LA-UR-12-21014

CCSI™

Carbon Capture Simulation Initiative

Multi-Track Strategies for Risk Assessment

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NETL · Berkeley Lab · Lawrence Livermore National Laboratory · Los Alamos National Laboratory · Pacific Northwest National Laboratory · U.S. Department of Energy

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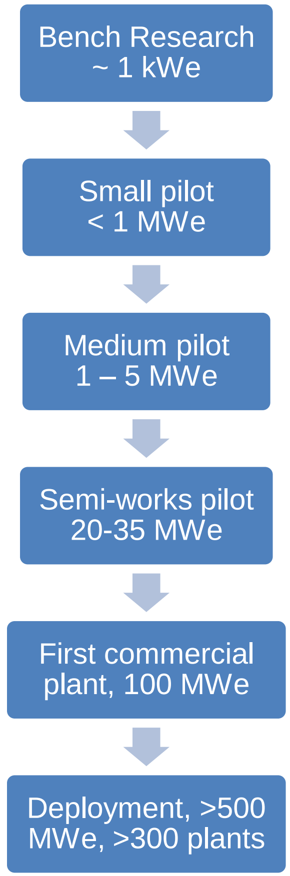
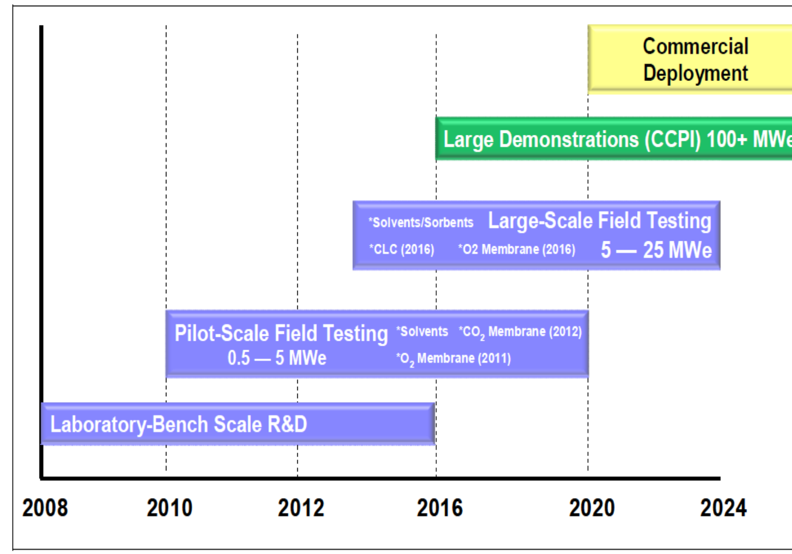
Carbon Capture Challenge

- The **traditional pathway** from discovery to commercialization of energy technologies is long[1], i.e., ~ 20-30 years.
- Technology innovation increases the cost growth, schedule slippage, and the probability of operational problems.[2]
- President's plan[3] requires that barriers to the widespread, safe, and cost-effective deployment of CCS be overcome within 10 years.
- To help realize the President's objectives, new approaches are needed for taking concepts from lab to power plant, quickly, at low cost and with minimal risk.
- CCSI will accelerate the development of CCS technology, from discovery through deployment, with the help of science-based simulations .





Source: Ciferno, "DOE/NETLs Existing Plants."

1. *International Energy Agency Report: Experience Curves for Energy Technology Policy," 2000*
2. *RAND Report: "Understanding the Outcomes of Mega-Projects," 1988;*
3. *http://www.whitehouse.gov/the-press-office/presidentialmemorandum-a-comprehensive-federal-strategy-carbon-capture-and-storage*

Risk Definition

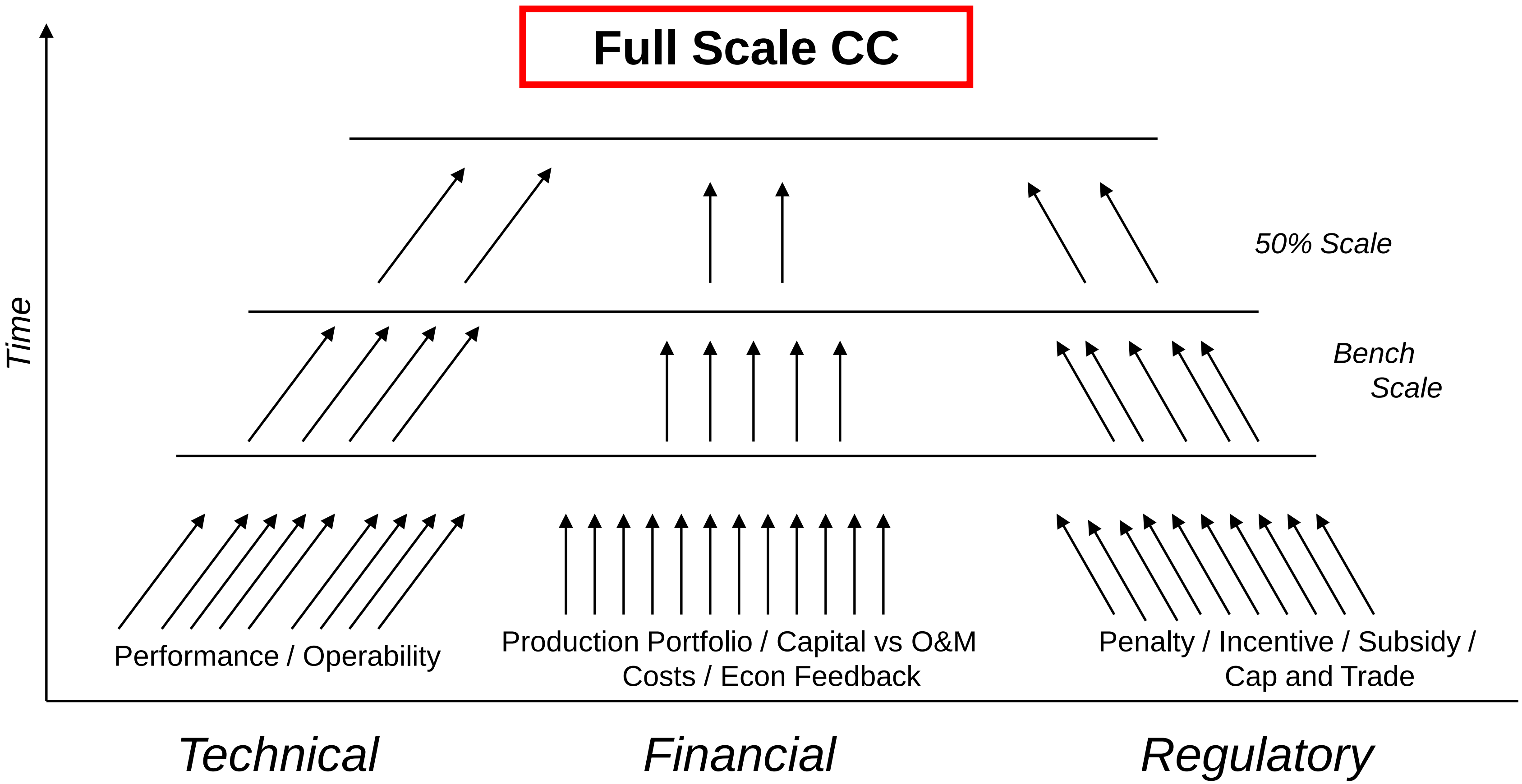
- Stated Goal of CCSI Program is removing barriers to widespread carbon capture within ***10 years*** at minimum cost and ***low risk***
- Risk has many facets associated with negative or adverse outcomes (undesired consequence)
- Always has a flavor of relative frequency (times per year) or probability (chances in a thousand)
- Formal methods combine frequency and consequence to make choices despite uncertainty in:
  - Quality of information
  - Completeness of information
  - Details of physical complexity

Facets of Carbon Capture Risk

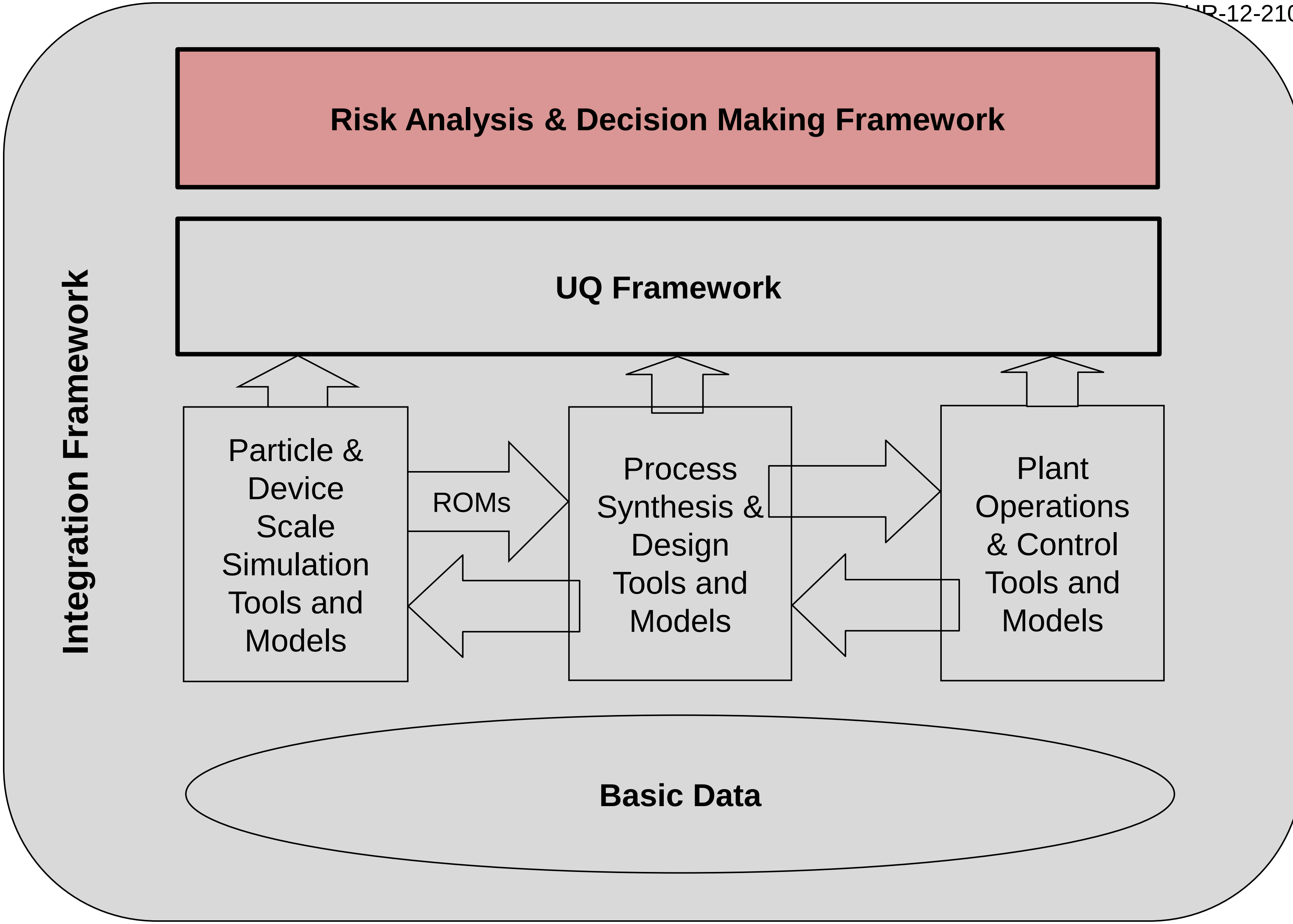
- Risk perspectives vary depending on goals and objectives (point of view)
- Risk of …
  - Not meeting 10-yr time compression schedule
  - Environmental impacts from new processes
  - Unacceptable COE impacts
  - Interrupting reliable electric power
  - Insufficient infrastructure to support capture/disposition
    - skilled labor, land, CO2 distribution, raw materials, design and construction services for specialty equipment

Each high-level risk measure can involve a complex system of factors and interactions

Decision Framework Architecture



- Focus on merger of Technical and Financial risk components
- Adopt risk perspectives of power producer – ultimate technology customer
    - Interpret all technical risk factors in financial business perspective


Risk Analysis & Decision Making Framework
UQ Framework
Integration Framework
Particle & Device Scale Simulation Tools and Models
ROMs
Process Synthesis & Design Tools and Models
Plant Operations & Control Tools and Models
Basic Data

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MultiTrack Strategy for CCSI Risk Assessment

- Enumerate risk contributors for qualitative prioritization and tracking
- Define traditional development path using tailored Technology Readiness Levels (TRL) and chemical process maturation cycle
- Functional Analysis of capture process performance vulnerability
  - FMEA, Fault Tree, Bayesian Updating
- Interface both qualitative and quantitative performance attributes in a comparative financial lifecycle analysis
- Propagate uncertainties into formal decision metrics affecting implementation

"Multitrack Strategy" is now growing towards integrated decision analysis model

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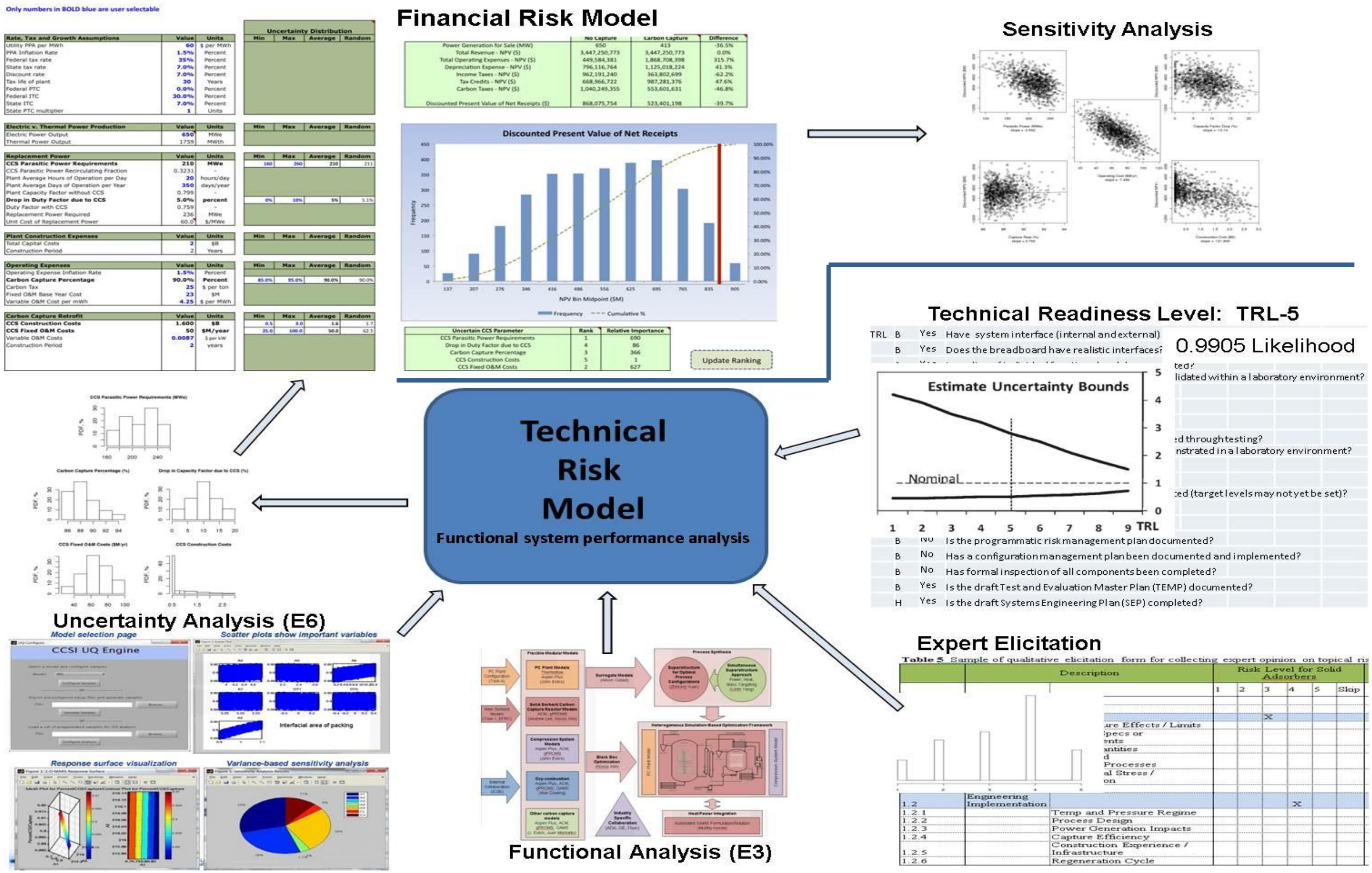
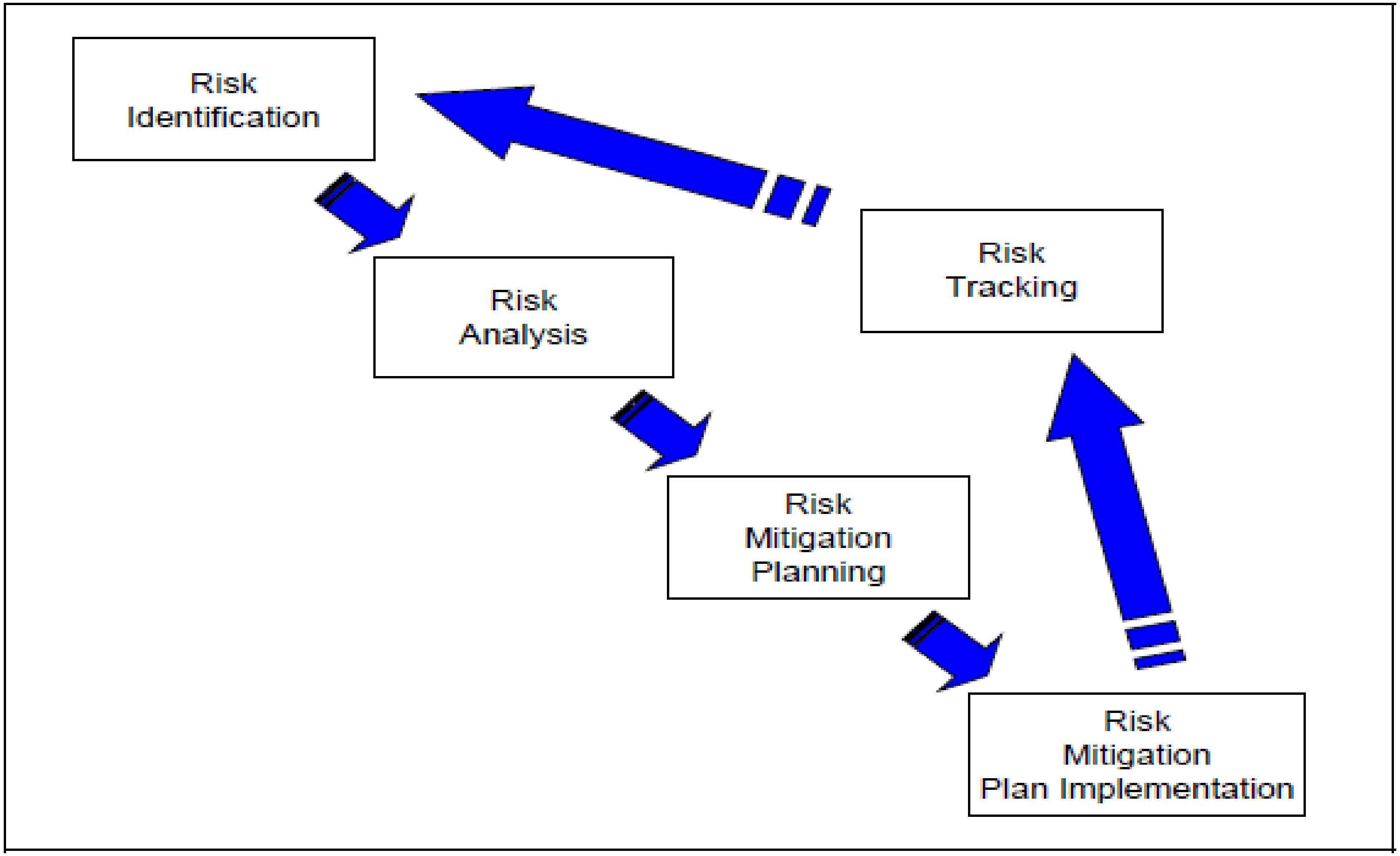
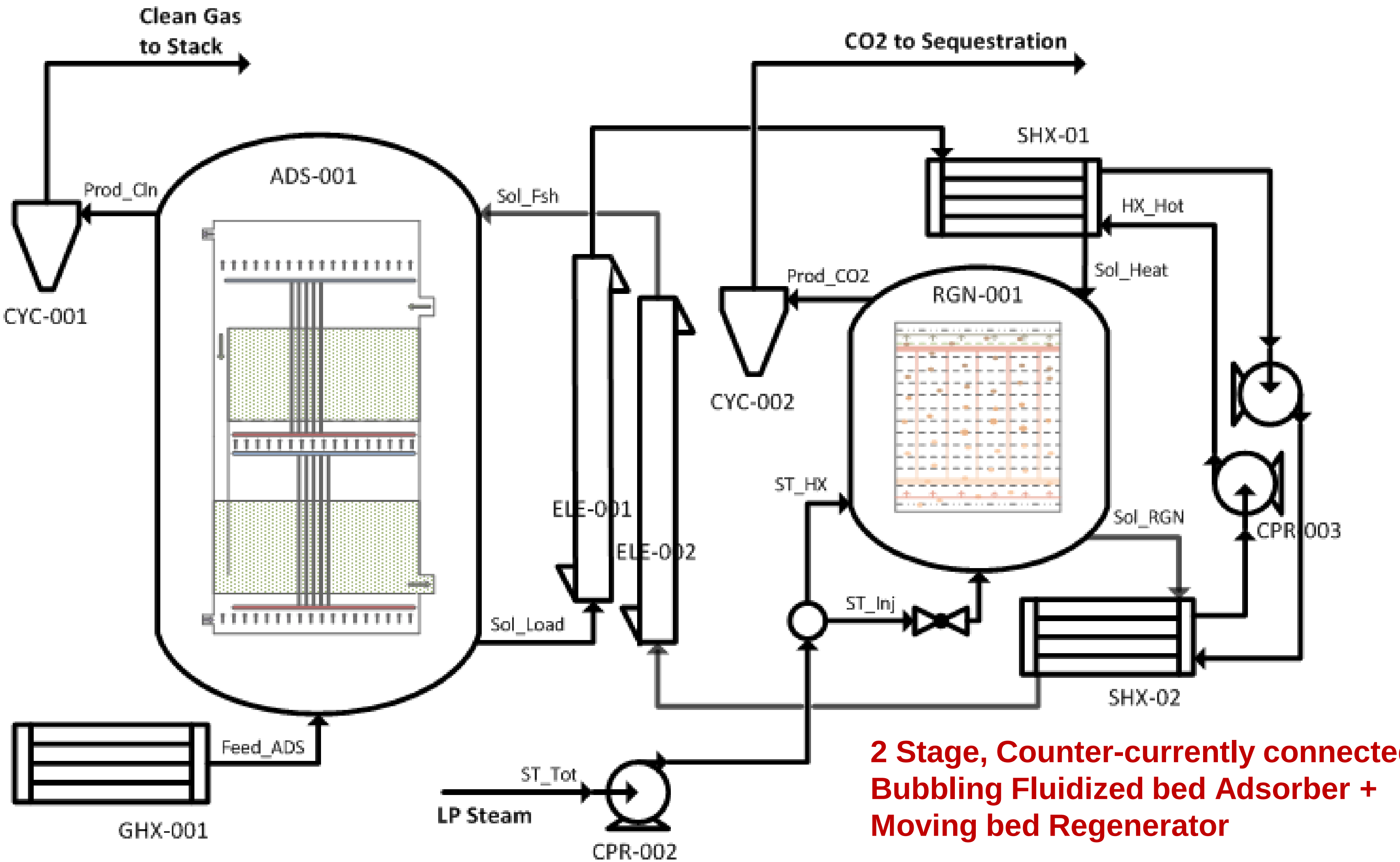
Decision Making Framework



Technical Risk Approach: Evolves with Maturity

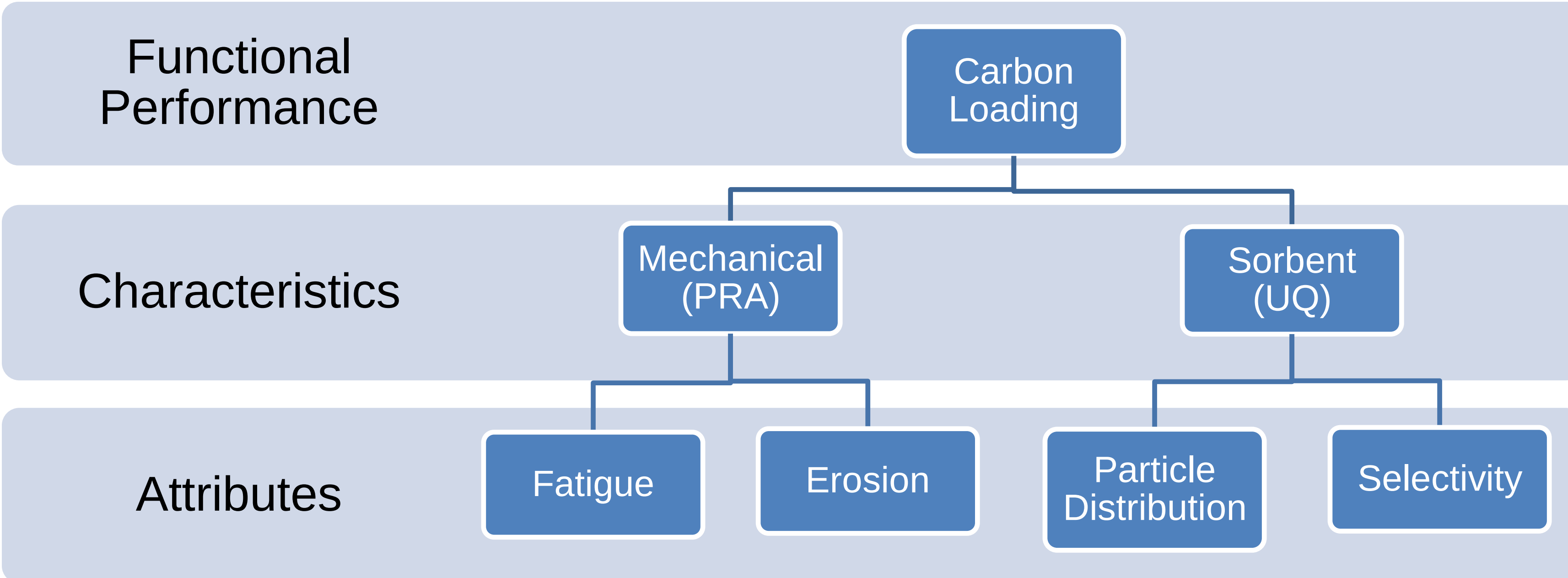


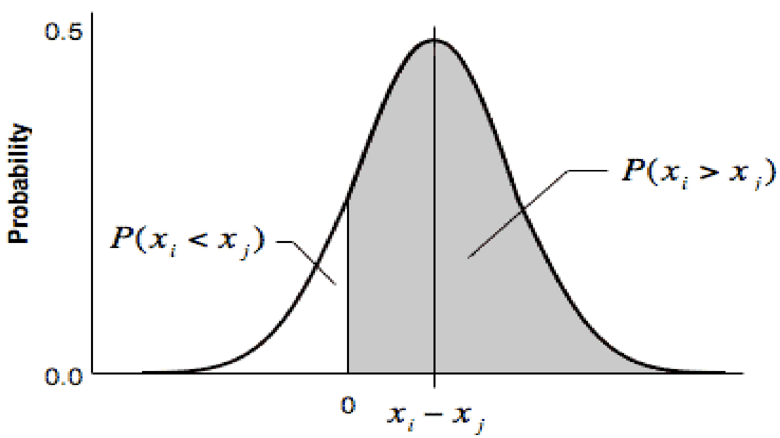
Carbon Capture Process System: Solid Sorbent

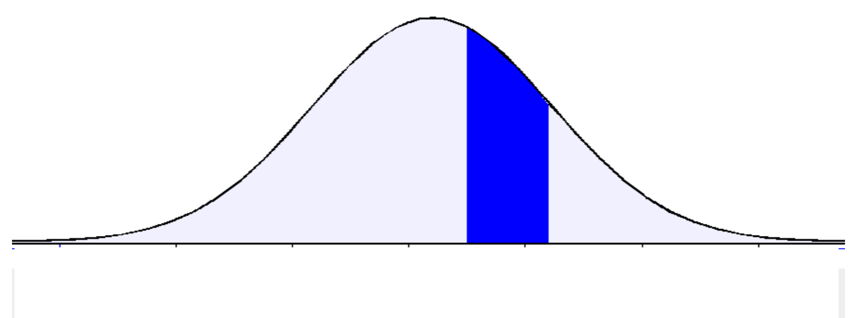


2 Stage, Counter-currently connected Bubbling Fluidized bed Adsorber + Moving bed Regenerator

Risk Analysis







Technology Maturity

CCSI Technology Readiness Level (TRL) Questionnaire

TRL 4:			Has a lab-scale testing of equipment (bench) been completed in simulated (controlled) environment?	1 kW
TRL	H	Yes	Has acceptance testing of individual components been performed?	
	H	Yes	Has performance of components and interfaces between components been demonstrated (bench)?	
	B	Yes	Does draft system architecture plan exist?	
	B	Yes	Does technology demonstrate basic functionality in simplified environment?	
	B	Yes	Have performance characteristics been demonstrated in a laboratory environment (bench)?	
	S	No	Does prototype solve synthetic full-scale problems or process fully representative data sets?	
	B	No	Have low-fidelity assessments of system integration and engineering been completed?	
MRL	H	Yes	Are most system components available (laboratory surrogates in some cases)?	
	S	Yes	Have designs been verified through formal inspection process?	
	H	Yes	Have scalable technology prototypes been produced?	
	B	Yes	Have integration studies been started?	
PRL	B	Yes	Have system performance metrics been established?	
	B	Yes	Have design requirements been derived from system requirements?	
	B	Yes	Have initial cost drivers been identified?	
	B	No	Are scaling studies and architecture diagrams completed?	
	B	No	Has a formal risk management program been initiated?	
	B	Yes	Has project risk management been integrated with project management?	
	B	No	Have functional requirements been finalized?	

0.9846

TRL is Technology Readiness Level
MRL is Manufacturing Readiness Level
PRL is Programmatic Readiness Level

S is for software
H is for hardware
B is for both software and hardware

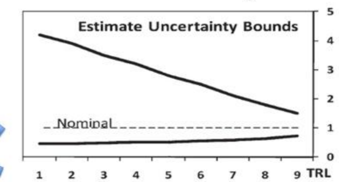
Technology Readiness Level (TRL)		
9	Commercial operation in relevant environment	
8	Commercial demonstration, full scale deployment in final form	650 MW
7	System prototype in an operational environment	> 100 MW
6	Fully integrated pilot (prototype) tested in a relevant environment	10 - 50 MW
5	Component validation in relevant environment (coal plant)	1 MW
4	Component validation tests in laboratory environment	1 kW
3	Analytical and experimental critical function proof-of-concept	
2	Formulation of application	
1	Basic principals	

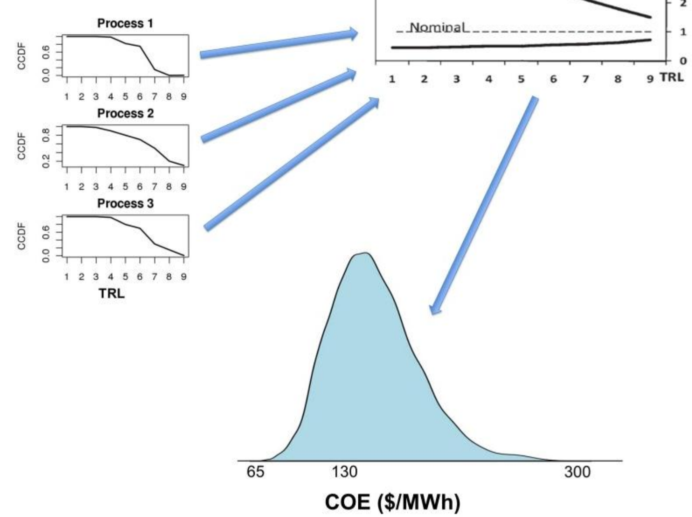
EPRI 2011 & GAO 2010

TRL Likelihood

$$L_i^j = f(k; n, p) = \binom{n}{k} p^k (1-p)^{n-k}$$

Estimated uncertainty bounds



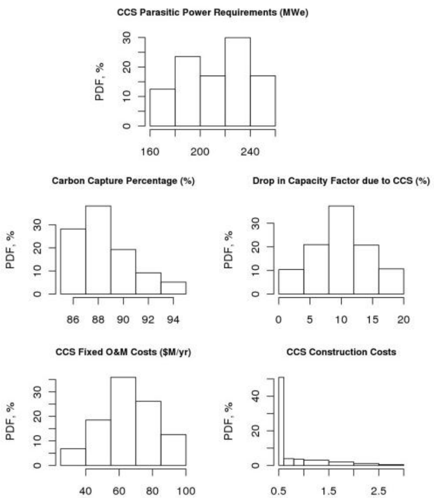


Financial Risk Model

- Risk attribute propagation through a financial balance sheet that incorporates variable lifecycle costs and other factors related to carbon capture
- Illustrates information flow from qualitative risk factor assignment and UQ from other CCSI tasks into familiar decision metrics like 30-year net present value
- Provides sensitivity measures for determining which factors are most critical for ensuring the successful adoption of carbon capture technology
- Provides means for weighing relative merits of improving carbon capture technology and determine which factors (e.g., carbon capture percentage, capital costs, operating costs, parasitic power losses, etc.) are most important contributors to financial risk
- Illustrates concepts of probabilistic decision making that are less familiar to power production industry

Preliminary Risk Analysis

Technical Risk Results



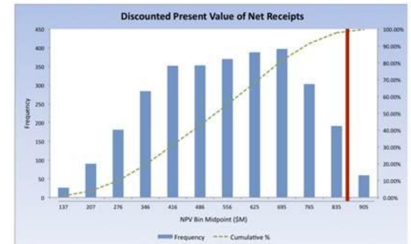
Only numbers in BOLD blue are user selectable

Rate, Tax and Growth Assumptions	Value	Units	Min	Max	Average	Random
Utility PPA per MWh	60	$ per MWh				
PPA Inflation Rate	1.5%	Percent				
Federal tax rate	35%	Percent				
State tax rate	7.0%	Percent				
Discount rate	7.0%	Percent				
Tax life of plant	30	Years				
Federal PTC	0.0%	Percent				
Federal ITC	30.0%	Percent				
State ITC	7.0%	Percent				
State PTC multiplier	1	Units				
Electric v. Thermal Power Production	**Value**	**Units**	**Min**	**Max**	**Average**	**Random**
Electric Power Output	650	MWe				
Thermal Power Output	1759	MWth				
Replacement Power	**Value**	**Units**	**Min**	**Max**	**Average**	**Random**
CCS Parasitic Power Requirements	**210**	**MWe**	160	260	210	211
CCS Parasitic Power Recirculating Fraction	0.3231	-				
Plant Average Hours of Operation per Day	20	hours/day				
Plant Average Days of Operation per Year	350	days/year				
Plant Capacity Factor without CCS	0.799	-				
Drop in Duty Factor due to CCS	**5.0%**	**percent**	0%	10%	5%	5.1%
Duty Factor with CCS	0.759	-				
Replacement Power Required	236	MWe				
Unit Cost of Replacement Power	60.0	$/MWe				
Plant Construction Expenses	**Value**	**Units**	**Min**	**Max**	**Average**	**Random**
Total Capital Costs	2	$B				
Construction Period	2	Years				
Operating Expenses	**Value**	**Units**	**Min**	**Max**	**Average**	**Random**
Operating Expense Inflation Rate	1.5%	Percent				
Carbon Capture Percentage	**90.0%**	**Percent**	85.0%	95.0%	90.0%	90.0%
Carbon Tax	25	$ per ton				
Fixed O&M Base Year Cost	23	$M				
Variable O&M Cost per mWh	4.25	$ per MWh				
Carbon Capture Retrofit	**Value**	**Units**	**Min**	**Max**	**Average**	**Random**
CCS Construction Costs	**1.600**	**$B**	0.5	3.0	1.6	1.7
CCS Fixed O&M Costs	**50**	**$M/year**	25.0	100.0	50.0	62.5
Variable O&M Costs	0.0087	$ per kW				
Construction Period	2	years				

Uncertainty Distribution

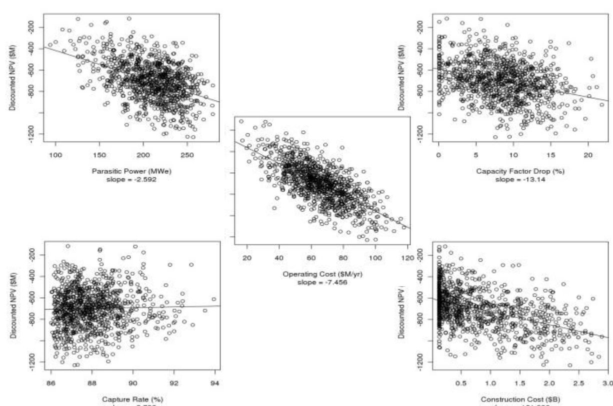
Financial Risk Model

	No Capture	Carbon Capture	Difference
Power Generation for Sale (MW)	650	413	-36.5%
Total Revenue - NPV ($)	3,447,250,773	3,447,250,773	0.0%
Total Operating Expenses - NPV ($)	449,584,381	1,868,708,398	315.7%
Depreciation Expense - NPV ($)	796,116,764	1,125,018,224	41.3%
Income Taxes - NPV ($)	962,191,240	363,802,699	-62.2%
Tax Credits - NPV ($)	668,966,722	987,281,376	47.6%
Carbon Taxes - NPV ($)	1,040,249,355	553,601,631	-46.8%
Discounted Present Value of Net Receipts ($)	868,075,754	523,401,198	-39.7%

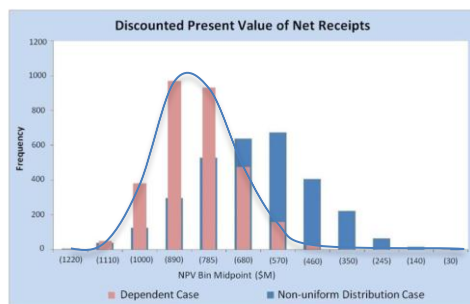


Uncertain CCS Parameter	Rank	Relative Importance
CCS Parasitic Power Requirements	1	690
Drop in Duty Factor due to CCS	4	86
Carbon Capture Percentage	3	366
CCS Construction Costs	5	1
CCS Fixed O&M Costs	2	627

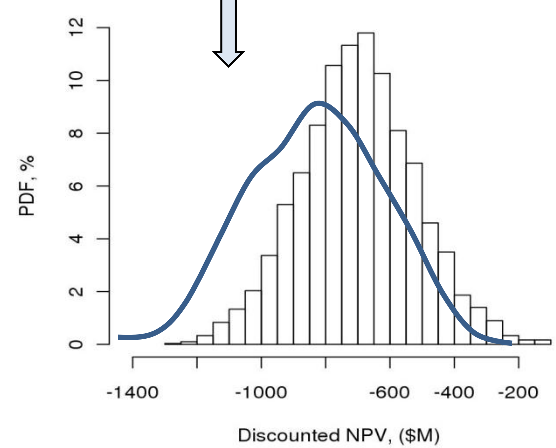
Update Ranking



Sensitivity analysis, showing effect of each parameter on the financial risk model results (NPV)



Showing affect of factor independence assumption



Comparison of marginal distributions on the financial risk model results (NPV) (line represents uniform, while the histogram represent non-uniform)

Risk Evaluation Summary

- The technical risk approach is designed to provide increasing reliability of the system as details mature
  - Identifies vulnerabilities and their relative importance
  - Suggests prioritized areas for additional R&D, functional analyses, or design improvements
- TRL provides baseline to traditional development scales and can be tailored to track independent components
- Qualitative risk factor elicitation provides perspectives on completeness and quantifies stakeholder confidence
- Financial lifecycle analysis provides monetized business context in which to evaluate the effects of complex physical systems

Ultimate Value

- Diagnostic risk evaluation can direct further simulation and experimental studies for optimum risk reduction
- Fully integrated framework will support technology comparison

R&D Analysis Team Members

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