UTILIZATION OF INDIGENOUS TECHNOLOGIES IN SALT PRODUCTION, INTERMEDIATE CHEMICALS AND ELECTROLYSIS OF BRINE FOR THE PRODUCTION OF SODIUM HYPOCHLORITE, CHLORINE GAS & SODIUM HYDROXIDE

A PROPOSAL SUBMITTED

TO

THE NATIONAL AGENCY FOR SCIENCE AND ENGINEERING INFRASTRUCTURE (NASENI)

FOR THE

NASENI RESEARCH COMMERCIALIZATION GRANTS PROGRAMME (NRCGP)

SEPTEMBER, 2025

Thematic Area: Health and Biotechnology

Project Title: Utilization of Indigenous Technologies in Salt Production, Intermediate Chemicals and Electrolysis of Brine for the Production of Sodium Hypochlorite Chlorine Gas & Sodium Hydroxide

Executive Summary:

Importation of refined salt into the country stood at US$2.3 billion annually as at 2017 (BGL Research). To drive the development of salt value chain and encourage the local utilization of salt, technologies for the production of high-value chemicals such as sodium hydroxide and chlorine from salt must be developed. Despite the global demand and local consumption of these chemicals, either directly or indirectly, they are largely imported into the country. Such importations unnecessarily increase the demand on US dollar, the devaluation of Nigerian Naira with unwanted consequences affecting the whole country. These importations and their consequences are partly due to the unavailability of the chemical process technology for the processing of salt and production of these value chemicals.

Production of sodium hydroxide, chlorine gas, sodium hypochlorite and intermediate chemicals from salt is integral to industrial development in Nigeria. Electrolysis of salt yields these key chemicals, with sodium hydroxide playing a vital role in the production of soaps, detergents, and textiles. Sodium hypochlorite derived from chlorine and sodium hydroxide, is a potent disinfectant crucial for ensuring clean water supplies. The establishment of efficient production facilities supports domestic industries, fosters economic growth, and contributes to overall industrial development in Nigeria.

The project offers concise insights into diverse technologies utilized in the production of sodium hydroxide, chlorine gas and sodium hypochlorite from brine. The design of the pilot plant was executed using cutting-edge process simulation software. Additionally, estimates for the cost of fabricating, installing, and commissioning the pilot plant are provided in this proposal. A Chinese company has been identified as a potential turnkey project supplier for the pilot plant. The outcomes of the project will contribute to advancing sustainable utilization of local salt deposit in the production of sodium hydroxide, chlorine gas, sodium hypochlorite and other intermediate chemicals. Also this will help in carrying out a re-engineering of the plant.

1.0 Introductory Background and Statement of Need:

Salt (sodium chloride), required for the production of valuable chemicals is readily available in Nigeria. Brine lakes, which is essentially naturally occurring salty water, can be found in Imo, Plateau, Ebonyi and Nasarawa States. Rock salt, on the other hand, is reported to be available in other states including Benue. Nigeria has an estimated reserve of at least 1.5 billion metric tonnes of rock salt deposit, while the consumption of refined salt is reportedly 600,000 metric tonnes. Despite the consumption/demand and availability of raw salt, the importation of refined salt into the country stood at US$2.3 billion annually as at 2017 (BGL Research). To derive the development of salt value chain and encourage the local utilization of salt, technologies for the production of high-value chemicals such as sodium hydroxide and chlorine from salt and subsequently sodium hypochlorite (bleach) must be developed.

Chlorine is an intermediary chemical used for the production of large number of consumer chemicals and polymers. Sodium hydroxide is employed in the production of soaps, neutralization of chemical processes amongst other application. It is also used in the pulp and paper industry for the production of cellulose. Sodium hypochlorite, also known as bleach, is a product of the reaction of chlorine with sodium hydroxide. It is used as a bleaching agent and a disinfectant. It is very useful in disinfecting surfaces suspected of being infested with the dreaded pandemic, Corona Virus Disease (COVID-19). Despite the global demand and local consumption of these chemicals, either directly or indirectly, they are largely imported into the country. Such importations unnecessarily increase the demand on US dollar, the devaluation of Nigerian Naira with unwanted consequences affecting the whole country. These importations and their consequences are partly due to the unavailability of the chemical process technology for the processing of salt and production of these value chemicals.

For a true sustainable development, the lack of locally available technology for the processing and conversion of salt and the downstream processes is a critical issue. It is therefore in line with the local content development policy of the Federal Government that this project is aimed partly at resolving this critical issue by developing the expertise locally.

Finally, the development and subsequent transfer of the process technology for the co-production of sodium hypochlorite, chlorine and sodium hydroxide will have a positive impact on the economy of the country in the long term. The project team will gain valuable transferable skills. The project if properly deployed through entrepreneurs will substantially aid in achieving the government's goals of import substitution.

This proposal responds directly to NASENI's call for research commercialization grant under the Renewed Hope Agenda in Health and Biotechnology. National Research Institute for Chemical Technology (NARICT), Zaria, have designed a one (1) ton per day pilot plant for the production of sodium hypochlorite and other in preparation to its commercialization. Figure1 below shows the process flow diagram of the plant. This design was carried out using cutting age software.

Plate 1: The Turnkey Plant expected from China for the Production of Sodium Hypochloride, Sodium Hydroxide, Chlorine Gas etc.

1.1 Research Idea/Innovation

The raw material, essentially brine, required for the co-production of sodium hypochlorite, chlorine gas and sodium hydroxide and other intermediate chemicals is readily available in Nigeria. Despite the huge consumption of these chemicals, they are largely imported into the country. Such importations unnecessarily increase the demand on US dollar and the devaluation of Nigerian Naira with unwanted consequences bedeviling the whole nation. With this innovation, the project would consolidate expertise in the Indigenous technology for the Process Design and Production of Sodium Hypochlorite (bleach), Sodium Hydroxide, Chlorine Gas and other intermediate chemicals from Salt. This will reduce importation and thereby contribute in the diversification of the nation's economy through commercialization of the technology.

1.2 Project Justification

The project is key as it offers innovative solutions to address the challenge in importation of these chemicals with negative consequences bedeviling the whole nation. Such importations unnecessarily increase the demand on US dollar and the devaluation of Nigerian Naira.

Despite the large deposit of salt in the country, we still depend on imported refined salt and these valued added chemicals for our industrial usage. This situation justifies the utilization of the available raw material salt for the production of sodium hydroxide, chlorine gas, sodium hypochlorite and other intermediate chemicals, thus contributing to the economy diversification and sustainability in the long term.

1. **Economic Impact:**
    a. **Reduction in Import Dependency:** The project aims to decrease the reliance on imports for sodium hypochlorite and sodium hydroxide, leading to reduced demand for foreign currency and potential stabilization of the Nigerian Naira.
    b. **Job Creation:** Establishing local production plants will create job opportunities across various skill levels, contributing to economic growth and poverty reduction.

2. **Technological Independence:**
    a. **Technology Transfer:** By developing local expertise in chemical process plant design, the project facilitates the transfer of advanced technology, reducing the need for foreign expertise in the long run.
    b. **Knowledge Economy:** Fostering local knowledge and skills in chemical manufacturing builds a foundation for a knowledge-based economy, enhancing overall technological capabilities.
3. **Environmental Impact:**
    a. **Reduced Carbon Footprint:** Local production minimizes the environmental impact associated with the transportation of chemicals over long distances, contributing to sustainability goals.
    b. **Waste Management:** Implementing optimized processes can lead to better waste management practices, ensuring environmental compliance and sustainability.
4. **National Security:**
    a. **Reduced Dependency on Imports:** The project enhances national security by reducing dependency on external sources for critical chemicals, ensuring a stable and secure supply chain.
5. **Research and Development:**
    a. **Pilot Plant Optimization:** Establishing a pilot plant provides an opportunity for research and development, optimizing processes and collecting data for future scale-up.
    b. **Innovation:** The project encourages innovation and the development of new technologies within the chemical manufacturing sector, positioning Nigeria as a hub for such advancements.

1.3 Project Goals & Objectives

The major goal with its respective specific objectives.

Goal: Development of a pilot plant for co-producing sodium hydroxide, chlorine gas, sodium hypochlorite and intermediate chemicals from brine.

Objectives for goal

i. To design and develop of a pilot plant
ii. Development of indigenous expertise in chemical process plant design
iii. Development of indigenous technology in the production of sodium hypochlorite from brine

iv. To optimize the pilot plant and collect data required for scale-up
v. Employment and wealth generation
vi. Reduction in capital flight arising from importation of products

1.4 Conceptual/ Theoretical Framework

Sodium hypochlorite derived from the hydrolysis of salt and intermediate chemicals is integral to industrial development in Nigeria. NARICT as a research institute has completed the design of a process plant for the production of sodium hydroxide, chlorine gas, sodium hypochlorite and other intermediate chemicals from raw salt as a potent disinfectant for clean water supply and other applications, respectively. The next phase is now the fabrication and installation of the pilot scale plant.

It is, the establishment of efficient production facilities for sodium hypochlorite (bleach) will support domestic industries, fosters economic growth, and contribute to the overall industrial development of Nigeria.

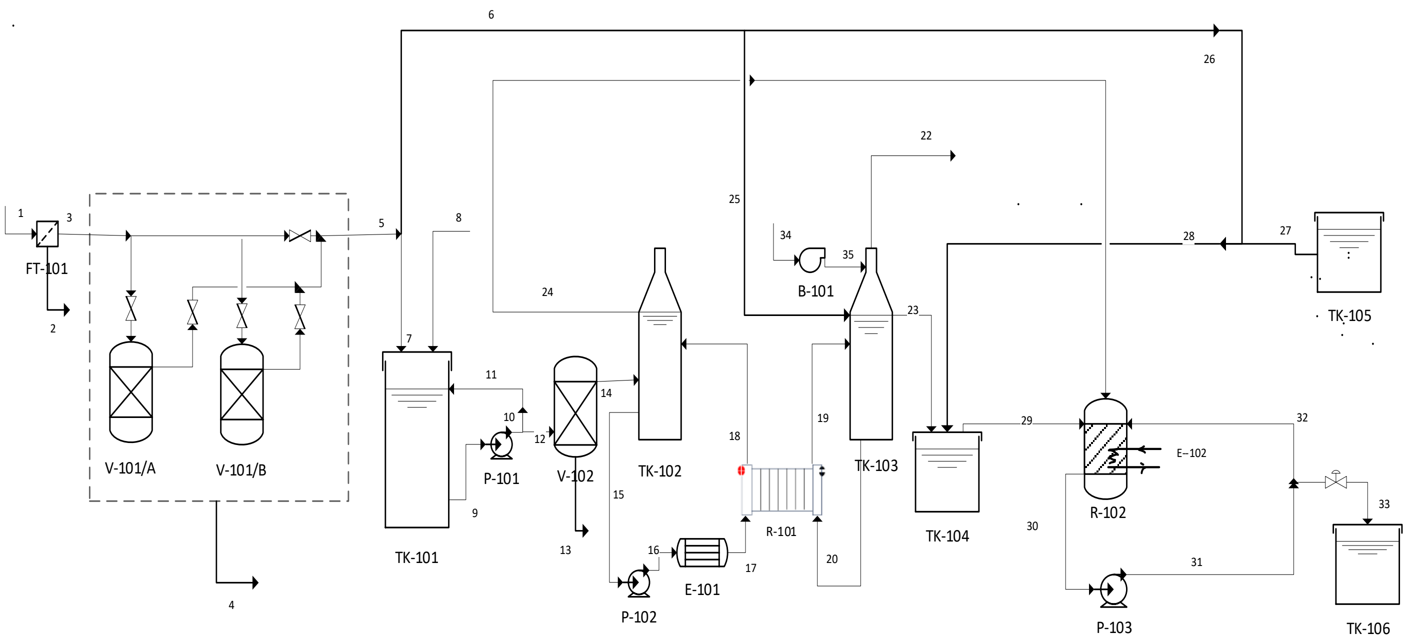

Figure 1: Process Flow Diagram of the Selected Process

The electrolytic cell is the major equipment in the production process and can be operated in either separated or unseparated form. Unseparated cells consist of two or more electrodes that are immersed in a brine stream based on sodium chloride (NaCl) that is usually pumped through the cell. The overall chemical reaction that occurs within an unseparated electrolytic cell is the production of sodium hypochlorite (NaOCl) and hydrogen (H_2) gas from a sodium chloride (NaCl) solution in water.

$$NaCl + H_2O \rightarrow NaOCl + H_2\uparrow$$

In the case of the separated cells, the anode and cathode sides of the cell are separated by a membrane that allows for current to flow from anode to cathode but does not allow the solutions contained within the anode and cathode compartments to mix. The overall chemical reaction is:

$2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2\uparrow + H_2\uparrow$

The caustic soda and chlorine from the separated electrolytic cell can be further reacted to produce sodium hypochlorite according to the following reaction:

$2NaOH + Cl_2 \rightarrow NaOCl + NaCl + H_2O$

Since our aim is to co-produce caustic soda, chlorine and sodium hypochlorite, then the separated electrolytic cell was adopted.

Two product streams leave the electrolyser. These are the depleted brine stream (18) and the caustic outlet stream (19). The depleted brine stream goes to the catholyte tank where it gets separated into a vapor stream consisting of mainly chlorine (Stream 24) and an aqueous stream of depleted brine (Stream 15) which is recycled back to the electrolyser. The caustic outlet stream enters the catholyte (TK-103) where it gets separated into a hydrogen stream (22) and caustic streams (20 and 23). An air blower (B-101) is used to dilute the hydrogen stream for safe disposal to the atmosphere. Stream 20 is recycled back to the electrolyser, while Stream 23 is sent to the caustic storage tank, TK-104. A makeup stream of 50 wt% caustic, Stream 28, from TK-105, is sent to TK-104.

Chlorine gas (Stream 24) from the anolyte tank unit is fed to the hypochlorite conversion reactor, R-102. Also fed to the R-102 is the diluted NaOH from the caustic tank (Stream 29). The two streams react to form a sodium hypochlorite solution in the hypochlorite conversion reactor according to the following reaction:

$$2NaOH(aq) + Cl_2(g) \leftrightarrow NaOCl(aq) + NaCl(aq) + H_2O(l)$$

The sodium hypochlorite reaction is exothermic and requires cooling. Therefore, cooling water which passes through heat exchanger, E-102, is used to maintain a temperature of 35°C in the hypochlorite conversion reactor (R-102). The product stream from the reactor, Stream 30, is fed to the product recycle pump P-103, The stream leaving P-103, Stream 31, is split into two, one portion of which, Stream 32, is returned to the reactor to provide mixing. The other portion, Stream 33, is sent the hypochlorite tank, TK-106, as the final product.

The process described above can be used for the production of sodium hypochlorite as the final product. The same process can be configured to produce chlorine and caustic soda as the main products.

2.0 Technology Readiness Level (TRL-02)

NARICT has successfully designed a 1,000 kg/day capacity pilot plant for the production of sodium hydroxide, chlorine gas and sodium hypochlorite and other intermediate chemicals from available salt deposit in the country. The present status of the project is seeking for collaboration to actualize the plant’s fabrication, installation, test-run, and technology transfer to entrepreneurs for commercialization.

3.0 Methodology & Technical Approach

To achieve the set scope, raw materials (salt and water) will be characterized using proximate analysis, XRF, GC-MS to determine purity of the samples.

The project's scope involves two phases:

Phase I: -

- Design of a pilot plant for the production of sodium hypochlorite, chlorine gas and sodium hydroxide from (salt) brine.(this is already completed)
- Procurement, installation and commissioning of the plant the Turnkey Plant
- Optimizing operations for efficiency and scalability.

Phase II: -

To achieve the set scope, the products obtained at different operating stage will be collected and characterize for each run using XRF (elemental composition), GC-MS (concentration of sodium hydroxide) and Gas Chromatography (determination of the concentration of chlorine gas)

- Backward Engineering of the Electrolytic part of the plant
- Scaling up of the pilot plant to commercial size
- Test-runs, and trouble shooting of the plant
- Establishing collaboration with industrial partners for deployment

4.0 Expected Outputs and Method of Dissemination

i Development of indigenous expertise in chemical process plant design

ii Development of indigenous technology on some aspect of the process for the co-production of sodium hypochlorite, chlorine gas and sodium hydroxide from salt

iii Transfer of the indigenous developed technology to entrepreneurs

iv Drastic reduction in capital flight arising from importation of these chemicals

v Employment generation across various stages of production, supply, and related services

vi Creating opportunities for export to regional and international markets, thereby contributing to foreign exchange earnings and overall economic growth

5.0 Expected Impact

Development of indigenous technology for the co-production of sodium hydroxide, chlorine gas and sodium hypochlorite (bleach), that will lead to import substitution and thereby reduce the increasing demand on forex. The project team will gain valuable transferable skills and it will also contribute to the government's efforts in the diversification of the nation's economy. The ultimate goal being development, deployment and transfer of the technology innovation to entrepreneurs.

6.0 Project Team Members and Specialization

Project Team Members and their specializations are shown in Table 1 below.

1. Engr. Dr. Kabiru Muazu is the DG/CEO, NARICT with discipline in Chemical Engineer, he will provide technical support to ensure success overall project. With over 40 publications in peer reviewed journals and conferences, his expertise in reactor design and process scale up is critical for this project. His role will ensure the pilot plant's design aligns with thermodynamic principles and engineering best practices. He will also design the process flow diagrams (PFDs), specifying major equipment, and developing the plant's operational protocols to ensure a safe, scalable, and economically viable system

2. Nwobi Egbi Bridget, a Chemical Engineer and Ag. head, Pilot Plants and Fabrication Technology Department and a researcher at NARICT with over 30 publications in peer reviewed journals and conferences. her expertise in process plant design and scaling of laboratory data to pilot scale. Also, she will serve as the co-principal investigator (Co-PI), providing overall project leadership, strategic direction and technical oversight.

3. Engr. Dr. Omar Ahmed Umar, an Associate Professor of Chemical and Process Engineering with over 50 publications, offers academic rigor and specialized knowledge in the electrolysis of salt to sodium hypochlorite. He will serve as an external collaborator, providing advanced expertise in process modelling and validation of reactor performance. His expertise will be pivotal in optimizing the electrolysis of salt to sodium hypochlorite and other intermediate chemicals.

4. Engr. Samuel Akuso Alkali, a chemical engineer and head, Production and Process Division, Pilot Plants and Fabrication Technology Department at NARICT with over 35 publications in peer reviewed journals and conferences. His expertise in process plant design and scaling of laboratory data to pilot scale. He will also assist the principal investigator to provide technical support to aid the success of the project.

5. Salisu Mohammed, a chemical engineer and staff of Production and Process Division, Pilot Plants and Fabrication Technology Department at NARICT with over 20 publications in peer reviewed journals and conferences. His expertise in process plant design and scaling of laboratory data to pilot scale.

6. Engr. Joseph O. O., a mechanical engineer and head, Fabrication Technology Division at NARICT with over 25 publications in peer reviewed journals and conferences. His expertise in fabrication, installation and test-run of the plant.

7. Uzairu Adamu Ibrahim, a Principal Technologist 10 publications, He will be the Pilot Plant Operations and Safety Lead, directly responsible for the day-to-day running of the laboratory activities, maintenance, troubleshooting, and enforcing strict health, safety, and environmental (HSE) protocols throughout the project's duration.

8. Shehu Muhammed, a Principal Technologist with over10 publications, He will be the Pilot Plant Operator and Safety Lead, directly responsible for the day-to-day running of the laboratory activities, maintenance, troubleshooting, and enforcing strict health, safety, and environmental (HSE) protocols throughout the project's duration.

6.1 Track Record and Demonstration of Expertise

NARICT is known with a lot of expertise in Design, Fabrication and Pilot Scaling of research works; and has successfully completed scaling up amongst others, Essential Oils extraction plants. Presently, NARICT has Installed and commissioned two commercial Plants at the Centre of Excellence in Reproductive Health Innovation (CERHI), University of Benin, Edo State and Eco Growth Pattern Limited Kakana Village, Mambilla Plateau, Taraba State, organo-mineral fertilizer production plant, hydrated lime production plants (rotary and box type kilns), respectively. There are also journal publications and books published to this effect. NARICT is proud of having calibre of man power composing of Researchers, engineers, and laboratory technologists.

Plate 2: The Essential Oil Plant at Eco Growth Pattern Limited Kakana Village, Mambilla Plateau, Taraba State

The Principal Investigator (PI) and the Co-Principal Investigators are Chemical Engineers, their specialty is in process engineering. They were involved in the installation and running of the Katsina Neem Processing Plant (https://youtu.be/DOvWSOQ2RZY?si=MijcyYWkW-MI5fMB). The person in the video on the platform is the PI. The PI has over a decade research experience in the area of process plant design. The project team is composed of interdisciplinary such as chemical engineering, process engineering, mechanical engineering, chemistry, and electrical engineering.

7.0 Sustainability & Commercialization Plan

Nigeria has an estimate reserve of at least 1.5 billion metric tonnes of rock salt deposit, while the consumption of refined salt is 600,000 metric tonnes (BGL Research, 2017). In Nigeria, salt processing is mostly done locally by rural dwellers and thus cannot meet national demand. According to the Raw Materials Research Development Council (RMRDC), the national demand for table salt, caustic soda, among others exceeds one million tonnes. Data from the National Bureau of Statistics (NBS) also show Nigeria spent at least N155 billion in 2021 and 2022 on the importation of salt and other locally available products from Asia and South America. Salt is used mostly in cooking, preservation, soap, detergents, chemical industries, water treatment, stain removal, mineral supplement for livestock, de-icing roads and highways in cold regions, dyes and among others.

Therefore, Nigeria can leverage on this natural wealth (if effectively harnessed) for sustainable development and economic prosperity.

To certify the sustainability and commercialization of this project with the abundant deposit of salt in the country, all stake holders must be desperate in achieving the objectives of the project through public awareness, seminars and conduct financial projection to attracts the private sector investors and small industries the economic benefits in sodium hypochlorite production and other intermediate chemicals from salt.

8.0 Timeline

The project is expected to take off by 2026 and anticipate to complete within the span of 24 months calendar by the end of 2027.

Table 1: Timeline to execute the project

S/N	Tasks (Month)	2	4	6	8	10	12	14	16	18	20	22	24	26	28
1	Purchase of Turnkey pilot plant for the production of sodium hypochlorite														
2	Installation of the plant and test running														
3	Trouble shooting, optimization and commissioning of the plant														
4	Data analysis and report														
5	Backward Engineering of the Electrolyser														
6	Fabrication, Installation and Test running														
7	Final Reporting														

9.0 Monitoring and Evaluation

The project team will perform systematic progress appraisals, identify possible challenges, and develop emergency plans, backup suppliers for materials. Evaluation will be conducted by assessing Key Performance Indicators (KPIs)

9.1 KPIs and Measurable Indicators

Table 2: KPIs and measurable indicators

S/N	KPI’s	Measurable Indicators
1	Pilot plant	The design of the pilot plant was performed using cutting-edge process simulation software
2	Material selection	Selection of the materials to be used for fabrication. The material selection will be done in accordance with design standard and specifications
3	Fabrication, Installation and test run	Fabrication, assembling and installation including test run
4	Optimization	Process and plant optimization
5	Patency	Application for patent certification for the technology

9.2 Risk Management Plan.

Safety is an issue that must be considered whenever or wherever people are involved with equipment operation in particular chemical reactions. Under normal operating conditions, hypochlorite systems are leak proof. However, leakage and spillage may occur during system operations. Sodium hypochlorite and chlorine gas are considered hazardous and potentially dangerous to operating personnel and must be aware that the direct mixture of sodium hypochlorite solution with hydrochloric acid while making the cleaning transition process will release free chlorine gas. Reaction of chlorine gas and sodium hydroxide are hazardous and is exothermic which demands temperature control and should be handle with care. The temperature must be maintained below 35 °C. While financial risks will be mitigated by phase disbursement of funds, external audits and sourcing for other grants.

The following information should be made available to all personnel:

Sodium hypochlorite handling hazards

- Ingestion of NaOCI by mouth has a very serious poisoning effect, which could lead to death.
- Inhalation of NaOCI vapor can give rise to headaches, irritation of the mucous membrane, lack of coordination, and loss of consciousness.
- Persistent absorption of NaOCI through the skin may lead to skin disorders.

Splashes on the skin

- Remove the affected clothing immediately and wash the skin thoroughly until all contamination has been removed.
- Refer the patient to a doctor or a hospital for further treatment.

Gassing and ingestion by mouth

- Obtain medical assistance immediately.
- Move the patient to a fresh air environment as soon as possible.
- Keep the patient warm with blankets and resting quietly.
- Oxygen must be administered by qualified personnel.
- If breathing fails, administer artificial respiration immediately and continue until the patient breathes again or until a doctor instructs otherwise.
- If NaOCI has been swallowed, do not induce vomiting but obtain medical aid immediately.

10.0 Project Budget and Justification

Table 10.3: Procurement of Turnkey plant, analytical equipment, Re-Engineering etc

S/n.	Item	Amount (N)
1	Turnkey Plant	225,000,000:00
2	Clearance, Transport, Freight charges & Logistics from Lagos to Zaria(20%)	45,000,000:00
3	Installation &Training(10%)	2,250,000:00
4	Consumable	12,000,000:00
4	Design & Fabrication of Pilot Plant(Revise Engineering)	250,000,000:00
8	XRF	50,000,000:00
9	Gas Analyser	39,175,000:00
10	Total Suspended Solid Analyzer (TSA)	10,815,000:00
11	Fume Cupboard	7,815,000:00
12	Training, workshops & Conferences for team members	16,055,000:00
13	Publications of Research Finding in High Impact Journals	750,000:00
14	Architectural Prototype of the Plant	2,000,000:00
15	Utilities and Installation	2,500,000:00
16	Environmental Impact Assessment Safety	4,500,000:00
17	Contengency 10%	65,586,000:00
	SUB-TOTAL A	**721,446,000:00**

Turnkey Plant:

A company has been contacted a company in China that is ready to fabricate the design plant we have carried out. They are contacted because of the Electrolysis unit which we don't have the technology. When we get this we will be able to carry out a reverse engineering on the plant to get a pilot scale.

Clearance, Transport, Freight & Logistic from Lagos to Zaria:

The turnkey plant contract will be to get it to Lagos, hence the plant will be cleared at port and transported to Zaria. This is assume to be 20% of the cost of the turnkey plant

Installation and Trainging:

The Turnkey Plant will be install and test run and the team members will be trained at an estimated cost of 10% of the cost of the plant.

Utilities and Installation

Includes piping, electrical connections, and insulation, which are essential for plant integration. Civil works such as foundations and housing structures are budgeted to ensure plant safety and durability.

Environmental Impact Assessment and safety

Gas cleaning units and flare systems are essential for emission control of hazardous gasses, while personal protective equipment ensures operator safety. Compliance with environmental regulations is prioritized. This is basically because of the production of the Chlorine gas which is very hazardous

Laboratory Analysis

Analytical equipment such as GC–MS, XRF and gas analyzer are needed to characterize products properties in compliance with international standards.

Consumables and Operating Cost

This covers recurring expenses; feedstock procurement, utilities (electricity, water and other precipitating chemicals), and routine maintenance.

Personnel and Training

Skilled engineers, technicians, and operators are required for design, fabrication, and plant operation. Training programs are budgeted to ensure personnel are well-prepared to handle scaling-up challenges.

Pilot Scaling:

The Electrolyser will be opened and studied and it will be re-design and fabricated locally to meet our local need.

Contingency (10%)

A 10% of total project cost allocation covers unexpected costs during fabrication, installation, or operation, reflecting best practices in pilot plant budgeting.

References

1. Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali by European Commission, Industrial Emissions Directive 2010/75/EU, 2014

2. Chlor-Alkali Industry Review 2022-2023, Euro Chlor, Brussels.

3. Chlorine, in Kirk-Othmer Encyclopedia of Chemical Technology, T. V. Bommaraju et al., 5th edition, John Wiley and Sons, New York, 2002.

4. Chlorine: It's Manufacture, Properties and Uses, J. S. Sconce (editor), Reinhold, New York, 1962.

5. Chlorine: Principles and Industrial Practice, P. Schmittinger (editor), Wiley VCH, Weinheim. 2000.

6. ClorTec: On-Site Hypochlorite Generating Systems, brochure of Severn Trent Services, 2009.

7. Conversion to on-site sodium hypochlorite generation: water and wastewater applications, Leonard W. Casson and James W. Bess, Jr., CRC Press LLC., Florida, 2003.

8. Handbook of Chlor-Alkali Technology, T. F. O'Brien, T. V. Bommaraju, and F. Hine, Springer, New York, NY 2005.

9. Modern Chlor-Alkali Technology, J. Moorhouse (editor), Vol. 8, The Society of Chemical Industry, London, 2001.

10. On-Site Generation of Hypochlorite, Manual of Water Supply Practices—M65, First Edition, American Water Works Association, Denver, 2015.

11. *Perry's Chemical Engineers' Handbook,* Seventh Edition, Robert H. Perry, and Don Green, editors, 1997.

12. Salt, Chlor-Alkali, and Related Heavy Chemicals, T. F. O'Brien, in "Handbook of Industrial Chemistry and Biotechnology" (12th edition) Chapter 26, pp 1017-1038, J. Kent (editor), Springer, New York, 2013.

13. Sodium Chloride, in Kirk-Othmer Encyclopedia of Chemical Technology, S. R. Feldman, 5th edition, John Wiley and Sons, New York, 2002.

14. Sodium Hydroxide, in Kirk-Othmer Encyclopedia of Chemical Technology, T. Eggeman, 5th edition, John Wiley and Sons, New York, 2002.

15. The Chlorine Manual, Pamphlet #1, 6th ed., The Chlorine Institute, Washington, D.C., 1990.

16. *White's Handbook of Chlorination and Alternative Disinfectants* (*White's*). 5th ed. 2010. Hoboken, N.J.: John Wiley and Sons.

17. BGL Research, 2017

18. Raw Materials Research Development Council (RMRDC)
19. National Bureau of Statistics (NBS)