Systems Analysis & Integration Campaign Overview

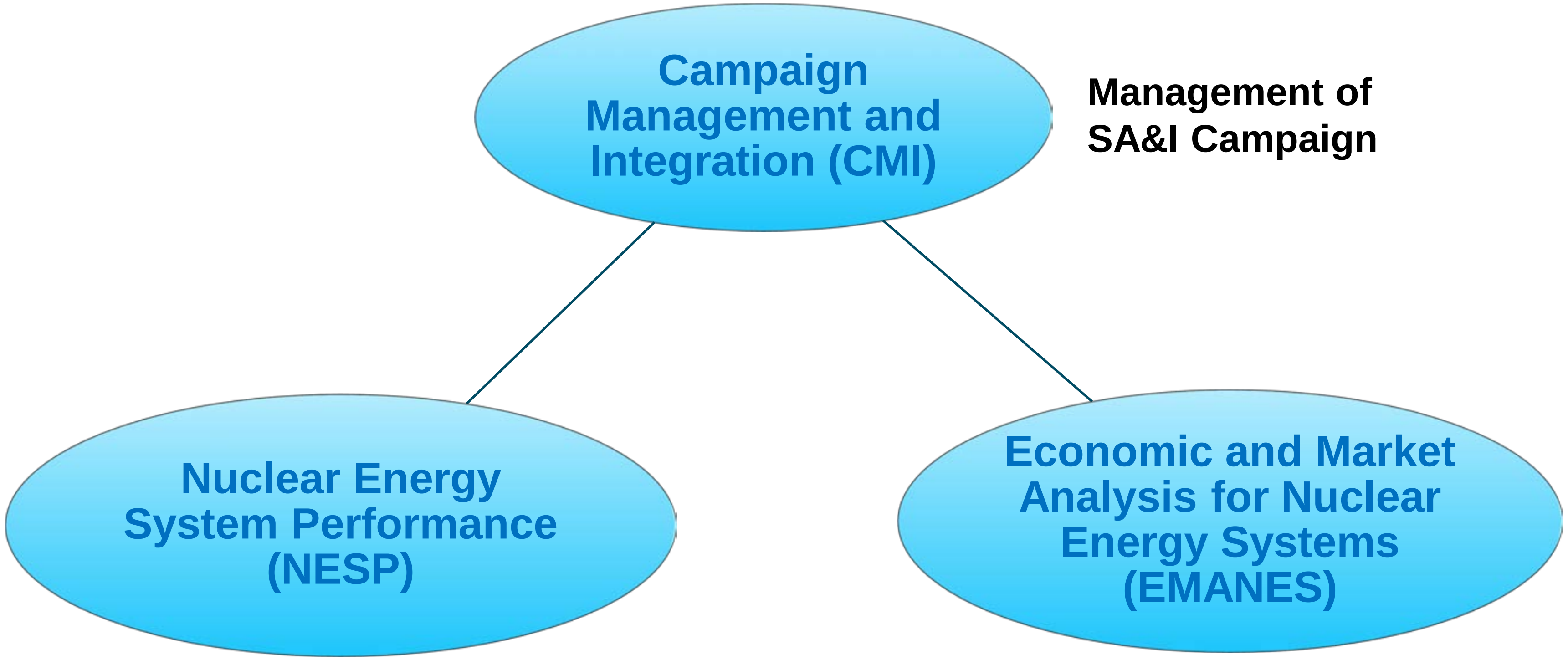
Brent Dixon
National Technical Director

GAIN-Industry INL Visit
June 7, 2022

SA&I Campaign Objectives

- **Perform comprehensive analysis of nuclear energy systems (NES) to determine technical and economic viability, identifying benefits and challenges**
  - Provide insights on legacy and newly proposed reactors and nuclear energy systems
  - Develop understanding of the role of nuclear energy and its competitiveness in current and future domestic and global energy markets
  - Identify and assess strategies to improve economics, technical and social sustainability of nuclear energy
- **Utilize and enhance leading-edge systems analysis tools, models & capabilities**
- **Facilitate integration of DOE NE-4/NE R&D portfolio and strategy**
- **Execute quick-turnaround requests from HQ**

SA&I Campaign Organization



Management of SA&I Campaign

Analyses of NESs to improve understanding of how specific sets of technology options function as a system

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

Early Campaign History – Actinide Burning, Fuel Cycle Options

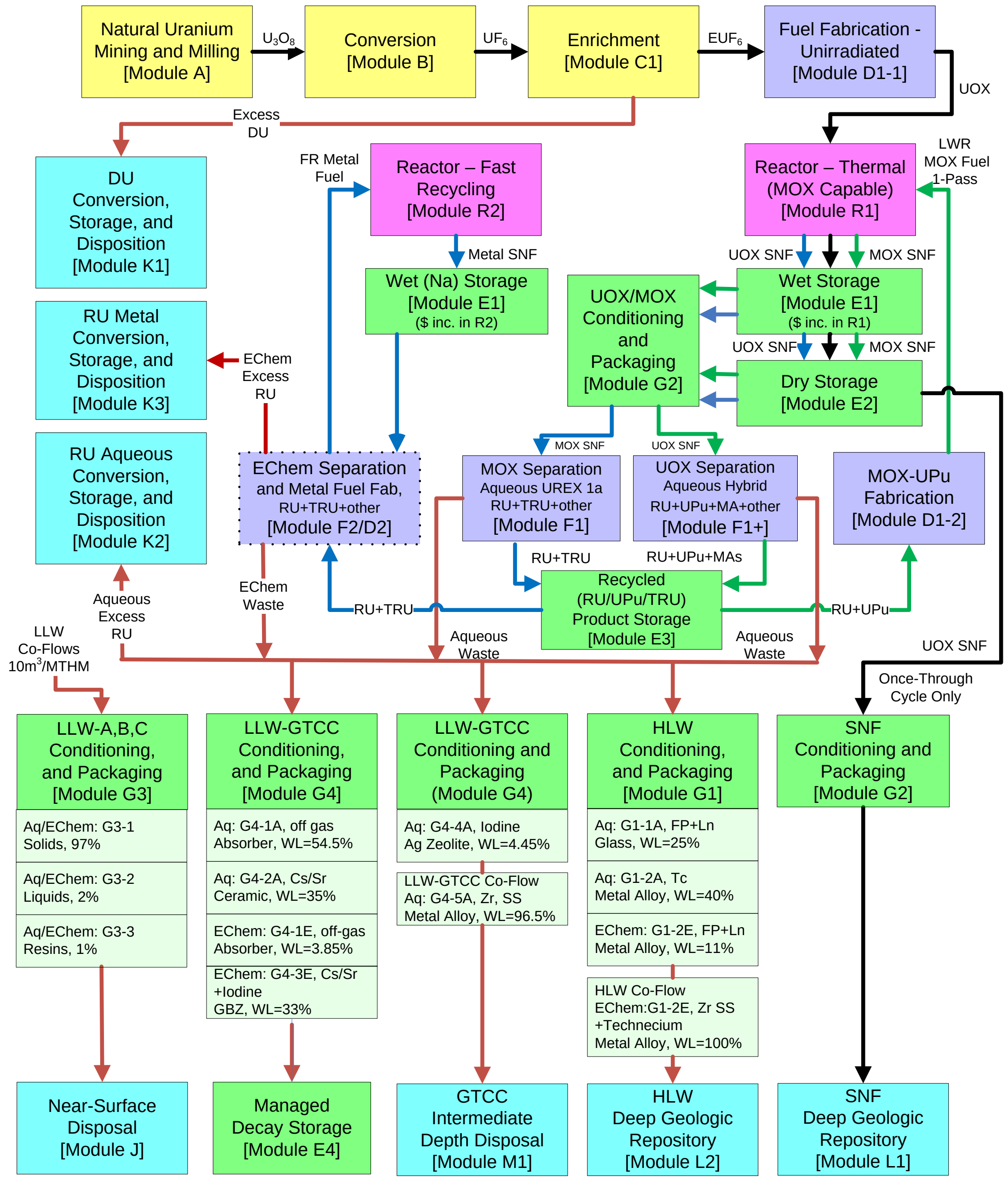
- **Advanced Transmutation of Waste Program**
  - Focus on physics associated with destruction of actinides, LLFP using accelerator-driven systems
  - ADS determined to be less effective for actinide burning than reactor-based systems

- **Advanced Fuel Cycle Initiative & Global Nuclear Energy Partnership**
  - Refocused on physics for actinide burning and repository heat load, cost of fuel cycle functions, contributions to reports to Congress
    - Advanced Fuel Cycle Cost Basis – unit costs for every nuclear energy system function (mining to disposal)
    - Dynamic Systems Analysis Report for Nuclear Fuel Recycle
    - Initial analyses of nuclear contributions to decarbonization

- **Fuel Cycle Research & Development Program**
  - Solution space expanded to include breeding, added deployment & implementation issues
    - Nuclear Fuel Cycle Evaluation and Screening report – comprehensive assessment of all possible fuel cycles
    - Minor Actinides study
    - Fuel Cycle Catalog
    - NE-Cost tool

Cost Basis Modules

Economic Analysis Modules and Primary Flows



Disposal costs charged at the time that energy is produced by R1.

Current Program

- **Nuclear Fuel Cycle and Supply Chain**
  - Emphasize on economics, deployment support
    - Technology and System Readiness Assessment (TSRA) methodology
      - Evidence-based method to manage R&D, develop maturation plans/roadmaps
    - Cost Basis Report augmented with reactor systems costing algorithms
      - Functional code of accounts to cover full range of reactor concepts from MWe to GWe
    - Nuclear role in decarbonization of multiple economy sectors
      - Net-zero energy mix
    - Daily market studies to assess importance of clean firm generation for grid stability
    - Tools for siting analysis, economic impacts, environmental justice
    - International Programs
      - NEA Working Parties on Nuclear Economics, Reactor Systems, Advanced Fuel Cycles

Current Program (cont.)

- **Recent deliverable highlights**
  - Transition Analysis summary report (2018)
  - Technology Maturity and Economic Performance Potential of micro-reactors (2019)
  - Lessons learned from LWR Deployment History (2020)
  - Journal Articles on Policy Impacts on Maintaining/Enhancing Role of Nuclear (2020)
  - Fuel Cycle Facilities Technology Readiness Assessment to support reactor deployments (2021)

- **Quick Turnaround Studies**
  - Initiated by NE-4 and Front Office requests
    - May be internal to NE, or support external collaborations/reviews
  - Recent examples –
    - Assessment of cost impact of Senate bill on economically challenged plants
    - Projection of HALEU needs for advanced reactors supporting decarbonization
    - Information/presentations to National Academies study on merits/viability of fuel cycles
    - Briefings to NE staff on energy markets, Texas polar vortex, etc.

FY 2022 Activities

Nuclear Energy System Performance

- Scenario Analysis and Technology Roadmap Studies of Fuel Cycle Facilities for Demonstration Reactors
- Investigate Benefits and Challenges of Converting Retiring Coal Plants into Nuclear Plants
- Nuclear Roles for Electricity Market Reliability in Deep Decarbonization Scenarios
- Quick Turn-Around Studies
- Fuel Cycle Analysis to Support Technology Campaigns
- Support DOE NE in International Engagements

Economic and Market Analysis

- Energy mix analysis for net-zero scenarios
- Pros and Cons Analysis of HALEU Utilization in Alternative Fuel Cycles
- Expand Cost Algorithm and Techno-economic Assessment Capabilities
- Cost Basis Report Improvement/Update
- Risks of Market-Driven Nuclear Power Plant Closures
- Incorporation of Detailed Cost Analysis of MARVEL Project

HALEU Needs Assessment Request

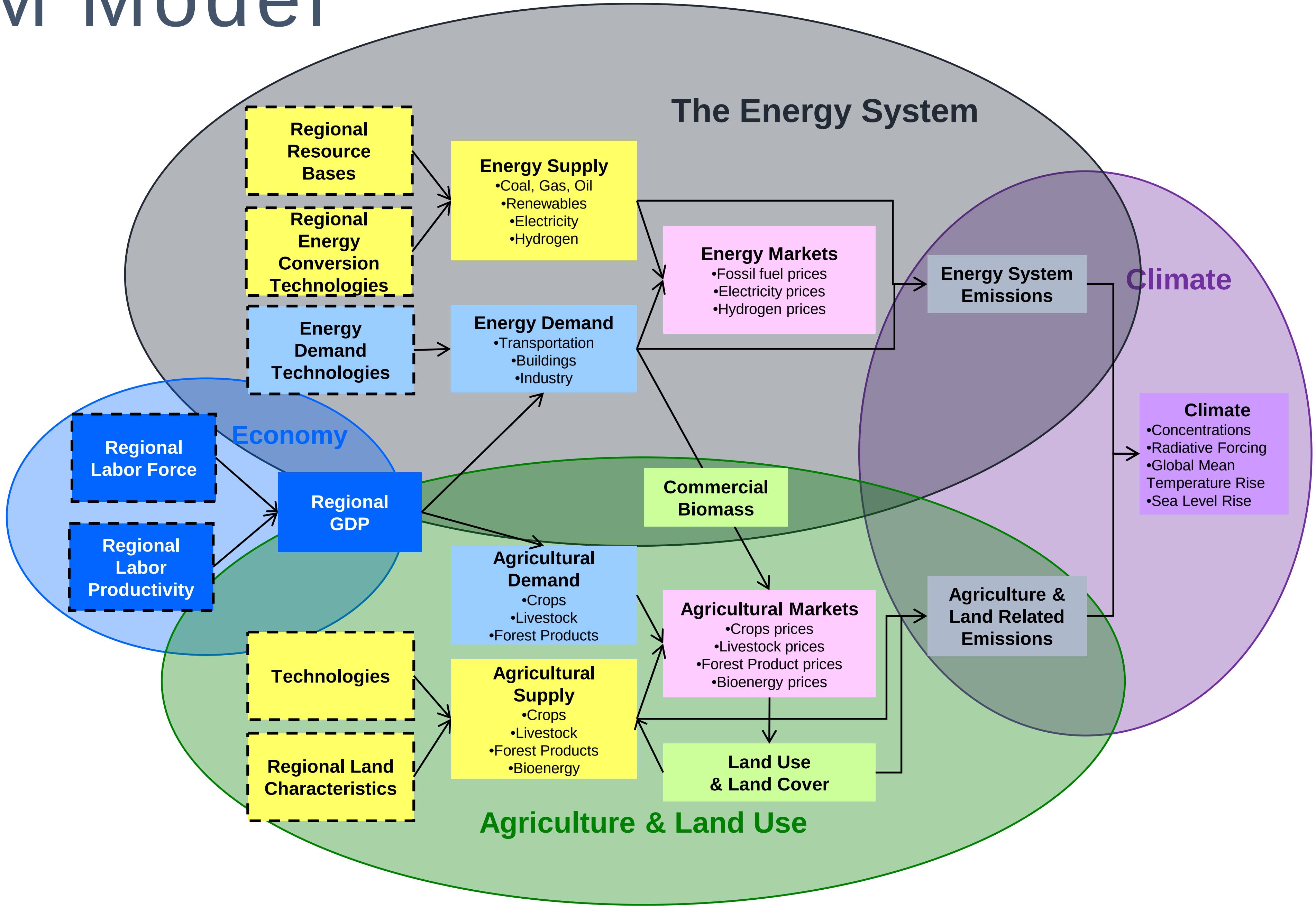
- **Provide a documented estimate of HALEU needs that may be used in DOE discussions with stakeholders as part of preparations to establish the HALEU Availability Program**

- **Initial quick turnaround request, April 2021**

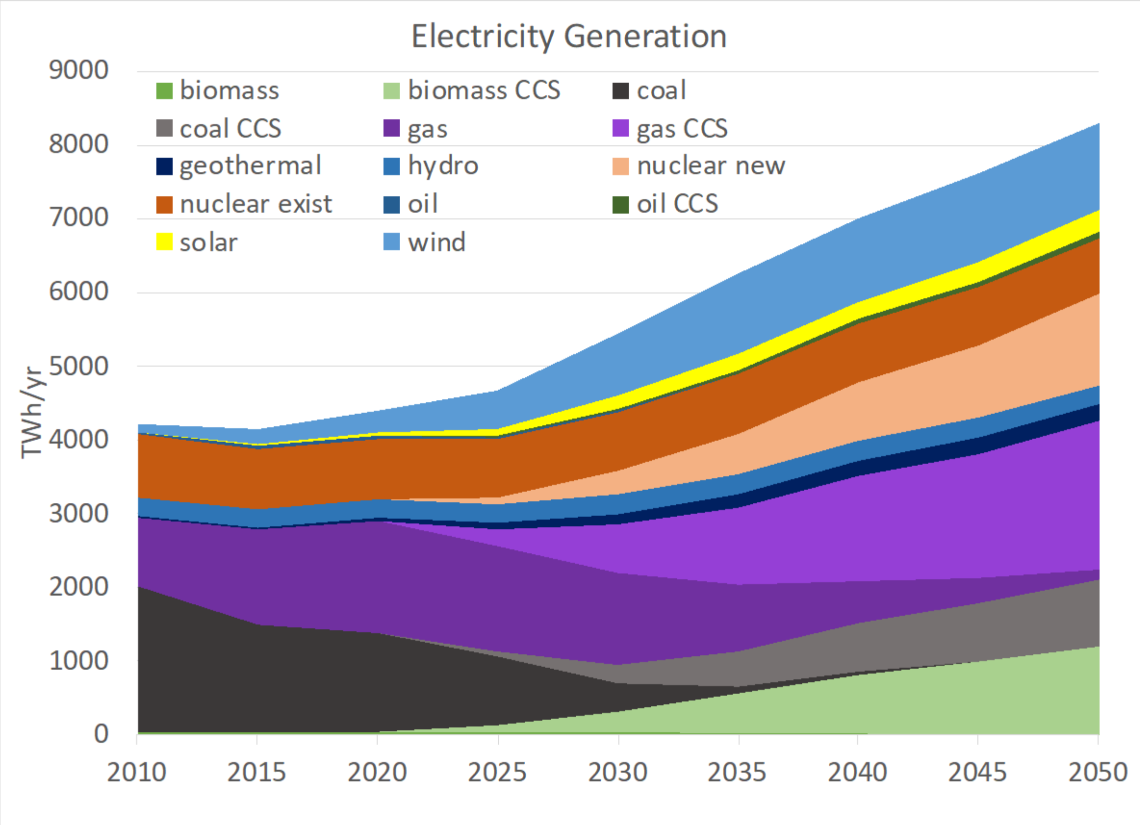
- **Subsequent request to issue as a publicly available report**
  - Final report approved for public release January 3
  - https://fuelcycleoptions.inl.gov/SiteAssets/HALEU%20Requirements%20for%20Net-zero.pdf

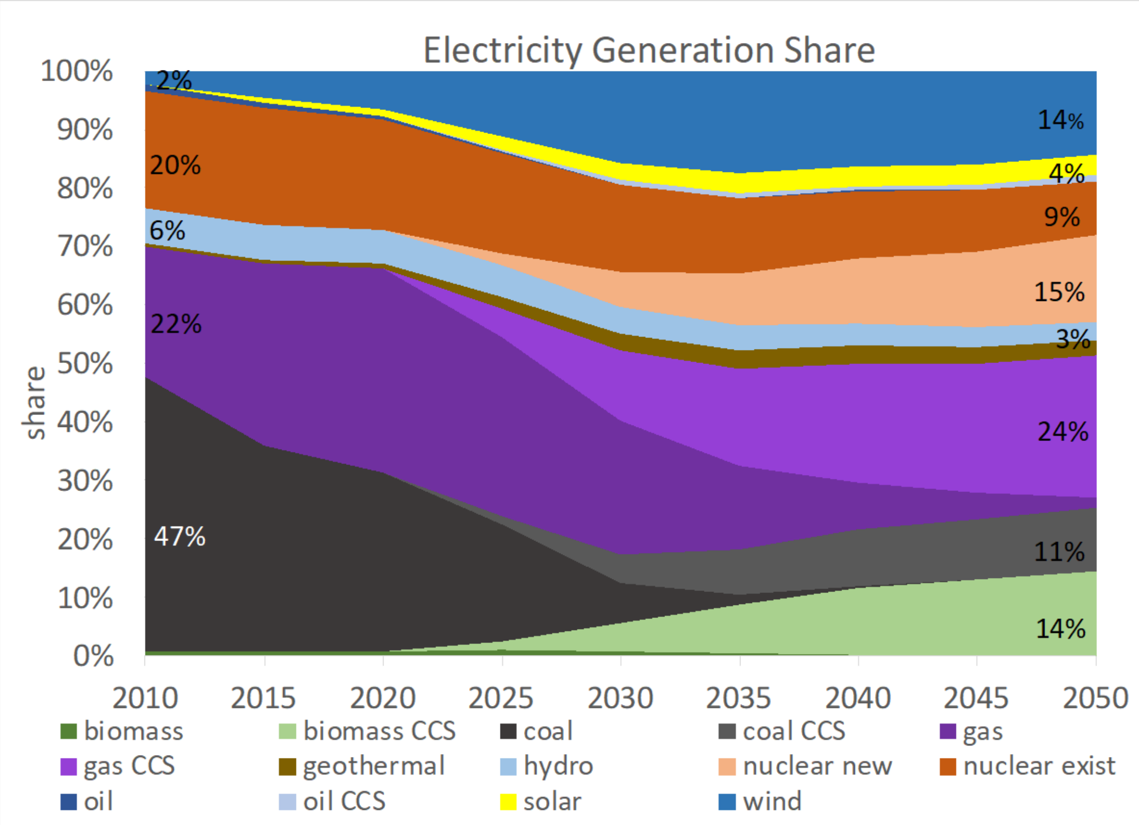
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

The GCAM Model



Step 1 - Electricity demand and composition with Net-Zero goal





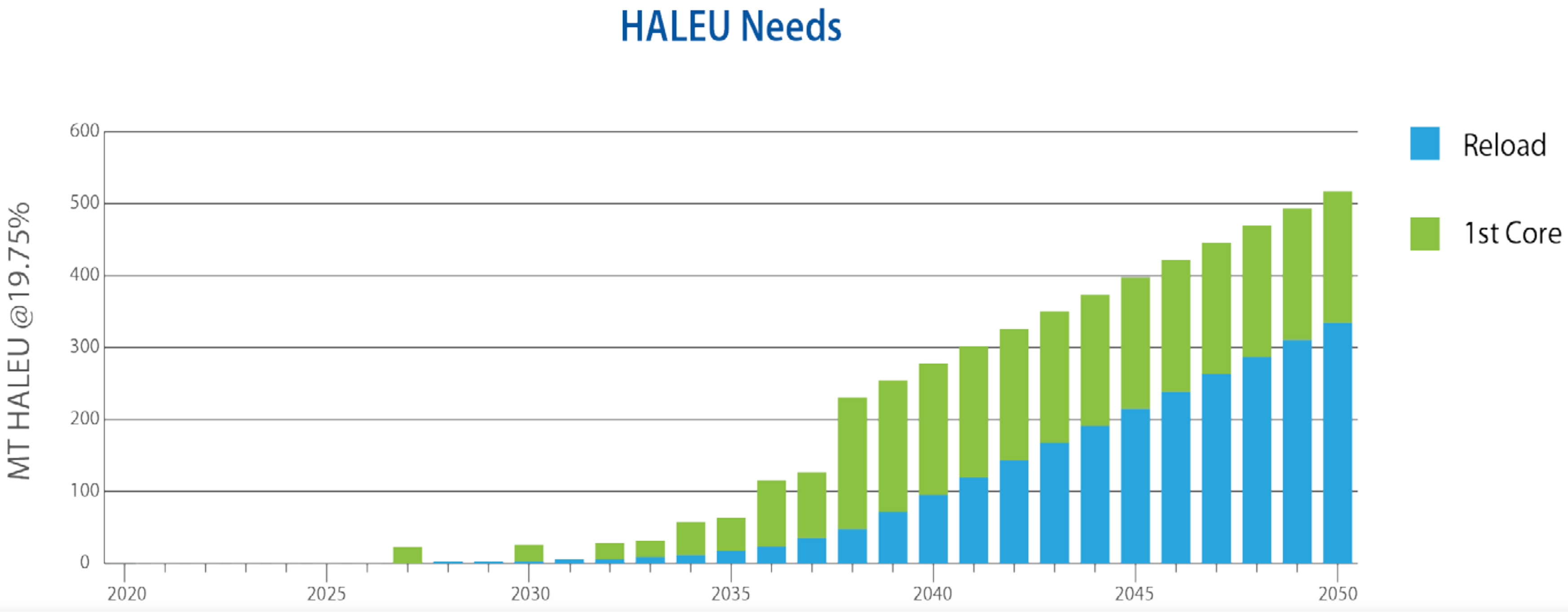
Step 2 - Reactor Deployment Schedule

New reactors were assumed to be constructed per the following approach:

- **Advanced LWRs (LEU fuel):**
  - Completion of Vogtle 3 & 4 in 2022-2023 and the initial LWR SMR (NuScale 12-pack) by 2030
  - Additional ALWRs completed starting in 2031 and SMRs in 2033, building by 2037 to 2 ALWRs (~2.2 GW) and 4 SMRs (~2.9 GW) completed per year
  - Total of 88 GW of new advanced LWRs by 2050
- **Advanced non-LWRs (HALEU fuel):**
  - Demonstration units of SFR (Natrium) and HTGR (Xe-100) completed in 2028
  - Additional SFR and HTGR units completed starting in 2031, building by 2040 to 8 SFRs (~2.8 GW) and 8 HTGR 4-packs (~2.6 GW) completed per year
  - Total of 74 GW of new non-LWRs by 2050

HALEU Needs Projection

- **Total cumulative HALEU needed by 2050 is ~5,350 MT @ 19.75%**
  - Range of 3,450 – 7,175 MT HALEU based on varying reactor mix



U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Coal to Nuclear Study

- **This study will yield an assessment of the scale of coal facilities feasible for repurposing to nuclear facilities across the US**
  - Findings based on three layers of screening criteria
  - Results across all technically feasible sites
- **The technology compatibility analysis will generate a technology mapping of characteristics from coal facilities to nuclear facilities**
- **Technology analysis will aid in cost model development and key drivers central to the decision to repurpose a site**
- **Economic study will reveal distributional impacts across households in terms of jobs and economic activity, which supports characterizing findings in terms of social and environmental justice**

Fitting this work into the literature

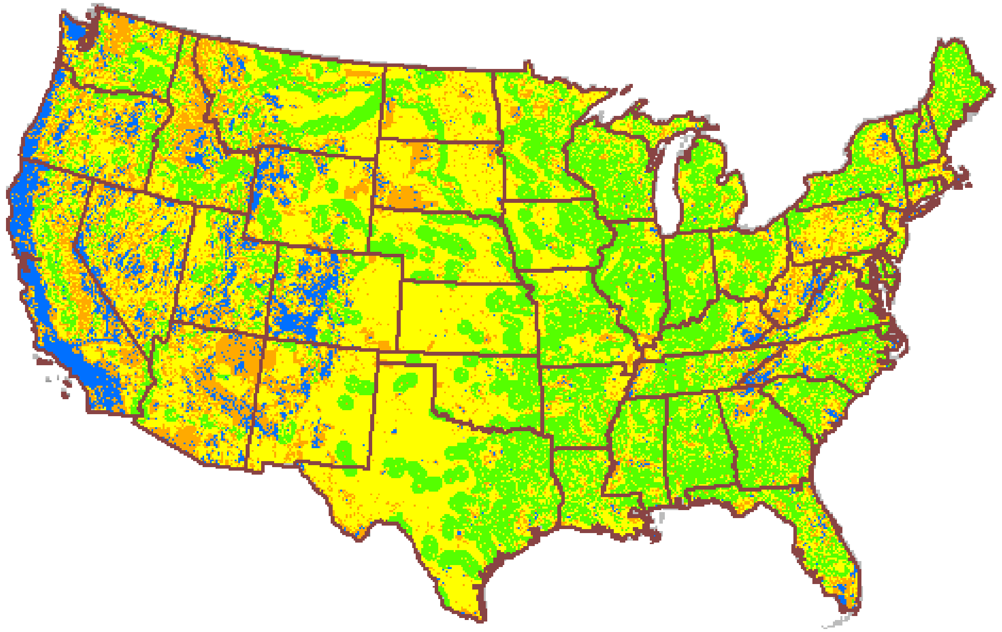
Summary of institutions working in this area

Summary of this study contribution

- **Scale** of feasible CPP repowered to NPP
- **Technical understanding** of advanced reactors to CPP
- **Cost model** for evaluating conversion decision
- Assessment of **economic impacts** on jobs, taxes, training requirements

Criteria used to evaluate coal sites

OR-SAGE Screening Criteria for Reactor Technologies	Large LWR	Advanced Reactors
Population density (people/square mile)	>500 ppsm within **20** miles	>500 ppsm within **4** miles
Safe shutdown earthquake (ground acceleration)	>0.3	>0.5
Wetlands/Open waters	Not allowed	Not allowed
Protected Lands	Not allowed	Not allowed
Slope	>12% grade	>18% grade
Landslide hazard (moderate or high)	Flag	Flag
100-year floodplain	Not allowed	Not allowed
Streamflow – cooling water makeup (X gallons/minute; closed cycle cooling; limited to 10% of resource)	200,000 gpm	NA
Proximity to hazards (buffer distance)	Flag 1-10 miles	Flag 1-10 miles
Proximity to fault lines (buffer distance)	Depends on length of fault	Depends on length of fault



- **Green – Meets all Criteria**
- **Yellow – Single issue**
- **Orange – Two issues**
- **Blue – 3+ issues**

Siting Summary (Draft)

- **39 of 50 states have at least one CPP site that is amenable to advanced reactor backfit based on the high-level OR-SAGE evaluation**
- **80% of the evaluated operational and retired CPP sites are amenable to advanced reactor siting**
- **Population/population density is the leading discriminating factor for backfit of an advanced reactor at CPPs**
- **Reactor backfit plans need to be incorporated into utility and IPP IRPs**
- **Future siting analyses should focus on operational CPPs that are planned for retirement 7-10 years or more in the future to allow for alignment of CPP resources with realistic advanced reactor deployment timeframes**

Agent-based assessment of decision drivers for Midwest CPP repowering

Input Signal

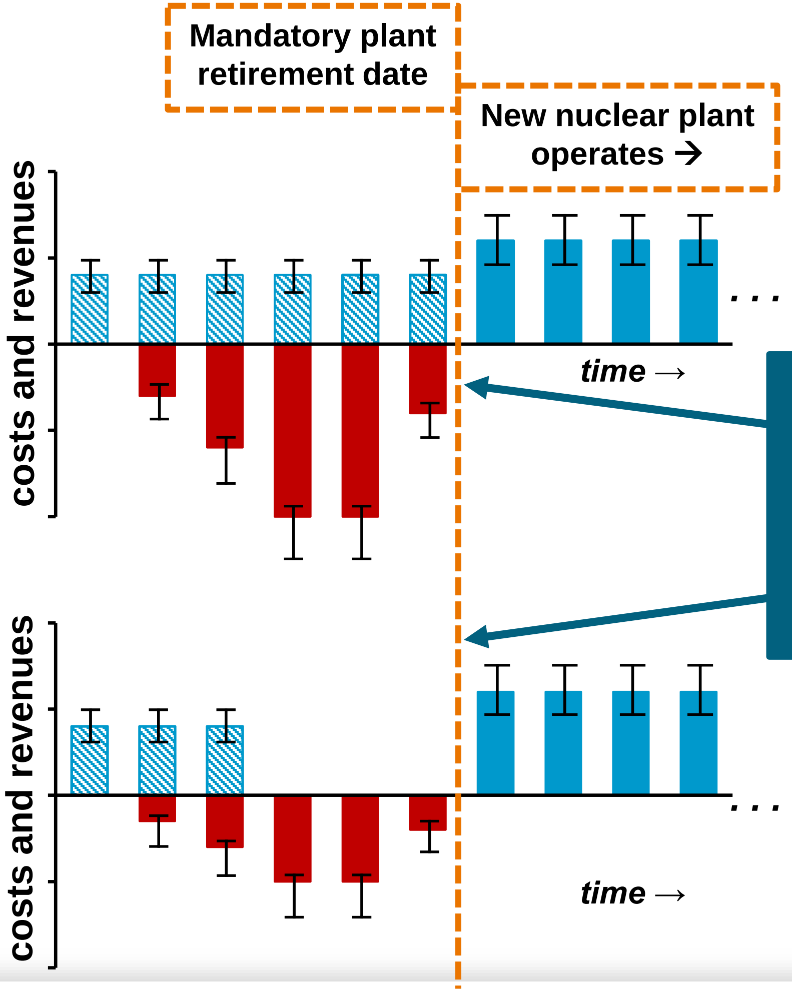
An agent's X00-MW coal unit will reach its end of useful life in 6 years.

Project Option 1

Retire coal + **greenfield nuclear**
- No revenue time gap
- Time flexibility

Project Option 2

Retire coal + **repower coal to nuclear**
- Some reduced costs and risks
- Revenue time gap
- Time flexibility



- Coal unit revenues
- Nuclear unit revenues
- Nuclear unit construction costs

Model evaluates decision-maker's assessment of costs, risks, and timing in presence of dynamic market conditions

Tax Impact Estimates (Draft)

Economic Impact Results ($ Millions)				
Impact Scenario	**Tax Impacts**			
	County	**State**	**Federal**	**Total Tax**
Pre Closure	$23.2	$32.1	-$4.6	$50.7
1 - Direct	$20.4	$27.8	-$6.1	$42.0
2 - Indirect	$2.3	$3.5	$0.9	$6.8
3 - Induced	$0.5	$0.8	$0.6	$1.8
All Nuclear	$36.8	$52.6	$7.7	$97.2
1 - Direct	$29.7	$42.1	$3.8	$75.6
2 - Indirect	$5.2	$7.7	$1.8	$14.8
3 - Induced	$1.8	$2.8	$2.0	$6.7
Net Change Coal to Nuclear	$13.6	$20.5	$12.3	$46.5
1 - Direct	$9.4	$14.3	$9.9	$33.6
2 - Indirect	$2.9	$4.2	$0.9	$8.0
3 - Induced	$1.3	$2.1	$1.5	$4.8
Note: All results are rounded, as a result the sum of direct, indirect, and induced impacts may not equal the grand total.				

Environmental Impact Estimates (Draft)

Impact Type	Scenario (Jobs)	Kg/Year	Kg/Year	Sq Meters	Kg/Year	Kg/Year	Kg/Year	Kg/Year	Cubic Meters
		Criteria Pollutants	Greenhouse Gases	Land Use	Mineral Use	Nitrogen and Phosphorus Release to Water	Pesticide Emissions	Toxic Chemical Releases	Water Use
Direct (PP Only)	**Pre-Closure (150)**	**5,406,176**	**2,595,982,880**	**1,833,454**	**0**	**36,656**	**0**	**28,790**	**297,446,454**
	Nuclear (150)	**4,006,213**	**7,977,364**	**1,358,670**	**0**	**27,167**	**0**	**21,335**	**220,420,840**
	Nuclear (270)	7,211.183	14,359,256	2,445,606	0	48,894	0	38,402	396,757,512
	Nuclear (360)	9,614,911	19,145,674	3,260,808	0	65,192	0	51,203	529,010,016
Total	Pre-Closure (150)	6,222,468	2,744,173,698	3,211,800	774,813	135,989	5	32,379	334,603,463
	Nuclear (150)	4,776,462	157,455,878	2,029,567	677,238	129,434	7	25,005	258,428,602
	Nuclear 270	8,597,632	285,220,581	3,653,221	1,219,028	232,981	13	45,009	465,171,484
	Nuclear (360)	11,463,509	380,294,108	4,870,961	1,625,370	310,641	17	60,012	620,228,645

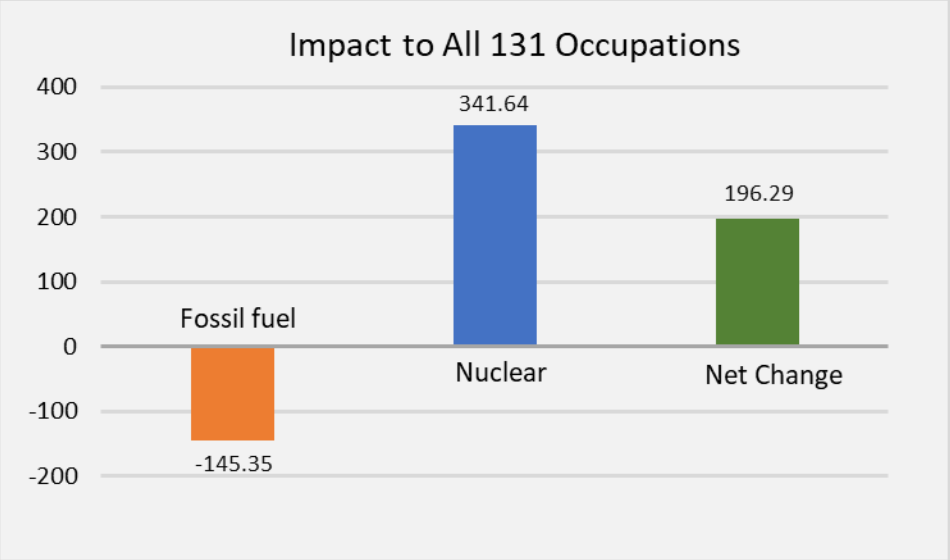
-99% from Pre-Closure (PP Only)

-86% from Pre-Closure (Total)

Workforce Transition Analysis (Draft)

Occupation Title	Fossil Jobs	Nuclear Jobs	Net Change
Power plant operators	-25.35	2.16	**-23.19**
Electrical power-line installers and repairers	-10.2	2.52	**-7.68**
Electrical and electronics repairers, powerhouse, substation, and relay	-7.8	10.44	**2.64**
Electrical engineers	-6.75	9.72	**2.97**
First-line supervisors of production and operating workers	-6.3	17.28	**10.98**
Customer service representatives	-5.25	0	**-5.25**
Industrial machinery mechanics	-4.65	9.36	**4.71**
First-line supervisors of mechanics, installers, and repairers	-4.5	8.64	**4.14**
Control and valve installers and repairers, except mechanical door	-3.45	0.72	**-2.73**
Electricians	-3	5.76	**2.76**
Power distributors and dispatchers	-3	1.08	**-1.92**
General and operations managers	-2.7	2.52	**-0.18**
Project management specialists and business operations specialists, all other	-2.55	7.2	**4.65**
Management analysts	-2.1	2.16	**0.06**
Electrical and electronic engineering technologists and technicians	-1.95	2.16	**0.21**
	-89.55	81.72	**-7.83**

- **Nuclear Power Industry employs 80 occupations. Fossil Electric Power Industry employs 118 occupations.**
- **Direct Jobs in Occupations Scenario: Fossil (– 150), Nuclear (+ 360)**



U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Social and Environmental Justice (Draft)

	Region	United States
	Demographics	
Population	78,000	331,893,745
People of Color	11%	40%
Low Income	34%	31%
Demographic Index	22%	
	Income and Employment	
Median Housing Value	$119,000	$229,800
Median Household Income	$56,000	$64,994
Civilian Labor Force	62%	63%
Unemployment Rate	4%	5%
Persons in Poverty	10%	11%
	Education	
High School Diploma	91%	89%
Bachelor's or Greater	21%	33%

- **Air quality can be improved**

- **Less diversity than comparison**
- **Economic gains for disadvantaged community**
- **Education shows qualified people, but some will need additional college**

Environmental Indicator Category	Value	EJ Index (adj.)	State Percentile
Superfund Proximity (site count/km distance)	0.02	-0.71	50
2017 Diesel Particulate Matter (ug/m3)	0.17	-0.82	49
2017 Air Toxics Cancer Risk (risk per MM)	21.91	-0.37	45
2017 Air Toxics Respiratory HI	0.30	-0.47	43
Particulate Matter 2.5 (ug/m3)	9.33	-0.87	42
Ozone (ppb)	44.12	-1.17	41
Hazardous Waste Proximity (facility count/km distance)	0.72	-0.42	41
Wastewater Discharge (toxicity-weighted concentration/m distance)	0.21	-0.90	39
Traffic Proximity (daily traffic count/distance to road)	242.89	-0.80	38
Lead Paint (% pre-1960s housing)	0.37	-0.75	28
Underground Storage Tanks	5.17	-1.13	25
Riks Management Plan Facility Proximity (facility count/km distance)	1.47	-0.80	22

Thank You

Questions?