High k Sourcing & the Supply Chain for Hafnium and Zirconium
Technology

- Rapid pace of technological change
- Increasing connectivity & ubiquity
- Data growth
- New innovations

Source: Hewlett Packard Enterprise

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Collection of Big Data by Sensors & Actuators

“Australian Strategic Materials & Alkane can supply up to 19 critical elements”

Connecting people and processes ubiquitously for Smart Systems and IoT

- Machine Vision / Optical Ambient Light
- Position / Presence / Proximity
- Motion / Velocity / Displacement
- Temperature
- Humidity / Moisture
- Acoustic / Sound / Vibration
- Force / Load / Strain / Torque / Pressure
- Electric / Magnetic
- Acceleration / Tilt
- Flow
- Leaks / Levels
- Chemical / Gas

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Lanthanum
Cerium
Praseodymium
Neodymium
Samarium
Europium
Gadolinium
Terbium
Dysprosium
Erbium
Ytterbium
Lutetium

Resourcing tomorrow’s technology

Gold
Silver
Tantalum

Hafnium
Yttrium
Zirconium
Niobium
Hafnium: The ideal memory material

First use of HfO$_2$
- DRAM Memory (by Samsung 90 nm 2003/2004):
  - Transition from HfO$_2$ to ZrO$_2$ took place at 65 nm
- High-k & Metal Gate (Intel; 45 nm, 2007):
  - HfO$_2$ is still in use

ALD Applications for Memory & Logic

Source: Techchet CA LLC
Hafnium: The ideal memory material

![Diagram showing the transformation of amorphous HfO₂ into its known crystalline states and into the newly discovered ferroelectric phase.](source)

**FMC - The Ferroelectric Memory Company**

Ferroelectric hafnium oxide

FE-HfO₂: The ideal memory material

FMC’s memory technology is based on a fundamental material discovery, i.e. the discovery of ferroelectric properties in hafnium oxide. During the days in which HfO₂ was researched as a DRAM capacitor dielectric, it was found that a previously unexpected crystal phase can be stabilized by doping and thermal treatment of the material. Within that crystal phase (an orthorhombic, non-centrosymmetric phase, see Fig. 1), the oxygen atoms of HfO₂ can reside in two stable positions, shifting either up or down according to the polarity of an externally applied electric field. Therefore and depending on the position of the oxygen atoms, a permanent electric dipole is created that can either point upwards or downwards in this way enabling the storage of two binary states. Hence, it is a bulk memory effect that can be controlled by application of an electric field only.

Due to the fact that the ferroelectric effect was so unexpected, the material was researched heavily during the last years in order to proof its potential as a memory material. The results of this research are given in Fig. 2. It has already been demonstrated that the material shows extreme temperature stability as well as endurance, retention and switching speed characteristics similar to classical ferroelectrics. However now with a ferroelectric material that is 100% CMOS compatible.

Source: ferroelectric-memory.com

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What is hafnium?

• A shiny, silvery metal that resists corrosion and can be drawn into wires.

• Discovered in 1923 by George Charles de Hevesy and Dirk Coster

• The name is derived from the Latin name for Copenhagen, 'Hafnia'

• In its natural state it is always bound up with zirconium compounds, from which it needs to be extracted using advanced metallurgical processing.

http://www.rsc.org/periodic-table/element/72/hafnium

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Properties of hafnium

Melting point: 2233°C, 4051°F, 2506 K
Boiling Point: 4600°C
Density (g cm\(^{-3}\)) : 13.3
Key isotopes: \(^{177}\text{Hf},^{178}\text{Hf},^{180}\text{Hf}\)
Electron configuration: [Xe] 4f\(^{14}\)5d\(^{2}\)6s\(^{2}\)

- High thermal neutron absorption cross section (~600 times zirconia)
- High stability & strength at high temperatures in metallic & compound form
- High dielectric constant
- Thermoelectric material
- High-index/low optical absorption properties
- The main source of hafnium is as a by-product from producing nuclear grade hafnium free zirconium metal
Hafnium traded as

Hafnium metal in ‘crystal form’
Source: http://www.periodictable.com/Items/072.5/index.html

Hafnium oxide (HfO₂)
Source: Alkane Dubbo Project

Hafnium tetrachloride (HfCl₄)
Source: http://onyxmet.com/?route=product/product&product_id=795

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Zirconium Industry: hafnium source

- Global market US$2-3B
- 2017 producer zircon inventories low
- Demand increasing/supply constrained
- CAGR anticipated at 3-5% pa for zirconium chemicals

China dominates downstream zirconium industry (Supply 75+%)
- Zirconium metal 5-6,000 tpa
- Nuclear zirconium metal 3,500 tpa

60 tpa Hafnium

Source: TCMS and Industry Sources

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Zr-Hf separation process

- Main source of hafnium is the Nuclear industry, where it must be removed from zirconium to produce hafnium free zirconium
- Main application is neutron-transparent fuel assemblies
- Most Hafnium supply is Nuclear industry dependent

Zr:Hf
50:1
1,000t : 20t HfO₂
17t Hf metal

Current world supply

2016 Hafnium supply
Estimated 70 tonnes

- By-product from zirconium metal purification
  - Depends on nuclear industry
- Prices escalating through demand by aerospace industries 2014 into 2015
- 3 western companies produce – hafnium (metal) from HfO₂
  - ATI (US)
  - Westinghouse (US)
  - Areva (France)
- Total world supply fits in a 40 foot shipping container

Source: Roskill ASM Internal report (draft)

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Historical hafnium pricing

Hafnium Pricing (2009 – 2017)

US$/kg

Time

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Resourcing tomorrow’s technology
Chinese zirconium metal capacities

<table>
<thead>
<tr>
<th>Company</th>
<th>Industrial Grade tpa</th>
<th>Nuclear Grade tpa</th>
<th>Nuclear Grade Expansion Plans by 2020 tpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>State Nuclear WEC</td>
<td>-</td>
<td>1,500</td>
<td>2,500</td>
</tr>
<tr>
<td>Guangdong Orient</td>
<td>600</td>
<td>150</td>
<td>1,000</td>
</tr>
<tr>
<td>Jinan H-Technology</td>
<td>0</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Others</td>
<td>1,400</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>2,000</td>
<td>1,750</td>
<td>4,200</td>
</tr>
<tr>
<td>Hafnium supply</td>
<td>0</td>
<td>30</td>
<td>70</td>
</tr>
</tbody>
</table>

- Chinese zirconium metal production ~1,500 tpa - 2014 (mostly industrial grade)
- China’s strategy is to be self-sufficient in nuclear power plants
- Maximise value adding across supply chain (same as for rare earths)
- China will require all hafnium for its own industry
1. Zirconium chemicals
   - Dealing with U+Th waste residues for ZOC production
     - ZOC production of 210,000 tpa requires 130,000 tpa zircon
     - Contains 65 tpa of U+Th
     - Where does it go now and in the future?
   - Occupational health and safety issues for workers
   - Environmental compliance is becoming increasingly difficult
   - 1/3rd of Chinese ZOC industry shut down in April 2017

2. Fused zirconia
   - Regulations require <500 ppm U+Th for USA or Japan
     - China and exports elsewhere?
   - Chinese Fused zirconia production of 45,000 tpa requires 70,000 t of zircon with U+Th <300 ppm to obtain U+Th <500 ppm
   - Where will premium zircon come from?
China: Critical Supply Issues to 2025

Made in China 2025 aims at substitution
Semi-official targets for the domestic market share of Chinese products (in per cent)

- New energy vehicles
- High-tech ship components
- New and renewable energy equipment
- Industrial robots
- High performance medical devices
- Large tractors above 200 hp and harvesters
- Mobile phone chips
- Wide-body aircrafts

Source: Expert Commission for the Construction of a Manufacturing Superpower

Source: European Chamber of Commerce, China

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## China Manufacturing 2025: A warning

### Ambitious goals: 10 advanced industries & technologies
- US$100Bs of support: subsidies, funds, and "other"
- Move away from low value, and polluting industries to manufacturing for high value markets
- Avoid the middle income trap: being squeezed between developed and developing countries
- Race to get rich before growing old: 400 million ageing baby boomers
- Targeting 70-80% domestic supply: large scale import substitution

### Factory of the world (2015)
- 90%+ of world's mobile phones
- 80%+ of world's air-conditioners
- 80%+ of world's computers
- 60% of world's colour TV sets
- Half of the world's steel
- 50%+ of world's refrigerators
- 41% of world's ships
- 28% of world's automobiles
- 24% of world's power, &
- 20% of global manufacturing

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China: Critical Supply Issues to 2025

Under Pressure: Industrialised countries will feel the heat of Made in China 2025
Vulnerability of select industrial countries to Made in China 2025

Source: European Chamber of Commerce, China

Source: European Chamber of Commerce, China

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Resourcing tomorrow’s technology
China: Critical Supply Issues to 2025

1. China Manufacturing 2025 is targeting 70-80% domestic supply by 2005 for key high value markets
   • Critical supply risk for rare earths as China supplies 90+% of world supply
   • High growth rates for magnets will reduce supply for export- China will need to be a net importer

2. China’s rare earth industry is US$3-4 billion, with a US$30-40 billion environmental clean up legacy
   • Rare earth prices will need to double in order to pay environment clean up costs over 10 years

3. With 40-50% of all rare earths coming from illegal mining: Western companies need to become accountable
Current global demand

2016 Hafnium demand
Estimated 67 tonnes

Major markets (global output by weight):

- Superalloy (60%)
- Plasma cutting tips (15%)
- Nuclear control rod (11%)
- Catalyst precursor (7%)
- Semiconductors (3%)
- Oxide for Optical (3%)

Source: Roskill ASM Internal Report (draft)
Other potential hafnium demand

1. Reusable spacecraft
   - Hafnium offers extreme heat and creep resistance
   - SpaceX uses C103 -10% hafnium & 90% niobium metals
   - Blue Origin, NASA, European Space Agency
   - U.K. Space agency, Russia/China/India/other

2. Thermoelectric generators

3. High temperature refractories

4. Hafnium carbide cutting tools

5. HfO₂ nanoparticles in radiation oncology

6. Radiative cooling
Hafnium Demand outlook 2016 - 2026

Depends on existing producers + expanded Russia/China supply

- Not sufficient for base-case demand growth
- Will impact price or substitution endeavours
- Constrained or abundant: If supply is more abundant demand may emerge from new sectors

Forecast demand increasing to 152tpa by 2026 (CAGR +5.3%)

Projected Hafnium Demand tpa

Source: Roskill ASM Internal Report (draft) CAGR min 2.4%pa low supply constrained to max 8.5%pa high supply unconstrained *5.3% base supply expanded

Alkane’s Dubbo Project is the only supply option not tied to nuclear industry and Chinese zirconium industry
Dubbo Project

- Large polymetallic resource - zirconium, hafnium, niobium (tantalum), yttrium and rare earths
- Defined resource supports 80+ years at 1 m tpa
- Pilot Plant at ANSTO has operated since 2008
- All State & Federal environment approved
- Outotec Finnish technology & engineering solutions company to present a fixed price EPC
- Sumitomo Mitsui Banking Corporation financial advisors
- Modular design option (halves CAPEX costs and output) for lower risk
- Dubbo infrastructure – roads, rail, power, gas, light engineering, people (pop~45,000)

DUBBO PROJECT IS CONSTRUCTION READY
A new Hf supply – Dubbo Project

- Hafnium concentrate has been successfully produced on the hafnium pilot plant at ANSTO from the zirconium refining circuit
- Orebody contains \( \sim 450 \text{ ppm hafnium oxide} \)
  - 1 million tpa production rate \( \times 450 \text{ ppm} = 450 \text{ tpa} \)
  - 50% recovery: \( \sim 200 \text{ tpa of hafnium oxide} \) (95% HfO\(_2\))
  - Initial start up output of 50 tpa
- Potential to increase hafnium supply as
- Independent of zircon and nuclear industry
- Sustainable and traceable supply
- Urban mining to recycle end of life materials
Modular Design

Construction 2017 - 2019
Estimated cost US$480M

Construction 2022 - 2023
Estimated cost US$360M

Estimated total Cost US$840M

Legend - Built to a production capacity of:
- 1 Mtpa
- 500 Ktpa
- 250 Ktpa

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Product Output

Dubbo Project Process Plant

- Rare earth chemical concentrate: 95% REO, 6,664 tpa (REO units)
- Zirconium as ZBC (carbonate) & zirconia: 99% ZrO₂, 16,374 tpa (ZrO₂ units)
- Hafnium as HfO₂ concentrate: HfO₂ conc, 50 tpa * (Hf units)
- Niobium as ferro-niobium: 65% Nb, 1,967 tpa (Nb units)

Total output approximately 25,200 tpa of all products

Tonnage based upon recoveries developed from mass balances of the demonstration pilot plant.

* Start up output: 200tpa potential depending upon market demand
Rare Earth Output

Tonnage based upon recoveries developed from mass balances of demonstration pilot plant, & preliminary solvent extraction stages on site at the DP. Total saleable RE products from site ~1,030 tpa and off site ~ 1,675 tpa.
Conclusions

Ideal Hafnium Supply Scenario?

- Independent of nuclear fuel industry
- Independent of Zircon
- Independent of Chinese zirconium industry
- Sustainable and traceable supply
- Urban mining to recycle end of life materials
- Complementary other technology metals
- Low sovereign risk
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Competent Person
Unless otherwise stated, the information in this presentation that relates to mineral exploration, mineral resources and ore reserves is based on information compiled by Mr D I Chalmers, FAusIMM, FAIG, (director of the Company) who has sufficient experience which is relevant to the style of mineralisation and type of deposit under consideration and to the activity which he is undertaking to qualify as Competent Person as defined in the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves. Ian Chalmers consents to the inclusion in the presentation of the matters based on his information in the form and context in which it appears.
### Dubbo Project – Mineral Resources

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Tonnage (Mt)</th>
<th>ZrO₂ (%)</th>
<th>HfO₂ (%)</th>
<th>Nb₂O₅ (%)</th>
<th>Ta₂O₅ (%)</th>
<th>Y₂O₃ (%)</th>
<th>REO (%)</th>
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<tbody>
<tr>
<td>Measured</td>
<td>35.70</td>
<td>1.96</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.75</td>
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<tr>
<td>Inferred</td>
<td>37.50</td>
<td>1.96</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.75</td>
</tr>
<tr>
<td>Total</td>
<td>73.20</td>
<td>1.96</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.75</td>
</tr>
</tbody>
</table>

These Mineral Resources are based upon information compiled by Mr Terry Ransted MAusIMM (Alkane Chief Geologist) who is a competent person as defined in the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves. Terry Ransted consents to the inclusion in the report of the matters based on his information in the form and context in which it appears. The full details of methodology were given in the 2004 Annual Report.

### Dubbo Project – Ore Reserves

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Tonnage (Mt)</th>
<th>ZrO₂ (%)</th>
<th>HfO₂ (%)</th>
<th>Nb₂O₅ (%)</th>
<th>Ta₂O₅ (%)</th>
<th>Y₂O₃ (%)</th>
<th>REO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proved</td>
<td>8.07</td>
<td>1.91</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.75</td>
</tr>
<tr>
<td>Probable</td>
<td>27.86</td>
<td>1.93</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.74</td>
</tr>
<tr>
<td>Total</td>
<td>35.93</td>
<td>1.93</td>
<td>0.04</td>
<td>0.46</td>
<td>0.03</td>
<td>0.14</td>
<td>0.74</td>
</tr>
</tbody>
</table>

These Ore Reserves are based upon information compiled by Mr Terry Ransted MAusIMM (Alkane Chief Geologist) who is a competent person as defined in the 2012 Edition of the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves. The reserves were calculated at a 1.5% combined ZrO₂+Nb₂O₅+Y₂O₃+REO cut off using costs and revenues defined in the notes in ASX Announcement of 16 November 2011. Terry Ransted consents to the inclusion in the report of the matters based on his information in the form and context in which it appears.

**Note:** ASX announcements 16 November 2011, 11 April 2013, 30 October 2013 and 27 August 2015 - the Company confirms that all material assumptions and technical parameters underpinning the estimated Mineral Resources and Ore Reserves, and production targets and the forecast financial information as disclosed continue to apply and have not materially changed.