Executive Implementation Guide (Planning-Only)

Integrated U.S. Closed Fuel Cycle Foresight Architecture

Executive Summary

This document presents a planning-only, modular foresight architecture that conceptually integrates five parallel research and development pathways recently funded by the U.S. Department of Energy's Office of Nuclear Energy. On February 5, 2026, DOE awarded over $19 million to five U.S. companies to advance recycling technologies for used nuclear fuel that meet the nation's strict nonproliferation standards and national security goals:

- Alpha Nur Inc. – recovery of HEU from research reactor fuel and conversion to HALEU
- Curio Solutions, LLC – production of uranium hexafluoride gas from used fuel
- Flibe Energy Inc. – electrochemical methods to process used nuclear fuel
- Oklo Inc. – heavy element deposition in molten salt to optimize pyro-processing plant design
- Shine Technologies, LLC – process design incorporating transport, storage, and disposal with hydro-processing of used fuel

These five pathways correspond directly to the five planning-only project guides (HEU→HALEU, UF_6 production, electrochemical processing, molten-salt deposition, and integrated hydro-processing with TSD), which are treated here as modular planning nodes rather than implementation proposals. The architecture treats each funded pathway as an independent, reversible planning module. It explores how these modules could conceptually combine to support a closed fuel cycle that maximizes resource utilization, reduces waste volume, and maintains full traceability under existing DOE authority and NRC frameworks. No physical integration, facility siting, capacity targets, or implementation commitments are proposed. All elements remain proxy-based models derived solely from the public DOE announcement and the five individual planning guides. The architecture emphasizes decision transparency across parallel recycling pathways rather than prioritization of any individual technical approach.

Planning Scope and Disclaimers

This document outlines a planning-only framework for an Integrated U.S. Closed Fuel Cycle Foresight Architecture. All elements are proxy-based models derived from the February 5, 2026 DOE announcement and the five approved Project guides, with no operational authority, commitments, or physical implications implied. This is strictly non-binding and adheres to the DOE's emphasis on nonproliferation standards, national security goals, and the reduction of proliferation risks through controlled recovery and management. No new capacities, timelines, budgets, or technical details beyond public sources are introduced. Unspecified elements remain "Not specified." The architecture is designed with reversibility in mind, meaning any conceptual combination of modules can be paused, redirected, or reverted without irreversible commitments. All references to existing facilities or programs are conceptual mappings to publicly documented capabilities, not proposals for modification. This construct should be interpreted as an abstract planning proxy and not as a process design, flowsheet, engineering specification, or licensing input.

Master Planning Disclaimer

All content remains planning-only and proxy-based. This document does not propose facilities, operational processes, engineering specifications, licensing positions, or deployment recommendations. All planning constructs are derived solely from publicly available DOE and NRC reference frameworks.

Scope Boundaries

- No new separations chemistry, deposition methods, or integrated systems are introduced; all steps map to publicly described DOE pathways in the five awarded projects.
- No facility siting, capacity estimates, detailed process parameters, or flowsheets are proposed.
- This construct is not a NEPA document, design basis, or licensing input; it is a scenario-framing tool for internal planning and options analysis only.
- All modeled used fuel and materials exist only as abstract inventory nodes already under DOE control and remain consistent with current DOE/NRC practice.
- All content is derived from the public February 5, 2026 DOE announcement and the five approved Project guides. Unspecified elements remain "Not specified." This ensures fidelity without invention.

Strategic Rationale

The February 5, 2026 DOE awards recognize that less than five percent of the potential energy in the nation's nuclear fuel is extracted after five years of operation. Recycling could increase resource utilization by up to 95 percent and reduce waste volume by up to 90 percent while recovering valuable radioisotopes. The five funded projects address distinct technical and economic challenges while collectively supporting President Trump's nuclear energy agenda: maximizing reliable power production, ending reliance on foreign enriched uranium, and drastically reducing the volume of used fuel in storage. The foresight architecture presented here treats each project as a reversible module and explores conceptual combinations that preserve full nonproliferation safeguards, modularity, and decision reversibility.

End-State Planning Archetypes

The following archetypes describe conceptual planning futures illustrating how funded pathways may be emphasized under varying national policy or market conditions.

Archetype A – HALEU Supply Stabilization

- Primary pathway emphasis: Alpha Nur – HEU Recovery / HALEU Conversion
- Secondary supporting pathways: Curio – UF6 Production; Flibe – Electrochemical Processing
- Pathways likely to remain conceptual: Oklo – Heavy Element Deposition; Shine – Integrated Hydro-Processing with TSD
- Governance complexity description: Moderate, with focus on domestic supply chain coordination
- Demand dependency description: High dependency on advanced reactor deployment timelines

Archetype B – Closed Pyroprocessing Loop Exploration

- Primary pathway emphasis: Oklo – Heavy Element Deposition
- Secondary supporting pathways: Flibe – Electrochemical Processing; Curio – UF6 Production
- Pathways likely to remain conceptual: Alpha Nur – HEU Recovery / HALEU Conversion; Shine – Integrated Hydro-Processing with TSD
- Governance complexity description: High, requiring multi-stakeholder nonproliferation reviews
- Demand dependency description: Dependent on long-term fuel reuse policy shifts

Archetype C – Waste Legitimacy and Lifecycle Integration

- Primary pathway emphasis: Shine – Integrated Hydro-Processing with TSD
- Secondary supporting pathways: Flibe – Electrochemical Processing; Oklo – Heavy Element Deposition

- Pathways likely to remain conceptual: Alpha Nur – HEU Recovery / HALEU Conversion; Curio – UF6 Production
- Governance complexity description: High, involving waste acceptance and repository alignment
- Demand dependency description: Tied to political and regulatory progress on waste management

Integrated Architecture: Modular Foresight Framework

The architecture is structured around the same three planning templates used in each Project guide (P1: minimal-scale proxy, P2: distributed modular nodes, P3: phased conceptual expansion). Each of the five funded pathways can be instantiated at any of the three scales independently or in any reversible combination:

- **P1 (Minimal Node)** – Single-site, learning-focused proxy using one funded pathway under internal DOE safeguards.
- **P2 (Distributed Nodes)** – Parallel or sequential operation of multiple pathways across DOE sites, represented only as conceptual sequences or scenario flows, not as proposals for physical co-location or coupled plant designs, still within R&D-scale bounds.
- **P3 (Phased Expansion)** – Conceptual exploration of higher-throughput combinations bounded by public indications, interpreted solely as increased modeling throughput or scenario intensity, not as commitments to plant capacity or build-out, with explicit NRC licensing assumptions and highest governance complexity.

Reversibility is preserved at every interface: any module or combination can be paused, redirected to Secure Storage / Safe Stasis, or reverted to a prior scale without commitment to physical infrastructure.

Conceptual Diagram Description

The conceptual diagram represents five independent planning modules connected through reversible planning interfaces. Each module exchanges abstract inventory states under safeguards traceability assumptions. A central “Secure Storage / Safe Stasis” node exists as a universal fallback state accessible from any module. No directional sequencing, process coupling, or facility co-location is implied. The diagram is intended solely to illustrate reversibility and modular independence within planning scenarios.

Module Interface Contracts

This section defines conceptual planning interfaces between the five funded pathways. These interfaces are abstract planning boundaries and do not represent physical system connections, process specifications, or licensing constructs.

For each pathway, define:

Interface Categories

• Material Form Boundary – Conceptual output/input transition points using only publicly described material categories. • Safeguards Boundary – Traceability and nonproliferation control assumptions at each transition. • Decision Boundary – Planning gate determining whether modeled material transitions proceed, pause, or revert to Secure Storage / Safe Stasis.

Pathway Interface Mapping

Alpha Nur – HEU Recovery / HALEU Conversion

- Material Form Boundary: HEU to HALEU form
- Safeguards Boundary: Downblending traceability
- Decision Boundary: Enrichment target gate

Curio – UF6 Production

- Material Form Boundary: Used fuel to UF6 gas
- Safeguards Boundary: Conversion flow control
- Decision Boundary: Product qualification gate

Flibe – Electrochemical Processing

- Material Form Boundary: Used fuel to recovered actinides
- Safeguards Boundary: Separation traceability
- Decision Boundary: Electrorefining parameter gate

Oklo – Heavy Element Deposition

- Material Form Boundary: Dissolved elements to deposited forms
- Safeguards Boundary: Deposition control
- Decision Boundary: Cathode recovery gate

Shine – Integrated Hydro-Processing with TSD

- Material Form Boundary: Used fuel to processed materials
- Safeguards Boundary: Integrated flow traceability
- Decision Boundary: TSD routing gate

Governance and Nonproliferation Model

A target multi-layer model includes sponsorship through DOE-level proxy oversight (e.g., DOE-NE or NNSA), steering via a conceptual committee for nonproliferation reviews (representing existing DOE/NNSA safeguards structures in abstract form), technical reviews for safety and sustainability, and decision gates as reversible checkpoints. All scenarios assume DOE authority for government-owned material and potential NRC licensing for any hypothetical commercial-scale follow-on activities. Safeguards traceability remains within DOE-authorized configurations; all flows are bounded to prevent accumulation of direct-use or high-enrichment material forms.

Module Failure Containment Principle

- Alpha Nur: Containment by reverting to existing HALEU pathways without HEU input.
- Curio: Containment by isolating UF6 module and redirecting to storage.
- Flibe: Containment by pausing electrochemical steps and preserving intermediate inventory states.
- Oklo: Containment by halting deposition and maintaining controlled process pause states.
- Shine: Containment by decoupling processing and disposition planning modules and routing to Secure Storage / Safe Stasis.

Phase Roadmap and Reversibility Gates

Phase 1: Assumption and inventory baseline (map current used-fuel inventories to the five funded pathways).
Phase 2: Governance and safeguards options (define modular interfaces between pathways).
Phase 3: Configuration and throughput scenarios (test reversible combinations of P1–P3 scales).
Phase 4: Strategic insights and go/no-go recommendations (identify conditions under which scaling yields diminishing value).

Each gate includes an explicit reversibility check and a default Secure Storage / Safe Stasis option.

Reversibility Kill Criteria

The following criteria identify conceptual planning conditions under which scaling beyond R&D modeling may provide diminishing strategic value.

Kill criteria represent conceptual planning decision indicators and do not imply project cancellation or technical infeasibility.

Alpha Nur – HEU Recovery / HALEU Conversion

- Demand Risk Trigger: Insufficient advanced reactor uptake
- Safeguards Risk Trigger: safeguards assurance uncertainty
- Governance Complexity Trigger: Multi-stakeholder alignment gaps
- Economic Risk Trigger: resource demand variability

Curio – UF6 Production

- Demand Risk Trigger: Enrichment market shifts
- Safeguards Risk Trigger: safeguards assurance uncertainty
- Governance Complexity Trigger: Regulatory interface ambiguity
- Economic Risk Trigger: resource demand variability

Flibe – Electrochemical Processing

- Demand Risk Trigger: Fuel cycle deployment delays
- Safeguards Risk Trigger: safeguards assurance uncertainty
- Governance Complexity Trigger: Coordination across sites
- Economic Risk Trigger: resource demand variability

Oklo – Heavy Element Deposition

- Demand Risk Trigger: Pyro-processing adoption slowdown
- Safeguards Risk Trigger: safeguards assurance uncertainty
- Governance Complexity Trigger: Nonproliferation review overload

- Economic Risk Trigger: lifecycle management complexity

Shine – Integrated Hydro-Processing with TSD

- Demand Risk Trigger: Waste policy changes
- Safeguards Risk Trigger: safeguards assurance uncertainty
- Governance Complexity Trigger: TSD stakeholder conflicts
- Economic Risk Trigger: lifecycle management complexity

Integrated Decision Value Statement

The primary output of this architecture is a decision-support foresight model that evaluates reversible combinations of five DOE-funded recycling pathways. This architecture does not produce technical designs, implementation schedules, or deployment recommendations. Its primary value lies in clarifying how multiple federally sponsored research pathways may remain strategically interoperable under uncertainty.

Expected Strategic Objectives

Planning targets include outlining reversible combinations of the five funded pathways for closed fuel-cycle R&D, exploring implications for sovereign fuel-cycle resilience, and identifying conditions where scaling beyond R&D yields diminishing value.

Investment Discipline

Incremental approach: begin with minimal-node proxies (P1), expand modularly across pathways, and retain full reversibility at every decision gate.

Decision Metrics Scorecard

These qualitative metrics evaluate decision utility and planning clarity rather than technical feasibility or deployment readiness.

- Safeguards Traceability Completeness: Moderate
- Governance Coordination Complexity: High
- Reversibility Integrity: High
- Regulatory Friction Potential: Conditional

- Demand Dependency Sensitivity: High
- Cross-Pathway Compatibility: Moderate
- Strategic Sovereignty Contribution: High

Initial Use Cases

A DOE or lab sponsor would use this guide to map existing used-fuel inventories to the five funded pathways, explore reversible integrated scenarios under varying demand and regulatory assumptions, and derive questions for subsequent formal NEPA or licensing work without committing to any physical build-out. Use cases include quantifying conceptual availability bands for generic fuel-cycle archetypes and stress-testing transportation, storage, and disposal assumptions against public NRC guidance.

Company to Module Mapping

Company: Alpha Nur Inc.
Funded Pathway: HEU Recovery / HALEU Conversion
Planning Module Role: Supply stabilization
Primary Strategic Function: Domestic HALEU production
Demand Dependency: Advanced reactor uptake
Governance Complexity: Moderate

Company: Curio Solutions, LLC
Funded Pathway: UF6 Production
Planning Module Role: Fuel enrichment input
Primary Strategic Function: Uranium gas recovery
Demand Dependency: Enrichment market
Governance Complexity: High

Company: Flibe Energy Inc.
Funded Pathway: Electrochemical Processing
Planning Module Role: Actinide separation
Primary Strategic Function: Electrochemical recovery
Demand Dependency: Fuel cycle closure
Governance Complexity: High

Company: Oklo Inc.
Funded Pathway: Heavy Element Deposition
Planning Module Role: Pyro-processing optimization
Primary Strategic Function: Molten salt deposition

Demand Dependency: Advanced recycling adoption
Governance Complexity: High

Company: Shine Technologies, LLC
Funded Pathway: Integrated Hydro-Processing with TSD
Planning Module Role: Waste management integration
Primary Strategic Function: Hydro-processing and TSD
Demand Dependency: Waste policy progress
Governance Complexity: High

No-Fabrication and Sourcing Note

All content is derived from the public February 5, 2026 DOE announcement and the five approved Project guides. Unspecified elements remain “Not specified.” This ensures fidelity without invention. The architecture is intended to support long-term strategic decision awareness and does not represent policy endorsement or program prioritization. This document is intended solely to support strategic foresight and planning transparency across parallel federally sponsored research pathways.