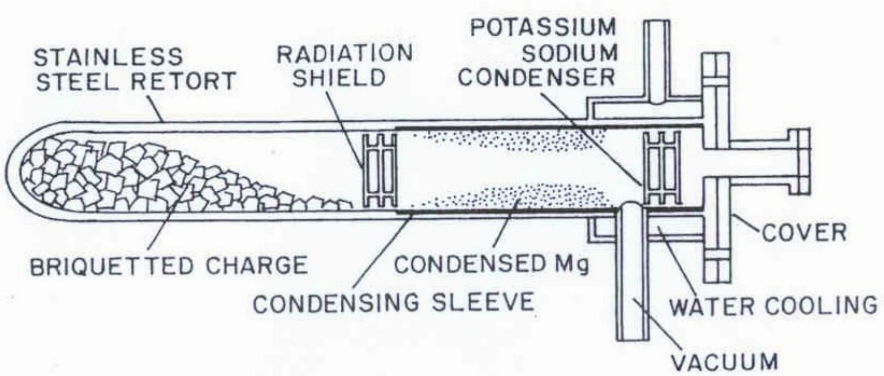
- High capital cost ($10,000/ton Mg) (Das,2008)
- Established technology
- Extensive feed preparations
- Dehydration of $MgCl_2$ is energy intensive, but more efficient

Magnesium Plant (novopro.ca)

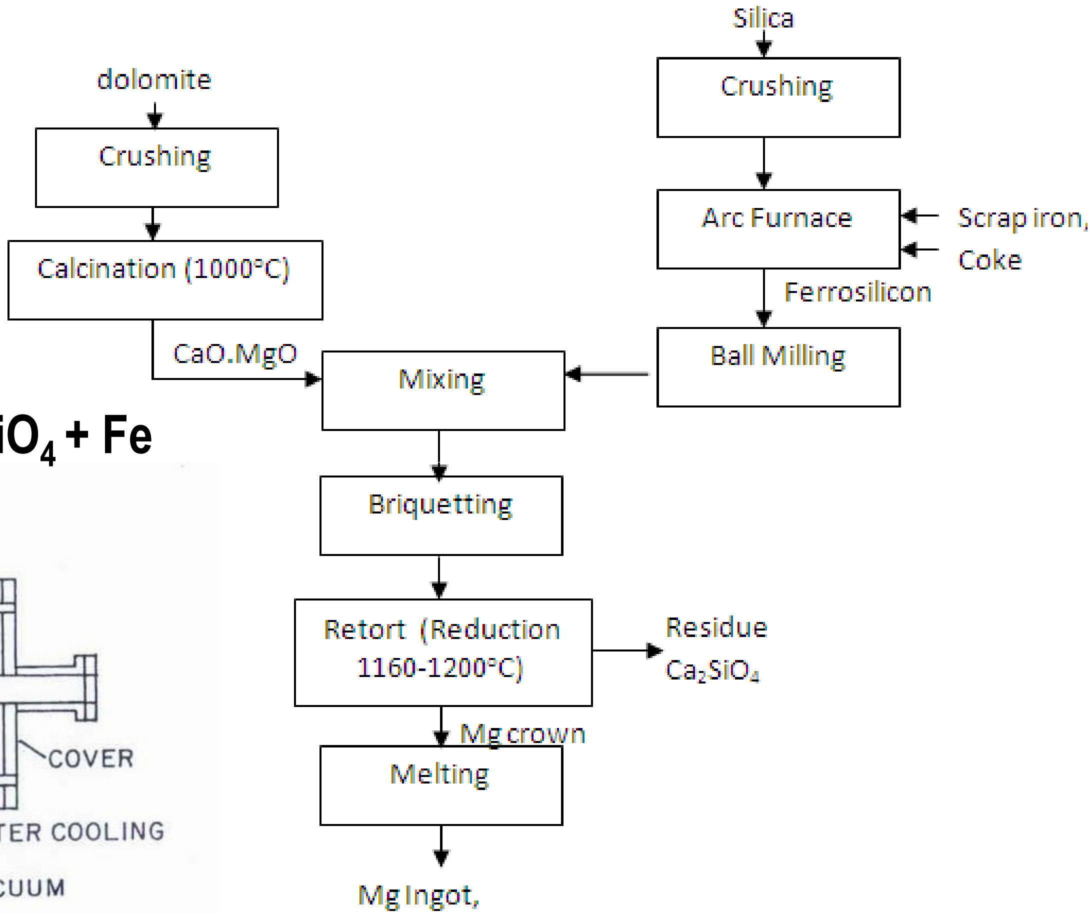
The Pidgeon Process

Reaction:

$2CaO.MgO + FeSi \rightarrow 2Mg_{(g)} + Ca_2SiO_4 + Fe$



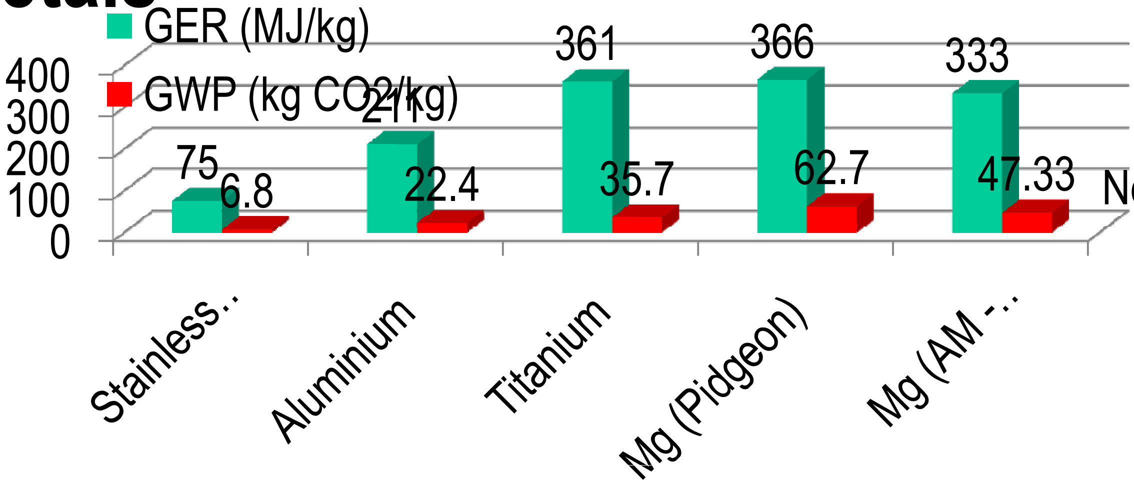
Schematic of Pidgeon Process Retort
(Kipourous & Sadoway, 1987)



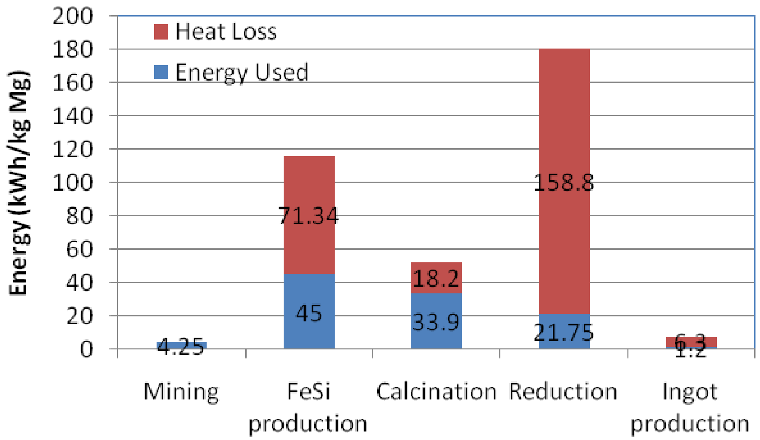
Pidgeon Process

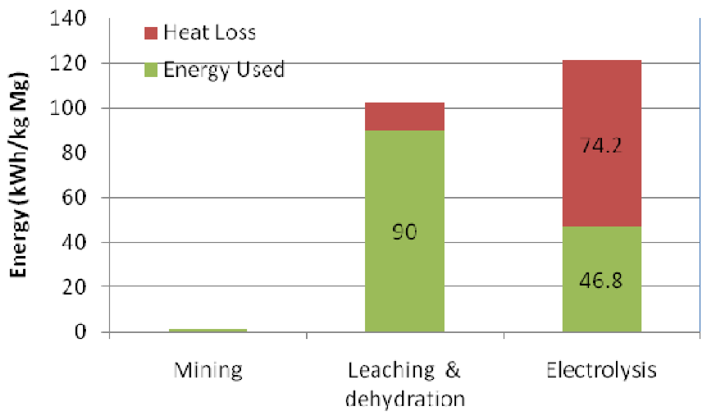
- Silicothermic reduction under vacuum (1200 ^{o}C and 10 to 20 Pa)
- Simple and versatile
- Labour intensive
- Slow reactions
- Relative high purity magnesium achieved
- Improvements proposed: integrating small smelters, utilisation of cleaner energy source (Aghion & Bartos, 2008)

Energy Requirement Magnesium and other Metals



Norgate and Rankin, 2007





Ramakhrisnan & Koltun, 2004

Alternative Routes

-Magnetherm Process

-Mintek Process

-Carbothermic Process

-Aluminothermic Process

-Solid Oxide Membrane Process

Silicothermic Routes

Magnetherm Process

- Silicothermic at 1550^{o}C, 0.05 atm

$$CaO.MgO + FeSi + Al_2O_3 \rightarrow Mg_{(g)} + Ca_2SiO_4.Al_2O_3 + Fe$$

- Ingress of air into condenser (20% downtime)

Mintek Process

- Possible continuous operation

Alternative Routes

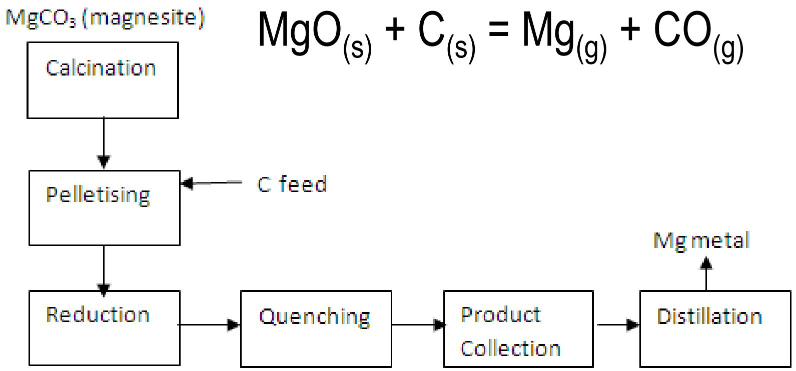
Mintek Process

- Silicothermic at 1 atm, 1700 ^{o}C
- Higher temperature means higher impurities formed
- Engineering challenges: condenser design and impurities

Carbothermic Process

- Cheap reducing agents
- Condition: 1 atm, 1500 – 1700 ^{o}C
- Quenching technology
- Issues: reversion, impurities, scale-up

$$MgO_{(s)} + C_{(s)} = Mg_{(g)} + CO_{(g)}$$



Brooks *et al* (2006)

Alternative Routes

Aluminothermic Process

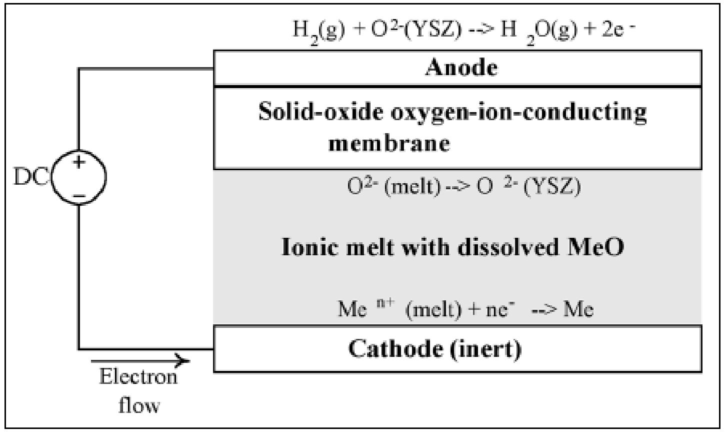
- Reaction:

$$4MgO + 2Al \rightarrow 3Mg_{(g)} + MgAl_2O_4$$

- Aluminium is stronger reducing agent compared to FeSi and C
- Only possible if there is a cheap source of aluminium

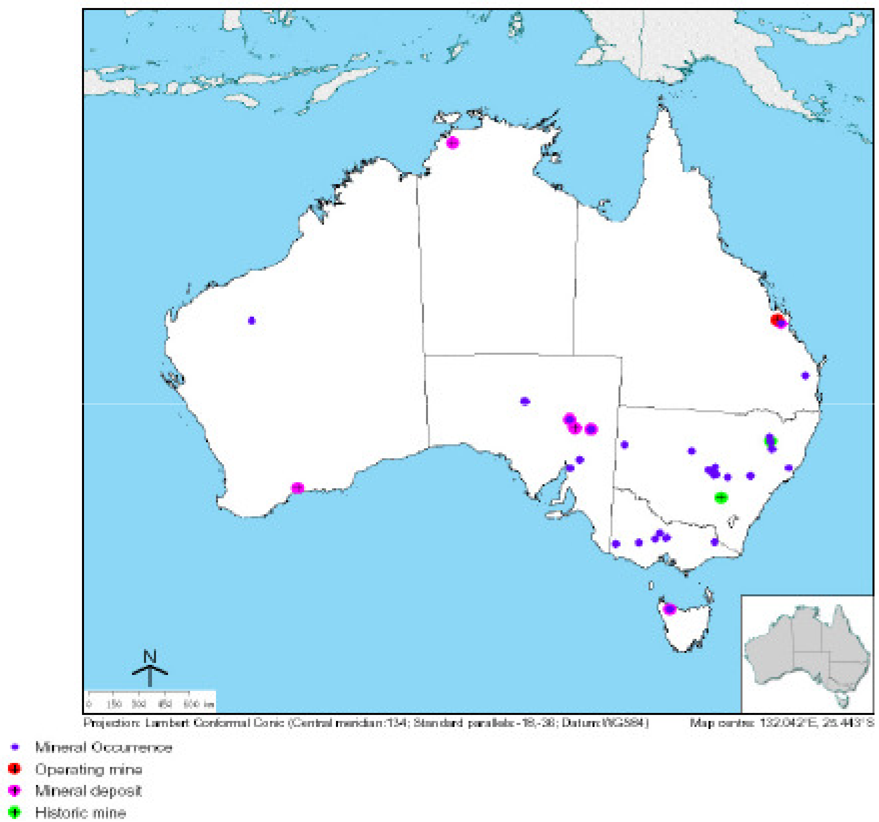
Solid Oxide Membrane Process

- Alternative to electrolytic
- Electrolysis of MgO in fluoride-based electrolytes
- Challenges: expensive, leakage of current, scale-up



Pal *et al* (2001)

Magnesium in Australia



- Magnesite deposits: Kunwarara QLD, Leigh Creek SA, TAS
- Australia has excellent Mg alloying technology
- Several Mg projects proposed, but did not commissioned

Discussion: Why energy consumption of magnesium processing is high?

- Energy consumption for producing metal is strongly linked to (Brooks & Subagyo, 2002):

  - ☐ Chemical Stability

    Chemical Stability of MgO >> Al_2O_3 >> Fe_2O_3

Reaction	Gibbs Free Energy (ΔG)at 25 °C (MJ/kg metal)	Enthalpy Formation (ΔH) at 25 °C (MJ/kg metal)
$Mg + 1/2O_2 \rightarrow MgO$	-23.42	24.76
$2\,Al + 3/2\,O_2 \rightarrow Al_2O_3$	-29.32	31.2
$2\,Fe + 3/2\,O_2 \rightarrow Fe_2O_3$	-6.66	7.30

  - ☐ Availability and richness of ores

  - ☐ Processing Routes

    The overall efficiency of electrolytic route is around 20.8%, while the Pidgeon process is 15%.

High Energy Processing vs Environmental Benefit

- High energy usage in primary magnesium offset environmental benefit of magnesium
  - ☐ weight reduction material in automotive industry will reduce fuel consumption, however
  - ☐ Replacing steel with Mg on a base automobile will lower weight by 5.7%, but only reduce energy usage by 1.3% (Du *et al*, 2010)

Conclusions

- Light-weighting of transportation and alloy development will continue be the driving force of the increasing demand of magnesium metal
- Lower energy usage need to be achieved by:
  - Improvement of existing technology
  - Development of new processes which has high productivity

Thank You