MINERALS IN AFRICA

Opportunities for the Continent's Industrialisation

Francis P. Gudyanga

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Figure 0.1 Map of Africa with countries and their capital and major cities

Source: www.shutterstock.com/search/africa+map

Foreword

Modern industry and enterprises rely on a variety of materials for functional economies, jobs and for improving the quality of life. Reliance on access to a growing number of materials has been necessitated by rapid technological progress which requires hi-tech goods. The origins of these materials include metallic ores as well as industrial minerals which anchor downstream industries. Thus, products derived from minerals are intrinsically linked to most industries across all supply chain stages, and consequently are essential to our societies. These products are growing in complexity and sophistication with a concomitant increase in the number and breadth of raw materials used in their production.

The African continent is richly endowed with minerals from which these industrial products are derived. Thus, Africa's export-oriented mining and quarrying is driven primarily by the commodity hunger of the world's largest economies. There is incessant concern that Africa is not receiving fair prices for its minerals on the global market. It has now become obvious that the greatest loss to Africa has resulted from the exportation of these minerals as raw ores or concentrates. To appreciate this fact, one has to look at the low status of the African economies, and contrast this with the contribution to world economies by minerals from Africa and the extent of colonial plunder of these minerals.

The increasing global need for minerals as industrial inputs has led to a sustained production of primary metals worldwide, as well as greater interest in mineral exploration in Africa. Ore deposits are being obtained with increasingly complex mineralogy and metallurgical properties as the more easily treatable resources are depleted. However, Africa is not exploiting to its own benefit the full potentials represented by this mineral wealth. The exploitation of minerals from Africa has been used to achieve advanced economic developments in the rest of the world, reflecting how they can, and should, be used for Africa's industrialisation.

The continent of Africa is today facing a NEW (North East West) colonial invasion, which is just as devastating in scale and impact as that from which it suffered during the nineteenth century. As before, the new colonialism is driven by a determination to plunder the natural resources of Africa, especially its strategic energy and mineral resources. There is a long-term involvement of the governments of the industrialised countries, through their trade and investment policies, to manoeuvre their foreign companies' access to African raw materials.

Therefore, the continent's minerals present a unique opportunity for cooperation between African countries when negotiating for favourable trade terms and prices with foreign industrialised countries. If Africa is to leapfrog into the technological advancement of the twenty-first century, the continent needs to develop, in concert, an adequate number of indigenous materials scientists, engineers and related professionals who will actively contribute to finding solutions to continental trading problems.

Africa's greatest need in the minerals industry is value addition. This has been recognised by the African leaders who have made pronouncements on the matter at various national, regional and continental fora. It is fortunate that Professor Gudyanga, an African metallurgist and materials scientist of notable expertise and breadth of technological skills has been prevailed upon to write such a book. We believe that his book will prove to be of great value to applied and practising metallurgists and materials scientists who wish to become engaged in the beneficiation/extraction and value addition of minerals found in Africa. This book will be useful also for those primarily responsible for policy issues pertinent to mining in Africa, who wish to know more about the formulation and implementation of suitable policies for the furtherance of Africa's industrialisation. This was envisaged by the African Mining Vision of 2009 in which were expressed aims of having the continent pursue "a transparent, equitable, and optimal exploitation of mineral resources to underpin its broad-based sustainable growth and socio-economic development".

The bridging of the gap between the so-called 'technical' and 'policy' dimensions of mining in Africa is essential for the rapid industrialisation of the continent. Professor Gudyanga has done a great service in helping to break down this wholly artificial barrier in one area at least. This is in sync with Agenda 2063 which is the blueprint and master plan for transforming Africa into the global powerhouse of the future, founded on the African Union (AU) Vision of "an integrated, prosperous, and peaceful Africa, driven by its own citizens and representing a dynamic force in the international arena".

The writing of this book was inspired by the desire to promote the continent's mineral-driven industrialisation by integrating information on African minerals, their beneficiation/extraction and value addition with mineral policy-oriented issues. It was also informed by concepts and continent-wide deliberations that resulted in the establishment, in 2016, of the Pan African Minerals University of Science and Technology (PAMUST), which is co-located with the Scientific and Industrial Research & Development Centre (SIRDC) in Harare, Zimbabwe. The aims and objectives of that university is to provide advanced and appropriate training in geosciences, metallurgy, mining engineering, materials science and engineering and mineral-enabling ICTs, as well as mineral economics. It is our considered view that the ideas expressed in this book are very relevant to PAMUST and SIRDC, and indeed to other institutions on the continent with similar programmes.

It gives me great pleasure to recommend this book to all who are interested in the mineral-driven industrialisation of Africa.

Professor Christopher J. Chetsanga

Founding Fellow and Inaugural President of the
Zimbabwe Academy of Sciences (ZAS)

Fellow of both the African Academy of Sciences (AAS) and
The World Academy of Sciences (TWAS)

Preface

Africa's dire need to industrialise is acknowledged continent-wide and it is evident that the continent's vast mineral resources can catalyse that industrialisation. This requires Africa's promotion of local beneficiation and value addition of minerals to yield materials on which modern Africa's industry and society can rely. This book is, therefore, about transforming Africa's comparative advantages in mineral wealth into the continent's competitive edge regarding materials. Mineral beneficiation and value addition form the basis and provide opportunities for mineral-driven industrialisation of Africa. The scope of this book is three-fold with interconnected relationships: information, technical, and policy oriented issues. For this reason, the book is organised into three parts as follows.

Part I: Information about minerals in Africa

This part is comprised of the first chapter of the book, Chapter 1, which presents a panoramic overview of minerals found on the African continent. The information about the minerals in Africa is summarised in Table 1.1 and Table 1.2. Table 1.1 lists the minerals found in each African country. Conversely, Table 1.2 lists the African countries in which a specific mineral is found. Underground mineral deposits may be found to stretch across territorial boundaries that are recognised on the surface. The map of Africa, Figure 0.1, in conjunction with Tables 1.1 and 1.2, provide information of geological and economic interest for neighbouring countries. The presence of a mineral in one country is a pointer to the likely possibility of that mineral being present in the neighbouring country, if it has not been identified already.

The chapter also serves as an introduction to the whole book, pointing out the paradox of the vastness of the mineral resources on the African continent and the poverty of its citizens. It is observed that these African mineral resources have been critical ingredients to the industrialisation of countries other than the continent itself. Reference is made to the efforts by African leaders to adopt and embrace appropriate strategies that can add value to mineral resources and resultantly improve the lives of citizens in African countries. It is the view of the current African leaders that the mining sector is a potential driving engine for the continent's development and industrialisation.

Part II: Mineral beneficiation and value addition

This part details, in eight chapters, the technical exploitation of about 120 minerals in different African countries. These 120 minerals are clustered into the following respective eight chapters: (2) precious metals, (3) base metals, (4) radioactive materials, (5) industrial

minerals, (6) precious stones, (7) semi-precious stones, (8) dimension stones, and (9) energy sources.

For each mineral a general brief *overview* is given covering its origins and geological occurrences on the earth's crust. In the case of metallic ores, the form in which the metal is found is given. Some metals like gold may exist as native metal, perhaps alloyed to a greater or lesser extent with other metals. For other metallic ores, the chemical compositions in which a metal exists with other elements is described.

The overview on the geological aspect of the mineral is followed by a description of its beneficiation. The term *beneficiation* in this book is used to refer to the entire processing of mineral-bearing ores to produce commercial end-products. In this case beneficiation starts with the process of removing gangue materials from the mineral ore to produce a higher-grade product (concentrate) and a waste stream (tailings). The sequential stages are: particle size reduction, separation of particle sizes, solid/liquid separation and concentration techniques which may be gravity separation, froth flotation, electrostatic and magnetic separation processes, as well as optical sensors. The beneficiation process ends with the recovery of the valuable product.

In some textbooks on extractive metallurgy the term beneficiation refers strictly only to the aforementioned processes. This is followed, for metallic ores, by *extraction* processes to recover the metals from concentrates produced by the mineral processing referred to prior. The extraction processes may be pyrometallurgical or hydrometallurgical and final recovery. Pyrometallurgy consists of the thermal treatment of minerals, metallurgical ores and concentrates to enable recovery of valuable metals in pure form or as intermediate compounds or alloys, suitable as feed for further processing. Hydrometallurgy is a technique involving the use of aqueous chemistry for the recovery of metals from ores, concentrates and recycled or residual materials. Hydrometallurgy is typically divided into three general areas: leaching, solution concentration and purification, as well as metal recovery which is achieved by electrowinning, precipitation, electrorefining, electroplating or electroforming.

The basic beneficiation and extraction processes in this section can be further learnt from textbooks on extractive metallurgy. In this Part II the essential ideas are described concisely in order to present the theory in the form in which it is to be used, and here a moderate knowledge of chemistry is assumed. Depending on the nature of the mineral, such as its mineralogy, all or some of the previously mentioned stages may be involved. In this book suitable techniques and technologies in each stage are described for the beneficiation of each mineral.

Lastly, the production of individual mineral concentrates/metals and fabrication of finished products, as well as the uses of each mineral and/or materials derived from them are described. This section is collectively termed *value addition*. The words *beneficiation* and *value addition* are often used interchangeably. In this book, a very subtle but key differentiation is made; beneficiation refers to the processing of mineral-bearing ores to produce concentrates or intermediate products, while value addition is the production of individual metals and fabrication of finished products, which have a much larger multiplier effect on the economy. Value addition therefore feeds-off and is subsequent to beneficiation/extraction; in other words, without beneficiation/extraction there can be no value addition.

Part III: Policy issues about mining in Africa

The last three chapters in Part III of the book discuss the contexts under which these minerals are, or can be, exploited: (10) mineral-driven Africa's industrialisation, (11) science and technology and (12) mineral economics.

Chapter 10 discusses the role that minerals can play in Africa's industrialisation. Observation is made on how the minerals from Africa have been successfully exploited by other countries for the benefit of their economies. Value addition is identified as an imperative for Africa's industrialisation. This issue leads to the discussion in Chapter 11 on the role of science and technology coupled to the need to the training of the critical mass of scientists, engineers, and the broad issue of the role of higher education for socio-economic development of the continent. Chapter 12 deals with mineral economics in the context of historical plunder of African minerals in colonial and neocolonial periods, dynamics of global trade, environmental issues, current corporate ownership of African minerals, taxations, investments and desirable governance policies. The purpose of these last three chapters is to create the conditions in which the advancement of Africa's industrialisation can take place notwithstanding the glaring underdevelopment of the continent in the context of current global challenges and opportunities.

The intended readership of the book is intentionally varied in an attempt to address the aspirations of stakeholders in and beyond the mining industry including, but not limited to: governments (who through their role as regulators, play a crucial role in enabling mining companies to maximise their contribution), investors, contractors and suppliers, service providers, mining-affected communities, civil society organisations, organised labour and academia and research institutions as well as downstream users. It is intended to inform the generality of the African public with policy and decision makers as a special target by providing basic information about what and how minerals can best contribute to the industrialisation of individual countries in Africa. Mineral economists can advise stakeholders on the trade and market opportunities for the mineral value-added products.

It is hoped that the book will be a useful reference material for mining undergraduate students on beneficiation and value addition of each of the minerals found in Africa. The book, while presenting a broad overview of beneficiation and value addition of Africa's minerals, provides crucial starting material for postgraduate research students and R&D institutions who wish to delve into more advanced methods of beneficiation/extraction and utilisation of mineral-derived materials that are in Africa for the purpose of industrialisation of the continent.

The overall desired contribution of the book is the promotion of full value addition of Africa's minerals, the production of mineral products that fetch premiums in their markets, create jobs, grow the economy and ultimately lead to better qualities of life for most people in Africa. The aspirations of the African citizens can only be met when the continent's minerals have been transformed locally into materials desired by the rest of the global society. This will be realised when Africa has transitioned from a resource-based economy into acknowledge-based economy. For Africa to transition from a resource-based economy to a knowledge-based economy demands significant investments in science and technology, at levels unprecedented in our continent's history.

Francis P. Gudyanga
2020

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I am very grateful to the former President of the Republic of Zimbabwe, Cde. R.G. Mugabe, for appointing me (during the years 2007–2017) Permanent Secretary of the Government of Zimbabwe in the following three Ministries: Science and Technology Development; Mines and Mining Development; and Higher and Tertiary Education Science and Technology Development. Those appointments afforded me opportunities for gaining policy insights that crystallised into some of the ideas which have found expression in Part I and Part III of the book.

I am also grateful to Professor C.J. Chetsanga, Inaugural President of the Zimbabwe Academy of Sciences, Ambrose Made, a geoscientist and remote sensing expert, and Emeritus Professor Erik Navara, a colleague metallurgist at the University of Zimbabwe and SIRDC, for their valuable input and editorial corrections to the manuscript of the book. None of them, of course, is in anyway responsible for errors, misrepresentations and misinterpretations that may remain; these are mine alone.

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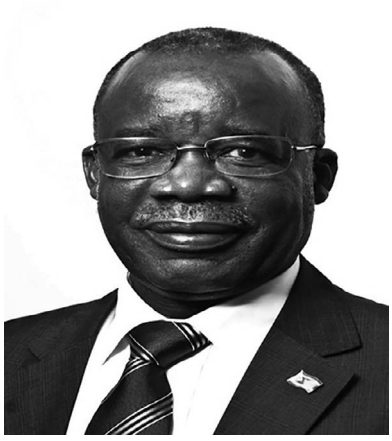
About the author



Francis P. Gudyanga

Professor Francis Gudyanga has a BSc (Hons) degree in *Applied Chemistry* from Hatfield Polytechnic (now University of Hertfordshire) (UK), MSc in *Analytical Chemistry* from Chelsea College, University of London, MPhil in *Metallurgy* from Brunel University, Uxbridge (UK). He obtained a PhD in *Mineral Technology* from the Royal School of Mines, Imperial College of Science, Technology and Medicine, University of London, concurrently with a DIC in *Electrochemical Engineering*. He is a metallurgist and applied chemist with over 30 years' experience in the minerals industry covering plant operations, management, R&D at institutions in the UK, South Africa and Zimbabwe, teaching university undergraduates and supervision of doctoral research students. His research interests are in extractive metallurgy, materials technology, and S&T policy. He serves on several national, continental and international committees and boards. He was a member of the Executive Board of the International Council for Science (ICSU), 2002–2008. He held senior positions in the Government of Zimbabwe including serving as Permanent Secretary for ten years in three ministries, namely: Science and Technology Development, Mines and Mining Development, and Higher and Tertiary Education Science & Technology Development. Professor Gudyanga is a past (2016–2019) President of the Zimbabwe Academy of Sciences.

Acronyms

2IE	International Institute for Water and Environmental Engineering
AAS	African Academy of Sciences
AAS	atomic absorption spectroscopy
ACS	American Chemical Society
ADPA	Association of African Diamond Producing Countries
AIME	American Institute of Mining, Metallurgical, and Petroleum Engineers
AISTs	African Institutes of Science and Technology
AMASA	Annual Meetings of African Science Academies
AMD	acid mine drainage
AMRS	African Materials Research Society
AMV	African Mining Vision
APFO	ammonium pentadecafluoro-octanoate
APT	ammonium paratungstate
ASTM	American Society for Testing and Materials (now ASTM International)
ATL	amine-treated lignite
AU	African Union
AUC	African Union Commission
AUST	African University of Science and Technology
BFS	bitumen feedstock
BGS	British Geological Survey
BMR	base metal refinery
BTU	British Thermal Units
CBM	coalbed methane
CCA	chromated copper arsenate
CCM	caustic calcined magnesite
CE	circular economy
CEPR	Centre for Economic Policy Research
ICSU	International Council for Science
CIGS	copper indium gallium (di)selenide
CIMFR	Central Institute of Mining & Fuel Research
CSEM	Case Studies in Environmental Medicine
CSIRO	Council for Scientific and Industrial Research Organisation
CSIR	Council for Scientific and Industrial Research
CSR	coke strength after reaction
CSR	corporate social responsibility

CTL	coal to liquid
CUTS	Consumer Unity & Trust Society
CVD	chemical vapour deposition
CZT	cadmium zinc telluride
DBM	dead burned magnesite
DC	direct current
DCL/ICL	direct/indirect coal liquefaction
DIC	Diploma of Imperial College
DME	dimethyl aether
DSA	dimensionally stable anodes
DU	depleted uranium
EASAC	European Academies Science Advisory Council
ECA	Economic Commission for Africa
EEC	European Economic Community
Eh-pH diagrams	Pourbaix diagrams
EIA	environmental impact assessment
EoL	end-of-life
FIR (4IR)	Fourth Industrial Revolution (Industry 4.0)
FM	fused magnesia
FPDs	flat panel devices
GAN	gallium nitride
GDP	gross domestic product
GIA	Gemological Institute of America
GIS	Geographical Information System
GPS	global positioning system
GTAW	gas tungsten arc welding
GTL	gas to liquids
HAZ	heat affected zone
HCC	hard coking coal
HDI	Human Development Index
HPHT	high-pressure high-temperature
HREE	heavy rare earth elements
HSLA	high-strength, low-alloy
HSS	high-speed tool steels
IAC	InterAcademy Council
IAP	InterAcademy Partnership
ICMM	International Council on Mining and Metals
ICP	Inductively coupled plasma
ICs	integrated circuits
ICTs	information and communication technologies
IFC	International Finance Corporation
IFG	insulation fibreglass
IGCC	integrated gasification combined cycle
IHERD	Innovation, Higher Education and Research for Development
IJERA	International Journal of Engineering Research and Application
IPCS	International Programme on Chemical Safety
IR	infrared

ISAMPE	International Symposium on Advanced Mechanical and Power Engineering
ISG	International Study Group
ISO	International Standards Organisation
ITO	indium tin oxide
ITS	international temperature scale
IUGS	International Union of Geological Sciences
IUPAC	International Union of Pure and Applied Chemistry
KPCS	Kimberley Process Certification Scheme
LCD	liquid crystal diode
LCT	Li – Cs – Ta pegmatite
LD	lethal dose
LEDs	light-emitting diodes
LME	London Metals Exchange
LNG	liquefied natural gas
MARID	mica-amphibole-rutile-ilmenite-diopside
MG-Si	metallurgical grade silicon
MIC	microwave integrated circuits
MINTEKA	metallurgical R&D institute in South Africa
MIS	Management Information System
MMO	mixed-metal oxide
MOVPE	metalorganic vapour phase epitaxy
MSA	material system analysis
MTG	methanol to gasoline process
NASAC	Network of African Science Academies
NdYAG	neodymium yttrium aluminium garnet
NGL	natural gas liquids
NMAIST	Nelson Mandela African Institute of Science and Technology
NiMHB	nickel metal hydride batteries
NMI	The Nelson Mandela Institution
NIST	National Institute of Standards and Technology
OECD	Organisation for Economic Cooperation and Development
OEMs	original equipment manufacturers
OPEC	Organisation of petroleum exporting countries
PAMUST	Pan African Minerals University of Science and Technology
PCI	low pulverised coal
PFOA	pentadecafluoro-octanoic acid
PGE	platinum group elements
PGMs	platinum group metals
PHCC	premium hard coking coal
PMR	precious metal refinery
PPPs	public-private partnerships
PTFE	polytetrafluoroethylene
PV	photovoltaics
PVC	polyvinyl chloride
PWR	pressurised water reactor
R&D	Research and Development