



Techno-Economic Framework for Converting Routinely Flared Gas into Marketable Energy Products and Feedstocks

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ABSTRACT

This paper develops a stage-gated techno-economic framework that integrates engineering feasibility, market fit, uncertainty, emissions, and execution readiness for converting routinely flared gas into marketable energy products and feedstocks. The study responds to the problem that commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently, a pattern consistent with global flaring data showing that flared volumes have risen rather than fallen despite two decades of reduction commitments. It uses an integrative conceptual review of 95 scholarly and professional sources published to date, spanning gas-to-liquids, gas-to-power, mini-LNG and compressed natural gas monetization, methanol and petrochemical feedstock routes, and techno-economic analysis methodology. The framework organizes eight decision functions: resource characterization, market screening, technology matching, concept design, risk-adjusted cash-flow modelling, option and scenario analysis, delivery planning, and post-startup verification. It applies those functions across flare-gas sources, gathering network, pretreatment, conversion unit, product storage, and market and logistics interface. The analysis treats uncertainty, process safety, reliability, environmental performance, resource efficiency, economics, and organizational control as connected requirements. The proposed architecture links a system definition, evidence register, model assumptions, intervention portfolio, verification plan, and learning cycle. Its central proposition is that the framework should select and stage feasible routes for converting flare gas into pipeline gas, liquids, electricity, compressed or liquefied gas, methanol, or other products only when decisions preserve traceability from measured conditions to selected actions and verified outcomes. The paper offers testable propositions, an implementation roadmap, asset-specific application protocols, and a research agenda. The framework supports case-study testing and quantitative extension without claiming universal performance before field validation.

Keywords: flare-gas monetization; process engineering; reliability; process safety; risk management; asset integrity; environmental performance; decision framework

Introduction

Flare-gas monetization requires defined supply scenarios, credible composition data, verified safeguards, and accountable investment decisions (Kaplan & Garrick, 1981; Reason, 1997; Center for Chemical Process Safety, 2007; International Organization for Standardization, 2018). Global gas flaring has proven persistently difficult to eliminate: satellite-based tracking shows flared volumes climbing to their highest levels in years, releasing avoidable greenhouse gas emissions and forfeiting gas that could otherwise be captured, processed, and sold (World Bank, 2024, 2025; International Energy Agency, 2024; Intergovernmental Panel on Climate Change, 2022). Independent national and regional case studies corroborate this picture, attributing measurable air quality, public health, and economic costs to flare combustion efficiency and gas composition rather than to the absence of a viable conversion technology (Soltanieh, Zohrabian, Gholipour, & Kalnay, 2016; Fawole, Cai, & MacKenzie, 2016) (Michael & Ogunsola, 2024b; Michael & Ogunsola, 2021a; Falegan & Aniebonam, 2024) (Arumosoye & Obriki, 2023; Okonkwo et al., 2023; Aminu-Ibrahim & Ogbete, 2023). (International Organization for Standardization, 2016; Yeboah et al., 2025)

A monetization project links gas availability, conditioning needs, conversion technology, logistics, market demand, operating reliability, and project economics. In the context of flare-gas monetization, commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. Local actions affect adjacent equipment, utilities, product quality, emissions, workforce exposure, and supply continuity. Prior technology-focused reviews have compared gas-to-liquids, gas-to-power, mini-LNG, compressed natural gas, and methanol routes largely on thermodynamic and capital-cost grounds, without integrating the market, financing, and organizational conditions that determine whether a technically sound route is ever built (Abu et al., 2023; Elgarahy et al., 2024; Fleisch, 2015; Elbashir,

2018). Nigeria's experience illustrates the consequence: successive flare-out deadlines have been missed because policy, licensing, and commercial-model decisions were not coordinated with technology selection at the field level (Abdulkadir et al., 2019; Aigbe et al., 2023). A defensible framework must therefore define both the physical process and the decision system through which evidence becomes action. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Independent economic assessments of the scale of global gas flaring corroborate the persistence of this resource base across multiple monitoring periods (Ismail & Umukoro, 2012) (Ilodigwe & Adesemoye, 2024b) (Aneke et al., 2024; Aneke et al., 2022).

This paper aims to develop a stage-gated techno-economic decision framework for flare-gas monetization that treats engineering feasibility, market fit, financial risk, emissions performance, and execution readiness as one connected evaluation rather than as separate studies conducted by separate teams. The scope covers the physical chain from flare-gas source through gathering, pretreatment, conversion, storage, and market or logistics interface, and it covers gas-to-liquids, gas-to-power, mini-LNG, compressed natural gas, and methanol or petrochemical feedstock routes as the principal monetization pathways evaluated in the literature (Fleisch, 2015; Ledbetter, 2025; Kanshio, Agogo, & Chior, 2017). The contribution is threefold. First, it consolidates fragmented technology, market, and risk literatures into eight decision functions that most single-discipline reviews treat separately. Second, it embeds risk-adjusted cash-flow modelling and real-options logic directly into the stage-gate sequence rather than treating economics as a final checkpoint (Gazheli & van den Bergh, 2018; Jaimungal et al., 2018; Carozzani & D'Alpaos, 2025; Idowu & Adinya, 2026). Third, it proposes verification and learning mechanisms that convert a one-time feasibility study into an auditable operating capability. This addresses a gap in the literature: integrated, execution-ready decision frameworks for flare-gas monetization projects remain scarce even though the underlying technology and market reviews are individually well developed. The gas-to-liquids route alone spans a range of small-scale Fischer-Tropsch configurations whose comparative economics remain an active subject of technology review (de Klerk, 2016; Lewis, 2013) (Abdulhadi & Hamdan, 2026b; Michael & Ogunsola, 2023b; Aliliele & Iwuanyanwu, 2023b) (Aliliele et al., 2023; Mbonu et al., 2021; Mbonu et al., 2020).

The remainder of the paper proceeds as follows. The Theoretical Framework section develops the risk-based, techno-economic, and stage-gate theory that grounds the analysis and defines the system boundary and technology fundamentals. The Methodology section describes the review approach. The Findings and Discussion section develops the integrated framework and applies it across the flare-gas monetization value chain, including data architecture, screening criteria, risk and environmental assessment, operating-envelope integration, barrier assurance, techno-economic evaluation, asset-class application, implementation roadmap, governance, and performance measurement, and then synthesizes the supporting literature, presents testable propositions, and states the study's limitations. The Conclusion closes the paper (Eze & Akinleye, 2023).

Theoretical Framework

The framework rests on three theoretical foundations that the flare-gas monetization literature has developed separately. The first is risk-based decision theory, which defines risk as a structured set of scenarios, likelihoods, and consequences rather than a single point estimate, and which requires that evidence quality and accountable ownership travel with every decision (Kaplan & Garrick, 1981). Organizational-accident theory extends this view by showing that adverse outcomes typically result from the alignment of latent conditions across multiple defensive layers rather than from a single technical failure, which is why a flare-gas monetization decision must be evaluated against its organizational and procedural context and not against engineering feasibility alone (Reason, 1997). Risk-based process safety guidance operationalizes both ideas for process industries by requiring that hazard identification, risk analysis, and management-of-change disciplines be embedded in the same decision sequence that governs technology and investment choices (Center for Chemical Process Safety, 2007), and international risk-management guidance generalizes this requirement into a principle applicable to any organizational decision under uncertainty (International Organization for Standardization, 2018). Together, these sources establish the theoretical warrant for treating flare-gas monetization as a staged risk decision rather than a sequence of independent technical, commercial, and regulatory studies (Yeboah & Oloto, 2023; Ogbete & Ambali, 2021; Eze & Anene, 2024b) (Ogbete et al., 2021; Ogbete et al., 2019; Aminu-Ibrahim et al., 2024).

A second theoretical foundation concerns how economic value should be assessed under uncertainty. Conventional techno-economic analysis practice for energy and conversion technologies specifies consistent conventions for capital cost estimation, contingency, and uncertainty reporting so that competing technology options remain comparable (National Energy Technology Laboratory, 2023), but deterministic discounted cash-flow analysis of this kind treats managerial flexibility as fixed rather than valuable. Real-options theory corrects this by pricing the value of deferring, expanding, resizing, or abandoning an investment as uncertain variables resolve over time, which is directly relevant to flare-gas monetization projects that face variable supply, volatile product prices, and shifting policy commitments (Gazheli & van den Bergh, 2018; Jaimungal, Al-Arabi, & Cartea, 2018). Recent systematic reviews confirm that this option-based logic is increasingly applied to energy-investment decisions generally and to renewable and hybrid energy systems specifically, reinforcing its relevance to a resource, like flared gas, whose recoverable volume and market access change over the life of a project (Carozzani & D'Alpaos, 2025; Idowu & Adinya, 2026). This theoretical strand justifies embedding risk-adjusted cash-flow modelling and option-based reasoning directly into the decision sequence developed below, rather than treating economic evaluation as a closing checkpoint applied only after the technical concept has already been fixed (Okonkwo & Okeke, 2024b; Aminu-Ibrahim & Ambali, 2019) (Aminu-Ibrahim et al., 2019; Okonkwo et al., 2024; Ogbete et al., 2020).

A third foundation concerns how safeguards and decision sequences should be organized once risk and economic uncertainty are accepted as central. Barrier-based safety theory distinguishes prevention, detection, control, isolation, and mitigation functions, and it argues that each function must be separately specified, tested, and owned rather than treated as an undifferentiated part of the design (Sklet, 2006). Asset-management theory extends this

logic across the operating life of a facility by requiring documented ownership, performance review, and continual improvement rather than one-time verification (International Organization for Standardization, 2014). Stage-gate theory, originally developed for new-product development, supplies the organizing logic for sequencing decisions of this kind: it requires that a project pass through defined gates at which accumulated evidence, not elapsed time or sunk cost, determines whether the project advances, is revised, or is stopped (Cooper, 1988). Applied to flare-gas monetization, stage-gate theory explains why resource characterization, market screening, technology matching, concept design, risk-adjusted cash-flow modelling, option and scenario analysis, delivery planning, and post-startup verification should be treated as a connected sequence of accountable gates rather than as parallel workstreams that are reconciled only at the end (Ilodigwe & Adesemoye, 2019b; Ogbete & Iwuanyanwu, 2025b; Ilodigwe & Adesemoye, 2024a) (Ogbete et al., 2025; Aminu-Ibrahim et al., 2025; Aliliele et al., 2023).

Read together, these three theoretical strands (risk-based decision theory, real-options techno-economic theory, and barrier and stage-gate theory) converge on a single implication: a defensible flare-gas monetization framework must define the physical system it governs before it can meaningfully apply risk-based, economic, or gate-based logic to that system. The remainder of this section therefore establishes that system definition, together with the technology and process fundamentals that the methodology and findings developed below build upon (Ilodigwe & Adesemoye, 2025a).

System Boundary and Functional Requirements is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should identify physical, information, utility, organizational, and market interfaces. For conversion unit, the decision model must represent market volatility, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Market screening supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Market research frameworks developed for entry barriers in highly regulated industrial service sectors identify comparable market interfaces that a flare-gas monetization system boundary must capture (Sanni & Attah, 2023) (Sanni & Attah, 2023c) (Okonkwo et al., 2024).

System Boundary and Functional Requirements is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should identify physical, information, utility, organizational, and market interfaces. For product storage, the decision model must represent execution delay, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Technology matching supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record (Atakpa & Fobellah, 2023) (Dagodzo & Ahiaekpe, 2023).

System Boundary and Functional Requirements is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should identify physical, information, utility, organizational, and market interfaces. For market and logistics interface, the decision model must represent unverified emission reduction, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Concept design supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Offshore LNG monetization practice defines comparable market and logistics interfaces that this boundary definition must include (Alabi, 2022).

Technology and Process Fundamentals is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should explain governing mechanisms, equipment functions, constraints, and failure modes. For flare-gas sources, the decision model must represent feed intermittency, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Risk-adjusted cash-flow modelling supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Pipeline and gathering-system safety management practice similarly requires documented operating limits and management-of-change discipline for variable-rate gas sources (American Petroleum Institute, 2015). Emissions-modelling research on natural gas flaring provides the mechanistic basis for representing feed intermittency as a measurable rather than qualitative constraint (Umukoro & Ismail, 2017) (Ilodigwe & Adesemoye, 2026a) (Aliliele et al., 2024).

Technology and Process Fundamentals is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should explain governing mechanisms, equipment functions, constraints, and failure modes. For gathering network, the decision model must represent contaminant breakthrough, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Option and scenario analysis supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record.

Technology and Process Fundamentals is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should explain governing mechanisms, equipment functions, constraints, and failure modes. For pretreatment, the decision model must represent technology underutilization, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Delivery planning supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Materials degradation in pretreatment trains, including corrosion driven by acid gas and water content in untreated associated gas, remains a leading cause of technology underutilization when inhibitor selection is not matched to feed composition. Field experience developing small-scale flare-gas recovery units confirms that pretreatment underperformance more often reflects unmatched equipment selection than an intrinsically uneconomic resource (Caryana, 2022) (Atta & Adenuga, 2020).

Methodology

Conceptual Review Method is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should describe source selection, cutoff control, thematic coding, and synthesis logic. For flare-gas sources, the decision model must represent feed intermittency, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Delivery planning supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Combustion-modelling studies of flaring emissions informed the thematic coding applied to flare-gas source evidence in this review (Ismail & Umukoro, 2016) (Oluwadele & Adika, 2025).

Conceptual Review Method is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should describe source selection, cutoff control, thematic coding, and synthesis logic. For gathering network, the decision model must represent contaminant breakthrough, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Post-startup verification supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Techno-economic evaluation methodology developed for renewable-material construction projects informed the synthesis logic applied to gathering-network cost evidence in this review (Uduokhai, Garba, Nwafor, & Sanusi, 2024) (Dogbatsey & Ebhojie, 2026).

Conceptual Review Method is central to flare-gas monetization because commercial recovery fails when variable supply, composition, gathering distance, product markets, financing, operations, and regulatory obligations are assessed independently. The analysis should describe source selection, cutoff control, thematic coding, and synthesis logic. For pretreatment, the decision model must represent technology underutilization, including initiating conditions, detection limits, safeguards, recovery time, and downstream effects. Resource characterization supplies part of the evidence, but no single dataset establishes technical adequacy. The reviewer should record source date, operating mode, measurement uncertainty, model version, and accountable owner. This traceability prevents an apparently precise result from concealing weak assumptions. It also allows later operating experience to update the decision rather than remaining in a separate record. Simulation-based techno-economic evaluation of hybrid solar-diesel microgrids offered a comparable methodological reference point for coding pretreatment technology-underutilization evidence (Ijiga, Oladoye, Bamigwojo, & Ogboji, 2023) (Abdulhadi & Hamdan, 2026a).

Findings and Discussion

Data, Measurement, and Model Validation

Getting the underlying data right, clear variable definitions, quality rules, reconciliation steps, and a stated uncertainty band, matters more for flare-gas monetization than any single measurement, because commercial recovery collapses whenever supply, composition, distance to market, financing, operations, and regulation are judged in isolation rather than together. For flare-gas sources specifically, the model has to capture how feed intermittency actually behaves: what triggers it, how quickly it is detected, what safeguards respond, how long recovery takes, and what happens further downstream if it is missed. Evidence drawn from technology matching contributes to this picture, but by itself it cannot confirm that the equipment is technically adequate. Each input therefore needs a recorded source date, operating mode, uncertainty estimate, model version, and named owner, so that a tidy-looking output cannot quietly hide a shaky assumption, and so that operating experience gathered later can revise the decision instead of sitting unused in a separate file. Digital-twin architectures that couple real-time measurement streams with compliance models improve the traceability of resource characterization decisions for distributed procurement and monetization projects (Ike et al., 2025) (Nnabueze & Akokodaripon, 2021).

Flare-gas monetization depends on well-defined variables, quality rules, reconciliation logic, and an honest accounting of uncertainty, since commercial recovery breaks down whenever supply, composition, distance to market, financing, operations, and regulatory duty are evaluated one at a time instead of together. In the gathering network, the priority is contaminant breakthrough: the model needs to show what sets it off, how it is caught, what

safeguards limit it, how fast the system recovers, and what consequences follow if it is not caught in time. Concept-design work contributes some of this evidence, but no single study can certify technical adequacy on its own. Recording the source date, operating mode, measurement uncertainty, model version, and accountable owner behind every figure keeps a precise-looking number from masking weak assumptions, and lets later operating data feed back into the decision rather than being filed away separately. Quantitative risk models built from pipeline operating data support defensible reconciliation of gathering-network condition against safety and throughput targets (Zhang, Qin, & Wang, 2019) (Okojie & Abioye, 2020).

Sound data practice, consistent variable definitions, quality checks, reconciliation, and explicit uncertainty, underpins flare-gas monetization because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are judged separately rather than as a system. Pretreatment brings its own version of this problem: technology underutilization, and the model must reflect what triggers it, what limits exist for detecting it, which safeguards apply, how long recovery takes, and what it costs downstream if it goes unaddressed. Risk-adjusted cash-flow modelling supplies one input into that picture, not a complete technical verdict. Every figure needs a source date, operating mode, measurement uncertainty, model version, and accountable owner attached to it, both to stop a precise-looking result from hiding a weak assumption and to let later operating experience revise the decision rather than sit in an isolated record. Non-destructive testing and integrity-management data provide the calibration evidence needed to distinguish genuine pretreatment underperformance from instrumentation error, and data-led cost governance frameworks built for technology-intensive enterprises offer a template for the quality rules and reconciliation routines that pretreatment measurement systems should adopt (Adesuyi, Kalu, & Walawalkar, 2023) (Ilodigwe & Adesemoye, 2021).

Model development for flare-gas monetization needs a clear separation between what is assumed, what has actually been calibrated against evidence, how sensitivity has been tested, and where the acceptance limits sit, because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are treated as independent questions. Applied to flare-gas sources, this means the model must show how feed intermittency starts, how it is detected, what safeguards engage, how quickly the system recovers, and what happens downstream if it does not. Resource-characterization work feeds into this analysis but cannot substitute for it. Recording the source date, operating mode, uncertainty, model version, and accountable owner behind each figure keeps an apparently precise number from concealing a weak assumption, and it lets operating experience gathered afterward update the model rather than sit apart from it. Simulation-modelling research on algorithmic process optimization demonstrates how sensitivity testing can be linked directly to financial-impact assessment during model development (Tonoyan, Dada, & Ayivi-Donkor, 2022a) (Tonoyan & Ayivi-Donkor, 2025; Tonoyan & Ayivi-Donkor, 2023) (Tonoyan et al., 2025).

Separating assumption from calibrated evidence, and testing sensitivity before fixing an acceptance limit, is what makes a flare-gas monetization model defensible, since commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory questions being answered in isolation. For the gathering network, the relevant failure is contaminant breakthrough, so the model has to represent what sets it off, how detection works, what safeguards are triggered, how long recovery takes, and what the downstream cost of a miss looks like. Market-screening evidence forms part of this picture without settling it. As before, every number needs a documented source date, operating mode, uncertainty, model version, and owner, so a clean-looking output cannot hide a shaky premise and so later operating data can revise the model instead of being archived separately. Predictive cost-optimization models using machine learning offer a comparable calibration approach for gathering-network condition assessment (Tonoyan, Dada, & Ayivi-Donkor, 2022b) (Filani & Wedraogo, 2022) (Tonoyan et al., 2023).

A flare-gas monetization model only holds up if its assumptions, calibration evidence, sensitivity tests, and acceptance limits are kept visibly distinct, because commercial recovery collapses once supply, composition, distance to market, financing, operations, and regulatory duty are each judged on their own. Pretreatment introduces technology underutilization as the failure of interest, and the model needs to account for how it arises, how it is detected, what safeguards respond, how quickly the system recovers, and what it costs further down the chain if it is missed. Technology-matching findings contribute evidence here but do not close the question alone. Each figure still needs a source date, operating mode, uncertainty estimate, model version, and named owner behind it, so a precise-looking result cannot mask a weak assumption and so later operating experience can be folded back into the model rather than kept apart from it. Telemetry-driven economic evaluation research shows how real-time data pipelines can supply the calibration evidence pretreatment models require without waiting for periodic manual surveys (Ogundairo & Ayivi-Donkor, 2023) (Ogundairo & Ayivi-Donkor, 2023b; Efobi & Fasawe, 2022b) (Okonkwo et al., 2023; Okonkwo et al., 2021; Ogundairo & Ayivi-Donkor, 2023).

Screening, Decision Criteria, and the Eight-Stage Framework

Screening and prioritization set the criteria by which sources, assets, technologies, or interventions get ranked, and flare-gas monetization needs this discipline because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are ranked separately instead of together. For a conversion unit, the criterion that matters is market volatility: how it begins, how it is detected, what safeguards limit its effect, how fast the unit recovers, and what it costs downstream if unaddressed. Option and scenario analysis supplies some of the evidence behind that ranking, though not the whole of it. As elsewhere, each ranking input needs a source date, operating mode, measurement uncertainty, model version, and accountable owner, to stop a tidy score from hiding a weak assumption and to allow later operating results to change the ranking rather than sit outside it. Revenue-optimization research for energy distribution demonstrates how integrated financial planning can be embedded directly into ranking criteria for conversion-unit screening (Nnabueze et al., 2024) (Eze & Akinleye, 2022b).

Ranking sources, assets, technologies, or interventions against explicit criteria is the purpose of screening and prioritization, and flare-gas monetization depends on it precisely because supply, composition, distance to market, financing, operations, and regulatory duty cannot each be judged independently without commercial recovery breaking down. Product storage raises execution delay as the relevant risk, so the ranking criteria must

reflect how a delay starts, how it is caught, what safeguards apply, how long recovery takes, and what happens downstream if it is not addressed. Delivery-planning evidence informs this ranking without fully determining it. Every input still needs a recorded source date, operating mode, uncertainty, model version, and owner attached, both to keep a precise score from concealing a weak assumption and to let subsequent operating experience revise the ranking instead of remaining apart from it. Scenario-based financial modelling offers a comparable ranking approach for product-storage screening under variable execution-delay assumptions (Filani, Nnabueze, Sakyi, & Okojie, 2023).

Establishing the criteria that rank sources, assets, technologies, or interventions is what screening and prioritization contribute to flare-gas monetization, a discipline that matters because supply, composition, distance to market, financing, operations, and regulatory duty cannot be assessed piecemeal without commercial recovery suffering for it. At the market and logistics interface, the concern is unverified emission reduction: how a false or unsupported claim arises, how it would be caught, what safeguards prevent it from standing, how quickly it can be corrected, and what it costs downstream if it is not. Post-startup verification contributes evidence toward this ranking without settling it outright, and each input still needs a source date, operating mode, uncertainty, model version, and accountable owner, so a confident-looking figure cannot hide a weak assumption and so later operating data can revise the decision rather than being filed separately. These eight decision gates, their primary screening questions, required evidence, and possible decision outputs are summarized in Table 1. Reporting frameworks for greenhouse gas disclosure and ESG compliance in energy and infrastructure enterprises set the evidentiary bar against which claimed emission reductions from market and logistics interventions should be judged (Ominyi & Anichukwueze, 2022).

Figure 1 presents a stage-gated decision tree for selecting and screening flare-gas product routes. Table 1 instead compares the commercial metrics used to rank product routes, infrastructure choices, market access, and investment returns.

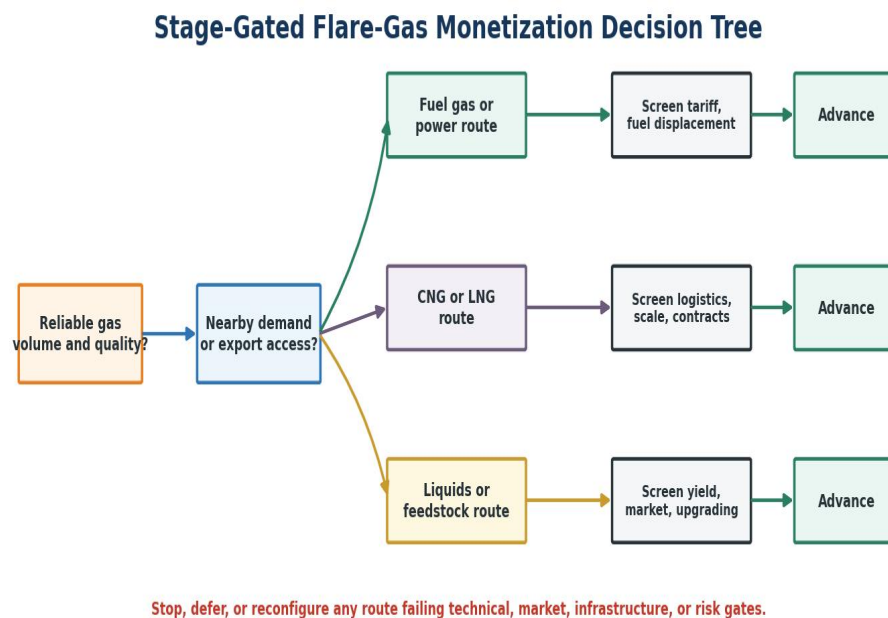


Figure 1. Stage-gated flare-gas monetization decision tree for product-route selection.

Table 1. Comparative Metrics for Flare-Gas Monetization Pathways

Commercial dimension	Metric	Interpretation	Screening decision
Supply scale	Recoverable volume per day	Capacity supported by the resource	Size the project
Supply reliability	P90 deliverable volume	Dependable feed over the project life	Set contracted capacity
Gas quality	Heating value and contaminants	Treatment and product-route requirements	Match technology
Capital intensity	Capital cost per unit capacity	Upfront burden of each pathway	Rank development options

Commercial dimension	Metric	Interpretation	Screening decision
Operating intensity	Operating cost per product unit	Recurring cost exposure	Test margin resilience
Market value	Delivered product netback	Revenue after transport and handling	Select target market
Logistics	Distance and delivery reliability	Infrastructure and market-access constraint	Choose delivery mode
Investment return	NPV, IRR, and breakeven price	Value and downside sensitivity	Advance or reject pathway

Risk, Reliability, Environmental, and Barrier Assurance

Connecting loss scenarios to reliability, safety, emissions, and resource outcomes is the task of the hazard, reliability, and environmental dimension of the framework, and it matters for flare-gas monetization because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being assessed one at a time. In a conversion unit, market volatility is the relevant hazard pathway, so the analysis has to trace how it starts, how it is detected, what safeguards intervene, how quickly recovery follows, and what the downstream consequences are if it does not. Post-startup verification contributes part of the needed evidence, though not all of it, and each figure still needs a source date, operating mode, uncertainty, model version, and owner, so that a precise-looking outcome cannot mask a weak assumption and operating experience gathered later can be used to update the decision rather than sit apart from it. Functional-safety standards for safety instrumented systems define the independence and testing intervals required before a conversion unit's protective layers can be credited in a risk model (International Electrotechnical Commission, 2016). Turbine-level techno-economic and risk analysis of flare-gas-fuelled power generation in Nigeria shows that fuel-gas variability accelerates hot-section degradation in ways that erode the assumed economics of gas-to-power routes unless maintenance intervals are adjusted accordingly (Allison, Ramsden, Pilidis, & Roupia, 2013) (Arumosoye & Ozobu, 2025; Obogo & Adio, 2025) (Arumosoye et al., 2025; Obogo et al., 2025).

The hazard, reliability, and environmental dimension of the framework links loss scenarios to reliability, safety, emissions, and resource outcomes, work that flare-gas monetization requires because commercial recovery fails once supply, composition, distance to market, financing, operations, and regulatory duty are each evaluated on their own. Product storage introduces execution delay as the pathway of concern, and the analysis must show how a delay begins, how it is picked up, what safeguards it triggers, how long recovery takes, and what it costs downstream if left unresolved. Resource characterization supplies part of this evidence base, not the whole of it, and each figure needs a source date, operating mode, uncertainty, model version, and named owner attached to it, so a clean result cannot hide a weak assumption and later operating experience can still revise the decision instead of being kept in a separate record. Barrier-based risk frameworks distinguish prevention, control, and mitigation functions, which clarifies which storage safeguards a delay in execution actually degrades (Sklet, 2006).

Linking loss scenarios to reliability, safety, emissions, and resource outcomes is central to the hazard, reliability, and environmental dimension, and flare-gas monetization cannot dispense with it because commercial recovery breaks down whenever supply, composition, distance to market, financing, operations, and regulatory duty are each judged separately. At the market and logistics interface, unverified emission reduction is the pathway that matters, so the analysis has to represent how such a claim originates, how it would be detected, what safeguards catch it, how quickly it can be corrected, and what the downstream cost is if it is not. Market-screening evidence contributes to this picture but does not complete it, and every figure still needs its source date, operating mode, uncertainty, model version, and accountable owner recorded, so a confident number cannot conceal a weak assumption and later operating data can be used to revise the decision rather than left in a separate file. Loss-prevention references catalogue the credible release and dispersion scenarios against which claimed emission reductions from flare-gas diversion should be checked before they are booked as verified (Mannan, 2012).

Operating-envelope integration is the step that turns design and model assumptions into day-to-day limits and a defined response to excursions, work that flare-gas monetization cannot skip because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are handled as separate problems. In a conversion unit, the envelope has to account for market volatility specifically: what sets an excursion off, how it is detected, what safeguards respond, how long recovery takes, and what happens downstream if it runs unchecked. Concept-design work contributes part of the evidence behind that envelope, not all of it, and each limit still needs a source date, operating mode, uncertainty, model version, and accountable owner behind it, so a precise-looking boundary cannot hide a weak assumption and later operating experience can be used to redraw the envelope instead of being set aside from it.

Translating design and model assumptions into daily operating limits, and into a defined excursion response, is what operating-envelope integration contributes to flare-gas monetization, and it matters because commercial recovery does not survive supply, composition, distance to market, financing,

operations, and regulatory duty being treated as unrelated questions. For product storage, execution delay is the excursion of concern, so the envelope must capture how a delay begins, how it is caught, what safeguards it triggers, how long recovery takes, and what the downstream effect is if it persists. Risk-adjusted cash-flow modelling supplies part of the evidence informing that envelope, though not the whole of it, and each limit needs a documented source date, operating mode, uncertainty, model version, and owner attached to it, so a precise-looking boundary cannot mask a weak assumption and operating experience gathered afterward can still be used to revise it rather than treated as a separate record.

Turning design and model assumptions into workable daily limits, with a defined response when the envelope is exceeded, is the job of operating-envelope integration within the flare-gas monetization framework, a job that matters because commercial recovery fails once supply, composition, distance to market, financing, operations, and regulatory duty are assessed independently of one another. At the market and logistics interface, the excursion of interest is unverified emission reduction, so the envelope must reflect how such a claim would arise, how it is detected, what safeguards catch it, how quickly it is corrected, and what the downstream cost is if it stands uncorrected. Option and scenario analysis contributes part of the supporting evidence, not all of it, and every limit still needs its source date, operating mode, uncertainty, model version, and accountable owner recorded, so a confident-looking boundary cannot conceal a weak assumption and later operating data can be used to update it instead of sitting apart from the decision.

Barrier and safeguard assurance evaluates the prevention, detection, control, isolation, mitigation, and emergency layers that stand between a hazard and its consequences, and flare-gas monetization depends on this evaluation because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are assessed one at a time. For flare-gas sources, feed intermittency is the layer being tested: how it starts, how it is detected, which safeguards respond, how quickly the system recovers, and what the downstream effect is if it is missed. Delivery-planning evidence contributes part of the picture without completing it, and each safeguard still needs a source date, operating mode, uncertainty, model version, and accountable owner behind it, so a precise-looking assurance score cannot hide a weak assumption and later operating experience can be used to revise it rather than left on its own. Risk-based inspection practice prioritizes safeguard testing toward the equipment most likely to fail first, which is particularly relevant where flare-gas feed intermittency accelerates fatigue and corrosion loading (American Petroleum Institute, 2016).

Assessing prevention, detection, control, isolation, mitigation, and emergency layers is the substance of barrier and safeguard assurance, and it is indispensable to flare-gas monetization because commercial recovery cannot withstand supply, composition, distance to market, financing, operations, and regulatory duty being judged in isolation. In the gathering network, contaminant breakthrough is the failure under review, so the assessment must show how it begins, how it is caught, which safeguards intervene, how long recovery takes, and what happens downstream if it is not caught in time. Post-startup verification supplies some of the supporting evidence, not all of it, and every safeguard still needs a source date, operating mode, uncertainty, model version, and named owner recorded against it, so a confident assurance rating cannot mask a weak assumption and later operating data can still revise it rather than being kept apart. Asset-management standards call for documented barrier ownership and performance review cycles that extend beyond individual maintenance work orders (International Organization for Standardization, 2014) (Mbonu & Uzoka, 2022a) (Ogbete et al., 2023; Aliliele et al., 2025; Aliliele et al., 2025).

Barrier and safeguard assurance works through the prevention, detection, control, isolation, mitigation, and emergency layers protecting a facility, a discipline flare-gas monetization relies on because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are treated as separate issues. Pretreatment introduces technology underutilization as the failure being tested, so the assurance work must trace how it arises, how it is detected, which safeguards respond, how quickly recovery occurs, and what the downstream cost is if it goes unaddressed. Resource-characterization evidence contributes part of the answer, not the whole of it, and each safeguard needs a source date, operating mode, uncertainty, model version, and accountable owner attached, so a tidy assurance figure cannot hide a weak assumption and later operating experience can revise it instead of standing apart from the record. Non-destructive weld-integrity testing provides direct evidence of barrier condition where visual inspection alone cannot confirm pretreatment vessel or piping integrity, and variance-analytics approaches to cost control in manufacturing and industrial enterprises offer a transferable model for tracking the cost consequences of deferred non-destructive testing in pretreatment systems (Aliliele, Eboh, & Oluwo, 2024) (Anene & Clement, 2022; Mbonu & Uzoka, 2021b; Adebayo & Ahmed, 2023) (Mbonu et al., 2021; Mbonu et al., 2021).

Techno-Economic and Resource Evaluation

Economic and resource evaluation connects capital cost, operating cost, downtime, recovery, emissions, and uncertainty into a single picture, a connection flare-gas monetization needs because commercial recovery fails once supply, composition, distance to market, financing, operations, and regulatory duty are priced separately instead of together. For a conversion unit, market volatility is the variable that most threatens that picture: how it arises, how it is detected, what safeguards absorb it, how quickly the unit recovers, and what it costs downstream if unaddressed. Market-screening evidence informs part of the evaluation without settling it, and each cost figure still needs a source date, operating mode, uncertainty, model version, and owner behind it, so a precise-looking estimate cannot mask a weak assumption and later operating results can revise the evaluation rather than sit apart from it. Techno-economic analysis guidelines developed for carbon-conversion and energy-system studies provide the cost-basis, contingency, and uncertainty-reporting conventions applied here to flare-gas conversion units (National Energy Technology Laboratory, 2023). Comparable techno-economic analyses of gas-to-methanol conversion confirm that plant configuration and scale materially shift the levelized cost of the product slate available to a conversion unit (Aimikhe, 2023; Yang & You, 2017) (Ogundairo & Ayivi-Donkor, 2024a) (Ogundairo & Ayivi-Donkor, 2024).

Bringing capital cost, operating cost, downtime, recovery, emissions, and uncertainty together in one evaluation is what economic and resource evaluation does for flare-gas monetization, work that matters because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being costed in isolation. Product storage brings execution delay into that evaluation, so the analysis must reflect how a delay starts, how it is detected, what safeguards limit it, how quickly recovery follows, and what the downstream cost is if it persists. Technology-matching evidence supports part of the estimate without completing it, and every figure needs a recorded source date, operating mode, uncertainty, model version, and accountable owner, so a confident estimate cannot conceal a weak assumption and later operating experience can revise the evaluation instead of standing apart from it. Natural-gas-liquids and condensate markets, which absorb much of the heavier fraction recovered from associated gas, are sensitive to storage and take-away capacity constraints documented in government market data (U.S. Energy Information Administration, 2012). Techno-economic and exergy analyses of small-scale liquefaction and regasification trains show that storage and boil-off management, not the liquefaction cycle itself, often dominate realized project costs (Remelje & Hoadley, 2006; Chandrayani, Haristyan, & Purwanto, 2024) (Sanni & Atima, 2020c).

Economic and resource evaluation ties capital cost, operating cost, downtime, recovery, emissions, and uncertainty together, and flare-gas monetization needs this because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are each priced on their own. At the market and logistics interface, unverified emission reduction threatens the credibility of that evaluation, so the analysis must show how such a claim would arise, how it is caught, what safeguards prevent it, how quickly it is corrected, and what it costs downstream if it stands. Concept-design evidence contributes part of the basis for the estimate, not all of it, and every figure still needs a source date, operating mode, uncertainty, model version, and accountable owner recorded, so a confident valuation cannot hide a weak assumption and later operating data can revise it rather than remain separate from the decision. Real-options techniques extend conventional discounted cash-flow evaluation by pricing the value of deferring, expanding, or abandoning a monetization route as market and policy conditions evolve (Jaimungal, Al-Arabi, & Cartea, 2018; Idowu & Adinya, 2026). Emerging monetization pathways that pair flare-gas conversion with on-site computing load or hydrogen co-production illustrate how additional revenue streams can be layered onto a conversion unit without committing to a single offtake market in advance (Snytnikov & Potemkin, 2022), a logic consistent with ESG-integrated supply chain models developed for corporate sustainability reporting (Okojie, Filani, Ihwughwawwe, & Sakyi, 2020).

Framework Application Across Technology Pathways and Asset Classes

Resource and deliverability characterization begins with a decision statement for flare-gas sources. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to feed intermittency, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority. Global flaring-volume tracking provides the resource baseline against which site-level deliverability studies should be benchmarked (World Bank, 2024). Industry assessments of stranded and flare gas monetization corroborate the scale of resource that deliverability characterization must account for at the field level (Sharma, 2024).

Validation of resource and deliverability characterization should use independent evidence from pretreatment systems wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include market volatility and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Ezeugwa et al., 2023). Independent validation evidence of this kind is central to distinguishing a genuinely monetizable resource from one whose apparent volume reflects measurement or reporting artifacts (Elgarahy et al., 2024) (Adelanwa & Anene, 2023b).

Market and product screening begins with a decision statement for gathering networks. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to contaminant breakthrough, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority (Ezeugwa et al., 2023). Screening should weigh gas-to-liquids, gas-to-power, mini-LNG, compressed natural gas, and methanol routes against the same market-access and offtake criteria rather than defaulting to whichever route is most familiar to the design team (Abu, Patchigolla, & Simms, 2023). Industry-facing surveys of flare gas

monetization options reach a similar conclusion, cautioning that route selection should follow market and offtake screening rather than precede it (Oakley, 2019), a pattern confirmed by economic assessments of gas-to-wire conversion specifically (Ojijiagwo, Oduoza, & Emekwuru, 2016).

Validation of market and product screening should use independent evidence from conversion units wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include execution delay and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Komi & Adamolekun, 2026). Policy and licensing uncertainty, documented in multi-level governance analyses of flaring regulation, can invalidate an otherwise sound market screen if it is not revisited at each gate (Aigbe, Stringer, & Cotton, 2023).

Technology matching begins with a decision statement for pretreatment systems. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to technology underutilization, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority (Komi & Adamolekun, 2026). Technology matching should draw on comparative assessments of small-scale gas-to-liquids, gas-to-power, and mini-LNG performance rather than single-vendor claims (Fleisch, 2015; Ledbetter, 2025; Ayasse & Ayasse, 2016). Techno-economic comparisons of compressed natural gas and gas-to-genset conversion routes provide comparable capital and contingency benchmarks for technology-matching decisions among small-scale options (Nafiscatoha & Saksono, 2020).

Validation of technology matching should use independent evidence from product storage wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include unverified emission reduction and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions. Methanol and other petrochemical feedstock routes remain technically underutilized in many flaring regions despite favorable feasibility studies, which points to a matching failure rather than a technology failure (Farahmandi, Saffaripour, Ashjaee, & Houshfar, 2025; Promoppatum & Viswanathan, 2016). Cluster-based small-scale LNG implementation experience shows that validated technology matching depends on modular deployment discipline as much as on liquefaction chemistry (Lee, Antara, & Kim, 2013) (Amayo & Isi, 2023b) (Odejobi et al., 2025).

Concept design and integration begins with a decision statement for conversion units. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to market volatility, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority. Concept-level integration should apply established techno-economic analysis conventions so that capital, operating, and contingency estimates remain comparable across candidate routes (National Energy Technology Laboratory, 2023). Recent assessments of gas-to-power system deployment in Nigeria show that concept-level integration decisions remain constrained by grid interconnection and offtake arrangements more than by turbine technology itself (Orekelewa, 2026; Oduniyi, 2026).

Validation of concept design and integration should use independent evidence from market and logistics interfaces wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include feed intermittency and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a

controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Ezeugwa et al., 2023). Concept designs should also be screened against the methane and carbon-dioxide-equivalent emission accounting conventions used in international climate assessments (Intergovernmental Panel on Climate Change, 2022) (Orise & Niniola, 2022) (Eyetezmitan et al., 2025; Mbonu et al., 2020).

Risk-adjusted cash-flow modeling begins with a decision statement for product storage. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to execution delay, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority (Ezeugwa et al., 2023). Discounted cash-flow models for flare-gas projects should be adjusted for the price and feedstock volatility documented in comparative flare-gas recovery economics (Elgarahy et al., 2024). Discounted cash-flow assessments of liquefied natural gas regasification alternatives confirm that financing and offtake assumptions, more than technology choice, drive the sensitivity of project value under uncertainty, a finding consistent with option-based valuation of oil and gas exploration and production projects facing recoverable-volume uncertainty (Ahmed, Mehran, Khan, & Ahsan, 2023; Nakaoka, 2008).

Validation of risk-adjusted cash-flow modeling should use independent evidence from flare-gas sources wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include contaminant breakthrough and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Komi & Adamolekun, 2026). Sensitivity testing should extend to the uncertainty ranges reported in techno-economic analysis guidelines rather than to arbitrary percentage swings (National Energy Technology Laboratory, 2023) (Aminu-Ibrahim & Iwuanyanwu, 2025c) (Aminu-Ibrahim & Ogbete, 2023; Ogbete et al., 2025).

Scenario and real-options analysis begins with a decision statement for market and logistics interfaces. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to unverified emission reduction, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority (Komi & Adamolekun, 2026). Real-options analysis is particularly suited to flare-gas monetization because it prices the value of staging investment as supply, price, and policy uncertainty resolve over time (Gazheli & van den Bergh, 2018; Carozzani & D'Alpaos, 2025). Foundational real-options syntheses confirm that the value of staged investment rises with the uncertainty being managed, reinforcing the case for embedding option logic in market and logistics interface decisions (Trigeorgis, 2010).

Validation of scenario and real-options analysis should use independent evidence from gathering networks wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include technology underutilization and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions. Learning-based extensions to real-options models allow the acceptance threshold itself to update as operating data accumulate (Jaimungal, Al-Arabi, & Cartea, 2018) (Atakpa & Abolaji, 2022).

Delivery and contracting strategy begins with a decision statement for flare-gas sources. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to feed intermittency, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority. Compressed natural gas and mini-LNG delivery

models depend on offtake and infrastructure commitments that are frequently the binding constraint rather than the conversion technology itself (Oluku & Olori, 2025; Egwuogu & Ekeh, 2025; Jamilu, 2026). Large-scale flare gas reduction programs at LNG terminals confirm that delivery and contracting strategy, not incremental conversion capacity, determines whether recovered gas reaches a paying market (Mirza, 2014).

Validation of delivery and contracting strategy should use independent evidence from pretreatment systems wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include market volatility and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Ezeugwa et al., 2023). Delivery economics should be reassessed whenever local flaring and infrastructure conditions change materially from the assumptions used at sanction (Chukuwendu, Orij, Ehikhamenle, & Okorie, 2025) (Ilodigwe & Adesemoye, 2020; Aminu-Ibrahim & Iwuanyanwu, 2025b) (Aminu-Ibrahim et al., 2025; Aminu-Ibrahim et al., 2018).

Post-startup verification begins with a decision statement for gathering networks. The team must specify what evidence will support the decision, which operating modes are included, and which assumptions require later confirmation. For flare-gas monetization, this stage should select commercially resilient routes for converting variable flare gas into saleable energy products and feedstocks. The analysis should represent normal operation, startup, shutdown, turndown, maintenance, and credible upset conditions. Particular attention should be given to contaminant breakthrough, because a locally acceptable condition may create a wider process, safety, environmental, or commercial consequence. Input records should identify source, timestamp, units, uncertainty, configuration, and accountable owner. A decision threshold should be approved before the final ranking is viewed. This reduces hindsight bias and prevents a favorable economic result from overriding mandatory safety or legal constraints. The resulting record should state the selected option, rejected alternatives, evidence gaps, interim controls, and residual-risk authority (Ezeugwa et al., 2023). Post-startup verification should reconcile measured flaring reduction against tracked national and global baselines rather than against the pre-project estimate alone (World Bank, 2025). Sustainable financing structures that condition green-bond and ESG investment on verified performance offer a template for the evidence a post-startup verification gate should require before claimed reductions are monetized (Sakyi et al., 2024).

Validation of post-startup verification should use independent evidence from conversion units wherever feasible. Acceptance should depend on observable performance rather than completion of a report or work order. Suitable measures include availability, detection coverage, response time, product compliance, avoided loss, energy intensity, maintenance burden, and verified risk reduction. The team should test sensitivity to uncertain supply, composition, equipment condition, utility availability, market conditions, and model error. A credible adverse case should include execution delay and the loss of one important safeguard or dependency. Differences between predicted and observed performance should trigger model review, not informal adjustment of the acceptance limit. Management of change should capture revised drawings, procedures, training, spares, software versions, alarm settings, and inspection requirements. This verification loop converts flare-gas monetization from a one-time study into a controlled operating capability. It also supplies comparable evidence for future investment and risk decisions (Komi & Adamolekun, 2026). Stage-gated verification of this kind mirrors the discipline used in other engineering and product-development settings to prevent premature advancement past an unresolved gate (Cooper, 1988).

Implementation Roadmap, Governance, and Organizational Learning

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving flare-gas sources. Record assumptions about feed intermittency, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving gathering network. Record assumptions about contaminant breakthrough, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving pretreatment. Record assumptions about technology underutilization, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving conversion unit. Record assumptions about market volatility, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving product storage. Record assumptions about execution delay, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Establish scope, accountable roles, minimum evidence, approval criteria, and a documented output. Apply the phase first to high-consequence scenarios involving market and logistics interface. Record assumptions about unverified emission reduction, test the decision with sensitivity analysis, and assign closure evidence. Advance to the next phase only when unresolved uncertainty has an explicit treatment and owner. Review interfaces with operations, maintenance, inspection, process safety, environmental management, commercial planning, and emergency response.

Implementation governance assigns ownership, decision rights, change control, competence, and assurance across the flare-gas monetization program, an assignment that matters because commercial recovery fails once supply, composition, distance to market, financing, operations, and regulatory duty are governed as separate concerns. For flare-gas sources, feed intermittency is the condition governance has to reach: who owns the response, how it is detected, what safeguards are triggered, how quickly recovery follows, and what the downstream effect is if governance lapses. Risk-adjusted cash-flow modelling supplies part of the supporting evidence, not the whole of it, and each governance decision still needs a source date, operating mode, uncertainty, model version, and named owner behind it, so a well-documented process cannot conceal a weak assumption and later operating experience can be used to revise governance rather than sit apart from it.

Assigning ownership, decision rights, change control, competence, and assurance is the work of implementation governance, and flare-gas monetization requires it because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being governed piecemeal. In the gathering network, contaminant breakthrough is the condition that governance must reach: how it begins, how it is detected, what safeguards respond, how quickly recovery occurs, and what the downstream cost is if governance fails to catch it. Option and scenario analysis contributes part of the evidence behind that governance, not all of it, and each decision still needs a source date, operating mode, uncertainty, model version, and owner recorded, so a well-documented process cannot mask a weak assumption and later operating data can be used to revise governance instead of being kept apart from it. Predictive vendor-risk and procurement-cost-optimization models developed for supply chain resilience define comparable decision-rights and change-control mechanisms for gathering-network governance (Tonoyan, Dada, & Ayivi-Donkor, 2024) (Tonoyan & Ayivi-Donkor, 2024a) (Tonoyan et al., 2024; Okonkwo et al., 2024).

Ownership, decision rights, change control, competence, and assurance are what implementation governance assigns across a flare-gas monetization program, an assignment made necessary because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are governed in isolation. Pretreatment brings technology underutilization into governance's remit: how it arises, how it is detected, what safeguards respond, how quickly recovery follows, and what the downstream consequence is if governance does not catch it. Delivery-planning evidence contributes part of the basis for governance decisions, not the whole of it, and each decision still needs a recorded source date, operating mode, uncertainty, model version, and owner, so a well-documented process cannot hide a weak assumption and later operating experience can revise governance rather than sit apart from it. Negotiation-optimization models for reducing procurement costs offer a template for the change-control and competence-assurance mechanisms this phase should assign to pretreatment systems (Akinleye & Adeyoyin, 2022).

Performance indicators and learning define the leading and lagging measures a flare-gas monetization program tracks, along with the thresholds that trigger a review, work that matters because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are measured in isolation. In a conversion unit, the indicator set has to reach market volatility: how it starts, how it is detected, what safeguards respond, how quickly the unit recovers, and what the downstream effect is if it is missed. Post-startup verification supplies part of the evidence behind those indicators, not all of it, and every measure still needs a source date, operating mode, uncertainty, model version, and accountable owner attached, so a tidy indicator cannot hide a weak assumption and later operating experience can update the threshold rather than sit apart from the decision.

Defining leading and lagging measures, with thresholds that trigger a review, is the task performance indicators and learning perform for flare-gas monetization, and it is necessary because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being tracked separately. Product storage puts execution delay into that indicator set: how a delay begins, how it is detected, what safeguards respond, how long recovery takes, and what the downstream cost is if it persists. Resource-characterization evidence contributes part of the basis for these measures, not the whole of it, and each indicator still needs a source date, operating mode, uncertainty, model version, and named owner recorded, so a clean-looking measure cannot mask a weak assumption and later operating data can update the threshold rather than being kept in a separate record.

Leading and lagging measures, together with the thresholds that trigger their review, are what performance indicators and learning define within the flare-gas monetization framework, a definition that matters because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are each tracked on their own. At the market and logistics interface, unverified emission reduction is the condition the indicator set has to catch: how such a claim would arise, how it is detected, what safeguards prevent it from standing, how quickly it is corrected, and what the downstream cost is if it is not. Market-screening evidence informs part of this measurement approach, not all of it, and each indicator still needs a source date, operating mode, uncertainty, model version, and accountable owner behind it, so a confident-looking measure cannot conceal a weak assumption and later operating experience can revise the threshold instead of remaining separate from the decision.

Literature Synthesis

The wider flare-gas monetization literature independently confirms that technology choice, policy design, and project finance must be evaluated together rather than in sequence (World Bank, 2024, 2025; Elgarahy et al., 2024; Aigbe et al., 2023).

Flare-gas monetization sits at the intersection of resource characterization, technology selection, market access, and project finance literatures that have largely developed in parallel. Global satellite-based flaring inventories establish the scale and persistence of the resource: annual gas flaring volumes have not fallen consistently despite two decades of reduction commitments, and recent tracking shows increases rather than the declines that voluntary and regulatory programs were intended to produce (World Bank, 2024, 2025; International Energy Agency, 2024). These tracking estimates rest on a satellite methodology that detects and radiometrically calibrates flare radiant heat from Visible Infrared Imaging Radiometer Suite nighttime imagery, with periodic recalibration used to improve volume accuracy over the historical record (Elvidge et al., 2015; Zhizhin et al., 2025). Technology reviews converge on a small set of monetization routes, gas-to-liquids, gas-to-power, mini-LNG, compressed natural gas, and gas-to-methanol, as the options best suited to the variable volumes and remote locations typical of associated and flared gas, while cautioning that no single route dominates across site conditions (Abu, Patchigolla, & Simms, 2023; Fleisch, 2015; Ledbetter, 2025). Techno-economic assessments of small-scale gas-to-liquids and flare-gas recovery systems generally find positive but marginal returns that are highly sensitive to gas price, capital cost, and plant availability assumptions, which is consistent with the framework's emphasis on risk-adjusted rather than deterministic cash-flow modelling (Elgarahy et al., 2024; Kabeh, Teimouri, Changizian, & Ahmadi, 2023). Government market data on natural gas liquids further show that the petrochemical feedstock value of recovered gas depends on downstream fractionation and pipeline access that many flaring sites lack, reinforcing the case for market screening as a distinct decision function rather than an assumption embedded in technology selection (U.S. Energy Information Administration, 2012). The earliest systematic satellite record of global flaring established the multi-year baseline against which subsequent recalibrations have been benchmarked (Elvidge et al., 2009). Engineering reviews of small-scale liquefaction process design corroborate that plant-level configuration choices, rather than liquefaction thermodynamics alone, differentiate competing mini-LNG monetization routes (Cao, 2012) (Orise & Niniola, 2025; Komi & Adeniji, 2024a; Atakpa & Abetoh, 2022) (Eboh & Aliliele, 2025; Mbonu et al., 2022; Komi & Adeniji, 2024).

Thermofluid optimization supports energy-efficiency comparisons among processing and conversion routes (Adewoyin, Ogunnowo, & Ezeugwa, 2020). Process-improvement and asset-lifecycle frameworks strengthen execution and sustained operation (Ezeugwa, Ogunnowo, & Adewoyin, 2023). Energy-transition research also supports broader evaluation of environmental performance, workforce readiness, and facility risk (Komi & Adamolekun, 2026). Nigeria's flaring history illustrates why these strands must be integrated rather than sequenced: successive flare-out deadlines have been missed not for lack of technology but because governance, licensing, and commercial-model decisions were not coordinated with engineering selection at the field level (Abdulkadir, Chinade, & Bawa, 2019; Aigbe, Stringer, & Cotton, 2023). Comparable governance failures recur outside Nigeria: Russian associated-gas flaring limits have been undermined by weak enforcement of formal rules and reliance on informal institutional bargaining (Korppoo, 2018), earlier flaring-reduction gains proved fragile once economic conditions tightened (Loe & Ladehaug, 2012), North Dakota's flaring policy produced uneven distributional impacts across operators and communities despite an explicit regulatory target (Srivastava, Oonk, Lange, & Bazilian, 2019), and a techno-economic assessment of Iraqi associated gas finds that flaring persists chiefly because of underpriced gas and weak infrastructure incentives rather than technology limits (Maaroof, Smith, & Zangana, 2026). Finance-side literature on real-options analysis offers a complementary lens, showing that the value of a flare-gas monetization project depends on the flexibility retained to defer, resize, or exit as gas supply, product prices, and policy commitments evolve, rather than on a single point estimate of net present value (Gazheli & van den Bergh, 2018; Jaimungal, Al-Arabi, & Cartea, 2018; Carozzani & D'Alpaos, 2025; Idowu & Adinya, 2026). Read together, this literature supports the paper's central claim: technically sound conversion technology, favorable market access, and disciplined risk-adjusted finance are individually necessary but only jointly sufficient conditions for flare-gas monetization, which is the gap the eight-function framework developed in this paper is designed to close. Financial due-diligence models developed to prevent investment fraud and strengthen investor protection reinforce the case for embedding financial-governance discipline throughout project appraisal rather than only at final sanction (Eboh & Aliliele, 2025). Comparative procurement-cost-optimization research spanning green-procurement criteria and cross-country benchmarking reaches a similar conclusion: vendor governance, not technology substitution alone, sustains flare-gas monetization economics over the asset life (Akin-Oluyomi, Atima, & Akinleye, 2023; Akokodaripon, Akinleye, Okoruwa, & Babatope, 2023) (Eboh & Aliliele, 2024; Oyeleye & Ebhojie, 2025; Eboh & Aliliele, 2025b) (Eboh & Aliliele, 2024; Aneke et al., 2023; Aminu-Ibrahim et al., 2025).

Research Propositions

Research propositions translate the relationships built into the framework into statements that can actually be tested, a translation flare-gas monetization needs because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are examined as unrelated questions. For flare-gas sources, feed intermittency supplies the test case: how it begins, how it is detected, what safeguards respond, how quickly recovery occurs, and what the downstream effect is if it is missed. Technology-matching evidence contributes part of what a testable proposition would need, not all of it, and each proposition still needs a source date, operating mode, uncertainty, model version, and named owner behind the data used to test it, so a plausible-sounding claim cannot hide a weak assumption and later operating experience can be used to confirm or revise it rather than stand apart from the record. Data-driven cost-management models for strategic financial planning provide an empirical template for testing this proposition against resource-characterization outcomes (Oduleye & Medon, 2021).

Turning the framework's internal relationships into statements that can be tested empirically is the purpose of the research-propositions section, and it matters for flare-gas monetization because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and

regulatory duty are treated as separate questions. Contaminant breakthrough in the gathering network provides the relevant test case here: how it starts, how it is detected, what safeguards intervene, how quickly recovery follows, and what the downstream cost is if it is not caught in time. Concept-design evidence supplies part of what a testable claim would draw on, not the whole of it, and each proposition still needs a source date, operating mode, uncertainty, model version, and accountable owner attached to the data behind it, so a plausible claim cannot conceal a weak assumption and later operating experience can be used to confirm or revise it instead of being left outside the record.

Converting the framework's relationships into empirically testable statements is what the research-propositions section contributes to flare-gas monetization, a contribution that is needed because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being examined in isolation. Technology underutilization in pretreatment offers the relevant test case: how it arises, how it is detected, what safeguards respond, how quickly recovery takes place, and what the downstream cost is if it goes unaddressed. Risk-adjusted cash-flow modelling supplies part of the evidence a testable proposition would need, not all of it, and each proposition still needs a source date, operating mode, uncertainty, model version, and named owner attached to the underlying data, so a plausible claim cannot mask a weak assumption and later operating experience can be used to confirm or revise it rather than being kept apart from the record.

- P1: Greater maturity in resource characterization improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P2: Greater maturity in market screening improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P3: Greater maturity in technology matching improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P4: Greater maturity in concept design improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P5: Greater maturity in risk-adjusted cash-flow modelling improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P6: Greater maturity in option and scenario analysis improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P7: Greater maturity in delivery planning improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.
- P8: Greater maturity in post-startup verification improves the traceability and effectiveness of flare-gas monetization decisions when data quality and organizational context are controlled.

Limitations and Future Research

Stating the limits of the evidence, its transferability, the model, and the implementation itself is the job of this closing section, a job flare-gas monetization cannot skip because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are assessed as unrelated problems. In a conversion unit, market volatility marks one such limit: how it begins, how it is detected, what safeguards respond, how quickly the unit recovers, and what the downstream effect is if it is missed. Option and scenario analysis contributes part of what is known here, not the whole of it, and each limitation still needs a source date, operating mode, uncertainty, model version, and accountable owner attached, so an apparently settled conclusion cannot conceal a weak assumption and future operating experience can be used to close the gap rather than leave it undocumented.

This section states where the evidence, its transferability, the model, and the implementation itself reach their limits, a statement flare-gas monetization needs because commercial recovery does not survive supply, composition, distance to market, financing, operations, and regulatory duty being judged separately. Product storage contributes execution delay as one boundary: how a delay begins, how it is detected, what safeguards respond, how long recovery takes, and what the downstream cost is if it persists. Delivery-planning evidence covers part of this limit, not all of it, and each limitation still needs a source date, operating mode, uncertainty, model version, and named owner attached, so a confident-sounding conclusion cannot hide a weak assumption and future operating experience can be used to close the gap instead of leaving it unaddressed.

Where the evidence, its transferability, the model, and the implementation reach their limits is what this closing section records, a record flare-gas monetization needs because commercial recovery fails whenever supply, composition, distance to market, financing, operations, and regulatory duty are treated as separate matters. At the market and logistics interface, unverified emission reduction marks one such limit: how such a claim would arise, how it is detected, what safeguards catch it, how quickly it is corrected, and what the downstream cost is if it is not. Post-startup verification covers part of this limitation, not all of it, and each one still needs a source date, operating mode, uncertainty, model version, and accountable owner attached, so a confident-sounding conclusion cannot conceal a weak assumption and future operating experience can be used to close the gap rather than leave it undocumented.

Gas-development studies support screening monetization routes against volume, composition, pressure, distance, and supply reliability (Strizhenok et al., 2019; Okonkwo et al., 2024; Shaimardanova et al., 2019; Bian et al., 2011; Sircar et al., 2021; World Bank Global Gas Flaring Reduction Partnership., 2015; Falegan et al., 2025; Ogbete et al., 2024; Huang et al., 2023; Ominyi et al., 2022; Rutherford et al., 2021; Agbabiaka et al., 2019; Okonkwo et al., 2018; Neagu et al., 2017; Zavala-Araiza et al., 2015).

Economic research reinforces lifecycle cash-flow analysis, uncertainty ranges, and explicit treatment of market and execution risk (Osiki, 2018; Liadi, 2023; Alvarez et al., 2018; Hinderaker et al., 2010; Kerunwa et al., 2020; Anomohanran, 2012; Ogundairo, 2025; Ogbete et al., 2024; Komi et al., 2023; Onyeke et al., 2022; Ben Seghier et al., 2020; Askari et al., 2019; Yu et al., 2018; Zavala-Araiza et al., 2017).

Energy-infrastructure evidence links project selection to logistics, utilities, maintenance capability, and downstream demand (Kukadiya et al., 2017; Ogunwale et al., 2021; Muharam et al., 2018; Khalilpour et al., 2009; Heath et al., 2015; American Petroleum Institute., 2009; Bertone et al., 2024; Okonkwo et al., 2024; Liadi, 2023; Velazquez et al., 2022; Matveev et al., 2020; Chebbi et al., 2019; Zavala-Araiza et al., 2018; Li et al., 2016).

Resource-efficiency literature supports comparing recovery pathways through common technical, environmental, and commercial indicators (Henderson et al., 2007; Pourmalek et al., 2020; Ramasamy, 2018; Ibragimov et al., 2000; International Organization for Standardization., 2015; Komi et al., 2026; Komi et al., 2024; Wang et al., 2024; Cao et al., 2022; Ben Seghier et al., 2021; Obogo et al., 2020; Budinis et al., 2018; Balcombe et al., 2017; Lyon et al., 2016).

Investment studies reinforce staged decisions, sensitivity testing, and post-startup review of realized production and revenue (Ejiogu, 2013; Ainge, 2019; Sitorus et al., 2018; American Petroleum Institute., 2021; NACE International et al., 2015; Adebayo et al., 2025; Komi et al., 2024; Asiedu et al., 2023; Komi et al., 2022; Roussanaly et al., 2021; Wang et al., 2020; Obriki et al., 2018; Johnson et al., 2017; Zabihi et al., 2016).

Additional energy-system evidence supports commercial screening across gas-processing resilience, logistics efficiency, carbon use, maintenance, and downstream infrastructure (Ogunwale et al., 2021; Shittu et al., 2026; Joseph et al., 2024d; Opara et al., 2024; Ijiga et al., 2023a; Adaramola et al., 2018).

Ewim's energy-systems research supports pathway screening across distributed power, biogas, low-carbon transport, industrial efficiency, and renewable generation (Nnaji et al., 2019; Dioha et al., 2021; Okwu et al., 2021; Ntuli et al., 2022; Babawarun et al., 2023).

Conclusion

This paper set out to address a specific gap: engineering feasibility, market fit, financial risk, emissions performance, and execution readiness for flare-gas monetization are well studied individually but rarely integrated into a single, auditable decision process. The eight-function, stage-gated framework developed here closes that gap by linking resource characterization, market screening, technology matching, concept design, risk-adjusted cash-flow modelling, option and scenario analysis, delivery planning, and post-startup verification into one traceable sequence, applied consistently across flare-gas sources, gathering network, pretreatment, conversion unit, product storage, and market and logistics interface (Oloto & Yeboah, 2025; Aliliele & Iwuanyanwu, 2023a) (Aliliele et al., 2023; Mbonu et al., 2018).

The literature synthesis above shows why this integration matters. Global flaring data confirm that the resource keeps growing even as reduction commitments accumulate, technology reviews show that no single conversion route dominates across site conditions, and Nigeria's repeated missed flare-out deadlines show that technically sound projects still fail when governance, market access, and finance are not coordinated with engineering selection. Embedding risk-adjusted cash-flow modelling and real-options logic directly into the stage-gate sequence, rather than treating economics as a closing checkpoint, is the framework's principal response to that evidence.

The framework's practical value lies in the traceability it imposes: every advancement from one decision gate to the next requires a recorded evidence base, an accountable owner, and an explicit treatment of unresolved uncertainty, so that operating experience can update the decision rather than sit in a separate record. This discipline applies equally to a gas-to-liquids concept study, a mini-LNG delivery contract, or a post-startup verification of claimed emission reductions. The paper's specific contribution is a stage-gated techno-economic framework that integrates engineering feasibility, market fit, uncertainty, emissions, and execution readiness for flare-gas monetization decisions that the existing literature otherwise treats separately. Future work should test the testable propositions above with operating data from gas-to-liquids, gas-to-power, mini-LNG, compressed natural gas, and methanol projects, and should report unsuccessful applications as carefully as successful ones.

Field-development and industry evidence reinforces the need to evaluate flare-gas projects through integrated resource characterization, surveillance, commercial screening, and lifecycle learning (Delphi Ventura Group, 2021; Babadagli, 2005; Bresnen et al., 2003; Clayton et al., 1998; Faseemo et al., 2009).

Declarations

Ethics approval and consent to participate: The flare-gas monetization analysis used published evidence and involved no human participants or animals.

Consent for publication: Not applicable.

Availability of data and materials: The reference list identifies the full evidence base for the techno-economic synthesis; no proprietary dataset was created.

Competing interests: The author declares no competing interests.

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