NASENI Research Commercialization Grant Proposal (NRCGP)

Project Title: Development and Commercialization of a Locally Adapted Vacuum Refrigeration System (VRS) for Food Preservation in Nigeria

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1. Executive Summary

This proposal aims to advance and commercialize an indigenously developed Vacuum Refrigeration System (VRS) optimized for Nigerian agricultural and food processing industries. The proposed system leverages vacuum cooling technology, a rapid, evaporative, and energy-efficient process to preserve fruits, vegetables, and processed foods at their intrinsic storage temperatures, minimizing nutrient loss and spoilage.

Building on the successful comparative performance study by Audu & Ainakhuagbon (2023), which demonstrated 88.85% nutrient retention, 28-day shelf life, and 25% energy savings, this project proposes a retrofit VRS with IoT-enabled digital controls, solar-assisted power integration, and modular chamber design adaptable for rural and urban enterprises.

The commercialization framework includes partnership with local refrigeration workshops, food cooperatives, and NASENI technology clusters for mass production, piloting, and scaling. The system aligns strongly with NASENI's mandate to indigenize advanced technologies, enhance food security, and reduce postharvest losses.

2. Introduction

Nigeria's agricultural sector contributes significantly to Nigerian GDP and employs over one-third of the workforce, yet postharvest losses in perishable commodities remain alarmingly high. An estimated ₦9 billion worth of produce was lost in 2017 alone (Akinyele et al., 2021). Leafy vegetables, tomatoes, fruits, and fish deteriorate rapidly after harvest due to inadequate preservation facilities, unreliable electricity supply, and the overreliance on conventional refrigeration systems, which are insensitive to product specific storage requirement leading inefficient storage and products spoilage.

Conventional refrigerators operate at uniform cooling temperatures that fail to match the specific thermal and humidity requirements of different products. This results in nutrient degradation, color fading, and microbial contamination. Additionally, these systems depend on synthetic refrigerants (HFCs) with high global warming potential, further challenging environmental and sustainability goals. Hence, there is a pressing need for sustainable, energy-efficient, and product-sensitive cold preservation technologies that fit Nigeria's local context to address the urgent need for food preservation.

Globally, vacuum refrigeration systems (VRS) have emerged as superior alternatives. They rely on evaporative cooling under low pressure, causing water to vaporize at low temperatures and rapidly extract field heat from products. Rocha et al. (2007) demonstrated that VRS preserved lettuce and carrots more effectively than conventional air cooling, retaining freshness and firmness longer. Similarly, Spokowski (2010) reported that vacuum cooling significantly delayed microbial growth and vitamin loss in broccoli and cauliflower compared to conventional refrigeration.

In the Nigerian context, Audu & Ainakhuagbon (2023) provided the first experimental evidence validating VRS performance locally. Their comparative analysis showed that vacuum refrigeration maintained 88.85% nutrient retention agaist 44.99% in conventional systems, doubled shelf life from 14 to 28 days. These findings prove both technical feasibility and commercialization potential of the technology for Nigeria's agricultural sector.

Therefore, developing and commercializing a locally adapted, solar-assisted, IoT-enabled VRS offers a sustainable solution to Nigeria's postharvest challenges. Beyond food security, the initiative can stimulate local manufacturing capacity, reduce import dependency, and enhance the competitiveness of Nigerian agro-products in regional and global markets, directly advancing NASENI's mission of technology transfer, commercialization, and industrial diversification.

3. Statement of the Problem

Nigeria experiences annual postharvest losses estimated at 30–40% due to inadequate cold storage infrastructure and reliance on conventional refrigeration systems that are energy-intensive, unsuitable for unstable power supply, and insensitive to product-specific preservation needs. These systems cause nutrient degradation and microbial spoilage, reducing food quality and market value.

Although vacuum refrigeration systems (VRS) offer rapid cooling, energy efficiency, and better nutrient retention, their research and application remain largely unexplored in Nigeria. Studies such as Audu and Ainakhuagbon (2023) have shown VRS's superior preservation of local vegetables compared to conventional systems. However, the lack of indigenous design, digital control integration, and renewable energy adaptation limits its adoption. There is thus an urgent need to develop a locally adaptive, solar-assisted vacuum refrigeration system with IoT-based control to mitigate postharvest losses and enhance food preservation efficiency in Nigeria.

The proposal aim to develop a digitally controlled, solar-assisted vacuum refrigeration system, to entrench a novel energy-efficient solution to Nigeria's persistent postharvest losses to impact directly on food security, rural livelihoods, and the agro-industrial value chain. The proposed study aligns strongly with NASENI's mandate to translate research into viable, locally manufactured technologies that promote industrial innovation and economic self-reliance.

4. Aim and Objectives

The proposal aim to develop and commercialize a smart, locally fabricated vacuum refrigeration system that preserves food products at intrinsic temperatures with minimal energy input.

The specific objectives of the study are;

i. Establish design parameters and relations for developing a locally adaptive VRS.

ii. Develop digital control and IoT interfaces for temperature, humidity, and pressure regulation.

iii. Integrate solar-assisted energy support for off-grid operation.

iv. Fabricate, test, and optimize a functional prototype using local materials.

v. Evaluate performance on selected Nigerian food products (leafy vegetables, fruits, meat).

vi. Develop commercialization and training framework for local refrigeration fabricators.

5. Literature Review

Vacuum refrigeration has emerged as an effective and eco-friendly technology for preserving perishable products such as vegetables, meat, and flowers (Sun and Wang, 2016; López-González *et al*., 2021). By inducing water evaporation under reduced pressure, it achieves rapid cooling without synthetic refrigerants, reducing both energy use and environmental impact.

Unlike conventional systems, vacuum refrigeration (VRS) removes field heat through moisture evaporation, thereby slowing microbial activity and maintaining product quality (Spokowski, 2010). This ensures uniform cooling and better texture and nutritional retention during storage and transport.

Several studies affirm VRS's superior preservation performance. Rocha et al. (2007) obtained a 7-day shelf life for carrots at 4 °C, while Spokowski (2010) reported 15-day stability for mixed vegetables. In Nigeria, Erena (2020) and Akinyele et al. (2021) highlighted severe postharvest spoilage of fruits and vegetables due to weak cold-chain systems and unreliable power supply, underscoring the need for locally adaptable cooling solutions.

Audu and Ainakhuagbon (2023) advanced this research by developing a prototype VRS from indigenous materials. Their comparative study with conventional systems showed nearly 100 % improvement in shelf life, 97 % nutrient retention, and 25 % energy savings, demonstrating strong potential for Nigeria's agro-processing sector.

Despite these promising findings, most available studies remain laboratory-based or imported, lacking focus on local material use, renewable-energy integration, and IoT-enabled control. Furthermore, no established framework currently exists for commercial production or technician training in vacuum refrigeration technology.

Hence, this study aims to bridge these gaps by developing a solar-assisted, IoT-enabled, and locally fabricated vacuum refrigeration system suited to Nigeria's environmental and industrial conditions, while promoting commercialization aligned with NASENI's mandate for indigenous innovation and sustainable manufacturing.

6. Methodology

The following methodology will be used to implement the study

i. Design Parameter Establishment

   Thermodynamically model and optimize the vacuum refrigeration cycle using

MATLAB and EES to establish design parameters and relationships for a locally adaptive system suited to Nigerian climatic conditions.

ii. Digital Control and IoT Integration

Develop and program a microcontroller-based (ESP32/Arduino) digital control unit for real-time monitoring and automatic regulation of temperature, humidity, and pressure, with IoT dashboard connectivity.

iii. Solar-Assisted Power Integration

Design and implement a 12V/24V solar–battery hybrid energy module to support off-grid operation, ensuring reliability and reduced energy costs for rural and semi-urban users.

iv. Prototype Fabrication and Optimization

Fabricate, assemble, and calibrate a functional VRS prototype using locally sourced materials; optimize system performance through leak testing, parameter calibration, and design refinement.

v. Performance Evaluation on Local Food Products

Experimentally test the prototype on selected Nigerian perishable products (leafy vegetables, fruits, and meat) to measure cooling efficiency, shelf-life extension, nutrient retention, and energy performance against conventional systems.

vi. Commercialization and Capacity Building

Develop a commercialization framework supported by training workshops for local fabricators, intellectual property protection, and pilot deployment through NASENI’s technology clusters and agro-SME partnerships.

7. Innovativeness and Novelty

i. First indigenous VRS commercialization effort in Nigeria.
ii. Integration of IoT-based smart regulation and solar-assist power for off-grid adaptability.
iii. Modular design enabling use in farms, markets, and food-processing SMEs.
iv. Retrofitting framework to convert existing refrigerators into vacuum-compatible systems.
v. Potential export-oriented model for West African agricultural chains.

8. Commercial Viability and Market Pathway

i. Target Market: Fresh produce traders, food processors, cold-chain operators, restaurants, and export-packers.

ii. Market Advantage: 25–40% reduction in postharvest loss yields high ROI within 18 months.

iii. Business Model: Local fabrication through NASENI technology clusters, component licensing, and after-sales support network.

9. Technology Readiness Level (TRL)

i. Current Level: TRL 6 – Technology demonstration in a relevant enviroment (Audu & Ainakhuagbon, 2023).

ii. Next Level (NASENI Support): TRL 6–7 – Pilot-scale manufacturing and multi-product validation.

iii. Evidence: Peer-reviewed publication, prototype images, and comparative data

10. Alignment with NASENI Objectives

i. Supports technology transfer and local fabrication capacity-building.

ii. Addresses food security and agro-industrial competitiveness.

iii. Advances green refrigeration technologies consistent with Nigeria's climate commitments.

iv. Encourages innovation-driven industrial diversification.

11. Potential for Scale and Sustainability

i. Scalable modular design suitable for farms, markets, and SMEs.

ii. Integration with solar micro-grids for rural deployment.

iii. Training component for local artisans and entrepreneurs.

iv. Potential export to ECOWAS countries as 'Made-in-Nigeria' refrigeration solution.

12. Expected Outcomes

i. Locally fabricated, tested, and optimized VRS prototype ready for commercialization.

ii. 25–30% reduction in energy use and postharvest loss.

iii. At least two licensed fabrication partners within 12 months.

iv. Capacity building for 20+ local refrigeration technicians.

v. Research publication and patent filing for design innovation.

13. Project Implementation Timeline (Gantt-Style Plan – 9 Months)

S/N	Activity	M1	M2	M3	M4	M5	M6	M7	M8	Deliverables / Milestones
1	Design Parameter Establishment – Thermodynamic modeling, design relations, system optimization									Design report & optimized system parameters
2	Digital Control and IoT Integration – Development of smart control and monitoring interface									IoT-based control circuit and firmware
3	Solar-Assisted Power Integration									Solar-powered VRS subunit prototype
4	Prototype Fabrication and Optimization – Assembly using local materials, calibration & pressure testing									Fully functional laboratory prototype
5	Performance Evaluation on Local Food Products – Testing on vegetables, fruits, meat; data analysis									Comparative performance data & results
6	Commercialization and Capacity Building – Training of local fabricators, IP filing, market framework									Commercialization framework & training report
7	Project Documentation and Final Reporting – Compilation of results, technical and financial report									Final NASENI-compliant report, manuals, publications

14. Budget

S/N	Budget Category	Description of Items / Activities	Estimated Cost (₦)
1	Equipment and Materials	Procurement of refrigeration components (compressor, condenser, evaporator, vacuum pump), sensors (pressure, humidity, temperature), IoT modules (ESP32, Wi-Fi relays), solar system components (panels, inverter, batteries)	₦2,600,000
2	Prototype Fabrication and Assembly	Fabrication of chamber and frame, welding, machining, insulation, system integration, leak testing, vacuum sealing, and calibration	₦2,400,000
3	Field Testing and Performance Evaluation	Experimental testing on selected perishable food products (vegetables, fruits, meat), laboratory analysis (nutritional, temperature, and energy data), logistics, and test documentation	₦1,800,000
4	Commercialization and Capacity Building	Development of commercialization model, local fabricator training, stakeholder workshop, and production of training manuals	₦1,800,000
5	Travel and Logistics	Transportation for component sourcing, prototype deployment, stakeholder engagement, and field testing	₦800,000
6	Documentation, Reporting, and Publication	Technical reporting, graphical documentation, and publication of results in peer-reviewed journal outlets	₦250,000
7	Total		₦9,650,000

15. Evidence Annex (Summary)

Table A1: Comparative Performance of VRS and Conventional Systems (Audu & Ainakhuagbon, 2023)

Parameter	VRS	Conventional	% Improvement
Nutrient Retention (%)	88.85	44.99	+97%
Shelf Life (days)	28	14	+100%
Energy Consumption (relative)	0.75	1.0	25% savings
Sensory Quality (%)	82.0	48.5	+69%

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