

Renewable Energy Power System for Mining

Building a Secure, Cost-Effective and Green Power Infrastructure for Remote Mining Sites

2026.V1

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Preface

Since the founding of the People's Republic of China, especially since the adoption of the reform and opening-up policy, scientific and technological progress and independent innovation have continuously injected vitality and impetus into the rapid development of China’s power industry.

China’s power system has entered an era characterized by large-capacity units, large-scale systems, AC/DC hybrid transmission, long-distance power transmission, and large-scale grid interconnection. Power automation serves as a critical technology to ensure the safe, economical, and environmentally friendly operation of power systems. Chinese power technology professionals have taken it as their mission to address challenges in the power industry’s development. Through persistent and unremitting efforts, they have achieved a number of significant scientific and technological breakthroughs with independent intellectual property rights in power automation technologies, including relay protection, power stability control, dispatch automation, and power electronics. These achievements have placed China at the forefront globally, with advanced and reliable domestically produced power automation equipment underpinning the sustained and healthy development of the country’s power industry.

Upholding pragmatic innovation and continuously addressing technical challenges in the power industry’s development—such as those in renewable energy development (e.g., wind and solar power), smart grid construction, and ultra-high voltage (UHV) grid development—is the honorable responsibility of China’s power technology professionals.

Chairman, NR Electric
Academician of the Chinese Academy of Engineering



About NR Electric
Renewable Energy
Power System for Mining

About NR Electric



IEDs Factory (Nanjing, 419,000m²)

NR Electric (NR), as a power stability expert, is dedicated to providing smart, reliable and environmentally friendly solutions for power generations, power grids and industries. Its products and solutions cover protection, automation & control, HVDC & FACTS, renewable energy & microgrid and engineering consulting & services. With more than 30 years of professional experience in high-tech innovations, NR provides a wide spectrum of power systems and power electronics solutions to enable its worldwide customers to address increasing demands for quality and safety. NR also offers turnkey and specialist electrical services delivered by more than 5,000 high-tech employees across the globe. NR, a recognizable multinational company, has expanded its presence to over 100 countries & regions.



Headquarters & R&D Center (Nanjing, 58,000m²)

Our power solutions, backed by distinctive expertise bridging both AC & DC power technologies and spanning conventional & renewable energy platforms, serve power systems ranging from large-scale power generation, long-distance high-capacity HVAC and HVDC transmissions, sub-transmissions, medium & low voltage distribution, energy-intensive industries to Industries to eco-friendly renewable wind and solar farms.

Our feedback-oriented approach and non-stop innovation help clients maximize investment efficiency while enhancing safety and reliability. NR's commitment to valuable mission, innovative technology, high-quality products, and field-proven experience enables the company to increase its contributions to power utilities and industrial needs.

Top3

Top 3 Global Suppliers of Power System Protection Equipment

20

Top 20 Chinese Enterprises in Software Productivity

10

Top 10 Most Competitive Enterprises in China's Electrical Industry

130

Reaching Markets Across 130+ Countries and Regions

Executive Summary

Global demand for strategic minerals — copper, lithium and cobalt — is entering a structurally driven growth phase, propelled by electric vehicles, grid-scale energy storage and digital infrastructure. According to the International Energy Agency (IEA), copper demand is forecast to grow from 26.7 million tonnes in 2024 to 34.3 million tonnes by 2040 (+28%), while lithium demand is expected to surge from 2 million tonnes to 9.2 million tonnes (+360%) over the same period.

Yet most greenfield mine and smelter developments are situated in remote regions of Sub-Saharan Africa, South America and high-altitude Asia — areas where power infrastructure ranges from inadequate to non-existent. For these projects, reliable power supply has shifted from a routine engineering consideration to a fundamental operational bottleneck.

The challenge is not a single problem but a convergence of three constraints: severe load transients (e.g., ball mill motor starts), weak or islanded grids, and zero tolerance for unplanned production outages in critical process steps. This combination makes pure diesel generation expensive and unreliable, while simply adding photovoltaic capacity without proper grid-forming support risks destabilising voltage and frequency.

NR Electric's solution centres on the NR-ISGrid grid-forming energy storage system, integrated with PV and a unified source-grid-load-storage control platform — enabling remote mines and smelters to operate at up to 100% renewable penetration with reliability equivalent to a conventional power plant.

Field-validated projects — including KPM Copper Mine (DRC), Kamoa smelter (DRC) and the 3Q lithium brine operation (Argentina) — demonstrate that in off-grid and weak-grid sites where diesel generation costs exceed USD 0.30/kWh, a PV + grid-forming energy storage solution can reduce the levelised cost of energy (LCOE) by 25–35%, raise green energy penetration above 60%, and materially reduce CBAM carbon border adjustment compliance costs.

Chapter 1

Strategic Context:
Power as the Pivotal Variable

Demand Growth: From Cyclical to Structural

Global mineral demand is no longer driven purely by economic cycles. The electrification of transport, expansion of grid-scale storage, and growth of data-centre infrastructure have created a durable, inelastic demand floor for copper, lithium, cobalt and nickel. Key IEA projections through 2040:

Mineral	2024 Output (Mt)	2035 Forecast (Mt)	2040 Forecast (Mt) / Growth
Copper	267	313	34.3 (+28%)
Lithium	20	45	9.2 (+360%)
Cobalt	22	31	3.3 (+50%)
Nickel	337	438	56.8 (+69%)

Source: IEA Global Critical Minerals Outlook 2025

At the same time, the supply side faces structural constraints that limit how quickly new capacity can be brought online:

Constraint	Manifestation	Impact on Projects
Remote location	New mines concentrated in Africa, South America, high-altitude Asia	Weak or absent grid and transportation infrastructure
Long lead times	8–12 years from exploration to first production	Unable to respond quickly to demand spikes
Declining ore grades	Lower mineral content per tonne of ore	Rising energy intensity per unit of output

The practical consequence: new production capacity increasingly depends on the availability of supporting infrastructure — especially reliable power — rather than on mineral resource endowment alone.

Power's Evolving Role: From Support Utility to Critical Constraint

In past project paradigms, power was an enabling utility — sized to meet load, procured as a package item. In today's weak-grid or off-grid contexts, the power system directly determines how much the mine or smelter can produce.

Power Scenario	Typical Issues	Operational Impact
Strong grid	No significant stability concern	Power is not a limiting factor
Weak grid	Frequent outages; voltage sags; insufficient capacity	Constrained throughput; equipment damage risk
Off-grid / islanded	Voltage/frequency instability; high diesel dependency	Production capped by fuel supply chain reliability

Recurring patterns observed across projects in the field:

- Unreliable grid infrastructure causes frequent production shutdowns, shortens equipment service life, and introduces safety risk.
- Renewable penetration is constrained when no grid-forming asset is present to anchor voltage and frequency.
- Power supply transitions from an operational support function to a hard production bottleneck.

Cost Structure: Energy and Carbon as Core Financial Variables

Energy-related costs already represent a significant proportion of total operating expenditure — and the share is rising:

Cost Category	Share of Operating Cost
Energy / Power	15% – 40%
Labour	10% – 20%
Equipment Maintenance	15% – 25%
Other	20% – 40%

In remote locations, diesel generation — still the primary power source for many mines — typically costs USD 0.30–0.50/kWh all-in (including transport and logistics). The emergence of carbon pricing adds a further layer of cost exposure:

- Production: carbon-intensive electricity raises the embedded carbon content of each tonne of output.
- Trade: exports face increasing carbon border adjustment costs (e.g., EU CBAM).
- Financing: ESG ratings increasingly influence lending rates and bond spreads.
- Market access: green electricity thresholds are becoming explicit procurement requirements from offtake partners.

Three Constraints — Simultaneously Active

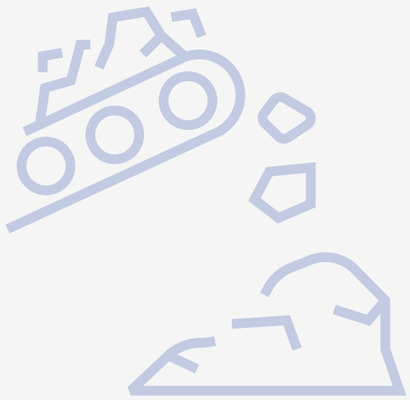
In practice, mining power challenges are rarely isolated. The three constraint categories operate concurrently and compound each other:

- Stability: weak grids, load transients from large motor starts, and fuel supply chain disruptions.
- Economics: high electricity tariffs and diesel costs erode project returns.
- Compliance: carbon emissions and ESG requirements affect market access and capital cost.

The fundamental engineering dilemma: the pursuit of green energy introduces output variability, which threatens operational stability; the pursuit of stability defaults to diesel, which raises cost and carbon exposure.

Engineering Fundamentals: Load Profiles Defined by Process

Power requirements in mining and metallurgical facilities are not generic industrial loads — they are dictated directly by the production process. Understanding this is the starting point for any viable power system design.



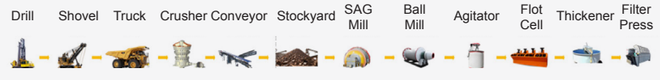
Chapter 2

Engineering Fundamentals: Load Profiles Defined by Process

Power requirements in mining and metallurgical facilities are not generic industrial loads — they are dictated directly by the production process. Understanding this is the starting point for any viable power system design.

Open-Pit & Underground Mining

Mining operations comprise three main stages: ore extraction, mineral processing (comminution, flotation, thickening), and tailings water recovery. Each stage has a distinct load profile:



	Mining	Crushing	Grinding	Flotation
Load Level	★	★★	★★★	★★★
Load Continuity	★	★★	★★★	★★★
Load Impact Characteristic	★★★	★★	★★★	★
Power Reliability Requirement	★	★★	★★★	★★★
Power Quality Requirement	★	★	★★	★★★

Mining load is not a single load category. It is a combination of high-impact transient loads, continuous process-sensitive loads, and dispatchable loads. Any compliant power system design must simultaneously address voltage support, power quality, and operational flexibility.

Pyrometallurgical Smelting

Once ore is concentrated, copper concentrate enters the pyrometallurgical circuit. Unlike mining, the primary risk in smelting is not load transients — it is supply interruption. Process steps are tightly coupled through material, thermal and gas flows; a loss of power propagates across the entire production chain.



	Conc. Drying	Flash Smelting	Flash Converting	Fire Refining	Electrolytic Refining
Load Level	★★★★	★★★★	★★★★	★★★★	★★★★
Load Continuity	★★★★	★★★★	★★★★	★★★★	★★★★
Load Impact Characteristic	★★	★★	★★	★	★
Power Reliability Requirement	★★★★	★★★★	★★★★	★★★★	★★★★
Power Quality Requirement	★★	★★★	★★★★	★★★	★★★

In flash smelting operations, the power system is not merely infrastructure — it is an active participant in process stability. Voltage and frequency disturbances in the air supply, oxygen plant, and offgas systems propagate directly into furnace chemistry.



Lithium Brine Extraction (DLE Process)

Salt lake lithium extraction follows a fundamentally different path: no furnaces, no high-temperature processes — the separation is chemical.



Brine	Pretreatment	Adsorption	Membrane Separation	Li Precipitation
Load Level	★★	★★★	★★★★	★★★★
Load Regulation	★★★	★★★	★	★★
Load Impact Characteristic	★	★★	★★	★
Power Reliability Requirement	★	★★★	★★★	★★★★
Power Quality Requirement	★	★★★	★★★	★★

The dominant load is fluid pumping and membrane separation. Typical characteristics:

- Low inrush, predominantly continuous load — no major motor start events.
- Long processing chain with high supply continuity requirements for pumps and membrane units.
- Certain adsorption and pre-treatment stages offer limited demand flexibility — useful for renewable energy integration.
- Altitude-related derating of equipment (many DLE projects sit above 3,500 m) must be accounted for in system design.

Additional Engineering Considerations

Beyond process-driven load requirements, remote siting introduces further engineering demands:

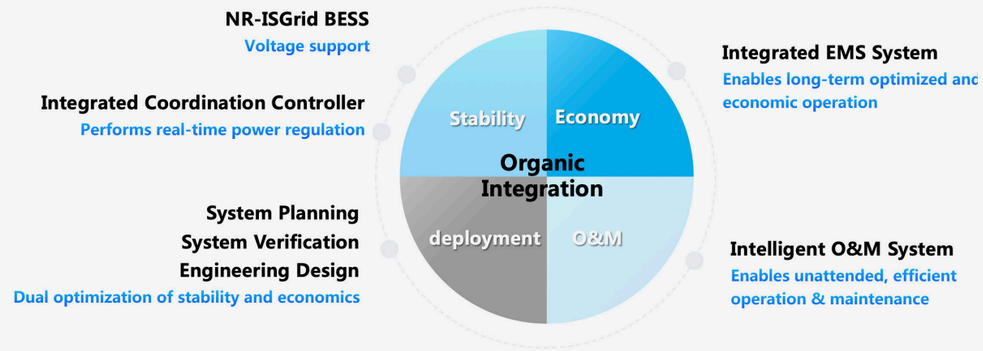
- Supply chain resilience: exposure to fuel logistics disruption requires a power system capable of extended autonomous operation.
- Remote diagnostics: limited on-site technical staff means condition monitoring, predictive maintenance and remote fault management are essential — not optional.
- Time-to-commissioning: power infrastructure is on the critical path for first production; delays directly defer revenue. Modular, pre-integrated system architectures are essential to meeting aggressive construction schedules.

Chapter 3

Renewable Energy Power System Solution for Mining

System Overview

Mining operations and smelting plants are often located in remote areas, typically endowed with abundant solar irradiance and low land costs. Coupled with the rapid maturation of new energy and energy storage system technologies, 100% renewable-energy supply is moving from theoretical feasibility to engineering practice. NR has proposed a technology architecture of a "grid-forming energy storage system + Renewable energy + integrated control" aimed at constructing a safe, high-quality, economical, and green mining renewable-energy power system, with four core characteristics: safety and stability, green economy, intelligent operation and maintenance, and efficient deployment.

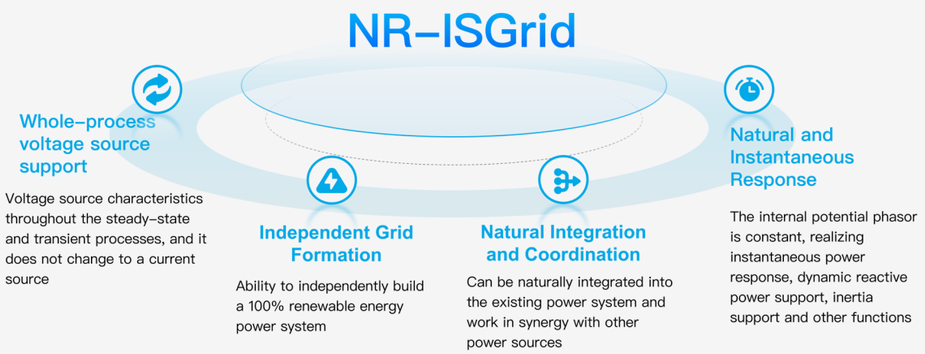


Grid-Forming Technology — The Engineering Foundation

Grid-forming technology is the critical innovation that breaks the conventional trade-off between renewable penetration and system stability.

Conventional inverters (grid-following) depend on an existing voltage reference to synchronise — they behave like someone walking behind a guide. Remove the guide (i.e., the strong external grid), and the system loses synchronism. Grid-forming converters operate fundamentally differently: through converter control algorithms, they generate a near-constant self-synchronising internal voltage source behind the converter output impedance — behaving like a powerful synchronous generator, actively establishing and sustaining stable voltage and frequency even in a fully islanded microgrid.

NR ISGrid BESS capabilities:

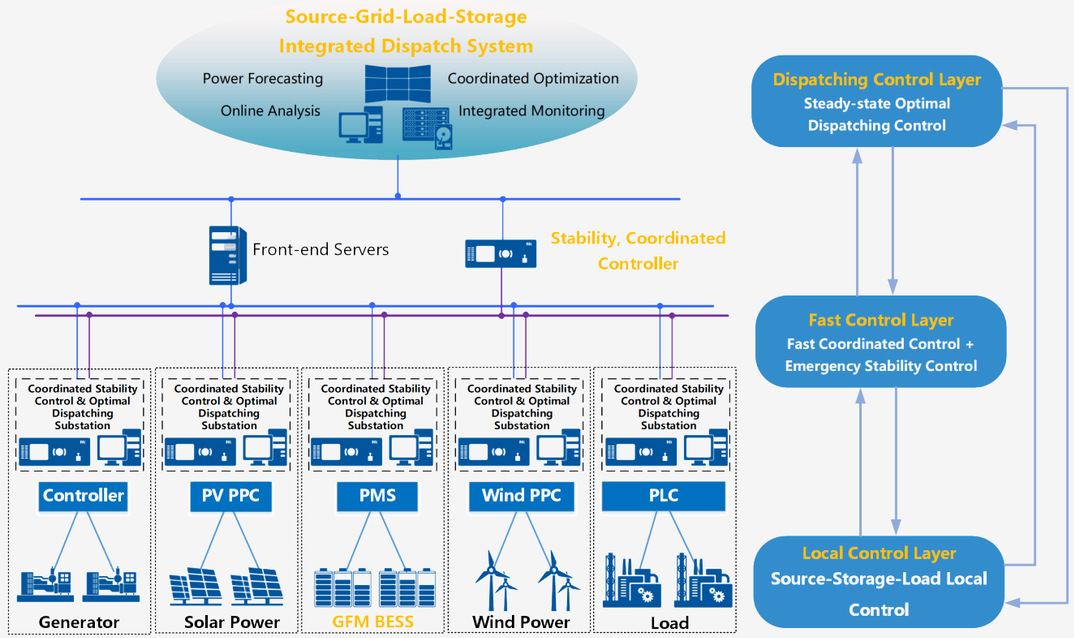


NR Electric's track record in grid-forming technology:

- Over 170 grid-forming projects executed, with aggregate installed capacity exceeding 20GW.
- First in the industry to complete black start validation at hundred-MW scale — full system re-energisation from a de-energised state, with no external power source.
- First in the industry to complete a three-phase short-circuit test in a pure off-grid configuration — a more severe test than ball mill start transients or sudden loss of 30–50% of renewable generation.

Integrated Coordination Control

Grid-forming technology establishes the stability foundation. The integrated coordination control system then optimises economics and operational efficiency on top of that foundation.



Layer 1: Coordinated Stability Control — "Always Stable"

Operating within a Three-Defence-Line framework, the system applies graduated control responses in proportion to disturbance severity:

Disturbance Level	Control Action	Outcome
Minor voltage / frequency deviation	GFESS & generation assets perform fast power regulation (ms-level)	Seamless ride-through; no production impact
Major event: renewable output drop, large motor start, or grid outage	Multi-source coordination (PV / storage / diesel); automatic on/off-grid transfer	Disturbance contained; production continuity maintained
Severe internal fault (e.g., short circuit)	Priority load protection; pre-defined load shedding sequence executed	Critical process loads protected; maximum recovery of production

Layer 2: Mining-Power Optimised Dispatch — "Economically Efficient"

A unified electrical and process control architecture coordinates supply-side resources and production-side flexible loads to maximise renewable utilisation while protecting production continuity:

Optimisation Lever	How It Works	Typical Benefit
Multi-source generation complementarity	Coordinates PV, wind, storage and diesel to maximise low-cost renewable uptake at all times	Higher renewable utilisation; lower diesel consumption
Process-side demand flexibility	Leverages dispatchable loads (e.g., adsorption circuits, pre-treatment) to shift consumption toward renewable generation peaks	Reduced peak-to-valley gap; smaller storage requirement
Predictive dispatch	Dynamic scheduling based on production plans, process sequencing and weather forecasts	Lower system LCOE; reduced curtailment

Chapter 3
Renewable Energy
Power System for Mining

Intelligent Operation & Maintenance

Most mine and smelter sites face a structural constraint: on-site technical staff availability is limited. NR Electric's intelligent O&M system is designed to turn this constraint into a competitive advantage through three integrated tiers:

- Perception Layer: Deploys online condition monitoring, digital instrumentation, video surveillance, acoustic fingerprinting, inspection robots and drones. Provides 24/7 real-time awareness of all critical assets. Typical outcome: equipment anomalies flagged 2–4 hours in advance; fault localisation time reduced from ~4 hours to under 30 minutes.
- Unified Management Platform: Consolidates all device and system operational data into a single management interface. Eliminates information silos across subsystems; enables cross-functional coordination. Typical outcome: site management can monitor entire electrical system status remotely without physical presence.
- Application Layer: Supports remote operation, intelligent fault prediction and site safety management. Predictive maintenance based on data analytics reduces unplanned downtime by over 50%. Full-lifecycle work-order risk monitoring protects personnel and equipment.

The end result: a "lean staffing, remote O&M, intelligent decision-making" operating model — converting the remote-location challenge into an operational differentiator.



Project Delivery Framework

NR Electric provides end-to-end technical services from concept through commissioning:

- System Planning: Source-load interaction methodology, multi-constraint joint production simulation, and grid-forming capacity optimisation via NRNGP planning software. Modular design supports phased capital deployment and reduces initial CAPEX exposure.
- Simulation & Validation: CNAS-accredited RTDS laboratory with 52 RACKs. Full-scenario transient and steady-state validation across 8,760 operating hours. Capability to integrate physical full-power GFESS units into hardware-in-the-loop simulation — the first in the industry to do so at GW scale.
- Engineering Design: Full-scope electrical design qualifications (substation and transmission, Class B). Unified design standards across electrical, civil and control disciplines; reduces interface complexity and change-order risk.





Chapter 4

Case Studies: Field-Validated Performance

The following three projects represent different mineral types, geographies and grid conditions — and together span the full range of challenges described in this paper.

Renewable Energy Power Solution for Mining

- Ejina Project (World's First Ultra-High Penetration System)
- Laguocuo Project（World's First High-Altitude）
- Jingjiang Steel Project
- Xibaipo Project
- Minning Green Power Town

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- (Overseas) DRC KPM Copper Mine (Overseas On/Off-Grid Mining）
- (Overseas) Argentina 3Q Salt Lake Lithium Project
- (Overseas) DRC Kimbowe Copper Mine
- (Overseas) DRC LAMIKAL Copper Mine
- (Overseas) Guinea Simandou iron mine

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KPM Copper Mine, DRC — Grid Resilience Under Extreme Outage Frequency

Project Background

Location: Likasi Industrial Park, Katanga Province, Democratic Republic of Congo

Process: Copper and cobalt production; two 120 kV substations connected to the local grid via dual 120 kV transmission lines

Power Challenge: Extremely unstable grid — average ~100 outages per month, individual outages lasting up to 20 hours; critical equipment (ball mills, electrolytic cells, water pumps) exposed to frequent unplanned trips

Solution Deployed

Phase I: 20 MW / 60 MWh grid-forming energy storage + 72 MWp photovoltaic

Phase II (immediate expansion): +50 MW / 150 MWh grid-forming energy storage following rapid customer confidence build

Phase III (under construction): total GFESS capacity 300 MW / 900 MWh; multi-point supply grid architecture

Scope: Core integrated equipment package + engineering design and technical advisory services

Key Outcomes

- Critical loads (ball mills, electrolytic cells, pumps) maintained 24/7 uninterrupted operation despite 10+ grid outages per day.
- Grid power allocation limited to 10–20% of production load demand — yet full production throughput maintained (grid restriction without production restriction).
- Combined payback period (including contribution from stable production growth): approximately 2 years.





Kamoa Copper Smelter, DRC — Process Continuity in Flash Smelting

Project Background

Location: Kamoa Copper Mine, southern DRC — Africa's largest copper mining and smelting project

Process: Flash smelting; designed annual copper output of 1 million tonnes at full capacity

Power Challenge: Chronic poor grid quality and stability; frequent production shutdowns disrupting tightly coupled smelting process chain

Solution Deployed

60 MW / 120 MWh grid-forming energy storage system

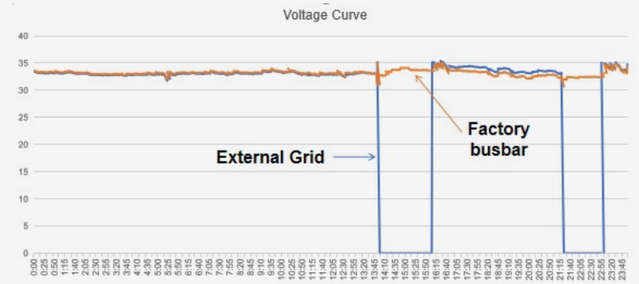
Integrated source-grid-load-storage control system

Control strategy advisory and commissioning support

Key Outcomes

- Since commissioning in January 2026, critical flash smelting auxiliaries (oxygen plant, compressed air systems) have maintained uninterrupted operation through 20+ monthly grid outages.
- Project delivered from initiation to energisation in 6 months — achieved through early-stage system planning, full-scenario RTDS validation, and integrated commissioning support.





3Q Lithium Brine Project, Argentina — Off-Grid Economics at Altitude

Project Background

Location: Andes Mountains, Argentina; two operating areas at 4,100 m (brine field) and 1,600 m (processing plant)

Process: DLE lithium extraction; designed annual output of 40,000–60,000 tonnes of battery-grade lithium carbonate

Power Challenge: Entirely off-grid diesel generation; all-in electricity cost exceeding USD 0.50/kWh (processing plant) and USD 0.60/kWh (brine field) — a structurally uneconomic operating position

Solution Deployed

40 MWp photovoltaic generation

20.8 MW / 50.4 MWh grid-forming energy storage system

Integrated source-grid-load-storage control system

Technical advisory services: stability studies, full-scenario RTDS simulation and validation

Key Outcomes

- Since commissioning in July 2025, DLE critical process circuits have operated without interruption at 4,100 m altitude.
- Payback period: approximately 4 years; project IRR meets investment threshold.
- Renewable energy penetration: 25% — with material upside potential as the system is expanded. Annual CO_2 reduction: tens of thousands of tonnes; measurable improvement in ESG compliance posture.





Chapter 5

Business Case and Investment Framework

The Investment Thesis in Two Lines

Replace expensive diesel with low-cost renewable generation — and make the grid stable enough to do so reliably.

The core return comes from two sources: (1) reducing the levelised cost of energy by substituting diesel with solar generation; (2) stabilising power supply to unlock production throughput that was previously constrained by grid unreliability.

Quantifying the return depends on project-specific variables — diesel price, solar irradiance, load profile, and project lifespan. Based on projects delivered to date:

- LCOE reduction: 25–35% vs. diesel baseline (in sites where diesel exceeds USD 0.30/kWh).
- Green energy penetration: 25–100% renewable share achievable, depending on configuration.
- Payback period: 2–4 years in projects with strong diesel cost baselines and high capacity utilisation.
- Production uptime improvement: 24/7 uninterrupted critical load operation, replacing unreliable grid-only or diesel-only configurations.

What We Need to Assess Your Project

Every site is different. To provide a meaningful technical and financial assessment, we ask that potential partners share the following project data:

Project Parameter	Why It Matters
Mineral type and process	Determines load profile, continuity requirements and flexibility potential
Peak load demand	Drives PV and storage power rating
Major transient loads	Determines voltage stability requirements and reactive compensation sizing
Current diesel cost (USD/litre or USD/kWh)	Primary basis for economic comparison and payback calculation
Solar resource (GHI) or GPS coordinates	Required for renewable yield assessment, capacity planning and load flow analysis
Grid connection topology (if applicable)	Required for load flow, N-1 contingency and fault level calculations
Target renewable penetration	Core determinant of generation mix and storage capacity
Project horizon	Required for LCOE and IRR calculation

With this information, NR Electric's engineering team can provide a preliminary technical configuration, indicative capacity plan, and economic comparison within 2–3 weeks.

Conclusion

The energy transition in mining is not a matter of choice — it is becoming a baseline requirement for competitiveness and regulatory compliance. As renewable energy costs continue to decline and ESG scrutiny intensifies, early movers gain a durable cost advantage and deeper technology integration.

The solutions presented in this paper are not conceptual. They have been engineered, validated and deployed at scale across multiple projects in Africa, South America and Central Asia — in some of the most demanding operational environments on earth.

NR Electric invites mining owners, developers, EPC contractors and project investors to engage with us on specific project opportunities. Our engineering team will provide a customised technical assessment and preliminary feasibility evaluation tailored to your project's actual conditions.

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