Overview of the Systems Analysis & Integration Campaign

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Nov. 6, 2025

U.S. DEPARTMENT OF ENERGY

SA&I SYSTEMS ANALYSIS AND INTEGRATION

Campaign Structure

SYSTEMS ANALYSIS AND INTEGRATION

D. Algama (DOE-NE)
Federal Program manager

- **Campaign Management and Integration (CMI)**
  T. Kim (NTD)/J. Hansen(DNTD)

Nuclear Energy System Performance (NESP)
N. Stauff (ANL)

Assess performance and provide insights on legacy and newly proposed NES

Economic and Market Analysis for Nuclear Energy Systems (EMANES) J. Hansen (INL)

Studies of potential drivers and strategies for nuclear energy system (NES) competitiveness

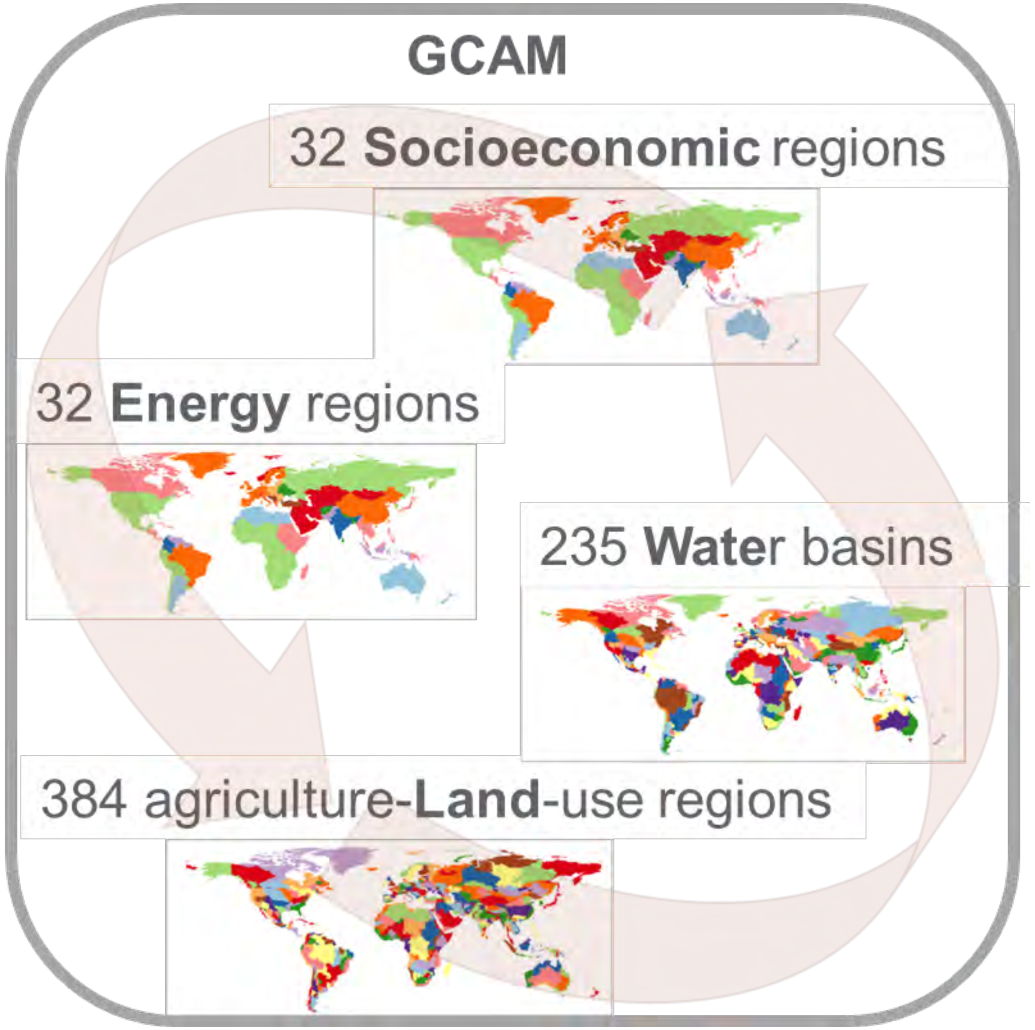
Uranium Fuel Supply
S. Bruffey (INL) / E. Davidson (ORNL)

Assessment of NU, LEU, HALEU supply chain and market

Economic Risk

Economic Risk

Global Change Analysis Model (GCAM v8.2)



- Global model that integrates energy, water, land, economic, and atmospheric systems
- Dynamic-recursive, market equilibrium
- Divides the world into 32 energy-economic regions
  - Flexible regional definitions
- Runs in five-year time steps from 2021-2100
- Inputs include assumptions about
  - Socioeconomic drivers, resources, technology, national and international policies
- Provides information about key outcomes
  - e.g., fossil and other resource utilization, energy technology deployment, land use and agricultural production, energy and ag commodity prices and trade, water supply and use
  - Greenhouse gases, aerosols and short-lived species
- Community model (https://github.com/JGCRI/gcam-core/releases)

One-slide Summary

Category	Barrier	Economic Effect	Research Activities On
Capital Costs	high capex, long time horizon, overrun risk, first-mover vs second-mover tension	deters investment, requires subsidies (built-in dependency), moral hazard	cost, tradeoffs (scale vs multiples), financial risk, materials and construction techniques
Supply Chain	manufacturing gaps, labor shortages, fuel availability, capacity constraints, trade	delays in construction, increases costs, fuel risk/energy security	industry survey, workforce analysis, market modeling, development pathways
Market Analysis	Mispriced reliability in wholesale markets Capacity expansion, Opportunities	undercompensates nuclear value	industrial economics, missing money/ capacity market, non-market values
Public Acceptance	safety fears, nimbyism, legacy issues	siting challenges, political friction	domestic and international outreach, economic impact modeling
Waste Management	no long-term disposal	adds risk (political, public acceptance), business case	fuel cycle analysis, break-even reprocessing, impact of closing the fuel cycle
Regulation	Licensing delays, rigid frameworks, risk to rate base, grid access	adds uncertainty, hampers innovation, revenue stability	risk-informed regulation, alternative business models

Technoeconomic Analyses

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- Potential Cost Reduction in New Nuclear Deployments Based on Recent AP1000 Experience (here)
  - Evaluated construction of Vogtle 3 & 4 and Chinese variants (CAP1000 and CAP1400)
  - Assessed potential learning curve benefits and identified implications for supply chain and workforce development
- Quantifying Capital Cost Reduction Pathways for Advanced Reactors (here)
  - *Nuclear Reactor Cost Reduction Pathways Tool* (here)
  - *Meta-Analysis of Advanced Nuclear Reactor Cost Estimations* (here)
    - Source for NREL ATB data on nuclear cost estimates
  - *Quantifying Cost and Risk Reduction Options from New Nuclear New Builds* (*current*)
- Advanced Fuel Cycle Cost Basis Report (here)
  - comprehensive cost data on fuel cycle operations
  - coordinated effort with applicable research campaigns (e.g., Advanced Fuels)

ACCERT Tool

- **INL is collaborating with Argonne National Lab on development of the Algorithm for Comprehensive Cost Estimation of Reactor Technologies (ACCERT).**
- **ACCERT code is:**
  - A database of cost and cost function/algorithms for reference nuclear power pants
  - A software to interact with and manipulate the database
- **Goal is to obtain high-level initial cost estimates that are transparent and parametrizable**
- **Models for: PWR12-BE, ABR-1000 (sodium) NGNP (gas), and Design A (micro)**

Example Algorithms:

- Yardwork: $\text{Yardwork} = (\text{Surface Area}) \times \$\,82/\text{m}^2$
- Containment: $\text{Containment} = (\text{Sub. Vol.}) \times \$\,130.8/\text{m}^3 + (\text{Cont. Vol.}) \times \$\,784.8/\text{m}^3$

```
accert{
    ref_model = "PWR12-BE"
    % Define the required parameters
    % The required parameters are thermal power and electrical power.
    power(Thermal){ value = 3000   unit = MW }  % Reference value for PWR-12BE is 3431 MW
    power(Electric){ value = 1000   unit = MW } % Reference value for PWR-12BE is 1143 MW
    l0COA(2){
        l1COA(21){
            l2COA(211){
            % Inside COA 211, there several cost elements
                % The first cost element is the factory cost
                ce("211_fac"){
                    alg("esc_1987"){
                        var(ref_211_fac){ value = 0.27   unit = million }
                        var(ref_211_mat){ value = 10.3   unit = million }
                    }
                }
            }
            l2COA(213){
                ce("213_fac"){
                    alg("MWth_scale"){
                        % This cost element is calculated by an algorithm called 'MWth_scale'
                        % The variable c_213_fac is 1.79 million USD
                        var(c_213_fac){ value = 1.79   unit = million }
                    }
                }
            }
            l2COA(217){
                % Instead of using the cost element '213_fac',
                % we can use the total cost as well.
                total_cost{value = 28149700 unit = dollar}
            }
        }
        l1COA(22){
            l2COA("220A"){
                l3COA("221.12"){
                    ce("221.12_fac"){
                        alg("unit_weights"){
                            var("c_221.12_cs_weight"){value = 538 unit = ton}
                            var("c_221.12_ss_weight"){value = 40340 unit = lbs}
                        }
                    }
                }
            }
        }
```

ACCERT Input

https://github.com/accert-dev/ACCERT

Cost Reduction Tool – An Improved Learning Rate Quantification

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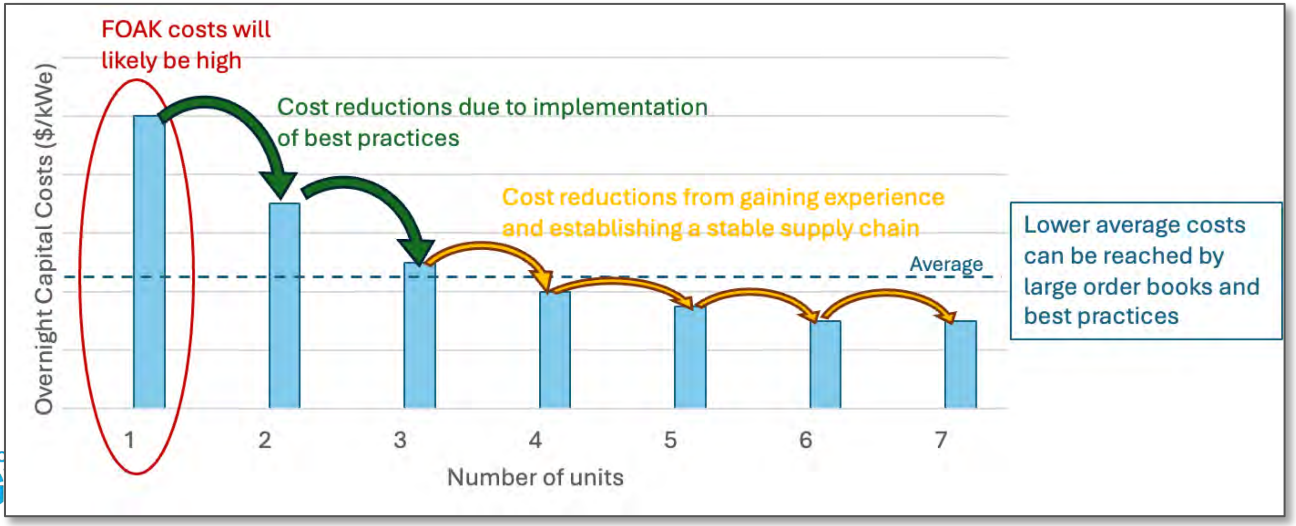
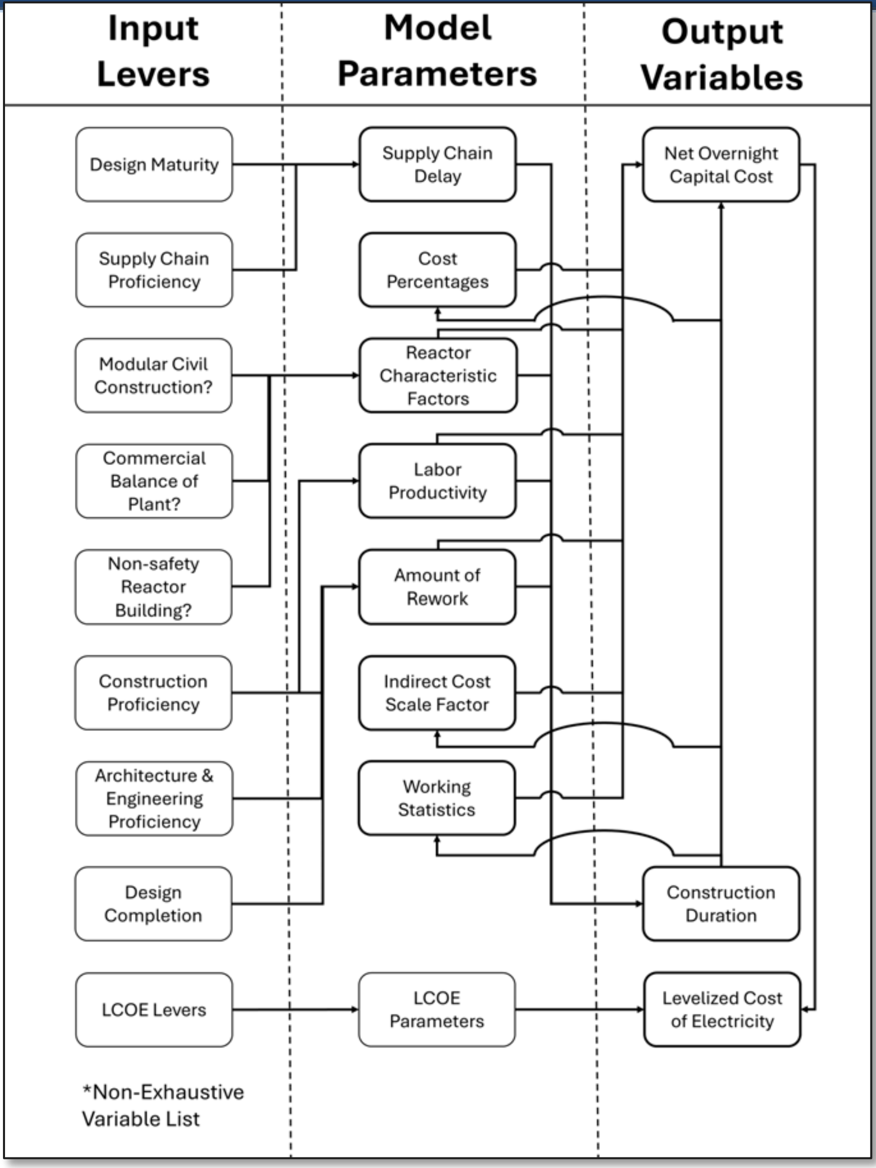
This tool improves on learning rate models and quantifies decision-driven cost drivers

- Traditional learning curves oversimplify cost evolution and obscure key drivers.
- The tool decomposes cost changes into specific, adjustable "levers."
- Enables scenario-based analysis tailored to stakeholder decisions and reactor designs.
- Provides transparency and traceability for cost reduction pathways.



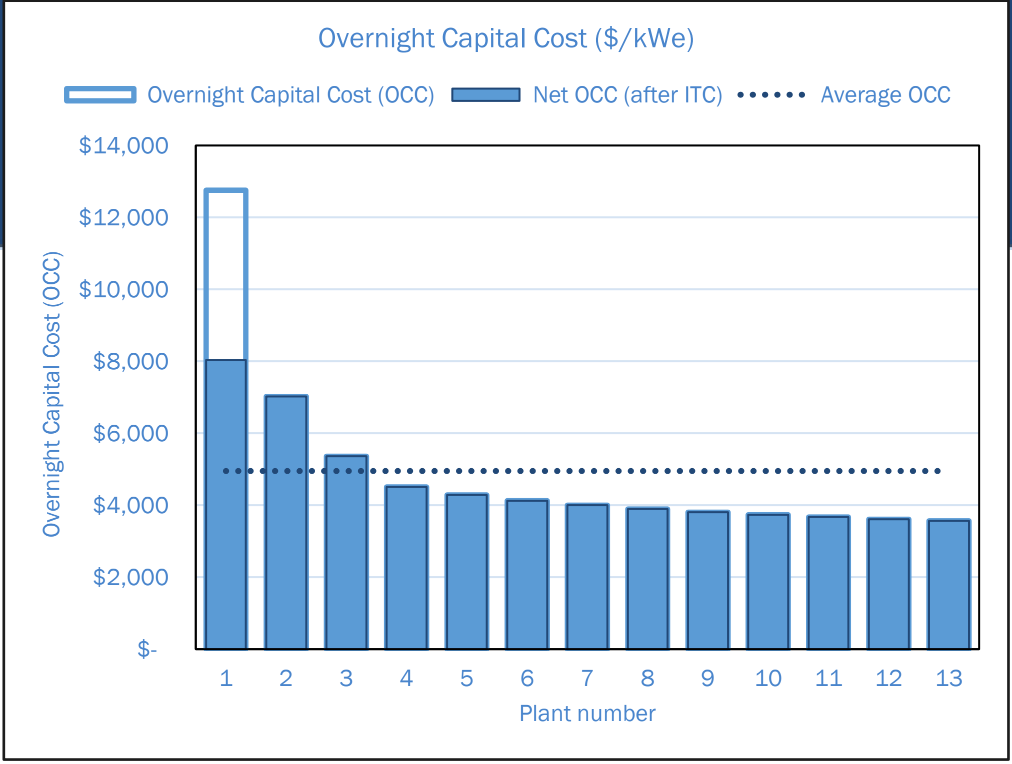


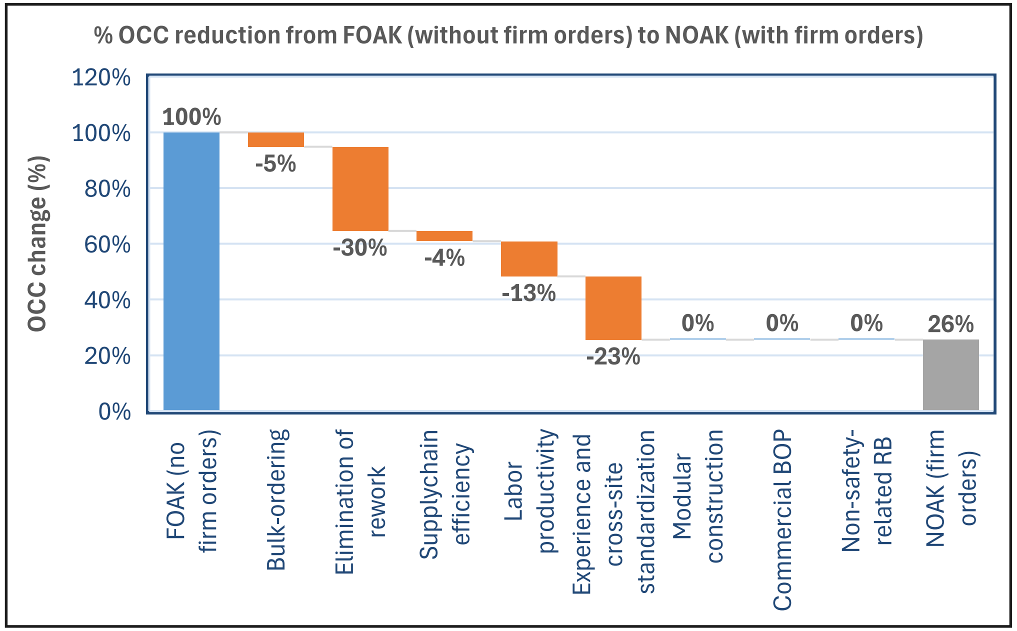
Levers Drive the Cost Pathways

Users adjust levers to simulate how costs evolve from FOAK to NOAK

- Levers represent stakeholder decisions that influence cost and schedule (e.g., design maturity, EPC proficiency, modularity).
- Each lever is linked to cost impacts through scaling relationships and empirical correlations.
- Relationships were developed using:
  - A meta-analysis of 30+ advanced reactor cost studies (INL 2023 Literature Review)
  - Bottom-up cost models like TIMCAT
  - Historical data (EEDB) (Vogtle)
- Levers evolve over time to reflect learning, standardization, and supply chain maturation.
- The tool applies these relationships deterministically to compute cost and schedule outcomes.

Number of Firm Orders	13
Interest Rate	6%
Design Completion	80%
Design Maturity (0, 1, 2)	1
Supply Chain Proficiency	0.5
A/E Proficiency	0.5
Construction Proficiency	1
Cross-Site Standardization	80%
Modular Civil Construction	TRUE
Commercial-Grade BOP	TRUE
Non-Safety-Related Reactor Building	FALSE
ITC Amount	40%
Number units with ITC	1





User Input and Tool Flow

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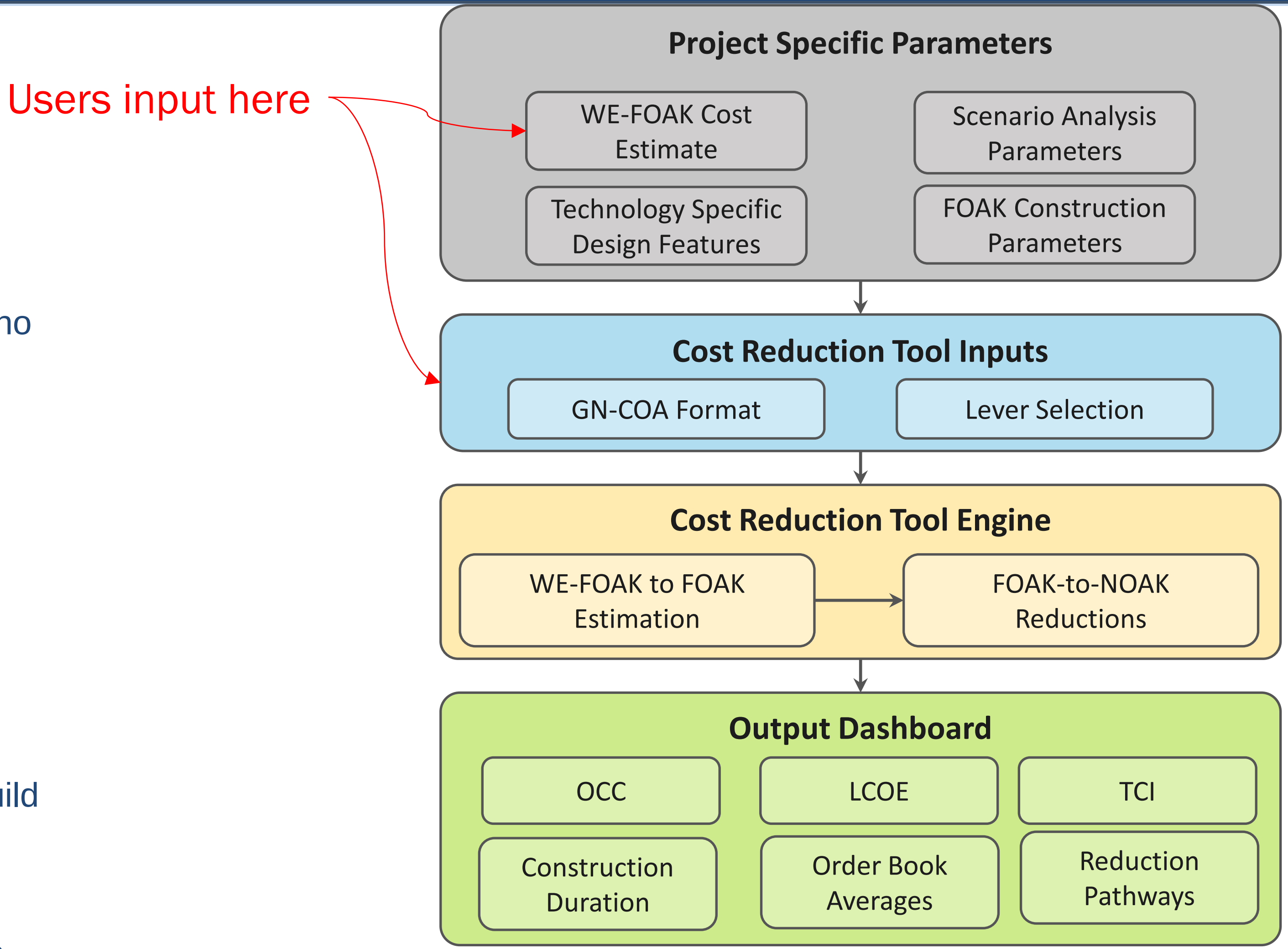
The framework works by inputting WE-FOAK cost estimates and deciding lever values

- **Step 1: Input WE-FOAK Baseline**
  - Use a well-executed FOAK cost estimate with no learning or overruns.
- **Step 2: Set Lever Values**
  - Define stakeholder decisions across design, construction, finance, and deployment.
- **Step 3: Run Calculations**
  - CRT engine applies scaling relationships to compute OCC, TCI, and construction duration.
- **Step 4: Review Outputs**
  - Analyze cost evolution, waterfall charts, and build timelines.
- **Step 5: Iterate Scenarios**
  - Adjust levers to explore trade-offs and optimize deployment strategies.



https://sai.inl.gov/report/nuclear-reactor-cost-reduction-pathways-tool/

Supply Chain Markets

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- Economic Systems Readiness Assessment (current)
  - add-in to: Technology Systems Readiness Assessment
  - based TRL approach and focuses upstream supply chain to assess resource availability
  - questionnaire based
- Advanced Reactor Supply Chain Assessment (here)
  - survey to supply chain vendors to assess readiness to scale up production
  - workforce availability and experience were the primary concerns
- Analyzing the Nuclear Industry Workforce Pipeline to Support Nuclear Energy Growth (current)
  - Projections of labor demand by 2030 for 3x and by 2050 for 4x
  - Analyzes labor supply, analyzes education/training for nuclear specific jobs, cross-over jobs (e.g., oil/gas)
  - Disaggregated to county-level, population trends, education trends, job categories occupied
- Modeling Potential Pathways for HALEU Market Growth (current)
  - Analysis of current and projected fuel cycle front-end capacities
  - Interacting projected demand growth for LEU vs HALEU fuel
  - Agent-based model populated with data on RFPs, cost

Agent-Based Modeling of Market for HALEU Fuels

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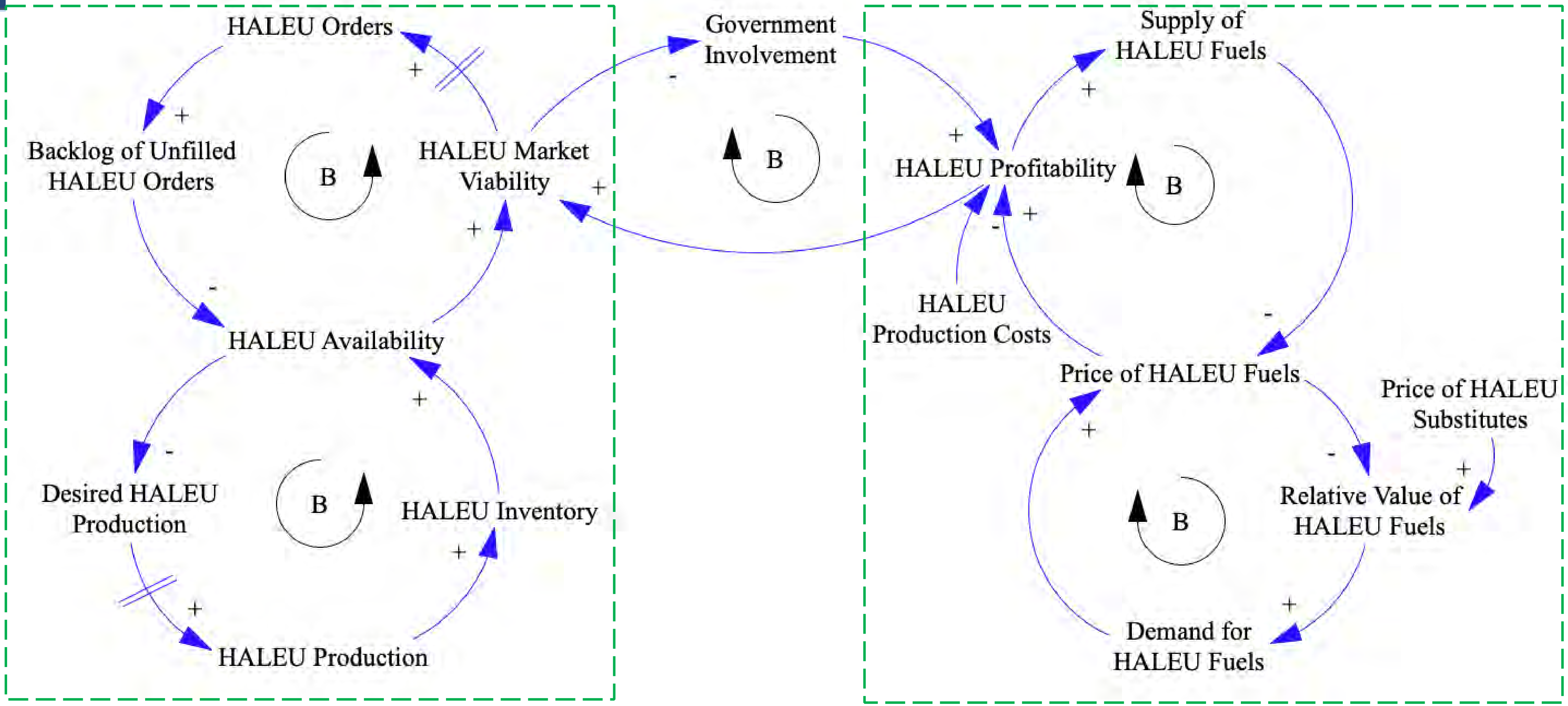

Bringing HALEU to Market

Functioning Market for HALEU Fuels

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Fuel Cycle

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- Economic Impact of Closing the Nuclear Fuel Cycle (**here**)
  - evaluates fuel cycles from *Nuclear Fuel Cycle Evaluation and Screening* (here)
  - estimates jobs and economic impact of today's fuel cycle, today's fuel cycle if all domestic, and closed fuel cycle options
  - does not reflect capacity goals for 2030 or 2050
- Cost-Benefit Assessment of Krypton and Xenon Recovery from Aqueous Reprocessing (**internal**)
  - market assessment of Kr and Xe to determine alternative methods of capture
  - collaboration DOE NE's, Material Recovery and Waste form Development Campaign
- Cost Comparison of Domestic-Focused Once-Through vs. Recycle for Advanced Reactors **(internal)**
  - Evaluates projected fuel cycle costs of once-through and recycle
  - Identifies cost drivers for each scenario and jobs needed to support
- Pros and Cons Analysis of HALEU Utilization in Example Fuel Cycles **(here)**
  - evaluates equilibrium of fuel cycles: once-through, limited recycle, and continuous
  - evaluates the cost levelized cost of fuel, excluding reactor costs

Questions?

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Co-Chair, Economic Modeling Working Group GenIV

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