Chemical Elements for South Africa's Future

NSTF

National Science & Technology Forum

Rare Metals in New Technologies

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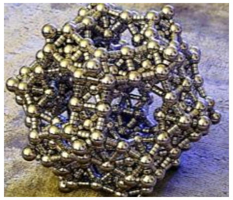
18 March 2019

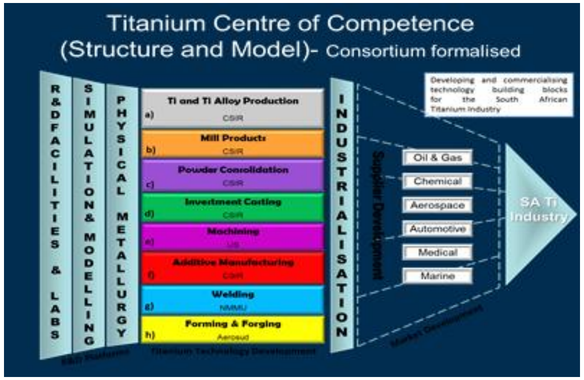
our future through science

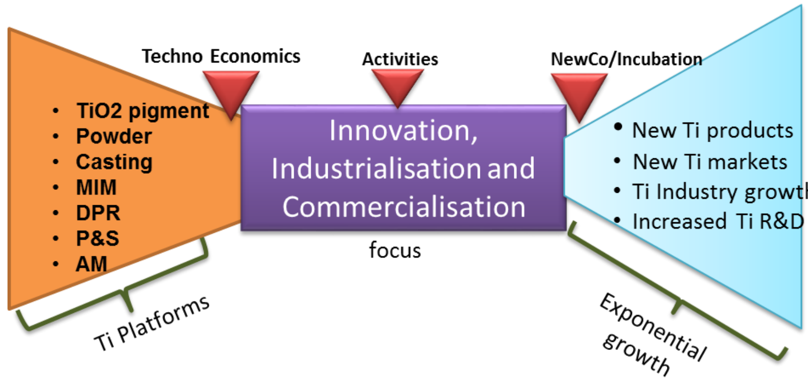
What are “Rare Metals”?



- **1.** Rare metals are defined according to the relative **abundance** of the chemical elements in the Earth’s upper continental crust.
- Total of **89 existing elements** in the natural world – over **half** of the elements are rare metals.
- Ti, Mn, Cr, which are found in abundance are sometimes also considered to be rare metals.
- **2. Ti** is considered a “rare” metal because it is a difficult metal to produce as high technology is required for refining the abundant ore in form of titanium oxide.
- Au and Ag which have been in existence since ancient times are not generally called rare metals.

Ti Beneficiation in SA





Ti Beneficiation Plan

Outcomes

- Techno-entrepreneurships created and reduced Ti price
- R4-5 bn Powder industry
- Usable knowledge generation and sharing
- Established sustainable and competitive SA Ti industry
- Established manufacturing capabilities and increased artisanal skills
- Economic growth and job opportunity/creation in SA
- Ti products improving the quality of life
- Continued innovation, built SA confidence and enhanced socio-economic benefits

Education, Training and Skills Development
- Exponential increase in post graduate students
- Special Training of interns, technicians etc
- Oversees training and exposure
- Researchers/student exchange
- Establishment of Research chairs
- Retention of TiCoC students and staff

Industrialisation and Commercialisation
- Piloting and industrialisation activities
- Incubation platform (NewCo)
- Spin out and technology transfer
- Impact Driven plan

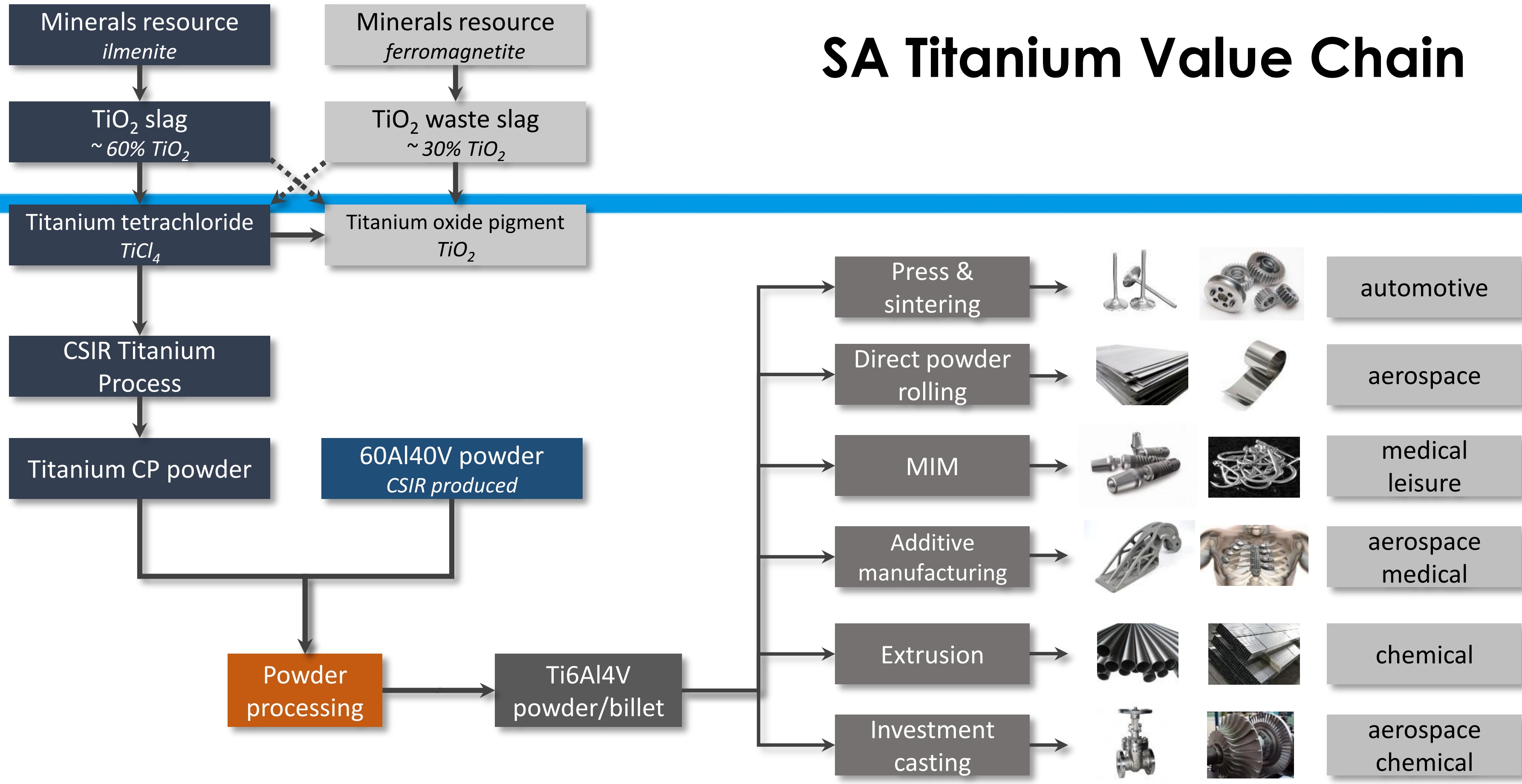
Marketing and Networking
- Marketing the Centre
- Marketing our products
- Website Development

Governance
- Advisory
- Steering Committee
- Consortium formalised
- Terms of reference/charter draft
- Triple helix and national priorities

Eight Point Plan (Technology Interconnectedness)
- Alignment of projects in the TiCoC value chain
- Acceleration mechanism
- Strong partnerships with key players

5 Pillars of the Plan

SA Titanium Value Chain



TITANIUM POWDER PRODUCTION

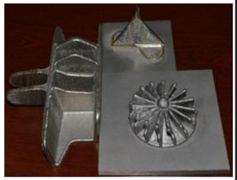
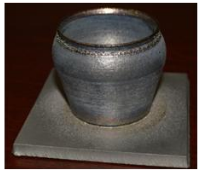
MANUFACTURING TECHNIQUES

TYPICAL PRODUCTS

TYPICAL INDUSTRY SECTORS

TRL 3	TRL 5	TRL 3	TRL 5	TRL 5	TRL 6	TRL 2	TRL 4	TRL 6-7
• Market size • dti-R4bn • Industrial facility • Various applications • 2 X SMME's	• Continuous • Pilot Plant • Batch • Upgrade • Powder Production • Quality…. • MoA Tronox	• CSIR produced • Quality met • Scale up • Rig designed • R2m investment • 1X SMME	• CSIR produced • Scaled up • Techno economics • Patent filed • 1X SMME	• CSIR produced • Scaled up • Techno economics • Versatility • O2 content • R30M GA • 1 X SMME	• Proven technology • Market size • CSIR feedstocks • Few parts produced • R10m furnace • 1-2 SMMEs	• Proven process • Automotive parts • Still at optimisation stages • 1 X SMME	• Proven process • Ability to make mill products • Semi-industrial facility • 1 X SMME	• CSIR know how • The facility is world class • Several components produced
Industrial Nano-TiO2	**Primary metal powder**	**Master alloy (Al60V40)**	**CSIR Ti64 alloy powder**	**CSIR Ti64 alloy billets/mill**	**MIM (eg Fish hooks)**	**P&S (eg. Auto part)**	**DPR (eg Ti Sheet)**	**Ti Investment casting**

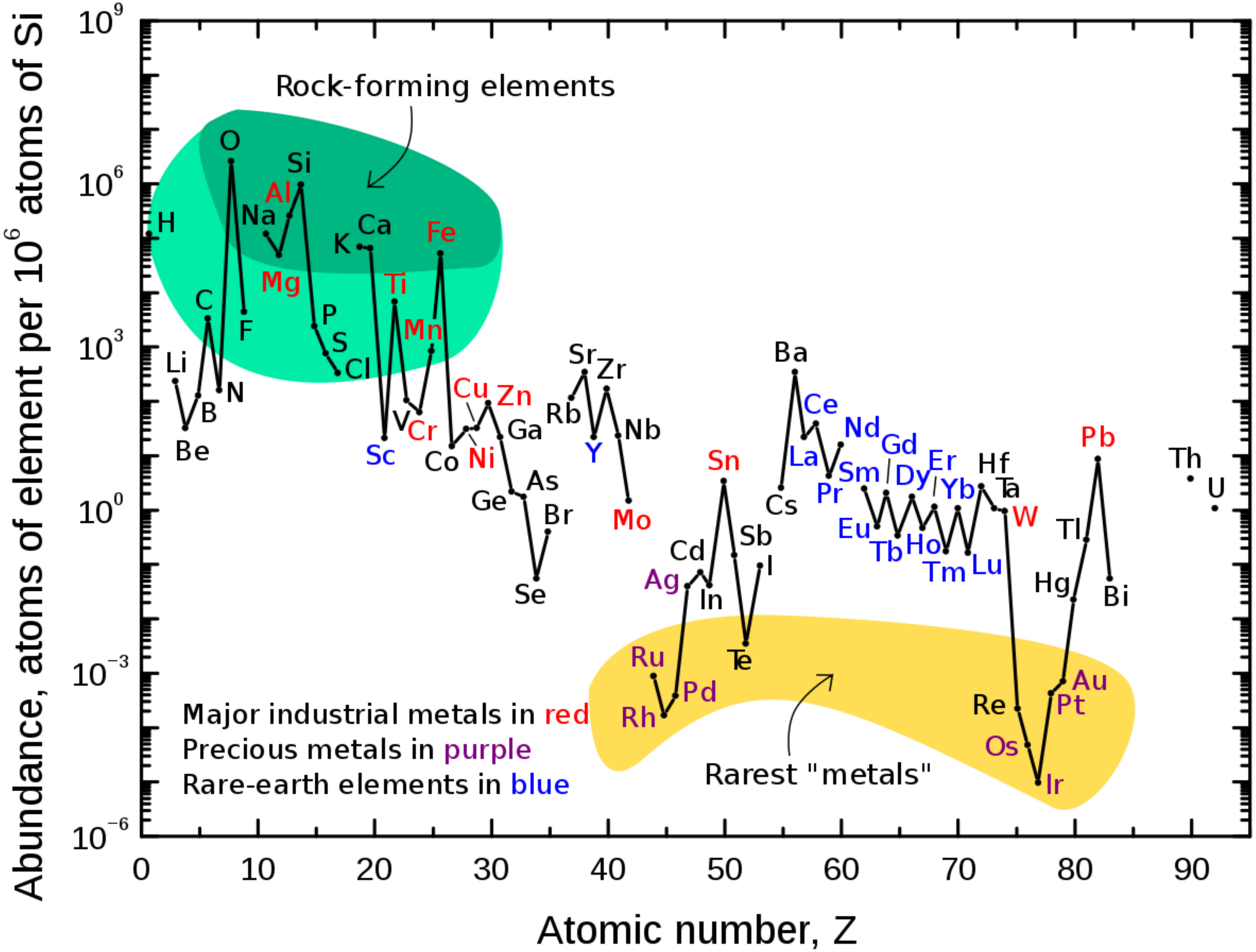
Ti Powder- Examples

Ti6Al4V Route	Powder	AM Component
1. Mechanical Alloying – 12.5kg	1. 	1. No fabricated component yet
2. Homogenisation Process – 15kg	2. 	2. No fabricated component yet
3. Commercial Billet- 280Kg	3. 	3.  
4. Free Forming – 37kg	4. 	4.  
5. Press and Sinter – 17.5kg	5. 	5.  

Rare metals

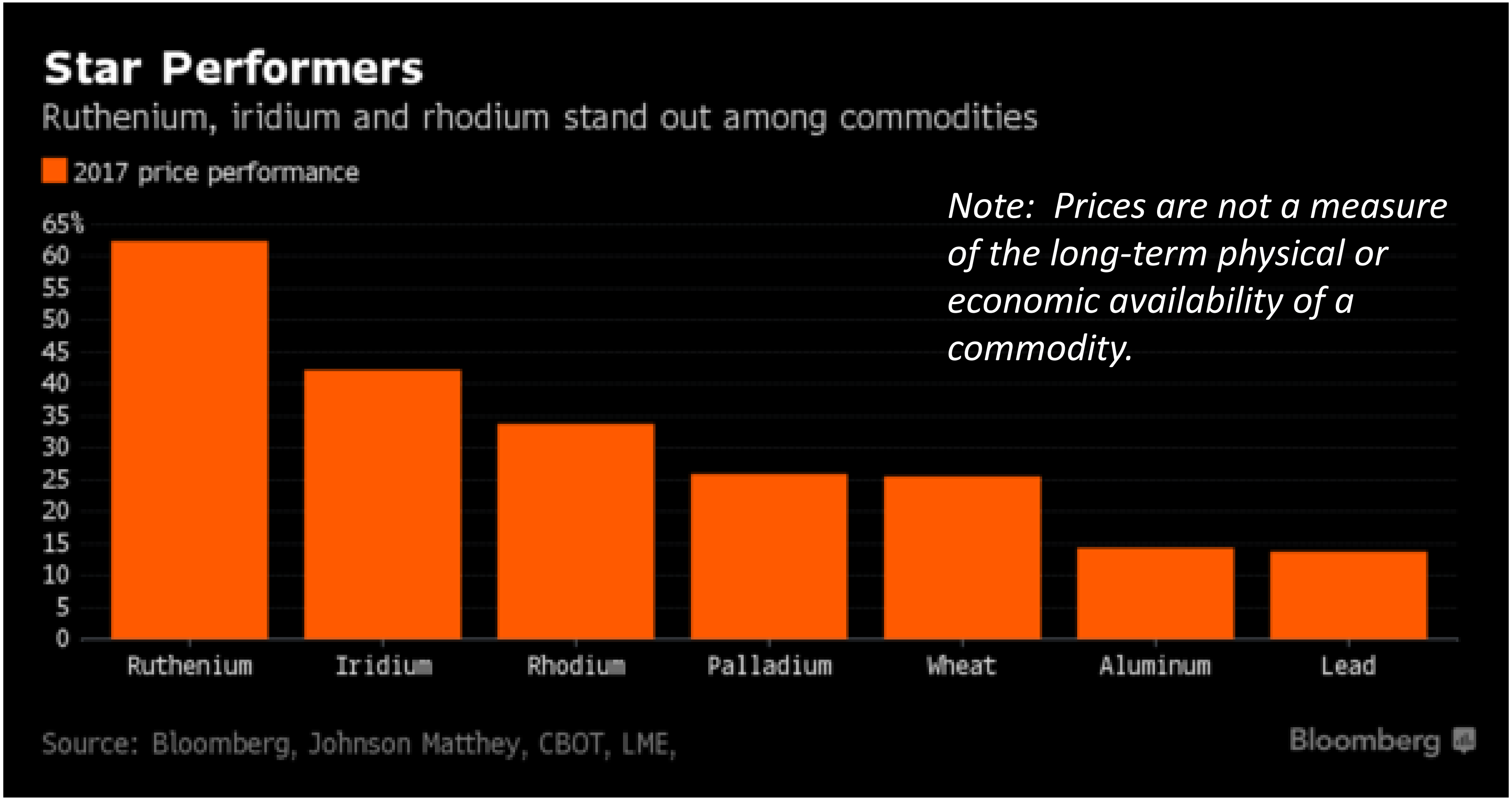
- Lithium and titanium are what David Abraham, author of ***The Elements of Power***, calls rare metals — *elements whose total annual production can fit into just a few rail cars.*
- "We don't realize that the products we need today are more tied to the ground than ever," "And the green products themselves are even more tied because of the materials that the rely upon."
- Rare metals are also essential to the hardware of clean energy — wind turbines, solar panels, and home batteries.
- As demand for green technologies rises, so will demand for rare metals.

"Rarest" Metals



Ru – Ruthenium
Rh – Rhodium
Pd – Palladium
Te – Tellurium
Re – Rhenium
Os – Osmium
Ir – Iridium
Pt – Platinum
Au – Gold

Rare metals – Price Performance



Note: Prices are not a measure of the long-term physical or economic availability of a commodity.

Importance of Materials

Economy

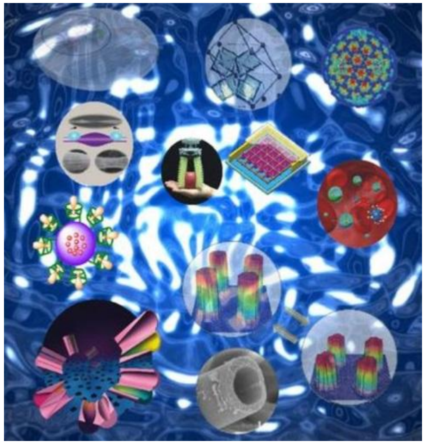
- Materials (including metals) are the pillar upon which most manufacturing is built and create more high skilled jobs per income earned.

Societal Needs

- Address need for better environmental stewardship, increasing water & energy usage, decreasing health & nutrition.

The complexity of modern materials

- Unlike normal materials which are generally classified according to their chemical bonding, advanced materials are often classified according to function or scientific classification:
  - Multi-functional materials
  - Multi-structural materials
  - Metamaterials & artificially structured functional materials
  - Nano-enabled materials
  - Bio and bio-based materials
  - Materials with target surface properties
  - Metals (incl. amorphous metals, etc.)
  - Ceramics (Incl. cement, glasses & reinforced composites)
  - Polymers
  - Soft materials



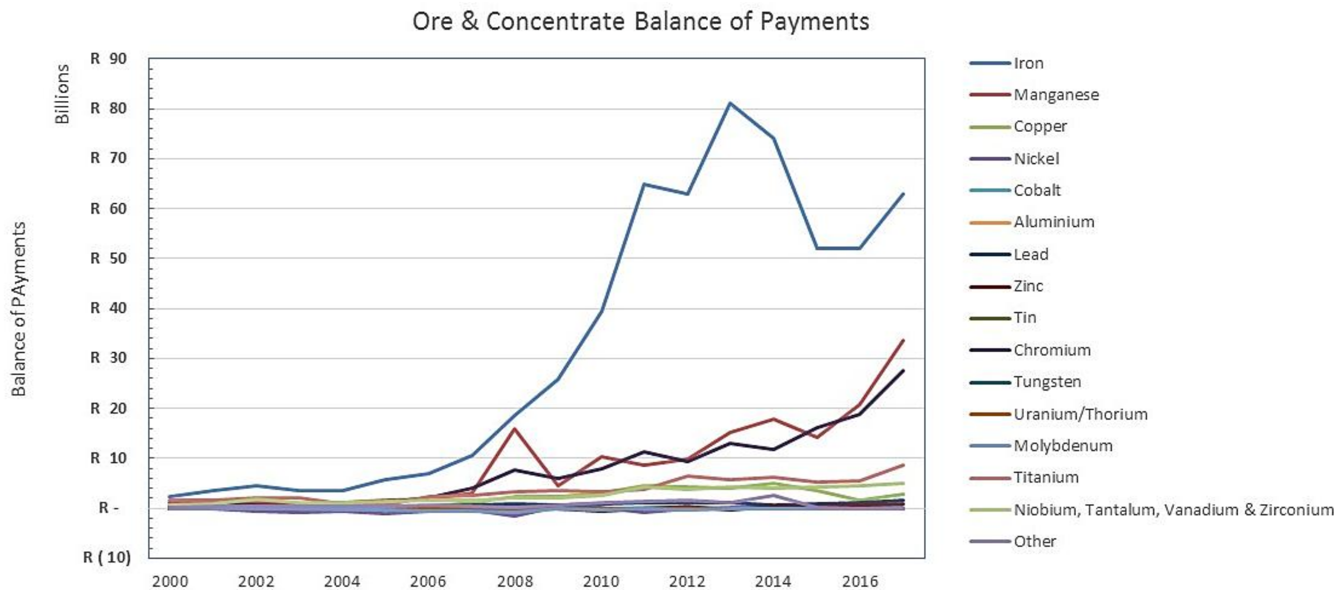
Global Markets for Advanced Materials

- Key Markets for Advanced Materials by 2030[1]:
  - Energy (€37.0 bn)
  - Environment (€ 86.8 bn)
  - Healthcare (€55.0 bn)
  - ICT (€70.7 bn)
  - Transport (Aerospace, Automotive, etc.) (€ 24.3 bn)
  - Other (€42.2 bn)
- Globally advanced materials will contribute $557 Billion per annum to broader materials sector by 2022.
- 13% per annum growth vs 3% for conventional materials.

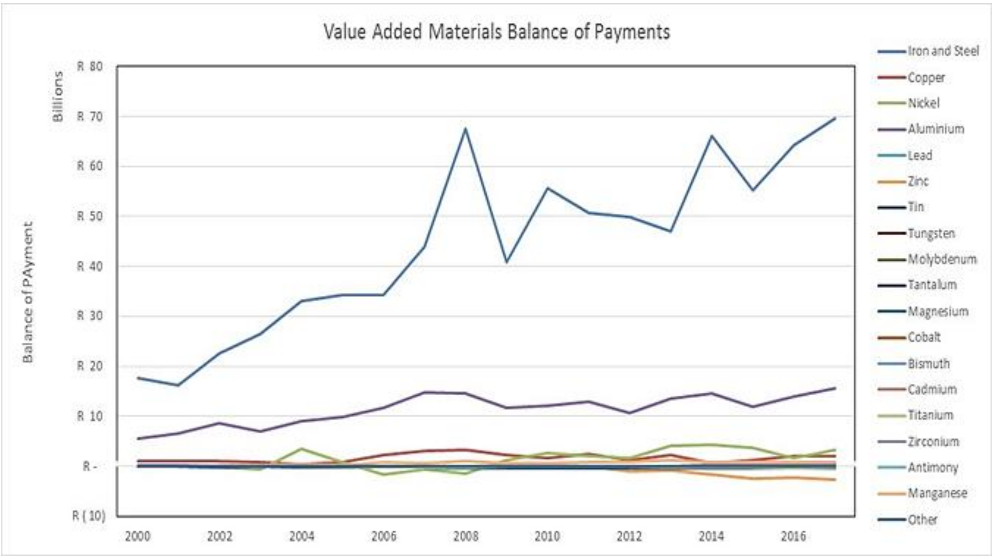
[1] **EU Report, Technology & Market Perspectives for future Value Added Materials, 2012**

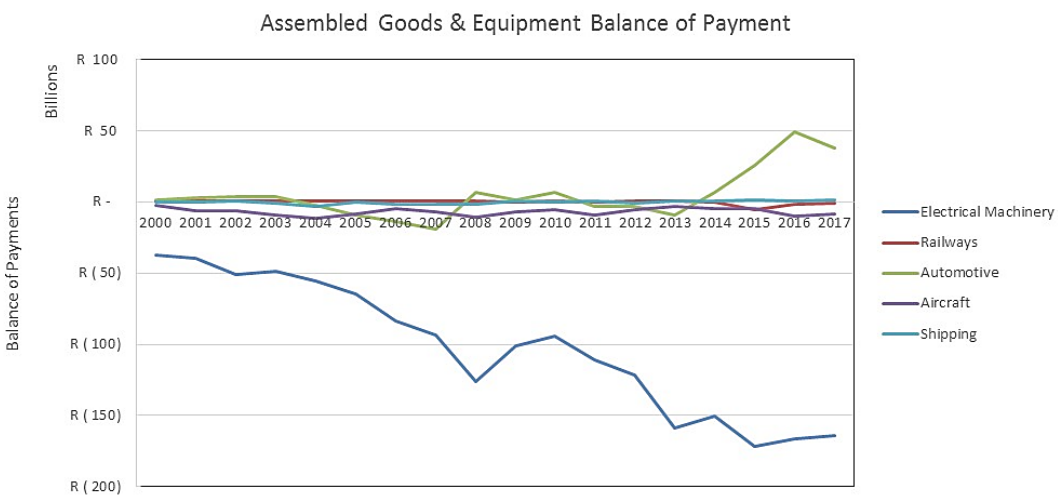
South African Overview

- **Importance of the sector**
- Raw materials contribute ~R48.1 billion while value added materials contribute ~R142.9 billion to the countries GDP(2017).
- The industry employs >500,000 people (2017).
- Significantly beneficiate local resources.



South African Overview



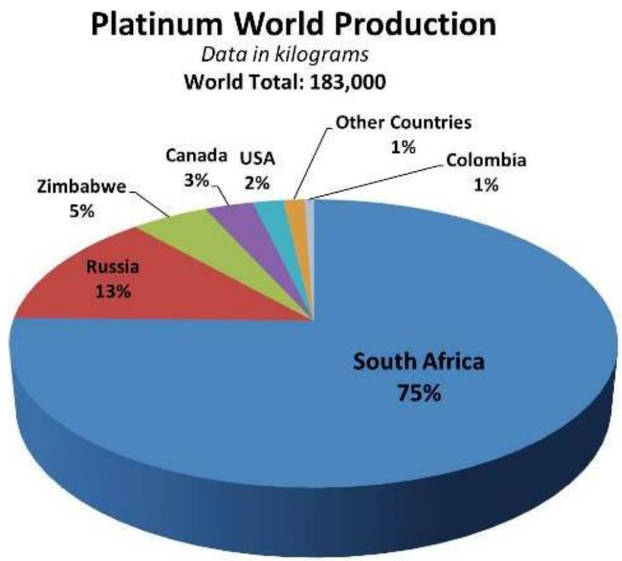


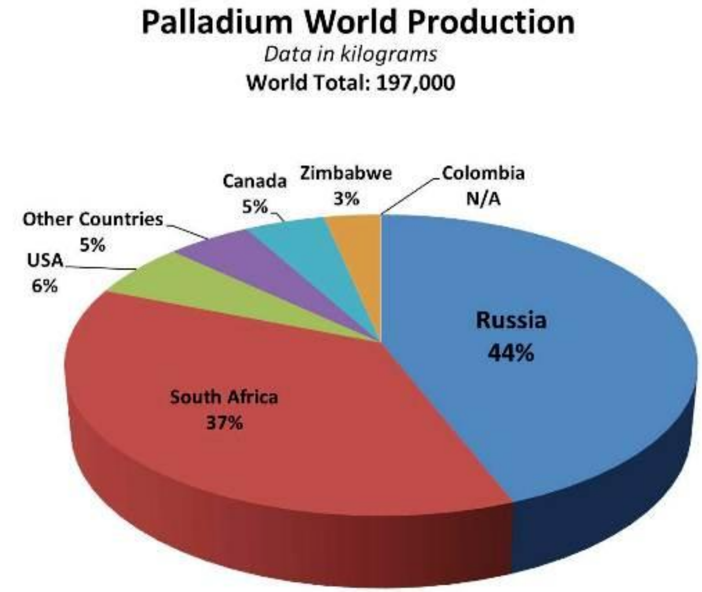
Balance of Payments graphs

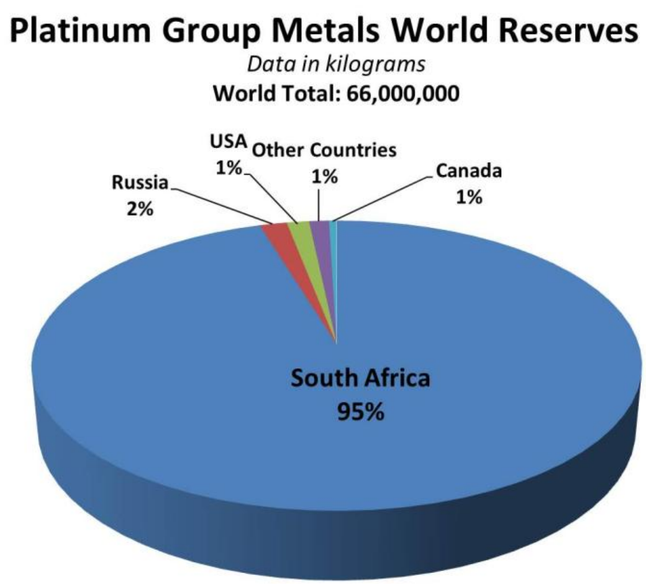
- **Ore & Concentrates** still the biggest influence
- **Value Added Materials** are low to stagnant
- **Assembled Goods & Equipment** are stagnant to negative

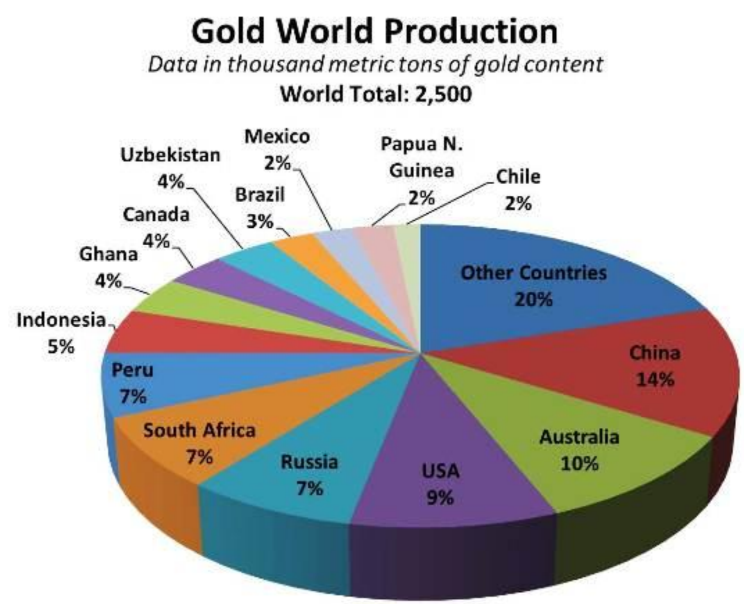
South Africa

- Ru – Ruthenium
- **Rh – Rhodium**
- **Pd – Palladium**
- Te – Tellurium
- Re – Rhenium
- Os – Osmium
- Ir – Iridium
- **Pt – Platinum**
- **Au – Gold**









Rare Metals

- Problematically, many rare metals are only mined as **by-products of more common minerals**.
- Selenium and tellurium are extracted from copper slag. As a by-product, they are cheap to produce. Mined on their own, they would be **prohibitively expensive**. Thus, even as the demand for rare metals increases, supply could remain static.
- **Production Steps**
  - Extract total metal values
  - Separate and purify the Individual rare earth elements
  - Reduce the purified separated individual metals to high purity metals
  - Alloy the metals
  - Manufacture components from the alloys

Common Technologies – current

TECHNOLOGY	KEY CHEMICAL ELEMENTS
Grid storage batteries	Lithium, Vanadium
Fuel cells	Platinum group metals, Lanthanum, Cobalt, Cerium, Gadolinium
Nuclear power	Indium, Cobalt, Gadolinium
Vehicle light-weighting	Magnesium, Titanium
Gas turbines	Yttrium
Catalytic converters	Platinum group metals, cerium
Photovoltaic cells	Indium, Gallium, Tellurium, Silver, Ruthenium
Thermo-electrics	Tellurium, various REE's

Technologies – current

- Rare metals are not only used in electric vehicles. They are used in alarm clocks, television sets and desktop PC's.
- Some electric toothbrushes contains **35** different metals.
- iPhone contains **half the elements found on Earth**.

Platinum – uses

- **Platinum Catalytic Converter**
- Catalytic conversion – Perhaps platinum's most common use is in the automotive sector as a key material for catalytic converters

- **Computer parts** – Hard disks, used within computers to store data, are partially made of platinum. Platinum works in the disks to boost the magnetic properties and therefore increase storage capacity. With the rise of the digital age, platinum is in higher demand than ever for making hard disks.
- **Oil refining** – Platinum's catalytic abilities are also used on crude oil to extract gasoline.
- **Jewellery** – Platinum is resistant to tarnishing and its lustre is unmatched. For these reasons, it's highly desirable for engagement rings and other forms of fine jewellery.

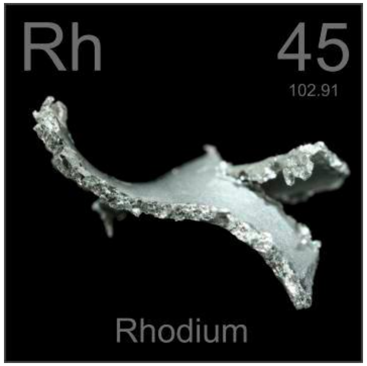
Palladium

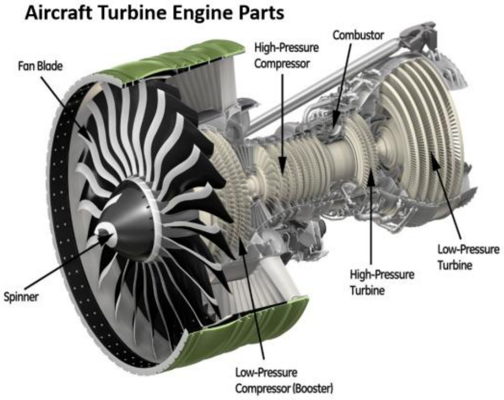
- Palladium is similar to platinum in several ways including coloration, hardness, and catalytic capabilities
- **Catalytic converters** – Like platinum, palladium is used as a catalytic converter in automobiles and other engines; however, palladium is cheaper.
- **Electronics** – For some cell phones and laptops, palladium is used in ceramic capacitors which help devices store charge.

- **Medical needs** – In some instances, palladium is combined with gold to create dental inlays and other orthodontic devices. Additionally, since palladium doesn't appear to show hostility toward the human body, scientists are researching palladium isotopes for treating certain types of cancers.
- **Jewellery** – While similar in appearance to platinum, palladium is not quite as dense and is more affordable. Plus, palladium and platinum don't tarnish like silver.

Rhodium

- Besides being a key component in the car industry, some of **Rhodium's** other principal uses are:
- glass making;
- as a finish for mirrors and jewellery;
- in electrical connections;
- and in aircraft turbine engines.
- **82% of world rhodium supply** comes from South Africa





Summary

PLATINUM	PALLADIUM	IRIDIUM	RHODIUM	RUTHENIUM
				
Automotive Jewellery Glass Chemical Investment Oil Drug	Automotive Electronics Dental Investment Jewellery Chemical	Automotive Electrochemistry Electronics	Automotive Glass Chemistry	Electro- chemistry Electronics
Catalysts Sensors Meshes Glass fiber bushings Bars/ coins Chemotherapy	Catalysts Dental alloys Bars/ coins	Spark plugs Crucibles for electronic industry Semiconductors	Catalysts Components/ alloys glass industry	Harddrives Anode coating

Emerging technology trends in 2019

- **Autonomous Things**
  - Robots, drones, and autonomous vehicles fall into the class of autonomous things, all of which use AI (Artificial Intelligence) technology
- **Empowered Edge**
  - Empowered Edge uses endpoint devices such as an individual's phone, as well as devices embedded around us.
- **Smart Spaces**
  - The report defines a smart space as an "environment in which humans and technology-enabled systems interact in increasingly open, connected, coordinated and intelligent ecosystems."
- **Quantum Computing**
  - Quantum computing (QC) is a type of nonclassical computing that operates on the quantum state of subatomic particles (for example, electrons and ions) that represent information as elements denoted as quantum bits (qubits).

New manufacturing technologies

- **Additive Manufacturing**
  - Advancements in additive manufacturing can help industry reduce energy costs, limit waste, and boost production.
- **Collaborative Robots**
  - The Robotics Industries Association (RIA) defines collaborative robots, also known as “cobots,” as robots specifically designed to work side-by-side with humans within a defined collaborative workspace.
- **Smart Manufacturing**
  - With machine learning and analytics now more readily available via CNC machines, manufacturers can use smart manufacturing to improve productivity and efficiency.

Challenges associated with new technologies

- **Cybersecurity**
  - Companies that don’t have a cybersecurity plan can start to protect their operations and their customers’ confidential information. For instance, while CNC machines have helped manufacturers grow, they also provide more computer access points for potential hackers and the time has come to start to address these vulnerabilities.
- **Workforce Development**
  - Technology advances offer numerous opportunities for the future of workforce development. Even now, employees who used to do repetitive assembly or inspection tasks taken on by robots are advancing their careers into higher-level positions that require problem-solving skills.

Raw materials for emerging technologies 2016

- Commissioned by the German Mineral Resources Agency at the Federal Institute for Geosciences and Natural Resources, Berlin
  - ISBN: 978-3-943566-39-0 (Print)
  - ISBN: 978-3-943566-38-3 (PDF)
  - ISSN: 2193-5319
- It is necessary to have a sound and up-to-date knowledge base about possible demand developments in mineral raw materials in order to better estimate possible long-term price and supply risks.
- In particular, key and emerging technologies that are resource-intensive or resource-sensitive can trigger strong demand impulses and have a significant influence on commodity markets.

Global metal demand for selected emerging technologies

Metal	$Demand_{20xx}/Production_{2013}$		Emerging technologies
	2013	2035	
Lithium	0.0	3.9	Lithiumion batteries, lightweight airframes
Heavy rare earths (Dy/Tb)	0.9	3.1	Magnets, e-cars, wind power
Rhenium	1.0	2.5	Super alloys
Light rare earths (Nd/Pr)	0.8	1.7	Magnets, e-cars, wind power
Tantalum	0.4	1.6	Microcapacitors, medical technology
Scandium	0.2	1.4	SOFC fuel cells
Cobalt	0.0	0.9	Lithium-ion batteries, XtL.
Germanium	0.4	0.8	Fiber optic, IR technology
Platinum	0.0	0.6	Catalysts, seawater desalination
Tin	0.6	0.5	Transparent electrodes, solders
Palladium	0.1	0.5	Catalysts, seawater desalination
Indium	0.3	0.5	Displays, thin layer photovoltaics
Gallium	0.3	0.4	Thin layer photovoltaics, IC, WLED
Silver	0.2	0.3	RFID
Copper	0.1	0.3	Electric motors, RFID
Titanium	0.0	0.2	Seawater desalination, implants

Development of global production of selected metals 1993-2013

Metal	CAGR %/a	Growth factor from 1993–2013
Aluminium (R)	4.5	2.4
Iron (M)	5.7	3.0
Germanium (R)	6.2	3.3
Indium (R)	8.9	5.5
Cobalt (M)	8.6	5.2
Copper (M)	3.4	2.0
Copper (R)	3.5	2.0
Lithium (M)	4.8	2.6
Palladium (M)	3.3	1.9
Platinum (M)	1.4	1.3
Rhenium (M)	3.5	2.0
Rare earths (M)	2.8	1.7
Silver (M)	2.8	1.7
Tantalum (M)	6.5	3.5
Titanium (M)	0.7	1.1
Tin (M)	2.2	1.5
Tin (R)	2.6	1.7

M: mined
R: refined production

Technology analyses - summary of the results

	Emerging technology	Chemical elements	Status of tech-nology 2013				Market 2035			Resource demand 2035			Recycling potential 2035			
			Research	Development	Prototype	On the market	Introduction	Penetration	Saturation	non-critical	intensive	sensitive	Yes	Limited	No	No, dissipative
Automobile manufacturing, aerospace, transport technology																
1	Lightweight steel construction with tailored blanks	Al, Mg, Ti		X					X	X			X			
2	Electric traction motors for hybrid, electric and FC cars	Nd, Dy, Pr, Tb (magnets); Cu				X		X			X	X	X			
3	PEM-fuel cells for electric vehicles	Pt		X				X			X		X			
4	Super capacitors for vehicles	Al		X				X		X				X		
5	Alloys for lightweight airframes	Al-Mg-Sc, Al-Li				X		X		X			X			
6	Automatic piloting of road vehicles	Nd, Y, Al			X		X				X			X		
7	Unmanned aircraft for commercial applications	Al-Mg-Sc-Zr (body); Rb, Cs, K (sensors)			X			X		X				X		
Information and communication technology, optical technologies, micro technologies																
8	Lead-free solders	Sn, Ag, Cu, Bi, Zn, In, Ni, Ge, Au, Pt, Sb				X			X		X			X		
9	RFID – Radio Frequency Identification	Ag, Cu, Al (antennas); Si (chips)				X			X	X					X	
10	Indium-tin-oxide (ITO) in display technology	In, Sn, Sb				X			X	X				X		
11	Infrared detectors in night vision equipment	V, Li, Nb, Pb, Ge, La, Sc, Nb, Ta				X		X		X					X	
12	White LED	Ga, In				X		X		X					X	
13	Fiber optic cable	Ge (doping)				X		X		X					X	
14	Microelectronic capacitors	Ta, Nb, Mn, Sb, Ag, Pd, Ni, Ti, Sn, Ba				X			X	X				X		
15	High performance microchips	Ga, As, Ge, Cd, Te				X			X	X					X	

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Energy, electrical and drive technologies																
16	Ultra efficient industrial electric motors	Cu				X			X	X			X			
17	Thermoelectric generators	Te, Sb, Ge, Ag, Bi, Pb, Si, Hf, Zr, Mn, Co, Ni, Fe, Sn, Sb, Ru			X			X			X			X		
18	Dye-sensitized solar cells	Ru (dyes); Ti (carrier); Sn, In, Pt, Ag (electrodes)			X			X		X				X		
19	Thin-layer photovoltaics	Semiconductor: Cu, In, Se, Ga, Te, Cd,				X			X	X				X		
20	Solar thermal power stations	Al, Ag (mirrors)			X			X		X			X			
21	SOFC – Stationary fuel cells	Y, Zr, Sc (solid electrolytes); Y, Zr, Sc, Ni, La, Sr, Mn (electrodes)			X			X			X			X		
22	CCS – Carbon Capture and Storage	Cr, Ni, Co, Mn, Mo, V, Nb (heat-resistant steel)		X				X		X			X			
23	Lithium-ion high performance electricity storage systems for passenger cars	Li; Co, Mn (cathodes)				X		X			X		X			
24	Redox flow batteries for storage	Cr, V			X			X		X			X			
25	Vacuum insulation	Si (core); Al (casing); lead-free solders (windows)		X				X		X				X		
26	Inductive transmission of electrical energy	Cu				X		X		X			X			
27	Thermal storage	K, Na, Li, Ca, Si				X		X		X			X			
28	Micro-energy harvesting of ambient energy	Sb, Se, Sn, Cr, Ti, Cu, Nd, Dy, Co				X			X	X				X		
29	Wind power plants	Nd, Dy, Tb, Pr (magnets/generators); Cu				X		X			X		X			

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Chemical, process and production technology, environmental technology, mechanical engineering																
30	Synthetic fuels	Co, Pt			X			X		X			X			
31	Seawater desalination	Al, Cr, Fe, Mn, Mo, Ni, Pd, Ti, V (stainless steel)				X		X		X			X			
32	Solid state lasers for industrial manufacturing	Nd, Y, Er, Yb (lasers)				X		X		X				X		
33	Nano-silver	Ag				X		X		X						X
Medical engineering																
34	Medical implants	Ti, Co, Cr, Mo				X		X		X				X		
35	Medical tomography	Gd (sensors, contrast mediums)				X		X		X			X			
Materials technology																
36	Superalloys	Ni, Co, Cr, Mo, W, Re, Ta, Nb, Hf				X		X			X		X			
37	High-temperature superconductors	Y, Bi, Tl, Hg, Sr, Ba, Ca, Cu			X			X		X			X			
38	High-performance permanent magnets	Nd, Dy, Tb, Pr				X		X			X			X		
39	Industry 4.0	Li, La, Sc, Nb, Ta, Ge, Pb (sensors)		X				X			X		X			
40	Carbon fiber reinforced plastics	*Potential reduction of global steel demand*				X		X			X			X		
41	CNT (carbon nanotubes)	*Potential reduction of global metal demand*	X					X		X					X	
42	Additive production („3D printer")	Cu (electric motors)				X		X		X			X			

Conclusions

- In general, the following measures may be considered to ensure the supply of raw materials to industry:
- Expansion **and improved efficiency** of ore mining or metal extraction,
- **substitutions** at the level of materials and technologies,
- **resource efficiency** in production and use,
- **recycling, ensured by recyclable designs**, recirculation strategies and efficient recycling technologies.
- When developing **new technologies**, existing options to ensure the supply of raw materials should be an integral part of the basic planning considerations.

Government/National Initiatives

energy
Department: Energy
REPUBLIC OF SOUTH AFRICA

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

the dti
Department: Trade and Industry
REPUBLIC OF SOUTH AFRICA

water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

- Solar Energy Technology Roadmap
- Advanced Manufacturing Technology Roadmap
- South African Additive Manufacturing Technology Roadmap
- South African Titanium Metal Industry Strategy
- South Africa’s Water Research, Development, and Innovation Roadmap: 2015-2025
- BioEnergy Atlas for South Africa
- Dirisa (data-intensive research infrastructure for south africa): A Roadmap for South African Research Data Infrastructures
- National Space Strategy
- South African Aluminium Industry Roadmap
- etc.

Challenges facing South African industries

- Import driven product, assembled goods and equipment sector
- Global sourcing by OEMs dictate volume spread
- Lack of large product or equipment programmes to drive development of advanced materials/metals
- Length of the supply chain and the cost of doing business
- Conservative nature of local industry
- Infrastructure inefficiencies and lack thereof
- Labour matters and a skilled workforce
- Increase regulation of materials/metals environmental compatibility
- Economic competitiveness issues
- Reliant on imports to move further up the value chain
- Lack of adequate skills & design capabilities
- Materials and process qualification & testing to ensure quality
- Implementation of Industry 4.0 paradigms

SWOT analysis

STRENGTHS	WEAKNESSES
• Largest value add metals market in Africa • Largest manufacturing and materials industry in Africa • Significant natural resources	• Protection of local value add materials providers • Lack of large programmes to drive materials RDI • RDI Collaboration across NSI • Conservative local industry leading to low local demand • Qualification and Testing Capabilities
OPPORTUNITIES	**THREATS**
• Water scarcity • Environmental and Waste concerns • Increasing cost of energy • Attractive export base • Existing but limited expertise and capabilities • Regional market	• Global competition • Long export supply chain • Significant international RDI funding in advanced materials sector • Uptake of new manufacturing technologies & paradigms (Industry 4.0) • International environmental controls

Thank you

Comments/Questions?