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**Debottlenecking
of Processes**

Engr. Adebayo B.
Olanrewaju, MNSE



**Semiconductor
Innovations**

Engr. Abdulfatai
Faro, MNSE



Leadership

Engr. Dr. AbdulRasheed
Babalola, FNSChE



**THE IMPACT OF
CHEMICAL
ENGINEERING
PRACTICE ON
NIGERIA'S
INDUSTRIALIZATION**



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NSChE VISION



“To be the Center of excellence for the Chemical Engineering Profession in Africa and the Prime Mover of Industrialization in Nigeria”.



NSChE MISSION



“To organize the Nigerian Society of Chemical Engineers into a virile professional body capable of promoting the relevance and versatility of the profession, achieving better training and updating of Chemical Engineers through its activities. Fostering of relationships with the academia, research institutes, industries, other professional bodies and government will be the basis for stimulating accelerated industrialization of the country and improving the quality of life of the Nigerian people”.

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 Engr. Ben Akaakar (*Assistant Editor*)
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All correspondence to:
 The Editor-in-Chief

NSChE National Secretariat: Infinite Grace House. Plot 4, Oyetubo Street, (4th Floor)
 Off Obafemi Awolowo Way, Ikeja, Lagos. **Tel:** 09035764128, 08023911323

Email: nsche_headquarters@yahoo.com, nationalhqtrs@nsche.org, nscheoffice@gmail.com

Website: www.nsche.org

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FROM THE

Editorial SUITE

We successfully crossed over to year 2026 with heightened hope for greater achievements as individuals, a professional society and a nation. The year is still young but it is not too early to do an appraisal and see how we can forge ahead relentlessly. By way of appraisal, we can say boldly that the Nigerian Society of Chemical Engineers (NSChE) is forging ahead with attention on the following prioritized activities as presented by Engr. Anthony Ogheneovo, Executive Secretary of NSChE in the Executive Secretary's column:

- i. Strengthening professional registration and membership growth
 - ii. Organizing annual conferences and technical exhibitions
 - iii. Expanding sectoral group activities
 - iv. Promoting mentorship for young chemical engineers
 - v. Facilitating industry-academia collaboration
- Some of these activities are placed in this edition in memorable pictures. The list includes the following:
- i. Visit to the MD/CEO of Renaissance Africa Energy Company Ltd
 - ii. Induction of the University of Lagos Chemical Engineering Graduating Class of 2025
 - iii. NSChE's 55th Annual Conference in November 2025
 - iv. Visit to the CEO of Nigerian Midstream & Downstream Petroleum Regulatory Authority

The communique issued at the end of the 55th Annual Conference/Annual General Meeting held in November 2025 in Enugu is placed in this edition for record and follow-up actions.

At this juncture, let us go back a bit into history. Precisely, I like to cite the Handbook of Nigerian Society of Chemical Engineers published in November 2004, inter alia, "The Nigerian Society of Chemical Engineers was formed in 1969 by a group of Nigerian Chemical Engineers who had trained abroad and returned to Nigeria to practise. The initial idea was conceived by Engr. Olu Awoyinka (now late) and Engr. Ayo Solanke, both of whom were process engineers in Lever Brothers Nigeria Limited (whose name was later changed to Unilever Nigeria Plc.). They discussed the



Engr. Donatus Uweh, FNSChE
(Editor-in-Chief)



idea with their boss. Engr. Anthony Shobo who gave his blessing. The preliminary meetings were held in the residence of Engr. Shobo and when the place became inadequate, they then moved to BP House (later AP House), Broad Street, Lagos".

NSChE has since been waxing stronger and stronger promoting professional discipline and ethics in the practice of Chemical Engineering. This professional and ethical disposition has resulted in great contributions to industrial development of Nigeria. In his short treatise on the topic, "The Impact of Chemical Engineering Practice on Nigeria's

Industrialization", Engr. Dr. AbdulRasheed Babalola, FNSChE, FNSE, shares the impact of Chemical Engineers on Nigeria's industrialization journey to date. It is an insightful piece worth reading.

Part of what shows that a country is industrializing is the presence of operating factories producing various products for local consumption and export. Producing without bottlenecks is the delight of factory management and what leads to the overall growth of the company and the national economy in general. Bottlenecks in production processes are removed by a process called "debottlenecking". In this edition, an experienced Chemical Engineering Consultant Engr. Adebayo Olanrewaju, provides a novel approach to debottlenecking. This is a case of 'old school' giving way gradually to 'new school'. Follow Engr. Olanrewaju's new school of thought on debottlenecking in this edition.

Significant advances in industrialization is what Nigeria needs. The semiconductor industry has a great potential in this respect. This is the assertion of an expert on the subject. He is Engr. Abdulfatai Faro. Check for details inside.

The second presentation on LEADERSHIP by Engr. Dr. AbdulRasheed Babalola is placed in this edition. He is a Chemical Engineering educator who is keen on sharing his thoughts on leadership. Learn as you read. Finally, we thank all the contributors to the successful publication of this edition. We urge you to continue to partner with us.

Relax and enjoy your reading!

Engr. Donatus Uweh, FNSChE
Editor-in-Chief

SYNOPSIS ON ACTIVITIES OF NIGERIAN SOCIETY OF CHEMICAL ENGINEERS (NSChE)

1.0 NSChE MEMBERSHIP AND REGISTRATION

NSChE provides several membership categories for professionals and students in chemical engineering. Admission is done quarterly, in January, April, July, and October. Please visit www.nsche.org for your online application.

a. Membership Categories

- i. Student Member – For students in Chemical Engineering program of studies
- ii. Affiliate Member – For professionals in related science/engineering fields
- iii. Associate Member – For HND holders with training in chemical engineering
- iv. Graduate Member – For holders of a B.Sc./ BEng. in Chemical Engineering after graduation / undergoing training
- v. Corporate Member – For practising engineers with at least 4 years of post NYSC professional experience
- vi. Fellow (FNSChE) – Awarded to distinguished engineers with 20+ years experience, a minimum of 10 years as a corporate member, and significant contributions to the Society

b. Key Benefits

- i. Access to the NSChE Journal and e-library
- ii. Attendance of Annual Conference
- iii. Professional development, through Chapters and Sectoral Group activities
- iv. Job opportunities

2.0 NSChE ANNUAL INTERNATIONAL CONFERENCE

The NSChE Annual International Conference, Exhibition and AGM is the society's largest professional gathering

a. Latest Conference: 56th Annual International Conference

Theme: "Advancing Nigeria's Industrial Revolution through Gas Valorisation and AI-Driven Engineering Imperatives"

Date: 12–14 November 2026

Venue: Obi Nwali Centre, Port-Harcourt



*Engr. Anthony Ogheneovo, FNSChE, FNSE
(Executive Secretary, NSChE)*

Activities include:

- i. Technical sessions, Panel discussions, Industry exhibitions, Industrial technical tours, Spouse program, Fellowship Investiture, Awards, Golf competition etc....
- ii. Registration: Registration fees are: Fellow: N60,000; Corporate Member N40,000; Graduate/ Associate/Affiliate N25,000; Student N15,000; Non-member N50,000; Foreign Delegate \$200
- iii. Early-bird discounts of 20% is available till 31st of July, 2026. Visit www.nsche.org/conference to register for the conference.

3.0 SECTORAL GROUPS (SG)

NSChE operates Sectoral Groups that focus on specific industry sectors to deepen the professional expertise of members.

Examples include:

- i. Petroleum Upstream Sectoral Group



“NSChE has strategic alliances with: Process Safety Initiative of Nigeria (PSIN), Nigerian Society of Engineers (NSE), Council for the Regulation of Engineering in Nigeria (COREN...”

- ii. Health, Safety & Environment (HSE) Sectoral Group
 - iii. Education & Research Sectoral Group
 - iv. Petroleum Mid/downstream Sectoral Group
 - v. Energy and Power Sectoral Group
 - vi. Agro, Pharm, and Bio Sectoral Group
 - vii. Consulting Sectoral Group
 - viii. IT & AI Sectoral Group
- These groups organise technical meetings, webinars and workshops, mini-conferences, industry research collaborations etc....

4.0 MENTORSHIP AND CAREER DEVELOPMENT

NSChE encourages structured mentorship between senior engineers and young professionals through:

- i. Mentorship Activities
- ii. Student chapters in over 30 universities offering Chemical Engineering program of studies
- iii. Young Graduate Engineers mentorship programs
- iv. Industrial attachment guidance
- v. Career development seminars
- vi. Professional competence preparation for NSE/COREN

These initiatives help students transition into professional practice

5.0 NSChE CHAPTERS & COMMUNITY ENGAGEMENT

The Society operates state chapters across Nigeria, allowing members to participate locally in:

- i. Monthly technical meetings
- ii. Industrial visits

- iii. Professional development workshops
- iv. Community engineering outreach programs
- v. Quiz for University students

6.0 PUBLICATIONS AND KNOWLEDGE SHARING

NSChE produces several knowledge resources:

- i. Journal of the Nigerian Society of Chemical Engineers (JNSChE)
- ii. e-Newsletter
- iii. Magazine
- iv. Technical conference proceedings
- v. Public lectures and seminars

7.0 STRATEGIC ALLIANCES

NSChE has strategic alliances with: Process Safety Initiative of Nigeria (PSIN), Nigerian Society of Engineers (NSE), Council for the Regulation of Engineering in Nigeria (COREN), Institute of Chemical Engineers, UK (IChemE), American Institute of Chemical Engineers (AIChE), National Organization for the professional advancement of Black Chemists and Chemical Engineers (NOBCCChE) etc.

In summary, NSChE currently focuses on:

- i. Strengthening professional registration and membership growth
- ii. Organizing annual conferences and technical exhibitions
- iii. Expanding sectoral group activities
- iv. Promoting mentorship for young chemical engineers
- v. Facilitating industry-academia collaboration

NSChE ACTIVITIES IN PICTURES



◀ The inauguration of the NSChE Deputy National President, Dr. Mrs. Francisca Nwafulugo (middle) at the Board Room of the National Secretariat of NSChE in Ikeja on January 24, 2026: From left to right, ES, Engr. Anthony Ogheneovo, PP, Prof. S.S Adefila, Dr. Mrs. Francisca, Nwafulugo, NP, Engr. Bayo Olarewaju-Alo and PP, Dr. N.J.D. Erinne

MD/CEO of Renaissance Africa Energy Company Ltd, Engr. Tony Attah (5th from left), his team and the President of NSChE, Engr. Bayo Olarewaju-Alo (4th from left) and his team after a meeting at the Renaissance facility in Ikoyi, Lagos on February 23, 2026



◀ Lagos/Ogun State Chapter Chairman, Engr. Olusegun Sodeinde and the ES, Engr. Anthony Ogheneovo at the induction ceremony of University of Lagos Chemical Engineering Graduating Class 2025 on January 19, 2026



◀ Chairperson of the opening ceremony of NSChE's 55th Annual Conference in Enugu on November 14, 2025, Lady Ada Chukwudozie (5th from right), National President, Engr. Bayo Olarewaju-Alo (6th from right), ES, Engr. Anthony Ogheneovo and other dignitaries who gave keynote addresses at the Conference



A group photo of NMDPRA and NSChE teams after their leadership meeting at the NMDPRA Headquarters in Abuja

CEO of Nigerian Midstream & Downstream Petroleum Regulatory Authority, Engr. Saidu Mohammed (R) exchanging pleasantries with the National President of Nigerian Society of Chemical Engineers, Engr. Bayo Olarewaju-Alo on January 13, 2026

▶ National President, Engr. Bayo Olarewaju-Alo (standing), at the press conference of the 55th Annual Conference in the International Conference Centre, Enugu on November 13, 2025





COMMUNIQUÉ OF THE 55TH ANNUAL CONFERENCE, EXHIBITION & AGM

HELD ON THE 13TH–15TH NOVEMBER 2025 AT THE INTERNATIONAL CONFERENCE CENTRE, ENUGU, NIGERIA

THEME: “THE ROLE AND CONTRIBUTION OF SMES TO NATIONAL INDUSTRIAL DEVELOPMENT AND GROWTH”

1. PREAMBLE

The Nigerian Society of Chemical Engineers (NSChE) held its 55th Annual International Conference, Exhibition and Annual General Meeting (AGM) at the International Conference Centre, Enugu, from 13th–15th November 2025, hosted by the Anambra/Enugu/Ebonyi States Chapter in collaboration with the Enugu State Government. The opening ceremony was chaired by Lady Dr. Ada Chukwudozie, Chairman of the Board of Directors, Keystone Bank Limited, and the keynote address was delivered by His Excellency, Barr. Peter Ndubuisi Mbah, Executive Governor of Enugu State. Goodwill messages from the Executive Governor of Ebonyi State, and other dignitaries, and technical exhibitions led by the National President of NSChE, Engr. Bayo Olarewaju Alo.

2. KEY FINDINGS

- I. Nigeria’s industrial growth cannot occur without reliable and affordable energy, making energy reform the most urgent national priority.
- II. SMEs are the core of Nigeria’s industrial future, supplying intermediate goods, generating employment, and strengthening domestic value chains.
- III. Technology and R&D-driven raw material processing are essential for reducing import dependence and stimulating rural industrialisation.
- IV. Sustainable waste management is both an environmental necessity and a viable industrial opportunity.
- V. Solid minerals growth must shift from extraction to value addition-beneficiation, integrating SMEs into refining, processing, and mineral-based manufacturing.
- VI. Chemical Engineers remain central to energy optimization, sustainable agriculture, waste transformation, mineral processing, and industrial design.

3. RESOLUTIONS

After extensive deliberations, the Conference resolved as follows:

3.1 ON ENERGY

- Government should declare energy security a national emergency and ensure policy continuity in power sector reforms.
- Expand investment in gas infrastructure, decentralise mini-grids, renewable energy parks, and local manufacturing of power technologies.

3.2 ON SMES & INDUSTRIALISATION

- Government should create SME-focused industrial clusters with shared infrastructure, renewable energy hubs, and quality control laboratories.
- Establish SME-friendly credit schemes, reduce collateral requirements, and tailored financing for agro-processing, renewable energy, and manufacturing.

3.3 ON RAW MATERIALS DEVELOPMENT

- Strengthen collaboration among PRODA, RMRDC, NASENI, Universities, and the Private sector to accelerate local technology adoption.
- * Enforce backward integration across all manufacturing value chains.

3.4 ON SOLID MINERALS

- Mandate local mineral beneficiation and value addition before export and enforce strict royalty compliance.
- Fast-track the establishment of the proposed Solid Minerals Development Bank.
- Solid Minerals Development Fund of Nigeria should continue to unlock financing to promote the mining sector.

3.5 ON WASTE MANAGEMENT & ENVIRONMENTAL SUSTAINABILITY

- States should adopt industrial–municipal waste separation systems, promote recycling enterprises, and support circular economy SMEs.
- Support SEDI and PRODA in producing local waste-to-wealth machinery for SMEs.

3.6 ON RESEARCH, INNOVATION & CAPACITY BUILDING

- NSChE should deepen collaboration with research institutes to develop industry-ready curricula and promote local fabrication of industrial equipment.
- Government should institutionalize research–industry linkage funds to accelerate commercialization of engineering innovations.

3.7 ON NATIONAL DEVELOPMENT & CHEMICAL ENGINEERING PRACTICE

- Chemical Engineers should be more actively included in national development planning, energy policy formulation, mineral processing strategies, and agricultural value-chain modernization.

4. CONCLUSION

The Conference concluded that Nigeria stands at a critical turning point where SMEs, backed by Chemical Engineering innovation, sustainable energy, raw materials development, and responsible mineral processing, can unlock a new era of national industrial growth.

The NSChE commits to continued collaboration with governments, industries, and partners to ensure that the resolutions of Coal City 2025 translate into measurable national progress.

Signed for and on behalf of the Conference Organizers and Participants



Engr. Bayo Olarewaju-Alo, FNSChE,
National President, NSChE



Engr. Anthony Ogheneovo, FNSChE
Executive Secretary, NSChE



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THE IMPACT OF CHEMICAL ENGINEERING PRACTICE ON NIGERIA'S INDUSTRIALIZATION

1.0 INTRODUCTION

Chemical Engineering, as a discipline, plays a pivotal role in transforming raw materials into valuable products through processes involving chemistry, physics, mathematics, and economics. In Nigeria, this field has been instrumental in driving industrialization, particularly in sectors like oil and gas, petrochemicals, manufacturing, pharmaceuticals, and agriculture. Since its emergence in the country during the 1960s, chemical engineering has contributed to economic diversification, job creation, technology transfer, and value addition to natural resources. However, challenges such as infrastructure deficits, policy inconsistencies, and environmental concerns have tempered its full potential. As of 2026, recent developments under initiatives like the "Decade of Gas" and the Nigerian Industrialization Policy signal a renewed push toward sustainable industrial growth, aiming to elevate manufacturing's GDP contribution to 20-25% by 2030.



Engr. Abdul Rasheed Babalola, PhD, FNSE, FNSChE, FNISafetyE, FNIFEngM
(Director, Centre for Facilities Engineering & Management, Akwa Ibom State University)

2.0 HISTORICAL DEVELOPMENT OF CHEMICAL ENGINEERING IN NIGERIA

Chemical Engineering started in Nigeria in the 1960s, primarily through graduates trained abroad in the United States and United Kingdom, many under the African Scholarship Program for American Universities. Domestic education in Chemical Engineering began in 1969 at the University of Ife (now Obafemi Awolowo University) with a chemical technology course, evolving into a full Chemical Engineering Program by 1972, producing the first locally trained graduates in 1973. Institutions like the University of Lagos and Ahmadu Bello University followed suit, graduating engineers in 1976 and 1977, respectively.

Early practitioners worked in emerging industries such as cement, soaps, paints, tires, and food processing at companies like Michelin, Dunlop,

Portland Cement, Lever Brothers, and ICI Paints. The 1970s oil boom shifted focus to the petroleum sector, where chemical engineers became key personnel resources in refining, gas processing, and petrochemicals. Today, 26 universities offer chemical engineering degrees, producing 1,500-2,000 graduates annually, alongside polytechnics training technology and technicians. The curriculum spans five years, emphasizing process design, thermodynamics, safety, and industrial internships. During the

Nigerian Civil War (1967 - 1970), chemical engineers at the University of Nigeria, Nsukka, innovated local bomb manufacturing using red oil, showcasing early ingenuity, though post-war policies reportedly hindered the department's revival (1).

This foundation laid the groundwork for Nigeria's industrialization, leveraging vast resources like 40 billion barrels of crude oil and 190 trillion standard cubic feet of natural gas, which contribute 80% of federal revenue and over 90% of foreign exchange.

3.0 KEY IMPACTS ON INDUSTRIALIZATION

Chemical Engineering has profoundly influenced Nigeria's industrial landscape across multiple sectors.

- i. **Oil, Gas, and Petrochemicals:** Nigeria's petroleum industry, the backbone of its economy, relies heavily on chemical engineers for upstream exploration, midstream refining (445,000 barrels per day capacity across three refineries), and downstream distribution. Petrochemical plants produce 1,540 tons per day of polymers and 3,860 tons of ammonia/urea, supporting fertilizers and plastics. Recent expansions, such as Dangote Fertilizer and Indorama Eleme Petrochemical Limited, position Nigeria to become a net fertilizer exporter by 2028, reducing import dependency. See Fig. 1. The SuperTech Methanol and Ammonium Bicarbonate plant,

relocated from China in 2025, produces 100,000 metric tons of methanol and 160,000 tons of ammonium bicarbonate annually, with plans to scale to 500,000 tons by 2026, boosting gas utilization and exports.

ii. Manufacturing and Value Addition:

In manufacturing, chemical engineers drive processes in chemicals, pharmaceuticals, and polymers, contributing 2.90% to manufacturing GDP in 2022. The sector absorbs 13% of total employment and generates 30% of non-import VAT. Innovations like AI-driven predictive maintenance and IoT in firms such as Dangote Cement and Nestlé Nigeria have reduced costs by 15-30% and emissions by 20%, enhancing productivity. Investments in 2024-2025 include Dangote's 6 million tons cement plant, Emzor's US\$23 million API facility, and Erakson's lubricant plant, fostering import substitution and job creation.

iii. Agriculture and Environmental Sustainability:

Chemical engineering supports agriculture through fertilizer production, with ammonium bicarbonate reducing costs and boosting yields. See Fig. 2. However, manufacturing's environmental footprint, including effluents from chemical processes, poses challenges. Life



Fig. 1: Oil, Gas and Petrochemical Plant, Port-Harcourt, Nigeria

cycle assessments highlight pollution in textiles and chemicals, urging sustainable practices like renewable energy integration.

Overall, these impacts have spurred economic growth, with manufacturing value added at US\$25.36 billion in 2024, though down from US\$55.9 billion in 2023 due to headwinds. Chemical engineering has facilitated technology transfer, skills development, and diversification from oil dependency.

4.0 RECENT DEVELOPMENTS (2020-2026)

Nigeria's industrialization has seen a reset amid challenges like exchange rate volatility and inflation from 2020 to 2026. The "Decade of Gas" initiative (2021-2030) has advanced infrastructure, with over 200 trillion cubic feet of gas reserves driving domestic utilization and decarbonization. The 2025 Nigerian Industrialization Policy, aligned with African Continental Free Trade Area (AfCFTA), focuses on six pillars: competitive production, value-chain deepening, import substitution, Micro, Small & Medium Enterprises (MSME) transition, trade competitiveness, and governance. It targets 20 - 25% manufacturing GDP share by 2030.

Technology adoption, including Industry 4.0 tools like robotics and blockchain, has transformed sectors, with SMEs like ReelFruit achieving 200% revenue growth through digital supply chains. The 2026 targets of National Agency for Science & Engineering Infrastructure (NASeni) emphasize commercializing research and partnerships for innovation. Sub-sectors like chemicals and pharmaceuticals show improvement, with policies like shea nut export bans stabilizing inputs.

5.0 CHALLENGES

Despite progress, challenges persist. Infrastructure gaps, including unreliable power (available only one-third of the time), cost manufacturers 40% of expenses. The chemical process industries (CPI) contribute less than 4% to GDP, down from over 10%, due to smuggling, high interest rates, and neglect. Education faces quality issues from underfunding,



Fig. 2: A sustainable agriculture

“Chemical Engineering has been a cornerstone of Nigeria’s industrialization, from historical foundations to recent tech-driven advancements.”

leading to graduate unemployment. Environmental degradation, such as CO₂ emissions and hazardous effluents, demands decarbonization strategies.

6.0 FUTURE PROSPECTS

Prospects are optimistic with power sector reforms, gas flaring elimination, and refinery privatization. The National Industrialization Policy and AfCFTA integration could position Nigeria as Africa’s industrial hub. Recommendations include a US\$500 million Tech Innovation Fund, regulatory harmonization, and Science, Technology, Engineering & Mathematics (STEM) upskilling to leverage the youth population projected 400 million by 2050. Sustainable practices, like renewable integration, will mitigate environmental impacts while driving growth.

7.0 CONCLUSION

Chemical Engineering has been a cornerstone of Nigeria’s industrialization, from historical foundations to recent tech-driven advancements. While challenges remain, strategic policies and investments as of 2026 promise a resilient, diversified economy. By harnessing its resources and expertise, Nigeria can achieve sustainable industrial prosperity.

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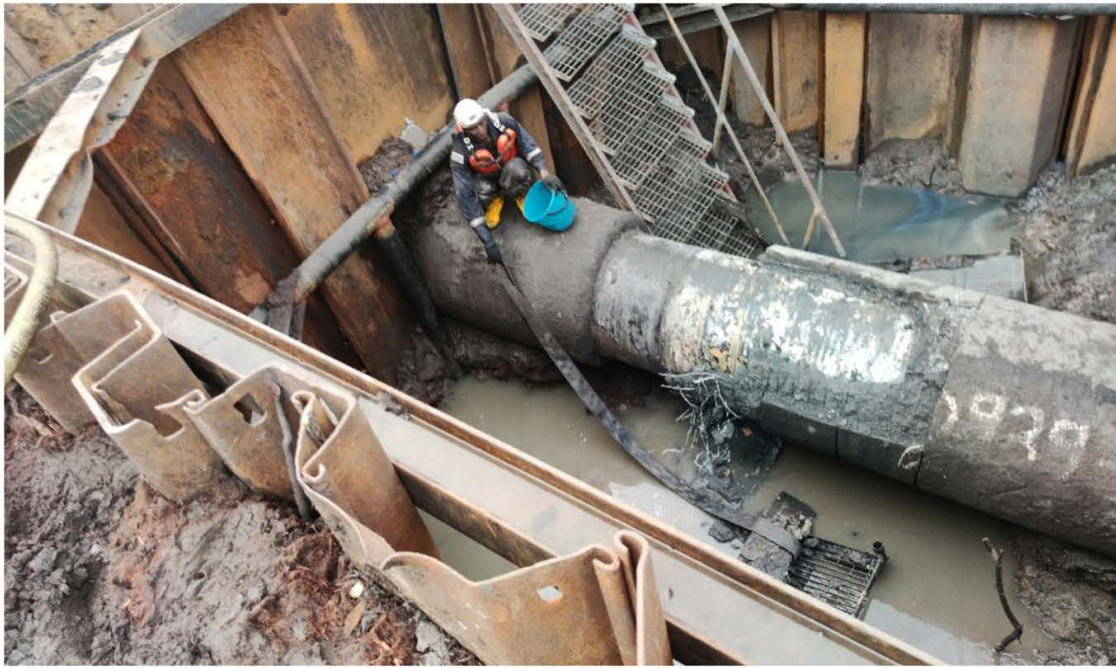
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Port Harcourt:
 Plot 40 Wopara Street
 Rumuobiokani, Port Harcourt,
 Rivers State.
 Tel: +234-84-750237, 0803-3023051
 Email: morpolph@morpfol.net

Abuja Area Office:
 No.5 Leribe Close, Off Kolda Link
 (Behind Oceanic Bakery), Wuse II, Abuja
 Tel: +234-8023271735, 0803-4503387



DEBOTTLENECKING INDUSTRIAL PROCESSES: TOOLS & CASE STUDIES

1.0 INTRODUCTION

Industrial production systems—whether upstream oil fields, refineries, chemical plants, or discrete manufacturing lines—are governed by constraints. At any given moment, throughput is limited by a single dominant restriction: a heat exchanger approaching fouling limits, a distillation column nearing flooding, a compressor constrained by surge margins, a robotic workstation starved of material, or a scheduling rule embedded deep within a control system. These constraints—commonly referred to as bottlenecks—define the true production capacity of an asset.

Historically, debottlenecking efforts focused on capital-intensive interventions: installing larger pumps, revamping columns, adding parallel reactors, or expanding storage and handling infrastructure. While effective, such approaches require significant capital expenditure, extended shutdown windows, regulatory approvals, and long project cycles. In an era defined by volatile commodity prices, decarbonization mandates, supply chain instability, and shareholder pressure for capital discipline, incremental capacity gains must increasingly come from smarter use of existing assets—not from new steel in the ground.

“Historically, debottlenecking efforts focused on capital-intensive interventions: installing larger pumps, revamping columns, adding parallel...”



Engr. Adebayo B. Olanrewaju, MNSE, MNSChE, MIChemE, CEng (CEO, Olanab Consulting Ltd)

Across oil & gas, chemical processing, and advanced manufacturing, a paradigm shift is underway. The convergence of high-fidelity process simulation, industrial IoT connectivity, advanced process control, artificial intelligence (AI), and digital twin technologies is transforming debottlenecking from a periodic engineering study into a continuous, data-driven discipline. Instead of static design limits and rule-of-thumb operating envelopes, organizations are deploying dynamic,

model-based systems capable of identifying shifting constraints in real time and optimizing operations against multiple objectives simultaneously—throughput, energy intensity, product quality, and reliability.

For example, upstream operators such as ExxonMobil have deployed machine learning to optimize artificial lift and field production strategies, achieving measurable increases in well output without additional drilling. Supermajors like Shell have implemented AI-driven predictive maintenance and digital twin frameworks to reduce unplanned downtime across thousands of rotating assets. Refining and petrochemical operators including Petrobras have used refinery-wide digital models to optimize energy integration and throughput, capturing substantial economic value. In discrete manufacturing, firms such as The Timken Company have leveraged simulation and workflow analytics to rebalance production systems and unlock double-digit productivity improvements.

These examples illustrate a fundamental reality: the modern bottleneck is often not a physical piece of equipment, but a control strategy, a scheduling assumption, a data visibility gap, or a suboptimal interaction between process units. As process systems become more integrated and nonlinear, bottlenecks shift dynamically in response to feed

variability, ambient conditions, equipment degradation, and market-driven operating targets. Traditional periodic engineering studies cannot keep pace with this variability. Continuous, model-based optimization is required.

This article examines how leading organizations are applying cutting-edge digital tools to systematically identify, quantify, and eliminate bottlenecks in industrial operations. It provides:

- A technical framework for understanding dynamic bottlenecks in complex process systems
- An in-depth exploration of digital twins, Artificial Intelligence/ Machine Learning (AI/ML) optimization, advanced simulation, and IoT-enabled visibility
- Real-world case studies from oil & gas, refining, chemicals, and manufacturing
- Implementation considerations, integration challenges, and organizational enablers
- Quantitative insights into performance metrics and return on investment.

For engineers, the paper provides methodological depth—covering modeling approaches, constraint management strategies, and optimization architectures. For operations managers, it highlights practical pathways for implementation and measurable performance improvements. For executives, it frames the strategic and financial implications of digital debottlenecking as a lever for capital efficiency and operational resilience.

2.0 UNDERSTANDING DEBOTTLENECKING TOOLS & TECHNIQUES

To move from theory to execution, organizations must adopt a structured, technology-enabled approach to identifying and relieving constraints. The following section examines the core digital tools—digital twins, AI/ML optimization, advanced simulation platforms, and IoT-enabled data architectures—that are redefining how industrial bottlenecks are detected, analyzed, and eliminated in real time.



Fig. 1: An oil refinery plant captured as a digital twin. Cosmo Oil (Japan) consolidated three refineries into one virtual model, enabling remote collaboration and “increased efficiencies... and maximized productivity” across its engineering teams. (Source: Cognite.com)

- Digital Twins:** Virtual Plants and Real-time Bottleneck Analysis: A digital twin is a dynamic, virtual model of a physical system (equipment, line, or entire plant) fed by live data. Unlike static spreadsheets or one-off models, a twin continuously syncs with IoT and control-system data to mirror real-time behavior. This allows engineers to run “what-if” scenarios or automated optimizations on a faithful plant replica. For example, factory twins can “simulate real-time bottlenecks” on the production line and uncover hidden process blockages. See Fig. 1. McKinsey reports an industrial plant that used a digital twin to redesign its production schedule, reducing overtime and cutting monthly operating cost by 5–7%. Similarly, a plant simulated in a digital twin identified optimal batch sizes and sequencing (using an AI scheduler) that drastically reduced changeover losses.

Digital twins also shine in oil & gas. For instance, Shell reports that AI/twin systems monitoring ~10,000 assets (pumps, compressors, valves) have cut unplanned downtime by 35% and reduced maintenance costs by 20%, saving on the order of \$2 billion per year. BP’s virtual-twin approach added ~30,000 barrels of oil in a year, while Petrobras saved \$154 million by fine-tuning refinery operations in near-real time. In reservoir and drilling, Chevron and ExxonMobil use digital replicas to optimize well plans, boosting hydrocarbon recovery and scheduling.

In all these cases, the twin combines IoT inputs (sensor readings, control setpoints) with advanced analytics to reveal where the true constraint lies.



Fig. 2: Operators at a process control station. Even experienced engineers find it hard to manually track evolving constraints; successful debottlenecking requires new analytics and workflow changes (Source: Imubit.com).

When multiple equipment or processes interact nonlinearly, only a comprehensive twin can capture shifting bottlenecks. As McKinsey observes, factory twins are already deployed by ~44% of manufacturers surveyed, and 86% see practical applications – a “frontier technology” delivering tangible throughput gains in live production.

ii. AI/ML and Advanced Control for Dynamic Optimization: Standard control systems often impose hidden limits on throughput. They typically run many independent PID loops with conservative setpoints and no awareness of downstream effects. In practice, the true throughput limiter can shift (e.g. between heat exchangers, columns, compressors) as conditions change. Advanced analytics and AI-driven controls can automatically hunt for these dynamic bottlenecks. For example, industrial AI platforms can continuously monitor constraint margins and adjust hundreds of manipulated variables in concert. Unlike fixed controllers, such systems use multivariable models and even reinforcement learning to “learn optimal control strategies directly from operational data”. An Imubit analysis highlights that while operators might assume equipment is at capacity, “the constraint often lies not in the equipment itself but in the control strategy managing it”. In other words, smarter control logic alone can often raise throughput without adding hardware.

By coordinating multiple loops and explicitly handling constraints, AI-driven control systems enable processes to run closer to their true limits. Plants using these technologies report simultaneous

gains in several dimensions: higher throughput, better energy efficiency, and tighter quality control. In one case, shifting from legacy control to advanced multivariable control unlocked enough capacity that no new equipment was needed – the “extra” production hit payoff almost immediately.

Machine learning models also excel at spotting nonlinear interactions that human operators miss. See Fig. 2. Leading manufacturers have found AI-optimization can deliver 10–15% higher production (and ~4–5% higher EBITDA) on existing assets. In the Bakken shale, ExxonMobil deployed an ML workflow to optimize gas lift rates on dozens of wells; the result was an average 5–7% production uplift across the field.

The ML system forecasts weekly outputs and uses Bayesian optimization to set injection, yielding an ongoing 7% boost in output once scaled to 200+ wells. Similar AI-driven forecasts and optimizers are finding use in refineries (yield/performance tuning) and plants (peak shaving schedules), capturing every incremental percent of capacity.

iii. Process and Discrete-Event Simulation: High-fidelity simulation software remains a cornerstone of debottlenecking analysis. In continuous processes (oil, gas, chemicals), steady-state and dynamic simulators (Aspen HYSYS/Plus, Pro/II, ChemCAD, DWSIM, etc.) let engineers test capacity changes before implementing them. For example, a major refinery gas plant used Aspen HYSYS with detailed exchanger models to evaluate minor revamps: the simulation showed a 20% capacity gain with only small hardware tweaks, and the upgrade paid for itself in under one month. Likewise, a chemical manufacturer (LG Chem) employed Aspen Plus and specialized exchanger tools to reconfigure a 1,3-butadiene unit; the simulation predicted a 15% capacity increase and significant energy savings with no new equipment. These tools also perform pinch and heat-integration analysis to recover heat and reduce fuel use, which indirectly raises throughput by cutting energy bottlenecks.

“In one warehouse case, adding a single conveyor (as tested in FlexSim) eliminated a traffic jam and raised throughput by 43% (from 70 to 100 pallets/hour).”

In batch/discrete industries (pharma, automotive, FMCG, warehousing), discrete-event simulation (DES) is used to find layout and scheduling bottlenecks. Packages like AnyLogic, FlexSim, Arena or Siemens Plant Simulation can model conveyor lines, work cells, workers, and inventory buffers. In one warehouse case, adding a single conveyor (as tested in FlexSim) eliminated a traffic jam and raised throughput by 43% (from 70 to 100 pallets/hour). A practical example comes from Timken’s bearing factory: by mapping workflows and running a DES model, engineers rebalanced tasks and material flow, achieving a 27% increase in labor productivity (hence throughput).

These simulations excel at exposing non-obvious constraints — e.g. equipment sequencing or worker shift patterns — and enable engineers to test improvements before shop-floor changes. In short, process simulators and DES complement digital twins by providing rich, tested models for what-if capacity studies, layout changes, and control strategy effects.

iv. IoT and Data Platforms for Visibility: Modern debottlenecking hinges on data connectivity. IoT sensors and integrated historians/Supervisory Control & Data Acquisition (SCADA) enable both twins and AI models to see current operating conditions. Real-time data streams give visibility into equipment health and flow rates that are invisible on paper. For instance, one manufacturing case study shows how outfitting an automotive-parts plant with non-invasive IoT sensors (monitoring uptime, vibrations, cycle times) and an ERP-integrated dashboard yielded an 18% jump in productivity and a 25% drop in downtime. Live machine monitoring let managers see when a press or robot was idling or faltering, so they could intervene before a full breakdown. Predictive alerts (e.g. for overheating or vibration spikes) prevented unexpected stalls, further boosting throughput. In summary,

IoT-driven monitoring tools can turn obscure constraints into dashboard alarms.

In oil & gas, similar connectivity has paid off. Integrating field SCADA data with cloud analytics enabled one operator to cut millions in maintenance/operating costs and sharply improve production efficiency. For example, centralized analytics can flag an imminent pump or compressor failure (a future bottleneck) long before it trips the unit. Elsewhere, linking distributed sensors to a digital twin or control system has identified fouling in heat exchangers early, so cleaning can be scheduled preemptively rather than letting performance drag.

In effect, IoT provides the “eyes and ears” that feed advanced tools. Live feeds also allow dynamic scheduling: some plants now automate line-balancing and lot prioritization based on real-time cycle times, smoothening flow and reducing starvation/blocking of workstations.

3.0 IMPLEMENTATION CHALLENGES AND ORGANIZATIONAL FACTORS

Deploying these technologies is not trivial. Data integration is often the biggest hurdle: many plants have legacy DCS/SCADA, siloed historians, or offline spreadsheets. Building a coherent digital system usually requires establishing a “single source of truth” (common data schema) and reliable IoT connectivity. Organizationally, success demands buy-in across engineering, IT, and operations. Operators must trust and learn new decision workflows – for example, accepting an AI’s suggestion to adjust a product spec or operating point. As one analysis notes, “successful implementation requires addressing both technical infrastructure and organizational readiness”. Skilled practitioners who understand both process engineering and data science are scarce, so training or hiring is needed. Cybersecurity is another concern: adding more sensors and connectivity

enlarges the attack surface. Finally, companies must overcome “project inertia” – proving quick wins so management funds larger rollouts.

Despite these challenges, many projects achieve rapid payback. For example, by first asking “how much capacity is untapped” before building new units, engineers have often found that software fixes pay off faster and cheaper than capital projects. In practice, a phased approach is common: start with data hygiene and simple analytics to show a few-percent gain, then iterate into AI or twins for bigger lifts. Cross-functional teams (operators, controls engineers, data analysts) and executive sponsorship are key to success.

When done right, these tools create a foundation of continuous improvement: as processes or feeds change (corrosion, fouling, market swings), the system keeps relearning the bottleneck and suggesting adjustments in near-real-time.

4.0 RETURN ON INVESTMENT AND PERFORMANCE METRICS

The ROI of digital debottlenecking is demonstrated by the performance gains reported in practice. Common metrics include throughput rate, product yield, energy per unit, uptime %, and output consistency. Industry reports show output uplifts on the order of 5–15% are typical. For instance, advanced control systems alone have yielded 5–7% capacity gains in pilot projects. AI-driven optimization is reported to boost production ~10–15% in leading plants. Concretely, an extra percent of throughput in a midsize refinery can translate to millions in annual margin, so even small percentage moves pay for themselves quickly. Energy savings come as a side benefit: running closer to thermodynamic optimum and cutting variability often reduces fuel usage, improving environmental and cost metrics simultaneously.

“...oil pilot (gas-lift optimization) achieved >5% more output. Petrobras’s digital twins at 11 refineries save >\$150M annually.”

Large corporations quantify these returns. Shell’s AI/twin system, for example, has reduced annual unplanned outages so much that it saves about \$2 billion each year. Petrobras’s real-time refinery twins delivered \$154 million in savings over ~11 plants. In manufacturing, data-driven scheduling cut one plant’s overtime costs by ~5–7%, while IoT-enabled monitoring gave an automotive supplier a one-year payback by raising throughput 18%. Even labor productivity improvements (e.g. the 27% gain at Timken) have definitive ROI when factored against labor cost.

To evaluate ROI, teams measure baseline metrics (OEE, yield, throughput per day, etc.), then track changes post-implementation. Many projects use A/B testing or shadow mode (running new AI suggestions in parallel without acting on them, then comparing outcomes) before full rollout. Key performance indicators often include percentage increase in throughput, percentage reduction in downtime, product quality consistency, and energy consumption per unit. The combination of case studies shows that modern debottlenecking consistently pays back in months, not years, and scales with plant size: bigger plants see multi-million-dollar impacts even for single-percent gains.

5.0 CASE STUDIES: INDUSTRY EXAMPLES OF SUCCESS

- i. **Oil & Gas:** Many upstream and refinery operators have deployed digital debottlenecking. ExxonMobil’s Bakken oil pilot (gas-lift optimization) achieved >5% more output. Petrobras’s digital twins at 11 refineries save >\$150M annually. Shell monitors its pump/compressor network with AI, cutting downtime 35%. Aramco and TotalEnergies use twins in complex gas processing and drilling rigs with similar results (higher uptime, energy savings).
- ii. **Chemicals & Process:** LG Chem reconfigured a butadiene plant via Aspen simulations, boosting capacity 15% without new equipment. Dow and BASF are testing twins for utilities and heat-exchanger networks to preempt bottlenecks in cooling water and steam. (BASF’s Antwerp site,

“Cutting-edge digital technologies are transforming how industrial plants debottleneck. By combining digital twins, AI/ML control, sophisticated simulation, and IoT, engineers can continuously find and relieve the real constraints on their process.”

for instance, built a physics-based twin of its water/steam grid to spot blockages and optimize biocide dosing.)

- iii. **Discrete Manufacturing:** One discrete-product plant used a factory-level twin to rebalance assembly schedules, cutting overtime by 5–7%. A German tier-1 automotive parts maker saw throughput jump 18% after installing IoT sensors and real-time dashboards. Timken’s bearings factory used a digital model to reorganize its shop floor, lifting labor productivity 27%. Consumer-goods companies (e.g. P&G, Nike) report similar gains using machine learning for production planning and quality control.

These examples underscore a pattern: successful implementations uncover a few percent of hidden capacity per constraint, which cumulate into double-digit overall gains. Oil & gas refineries often see 2–4% throughput lifts from AI control (worth tens of millions), while broad digital programs can add 5–15% more output across a plant. Every case also improved stability: quality off-specs fell and energy use per unit dropped when bottlenecks were raised.

6.0 CONCLUSION

Cutting-edge digital technologies are transforming how industrial plants debottleneck. By combining digital twins, AI/ML control, sophisticated simulation, and IoT, engineers can continuously find and relieve the real constraints on their process. Rather than defaulting to expensive expansion projects, companies now routinely achieve significant throughput and efficiency gains via smarter use of existing assets. The ROI evidence is compelling: top companies report multi-million-dollar annual savings from reduced downtime and increased production. For engineers and managers, the

message is clear: deploying these tools is no longer speculative. Early adopters in oil & gas, chemicals, and manufacturing have made debottlenecking an engineering discipline powered by data. In an era of tight margins and sustainability goals, digital debottlenecking delivers both growth and green benefits, and it is rapidly becoming standard practice for competitive operations.

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THE ROLE OF CHEMICAL ENGINEERS IN SEMICONDUCTOR INNOVATIONS IN NIGERIA

ABSTRACT

Semiconductors are pivotal to modern technology, driving innovations in electronics, renewable energy, and communication systems. This paper examines the crucial role of chemical engineers in advancing semiconductor technologies in Nigeria, relying on the country's abundant mineral resources, such as silica, gallium, and rare earth elements. It outlines the fundamentals of the semiconductor industry, including material properties, band gap classifications, and manufacturing processes, emphasising their relevance to Nigeria's energy future. The study highlights opportunities for localized manufacturing, skill development, and research partnerships to foster a domestic semiconductor ecosystem. By addressing challenges like grid instability and energy access through semiconductor-enabled solutions—such as solar photovoltaics, power electronics, and smart grids—Nigeria can enhance energy efficiency, integrate renewables, and drive economic diversification. Chemical engineers are positioned to lead in material purification, sustainable processing, and process intensification, transforming Nigeria's raw materials into high-value semiconductor products. Strategic investments and policy incentives are proposed to establish Nigeria as a regional hub for semiconductor materials, supporting technological sovereignty and sustainable development.



Engr. Abdulfatai Faro, MNSE, MNSChE (B.Tech Chem Eng, MRes Mech Eng, PhD Student Chemical Engineering University of Florida)

1.0 INTRODUCTION

Semiconductors are a class of materials whose electrical properties fall between those of conductors (metals) and insulators. Their defining characteristic is a moderate band gap—typically in the range of ~ 0.5 to 3 eV—which allows their conductivity to be precisely manipulated through doping, temperature control, and electric fields (Sze, 2007). Unlike metals, where the conduction band is partially filled and electrons can move freely, or insulators, where a large band gap prevents electrons from being excited into the conduction band under normal conditions, semiconductors possess a small enough energy gap that electrons can be thermally or optically excited, yet large enough to prevent excessive leakage current at room temperature.

2.0 BAND GAP CLASSIFICATION

i. Metals: Have no band gap; Have high density of free carriers that provide excellent conductivity. Examples are copper, aluminium and gold that are commonly used as interconnects in integrated circuits.

ii. Semiconductors: Have small to moderate band gaps; electrical conductivity can be tuned by impurities or external stimuli. Examples are silicon (Si), gallium arsenide (GaAs), gallium nitride (GaN).

iii. Insulators: Have large band gaps (>4 eV). Have negligible conductivity under normal conditions. Examples are silicon dioxide (SiO_2), aluminium oxide (Al_2O_3). See Fig. 1.

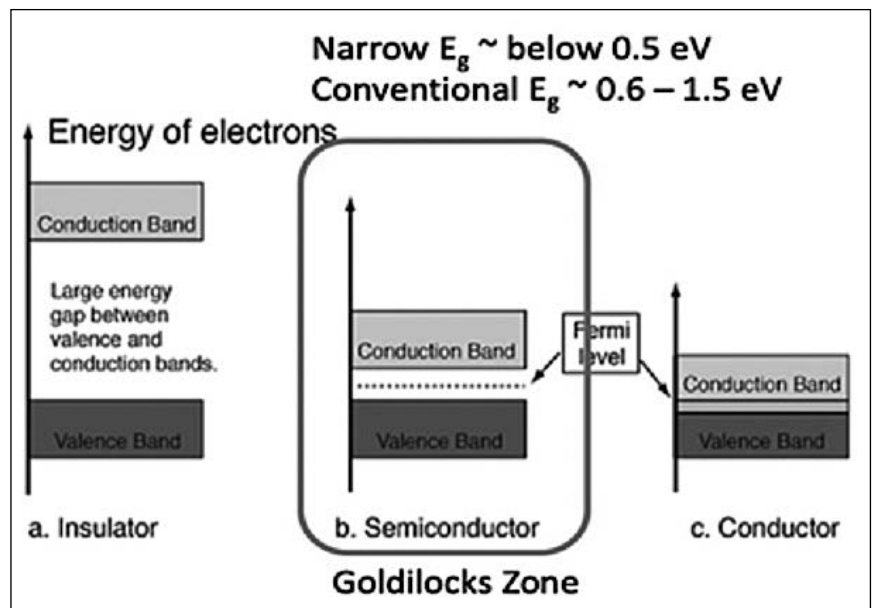


Fig. 1: Band Gap Classification

The exact boundaries between these categories are not rigid; the “semiconductor” designation depends as much on application and operational temperature as on intrinsic material properties. For example, wide-bandgap semiconductors such as SiC ($E_g \approx 3.26$ eV) and GaN ($E_g \approx 3.4$ eV) behave like insulators in bulk form but are engineered into high-performance devices for high-power, high-frequency, and high-temperature applications.

3.0 HISTORICAL PERSPECTIVE - THE SEMICONDUCTOR INDUSTRY LANDSCAPE

The semiconductor industry originated in the mid-20th century with the invention of the pointcontact transistor in 1947 by John Bardeen, Walter Brattain, and William Shockley at Bell Labs. This breakthrough replaced bulky vacuum tubes with a smaller, more reliable, and energy-efficient alternative. The commercialization of silicon transistors in the 1950s, followed by the development of integrated circuits (ICs) in the 1960s, set the foundation for the modern electronics revolution. The International Technology Roadmap for Semiconductors (ITRS) and Moore’s Law—the observation that the number of transistors on a chip doubles approximately every two years—drove decades of miniaturisation, cost reduction, and performance improvement.

Today, the industry supports everything from consumer electronics and telecommunications to aerospace, healthcare, and renewable energy. Semiconductors are at the heart of global technological competitiveness. Nations invest heavily in semiconductor R&D, manufacturing capacity, and supply chain security due to their centrality in defence systems, communications infrastructure, and economic growth (Wolf - 2000). The ongoing chip shortage episodes have highlighted the vulnerabilities of a highly globalised production network. The global semiconductor industry is valued at over \$600 billion annually and is strategically critical to modern economies. It comprises:

i. Materials: Substrates such as Si, SiC, GaAs, GaN, and

emerging materials like 2D semiconductors (e.g., Metal Oxide Semiconductor - MoS₂)

ii. Device Types: Logic devices (e.g., Central Processing Unit - CPUs, Graphics Processing Unit - GPUs), Memory devices (Dynamic Random Access Memory - DRAM, National Array of Neutron Detectors - NAND), Power electronics (Metal Oxide Semiconductor Field-Effect Transistors - MOSFETs, Insulated Gate Bipolar Transistors - IGBTs, High Electron Mobility Transistors - HEMTs), Optoelectronic devices (Light Emitting Diodes - LEDs, laser diodes, photodetectors)

iii. Manufacturing Processes: Wafer fabrication, lithography, etching, doping, deposition, packaging, and testing

iv. Applications: Information technology, automotive electronics, defence systems, renewable energy conversion, and the Internet of Things (IoT)

4.0 FUNDAMENTAL ROLE OF DOPING

Doping introduces controlled amounts of impurities into a semiconductor to modify its electrical behavior. The types include:

- i. n-type doping adds donor atoms (extra electrons) — e.g., phosphorus in Si.
- ii. p-type doping adds acceptor atoms (electron holes) — e.g., boron in Si.

This ability to engineer carrier concentrations underpins the operation of diodes, transistors, and integrated circuits. See Fig. 2.

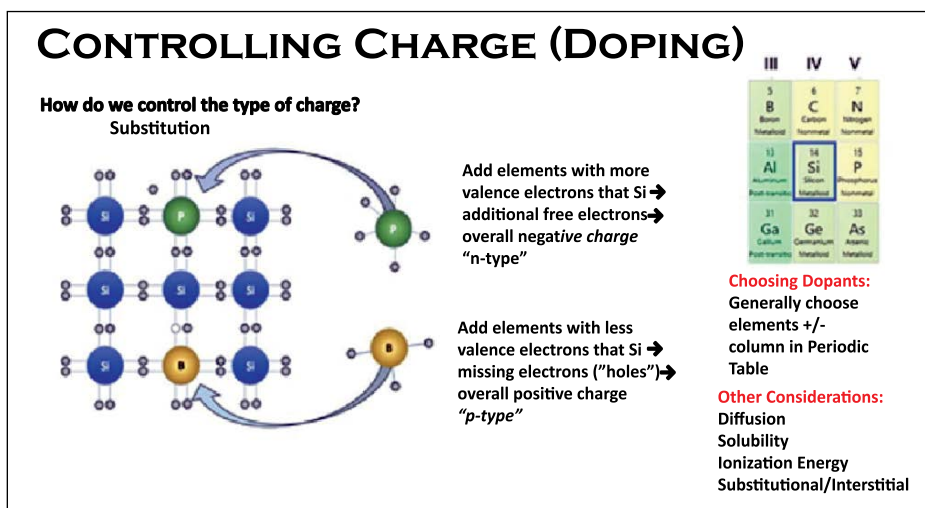


Fig. 2: Controlling doping charge (Hite, 2024)

5.0 SEMICONDUCTOR MATERIALS AND PROPERTIES

i. Distinguishing Semiconductor Materials

Semiconductors are distinguished not only by their electrical properties but also by their diverse material compositions, each suited for specific applications (Company-2024). Understanding the materials science aspect is fundamental to appreciating the capabilities and limitations of semiconductor devices. The band gap (E_g) is the energy difference between the valence band maximum and the conduction band minimum. See Table 1. The band gap determines:

- Electrical conductivity at a given temperature
- Optical absorption spectrum (relevant for photonic devices)
- Thermal stability and suitability for high-power applications

ii. Common Semiconductor Materials:

These are shown in Table 2.

iii. Emerging Materials

- **2D Semiconductors:** Metal oxide semiconductors (MoS_2), Tungsten disulfide (WS_2) — promising for ultrathin transistors
- **Organic Semiconductors:** Flexible electronics, displays.
- **Oxide Semiconductors:** Indium Gallium Zinc Oxide (IGZO) for display backplanes
- **Diamond:** Exceptional ultra-wide band gap (UWBG) properties for extreme environments

iv. Key Material Properties

The performance of a semiconductor device depends on several intrinsic material parameters. See Table 3 and Fig. 3..

Category	E_g Range	Examples	Applications
Narrow band gap	< 1 eV	InAs (0.36 eV), PbS (0.41 eV)	Infrared detectors, low-temp electronics
Standard band gap	1–2 eV	Si (1.12 eV), GaAs (1.42 eV)	Mainstream logic, RF electronics
Wide band gap	> 2 eV	GaN (3.4 eV), SiC (3.26 eV)	Power electronics, high-frequency devices, UV optoelectronics
Ultra-wide band gap (UWBG)	> 4.5 eV	Diamond (5.45 eV), BN (~6 eV)	Extreme power density, radiationhard devices

Table 1: Classification by Band Gap

Material	Band Gap	Advantages	Limitations
Silicon (Si)	1.12 eV (indirect).	Abundant and low cost. Well-established processing infrastructure (CMOS technology). Stable native oxide (SiO_2) enabling high-quality gate dielectrics.	Lower electron mobility than III–V semiconductors. Limited performance at high frequencies and high voltages.
Gallium Arsenide (GaAs)	1.42 eV (direct).	High electron mobility (~8500 $\text{cm}^2/\text{V}\cdot\text{s}$). Excellent for high-speed, high-frequency RF applications.	Brittle and more expensive than Si. No high-quality native oxide.
Silicon Carbide (SiC)	3.26 eV (4H polytype).	High breakdown field (~3 MV/cm). High thermal conductivity (~4.9 $\text{W}/\text{cm}\cdot\text{K}$). Suitable for high-voltage, high-temperature power devices.	Difficult crystal growth; higher defect density. More expensive wafer manufacturing.
Gallium Nitride (GaN)	3.4 eV (direct).	• High electron saturation velocity.	• Substrate availability; often grown on Si or SiC.
		• Strong polarization effects enabling high-density 2DEG channels. Excellent for RF power amplifiers and highefficiency power converters.	• Thermal management challenges.

Table 2: Common semiconductor materials

Property	Significance
Electron & hole mobility	Determines carrier transport speed and switching frequency.
Thermal conductivity	Affects heat dissipation and reliability.
Breakdown electric field	Determines maximum operational voltage.
Dielectric constant	Influences capacitance and device scaling.
Defect density	Impacts leakage current, reliability, and yield.

Table 3: Material parameters of semiconductors

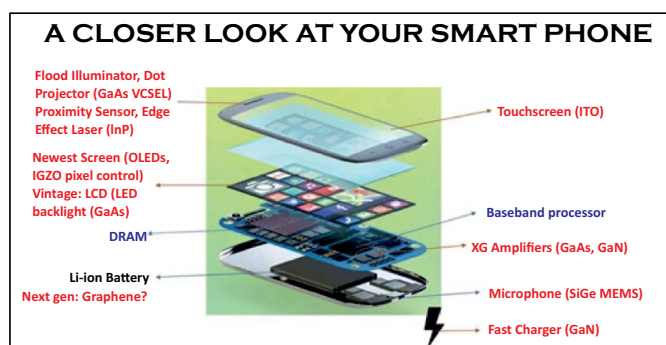


Fig. 3: Example of semiconductor materials applications (Hite, 2024)



Fig. 4: Semiconductor manufacturing process flow chart

6.0 SEMICONDUCTOR MANUFACTURING PROCESS

The manufacturing of semiconductors is a multi-stage, highly precise process that transforms purified raw materials into fully functional electronic devices. It involves nanometer-scale patterning, atomic-level material control, and ultra-clean environments. The process can be divided into front-end (wafer fabrication), middle-of-line (contact formation), and back-end (packaging and testing) operations (SIA - 2024). See Fig. 4.

6.1 HOW IS A CHIP MADE?

a) Making of a chip starts with sand. See Fig. 5a. With about 25% by mass Silicon is the second most frequent chemical element in the Earth’s crust after Oxygen. Sand – especially Quartz - has high percentages of Silicon in the form of Silicon dioxide (SiO₂) and is the base ingredient for semiconductor manufacturing.



Fig. 5a: Sand



Fig. 5b: An electronic grade Silicon



Fig. 5c: A Silicon ingot



Fig. 5d: Ingot slicing into discs

b) Melted Silicon: Silicon is purified in multiple steps to achieve semiconductor manufacturing quality, known as Electronic Grade Silicon. See Fig. 5b. Electronic-grade silicon may only have one alien atom in every one billion Silicon atoms. In this picture, you can see how one big crystal is grown from the purified silicon melt. The resulting mono-crystal is called an Ingot (Baliga - 2010).

c) Mono-crystal Silicon Ingot: An ingot has been produced from Electronic Grade Silicon. One ingot weighs about 100 kilograms (=220 pounds) and has a Silicon purity of 99.9999%. See Fig. 5c.

d) Ingot Slicing: The Ingot is cut into individual silicon discs called wafers. See Fig. 5d.

“The manufacturing of semiconductors is a multi-stage, highly precise process that transforms purified raw materials into fully functional electronic devices.”



Fig. 5e: A Silicon disc called wafer



Fig. 5f: Polishing of wafers

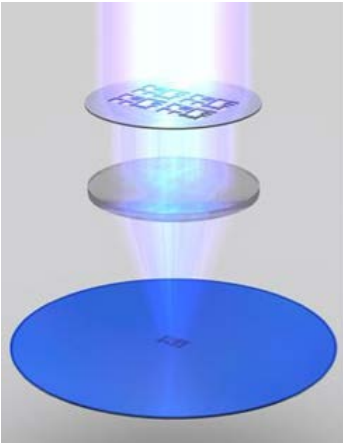


Fig. 5g: Wafer spinning

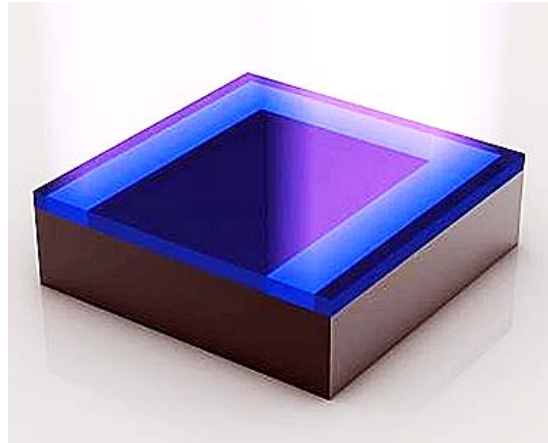


Fig. 5h: Photo-resistant wafer exposed to ultra violet light

e) **Wafer:** The wafers are polished until they have flawless, mirror-smooth surfaces. See Fig. 5e and Fig. 5f. Intel buys those manufactured wafers from third-party companies. Intel's highly advanced 45nm High-K/Metal Gate process uses wafers with a diameter of 300 millimetres (~12 inches). When Intel first began making chips, the company printed circuits on 2-inch (50 mm) wafers. Now the company uses 300 mm wafers, resulting in decreased costs per chip.

f) **Applying Photo Resistant Liquid:** The liquid (blue here) that is poured onto the wafer while it spins is a photo resistant finish like the one known from film photography. The wafer spins during this step to allow very thin and even application of this photo resistant layer. See Fig. 5g.

g) **Exposure:** The photo resistant finish is exposed to ultraviolet (UV) light. See Fig. 5h. The chemical reaction triggered by that process step is like what happens to film material in a film camera, the moment you press the shutter button. The photoresist finish that is exposed to UV light will become soluble (India - 2022). The exposure is done using masks that act like stencils in this process step. When used with UV light, masks create the various circuit patterns on each layer of the microprocessor. A lens (middle) reduces the mask's image. So, what gets printed on the wafer is typically four times smaller linearly than the mask's pattern.

h) **Exposure:** Although usually hundreds of microprocessors are built on a single wafer, this picture story will only focus on a small piece

of a microprocessor from now on, on a transistor or parts thereof. A transistor acts as a switch, controlling the flow of electrical current in a computer chip. Intel researchers have developed transistors so small that about 30 million of them could fit on the head of a pin.

6.2 OVERVIEW OF PROCESS FLOW

- 1. Material Preparation** – Production of high-purity semiconductor wafers
- 2. Wafer Fabrication** – Creation of active and passive device structures via patterning, doping, and deposition
- 3. Interconnect Formation** – Building metal wiring layers to connect devices
- 4. Wafer Testing** – Electrical verification before packaging
- 5. Packaging & Final Testing** – Protecting the die and ensuring performance meets specifications

6.3 WAFER SUBSTRATE PREPARATION ((MIDA), 2023)

(a) Material Purification

- **Silicon:** Extracted from quartz sand (SiO_2) via carbothermic reduction to produce metallurgical-grade silicon, then refined to electronic-grade silicon (>99.9999999% purity)
- **Compound Semiconductors:** Materials like GaAs and GaN are produced via methods such as Czochralski growth, Hydride Vapour Phase Epitaxy (HVPE), or Ammonothermal growth.

“Nigeria’s pathway to sustainable economic growth, energy security, and technological independence will increasingly depend on the integration of semiconductor technologies into its energy ecosystem...”

(b) Crystal Growth

- **Czochralski (CZ) method:** Used for single-crystal silicon ingots
- **Float-zone method:** Produces ultra-high-purity Si for power devices

(c) Wafer Slicing & Polishing

- **Ingots** are sliced into wafers (150–300 mm diameter, <1 mm thick).
- **Wafers** are polished to a mirror finish with nanometer-level flatness.

6.4 WAFER FABRICATION (FRONT-END PROCESSING)

(a) Oxidation

- Growth of a silicon dioxide (SiO₂) layer by thermal oxidation
- Serves as an insulator and mask for doping

(b) Photolithography

Photolithography defines patterns on the wafer surface:

1. **Coating** – Apply photo-resistant liquid
 2. **Exposure** – Use UV light through a photomask to transfer patterns
 3. **Development** – Remove exposed or unexposed resist (depending on resist type)
 4. **Etching** – Transfer the pattern into the underlying layer
- Current Technology: Deep UV (DUV) and Extreme UV (EUV) lithography enable sub-10 nm feature sizes

(c) Etching

- Wet etching: Chemical solutions remove material isotropically.
- Dry etching: Plasma etching provides anisotropic pattern definition.

(d) Doping (Ion Implantation / Diffusion)

- Introduction of controlled impurities (dopants) to create n-type or p-type regions
- Ion implantation uses accelerated dopant ions; diffusion relies on high-temperature dopant penetration.

(e) Thin-Film Deposition

- Chemical Vapour Deposition (CVD): Layers grown from gaseous precursors (e.g., Si₃N₄, polysilicon)
- Physical Vapour Deposition (PVD): Metal deposition via sputtering or evaporation
- Atomic Layer Deposition (ALD): Atomic-level thickness control

(f) Epitaxy

- Growth of a crystalline layer on a wafer substrate
- Enables hetero-structures (e.g., GaN on SiC) for advanced devices

7.0 WHY SEMICONDUCTORS MATTER FOR NIGERIA’S ENERGY FUTURE

Nigeria’s pathway to sustainable economic growth, energy security, and technological independence will increasingly depend on the integration of semiconductor technologies into its energy ecosystem (Agency - 2023). As the nation confronts rising electricity demand, aging grid infrastructure, and the need to diversify energy sources, semiconductors will play a central role in power generation, transmission, distribution, and end-use efficiency.

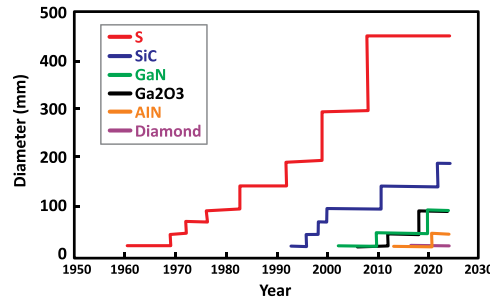
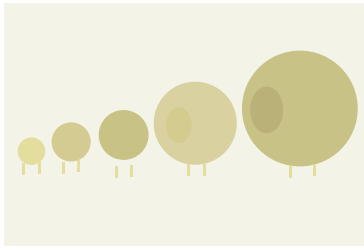
The current challenges are enumerated hereunder:

- **Electricity Access:** Over 85 million Nigerians still lack access to grid electricity.
- **Grid Instability:** Frequent outages and voltage fluctuations hamper industrial productivity.
- **Energy Losses:** Transmission and distribution losses exceed 40% in some regions.
- **Overdependence on Fossil Fuels:** There is limited integration of renewable energy sources.

The emerging opportunities arising from these challenges are as follows:

- Large-scale deployment of solar photovoltaics (PV) in rural and peri-urban areas
- Expansion of off-grid renewable micro-grids

HISTORY OF SUBSTRATE TECHNOLOGY



Wafer diameter scaling is critical for commercial manufacturing

$$DPW = \left[\frac{\pi r^2}{S} \right] = \left[\frac{\pi d^2}{4S} \right]$$

(S = die size)

SiC Substrate Vendors

- Wolfspeed
- Coherent

Ga₂O₃ Substrate Vendors

- Noven Crystal Technology (Japan)

GaN Substrate Vendors

- | | | |
|----------------------|--------------|---------------|
| United States | Japan | Europe |
| • Kyma | • Mitsubishi | • Lumilog |
| • SixPoint | • SCIOCS | • Ammono |
| • Soraa | | |

Most high quality substrates are from Japan and Europe (little US investment)

AlN Substrate Vendors

- Hexatech
- Crystal IS

Diamond Substrate Vendors

- Element Six
- Diamond Foundries

**Substantial US investment

Figure 6: History of substrate technology (Hite, 2024)

- Modernization of power electronics for a more efficient and reliable supply

7.1 ROLE OF SEMICONDUCTORS IN MODERN ENERGY SYSTEMS

(a) Renewable Energy Generation (IRENA - 2023)

i. Solar Photovoltaics (PV):

Semiconductors such as crystalline silicon, CdTe, and perovskites directly convert sunlight into electricity. Declining PV costs and Nigeria's abundant solar resource (~5.25 kWh/m²/day average) make solar a key candidate for rural electrification.

ii. Wind Energy:

Power control electronics (often based on SiC MOSFETs or IGBTs) optimise turbine efficiency and integrate variable output into the grid.

(b) Power Conversion and Management

i. Power Electronics:

Wide-bandgap semiconductors (SiC, GaN) enable high-efficiency inverters for solar farms and micro-grids.

Smart converters minimize losses during AC/DC and DC/DC conversion.

ii. Battery Storage Systems:

Semiconductor-based battery management systems (BMS) extend storage life and ensure safe, optimal charging/discharging cycles.

(c) Smart Grids

i. Advanced Metering Infrastructure (AMI)

uses semiconductor chips to enable: Real-time monitoring of energy consumption. They also use demand-response systems to balance load and generation.

ii. Grid Automation:

Microcontrollers, sensors, and communication chips enhance fault detection, self-healing grid functions, and voltage regulation.

(d) Electric Mobility

i. Electric Vehicles (EVs):

SiC-based inverters improve EV range and charging speed. Integrated charging infrastructure relies heavily on semiconductor-controlled converters.

7.2 STRATEGIC OPPORTUNITIES FOR NIGERIA (BARAL - 2023)

i. Localized Manufacturing and Assembly: While building a full-scale semiconductor foundry is capital-intensive, Nigeria can start with module assembly, packaging, and testing facilities for solar inverters, smart meters, and power electronics.

ii. Skill Development: Establishing semiconductor-focused programs at universities and technical institutes will produce engineers for the growing clean energy sector.

Collaborations with global semiconductor companies and research institutions can accelerate technology transfer and adaptation to local needs.

iii. Research and Development Partnerships: Collaborations with global semiconductor companies and research institutions can accelerate technology transfer and adaptation to local needs.

iv. Policy and Incentives: Tax breaks, import duty exemptions, and public-private partnerships can encourage domestic investment in semiconductor-based clean energy solutions.

7.3 BENEFITS FOR NIGERIA'S ENERGY TRANSITION

- **Improved Energy Efficiency:** Lower losses in generation and transmission
- **Greater Renewable Integration:** Stable integration of intermittent sources like solar and wind
- **Energy Access Expansion:** Scalable off-grid systems powered by PV and efficient electronics
- **Economic Diversification:** Growth of high-tech manufacturing and skilled jobs
- **Climate Action:** Reduction in greenhouse gas emissions through cleaner energy systems

8.0 NIGERIA'S KEY SEMICONDUCTOR MATERIAL RESOURCES

- i. Silicon sources:** Abundant silica sand deposits in states like Ogun, Rivers, and Bayelsa. These sources create potential for ultra-high-purity quartz processing
- ii. Rare earth elements (REEs):** Found in Nasarawa, Plateau, and Cross River—critical for magnets in chip manufacturing equipment
- iii. Metals & metalloids for compound semiconductors:** Tin (Sn) from Plateau and Nasarawa for SnO₂ transparent conducting

oxides and Gallium potential from bauxite ores also linked to aluminium industry.

There are Tantalum & Niobium from columbite-tantalite deposits for capacitors in electronics.

iv. Other supporting minerals: Limestone (for high-purity calcium compounds), graphite (for anodes and crucibles).

8.1 OPPORTUNITY LANDSCAPE

- i. Global market dynamics:** There is a growing chip demand linked to AI, EVs, IoT, 5G, solar photovoltaics. There has been a chip supply chain diversification push post-COVID and geopolitical tensions.
- ii. Local economic potential:** Mineral value addition instead of raw export; Creation of a domestic semiconductor materials industry as a stepping stone to device fabrication
- iii. Technology transfer opportunities:** Collaborations with global semiconductor foundries, materials suppliers, and research institutes

8.2 THE ROLE OF CHEMICAL ENGINEERS

- i. Material Purification & Processing:** Converting silica to semiconductor-grade silicon (9N–12N purity); Gallium extraction from bauxite refining waste streams; Hydro-metallurgical & pyro-metallurgical routes for rare earth element (REE) separation.
- ii. Process Intensification & Scale-Up:** Designing energy-efficient, low-emission refining processes; Applying continuous processing and automation in mineral upgrading

Nigeria's rich mineral resources provide a strong foundation for integrating into the global semiconductor supply chain. By leveraging...the country can attract investment, create jobs, and drive industrial growth in high-tech manufacturing.”

iii. Sustainable Processing: Recycling e-waste for rare metals; Waste heat recovery and carbon-neutral process design

iv. Advanced Material Development: R&D on compound semiconductors (GaN, SiC) for power electronics and 5G; Thin-film deposition and doping processes for local prototyping

v. Policy & Industry Interface: Advising on local content policies for semiconductor manufacturing; Driving start-up incubators for semiconductor material processing.

9.0 ROADMAP FOR NIGERIA

i. Resource Mapping & Characterization — quantify reserves of semiconductor-relevant minerals.

ii. Pilot Purification Facilities — start with silica → solar-grade silicon as an entry market.

iii. Skill Development — create semiconductor materials programs in Nigerian universities (chemical engineering, materials science, solid-state physics).

iv. Industrial Partnerships — joint ventures with foreign experts for technology transfer.

v. Local Policy Incentives — tax breaks, infrastructure support, R&D funding for semiconductor materials

10.0 CONCLUSION

The semiconductor industry underpins the modern digital economy, energy transition, and technological sovereignty. For Nigeria, embracing semiconductor technology — from raw material processing to power electronics and smart energy systems — represents a transformative opportunity.

Through strategic investments, skill development, and learning from global exemplars, Nigeria can position itself as a regional semiconductor hub, accelerating its energy future and industrial diversification. Chemical engineers will be vital enablers in this journey, translating natural resource wealth into high-value, sustainable semiconductor technologies.

Nigeria's rich mineral resources provide a strong foundation for integrating into the global semiconductor supply chain. By leveraging its reserves of silicon, gallium, indium, germanium, and rare earth elements, the country can attract investment, create jobs, and drive industrial growth in high-tech manufacturing. With the right policies, Nigeria could become Africa's leading semiconductor material hub, reducing dependence on imports and positioning itself as a key player in the future of technology.

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ggi_group@yahoo.com,
enquiries@ggigroupltd.com,
www.ggigroupltd.com

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East/West Road, Rumuodara,
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Port Harcourt Facility Annex 2

GGI Lane, Igwuruta,
Ikwerre LGA, Rivers State, Nigeria.

Lagos Office:

6 Ijora Causeway,
Ijora, Lagos State, Nigeria.

+234 (0)817 206 4304

Eket Office:

#7 Inyang Udofa Street, Eket,
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TRANSFORMATIONAL LEADERSHIP CHARACTERISTICS AND IMPACT ON ENGINEERING ORGANIZATIONS

1.0 INTRODUCTION

Transformational leadership is a leadership style that has gained immense recognition in recent times, especially within the field of engineering organizations. This type of leadership has proven to be highly effective in driving innovation, fostering a positive work culture, and increasing productivity within engineering teams. In this article, we will take an in-depth look at the characteristics of transformational leadership and its impact on engineering organizations.

2.0 CHARACTERISTICS OF TRANSFORMATIONAL LEADERSHIP

To understand the impact of transformational leadership, it is essential to first understand its core characteristics. The primary focus of this style of leadership is to bring about positive change and inspire individuals to achieve their full potential. Let us delve into the key characteristics of transformational leadership that make it unique and effective.

i. Visionary: Transformational leaders have a clear vision of where they want to take their team or organization. They possess the ability to articulate this vision in a way that motivates and inspires their team members. This vision serves as a guiding force for the team, giving them a sense of direction and purpose.

ii. Charisma: Transformational leaders are known for their charisma and ‘magnetic’ personality. They have a natural ability to connect with their team members and earn their trust and respect. This enables them to influence and persuade their team to achieve the desired results.

iii. Inspirational: One of the most crucial characteristics of transformational leadership is the ability to inspire individuals to reach their full potential. These leaders foster a sense of passion and commitment within their team members by setting high expectations and encouraging them to go above and beyond their capabilities.

iv. Intellectual Stimulation: Transformational leaders encourage creative thinking and problem-solving within their team. They challenge the status quo and push their team to come up with innovative solutions. This approach fosters a culture of continuous learning and growth within the organization.

v. Individualized Consideration: Transformational leaders recognize the unique strengths and weaknesses of each team member and cater their leadership style accordingly. They provide individualized attention and support to help each team member reach his full potential.



Engr. AbdulRasheed Babalola, PhD, FNSE, FNSChE, FNISafetyE, FNIFEngM
(Director, Centre for Facilities Engineering & Management, Akwa Ibom State University)

3.0 IMPACT OF TRANSFORMATIONAL LEADERSHIP ON ENGINEERING ORGANIZATIONS

Now that we have a clear understanding of the characteristics of transformational leadership, let us look at its impact on engineering organizations.

i. Fosters Innovation: In engineering organizations, innovation is key to staying ahead of the competition. Transformational leaders create a work environment that encourages out-of-the-box thinking, leading to the generation of new ideas and processes. This enables the organization to

constantly evolve and improve its products and services.

ii. Increases Employee Engagement: Transformational leaders empower their team members and involve them in decision-making processes. This approach not only increases employee engagement but also fosters a sense of ownership and commitment towards the organization’s goals.

iii. Enhances Team Collaboration: Transformational leaders focus on building strong relationships with their team members and promote a collaborative work culture. This leads to better communication, idea sharing, and problem-solving, resulting in improved team performance.

iv. Boosts Employee Morale: Transformational leaders create a positive work environment by recognizing and acknowledging their team members’ efforts and contributions. This leads to a boost in employee morale, resulting in increased productivity and job satisfaction.

“...focus of this style of leadership is to bring about positive change...inspire...”

In conclusion, transformational leadership is a powerful and effective style of leadership that has a significant impact on engineering organizations. Its characteristics, such as having a vision, inspiring and empowering team members, and fostering innovation, make it a valuable asset in today’s fast-paced and constantly evolving engineering world. Organizations that adopt transformational leadership style are likely to see an increase in productivity, employee engagement, and overall success.



08174589686
08094273826

vitavisconig
info@vitavisco.com.ng
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