Uncertainty Analysis with G4ECONS

Presented by

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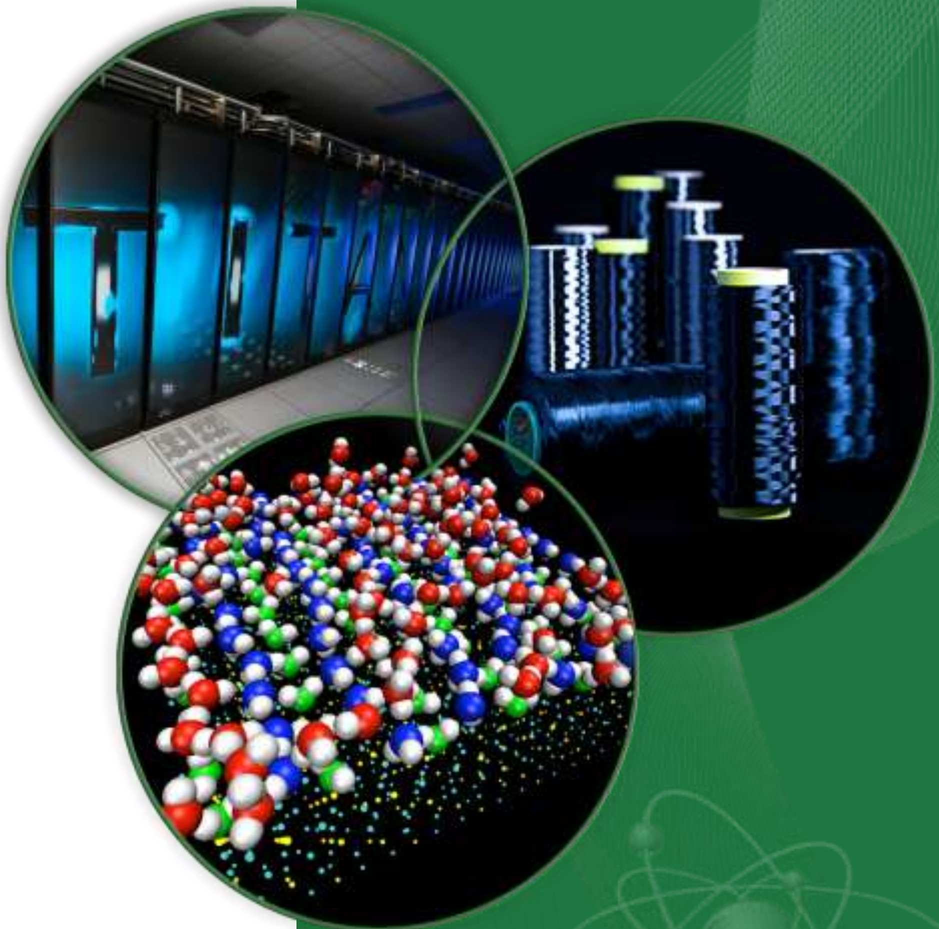

Presentation Outline

- The current production version of G4ECONS
- Some proposed changes to G4ECONS
- Sample uncertainty analysis results in G4ECONS
- Implications from using uncertainty analysis

Summary of the Presentation

- The current production version of G4ECONS is sufficient for levelised cost calculations
- Changes are being made to G4ECONS expand its applicability and utility to include uncertainty analysis
- Uncertainty quantification provides useful information, but care must be taken on how this is done

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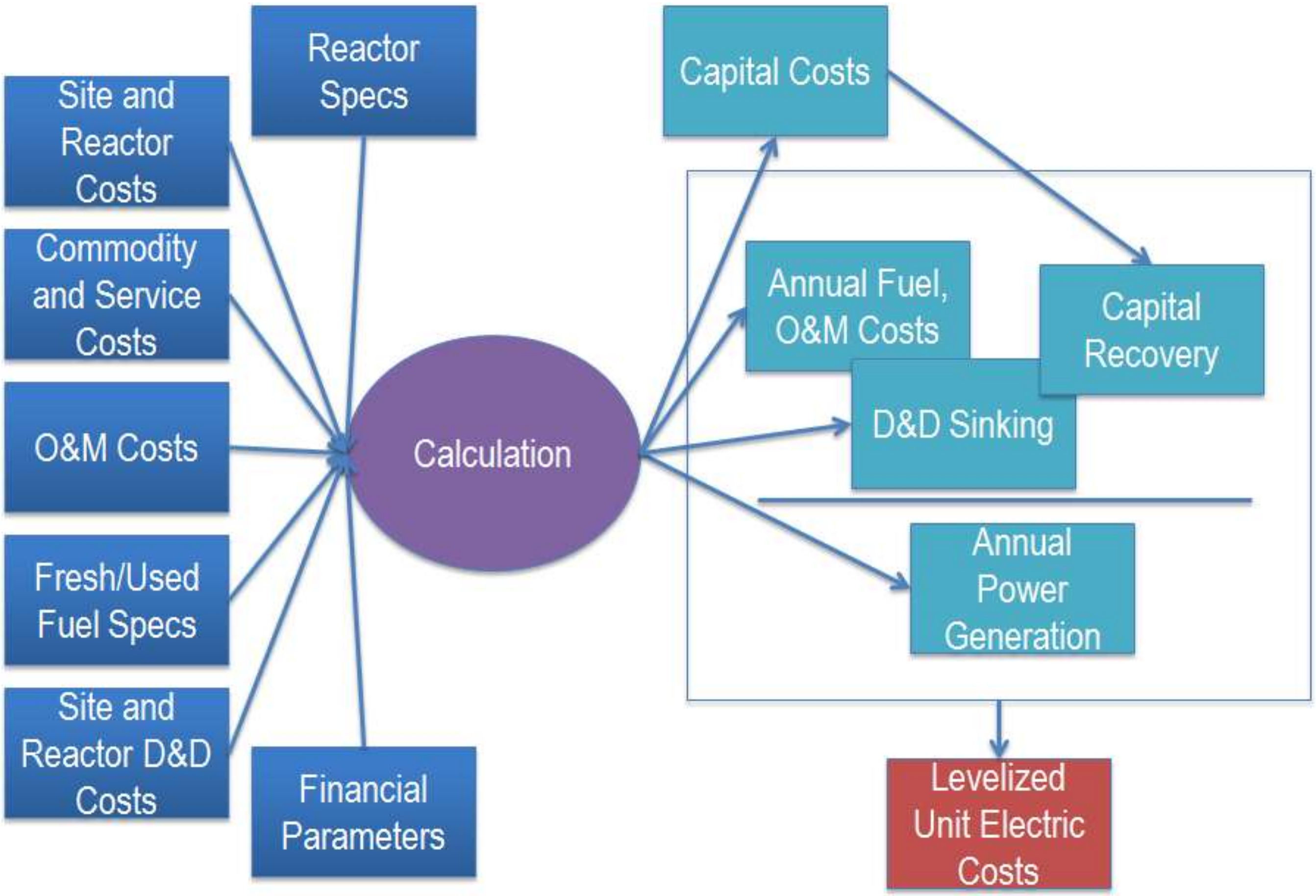
The current production version of G4ECONS calculates a Levelised Unit Electric Cost (LUEC)

- Dark blue inputs
- Light blue calculations
- Red output



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The levelised cost is an important piece of information, but it is only one piece

- It gives the cost to generate electricity
- It does not provide a measure of the economic feasibility, that is, whether the nuclear project is a good investment
- As a point estimate, it does not describe the uncertainty associated with the cost to generate electricity

The working revision to G4ECONS addresses these drawbacks

- Given an assumed price in an electricity market, a cash flow can be calculated
- Given an appropriate discount rate for that market's economy, a net present value (NPV) can be calculated from the cash flow
- Given a cost distribution for each component of cost, the overall uncertainty and component uncertainty can be calculated

These expansions make G4ECONS a more useful planning tool

- Placing the economic analysis within the context of a market allows planners to gauge the effects of changing conditions
- Evaluating the NPV provides a measure of the attractiveness for investors and industrial partners
- Uncertainty analysis shows which components would benefit most from research and development or market support

The LUEC calculation needs only a few technical input parameters

Parameter	Information
Reactor Type	PWR
Thermal Power	3900 MWt
Thermal Efficiency	33.33%
Power Density	38 MWt/MTU
Capacity Factor	90%
Fuel	3.78% LEU Oxide
Fuel Source	Natural U
Tails	0.21%
Burnup	43.68 GWtd/MTU
Lifetime	40 years
Interest Rate	5%

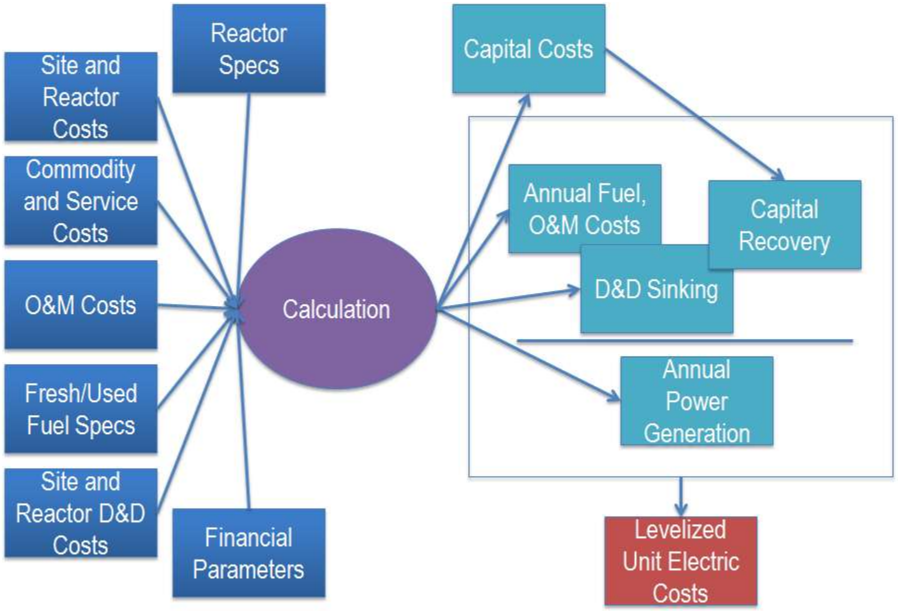
All values based on System 80 data

Nominal cost numbers are based on US DOE and System 80 benchmark data

Parameter	Cost
Natural U Mining/Milling	$110/kgU
Conversion	$10/kgU
Enrichment	$110/SWU
Fuel Fabrication	$350/kgU
DU Conversion	$6/kgU
Geologic Disposal	$1/MWeh
Construction Cost*	$2366/kWe
O&M Costs	$9.35/MWeh
D&D Costs	21.55% of construction

Fuel Cycle Costs based on AFCI Cost Basis
Construction costs based on System 80

Sample analysis from current version

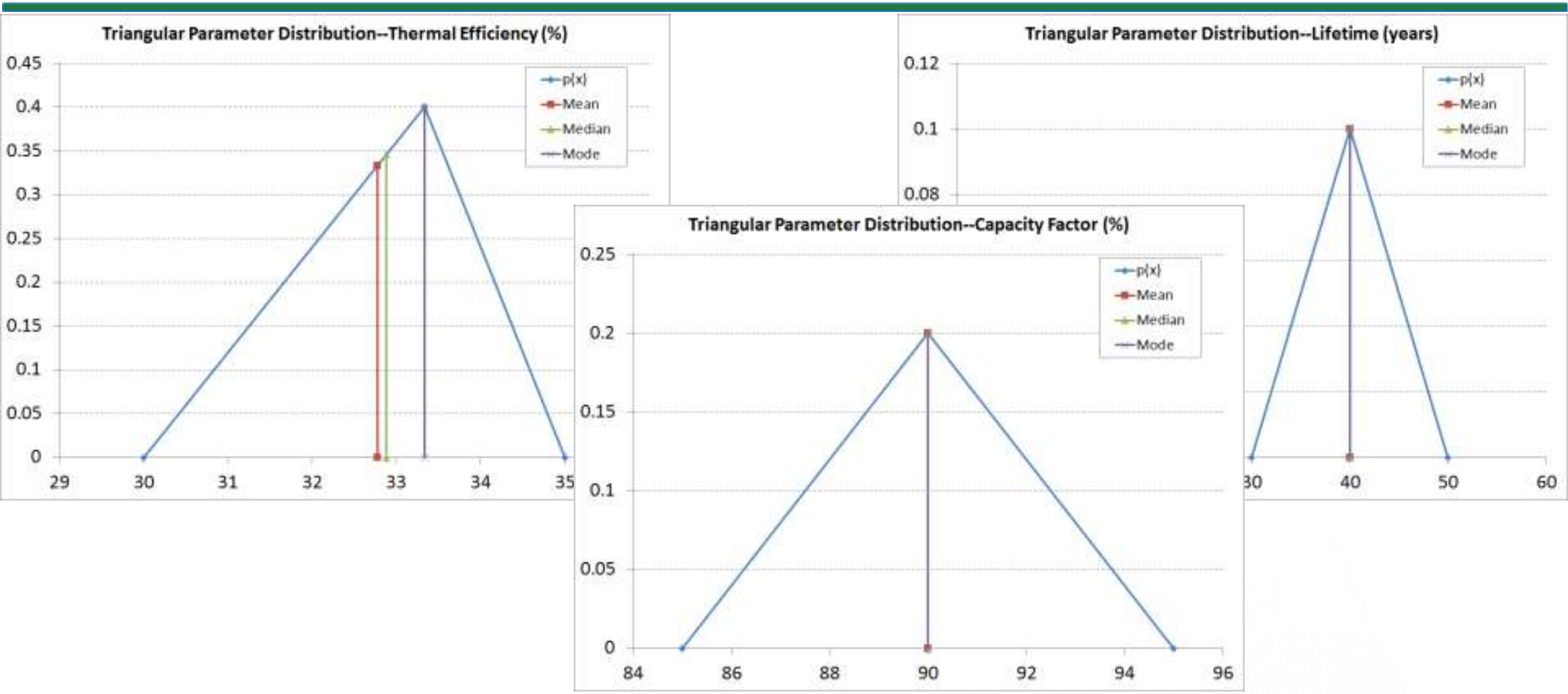


Component	Cost per MWeh
Capital	$20.27
O&M	$9.35
Fuel Cycle—Front End	$5.28
Fuel Cycle—Back End	$1.00
D&D Sinking Fund	$0.52
Total	$36.42

These are operational parameters including uncertainty

Parameter	Low	Nominal	High
Reactor Type		PWR	
Thermal Power		3900 MWt	
Power Density		38 MWt/MTU	
Fuel		3.78% LEU Oxide	
Fuel Source		Natural U	
Tails		0.21%	
Burnup		43.68 GWtd/MTU	
Thermal Efficiency	30	33.33%	35
Capacity Factor	85	90%	95
Lifetime	30	40 years	50
Interest Rate	3	5%	7

Efficiency, capacity factor, and lifetime assume triangular distributions



Triangular distributions show a "most likely" nominal value at the mode, but have definite end points

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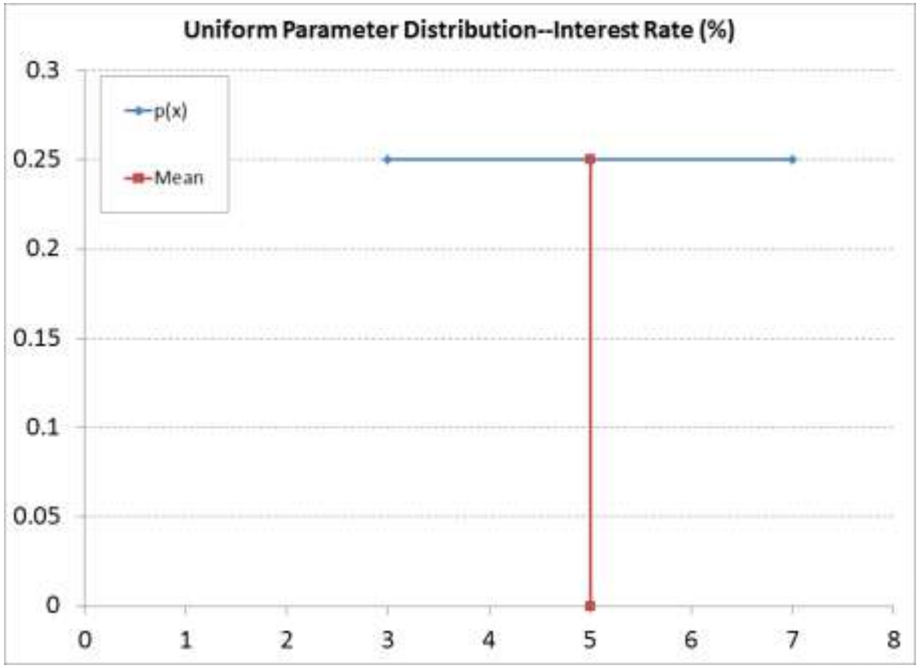
Interest rates assume a uniform distribution

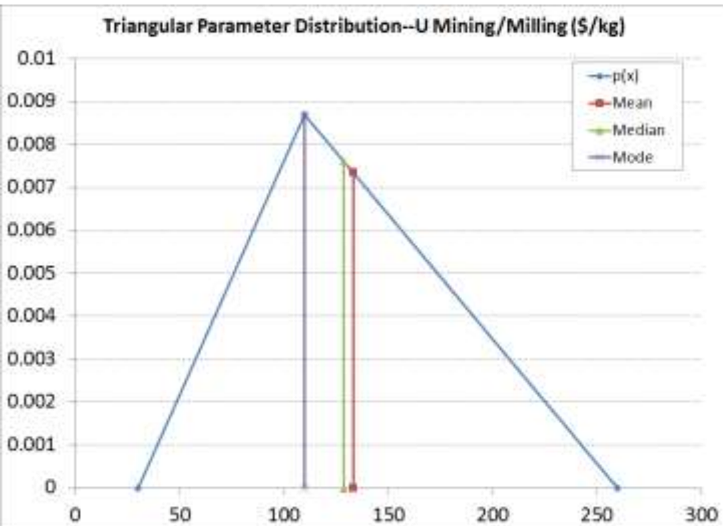


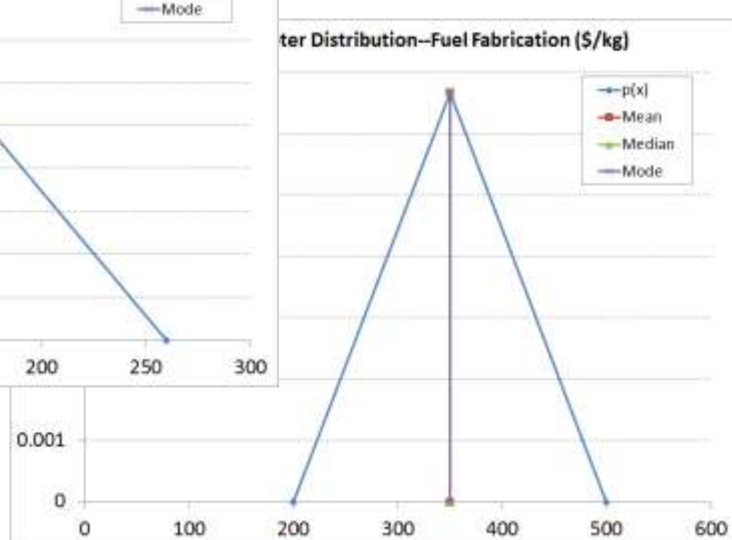
Uniform distributions have a range, without a "most likely" value (e.g., 5%)

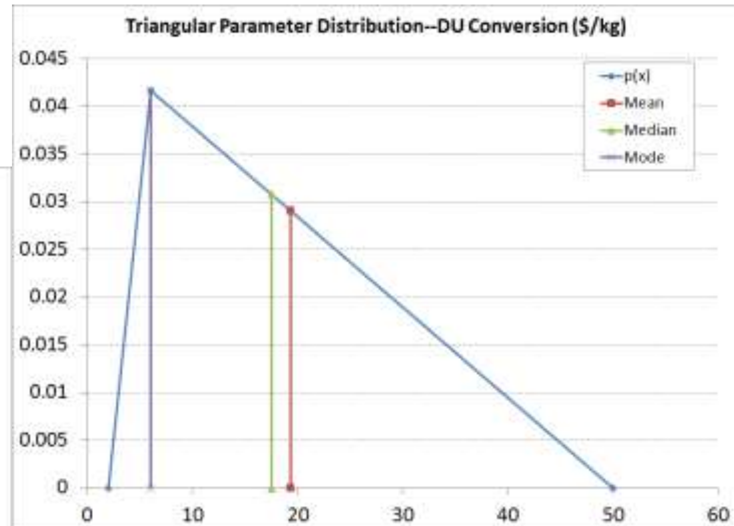
Fuel cycle and capital costs are assigned triangular distributions

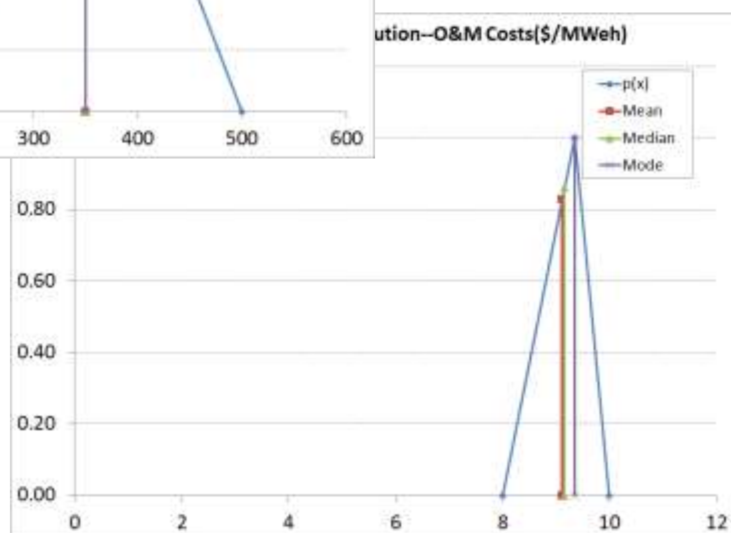
Parameter	Low	Nominal	High
Geologic Disposal		$1/MWeh	
D&D Costs		21.55% of construction	
Natural U Mining/Milling	$30	$110/kgU	$260
Conversion	$5	$10/kgU	$15
Enrichment	$85	$110/SWU	$135
Fuel Fabrication	$200	$350/kgU	$500
DU Conversion	$2	$6/kgU	$50
Capital Cost	$2000	$2366/kWe	$5000
O&M Costs	$8	$9.35/MWeh	$10

Most cost parameters are assumed to follow triangular distributions









These have a
"most likely" value

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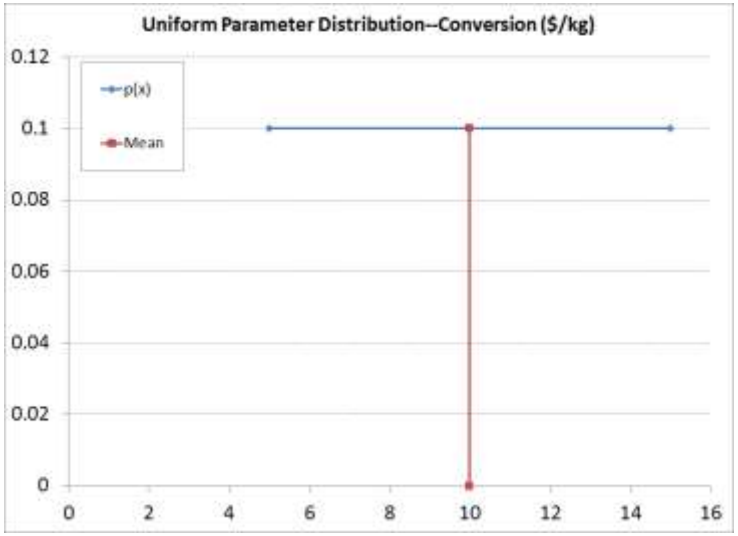
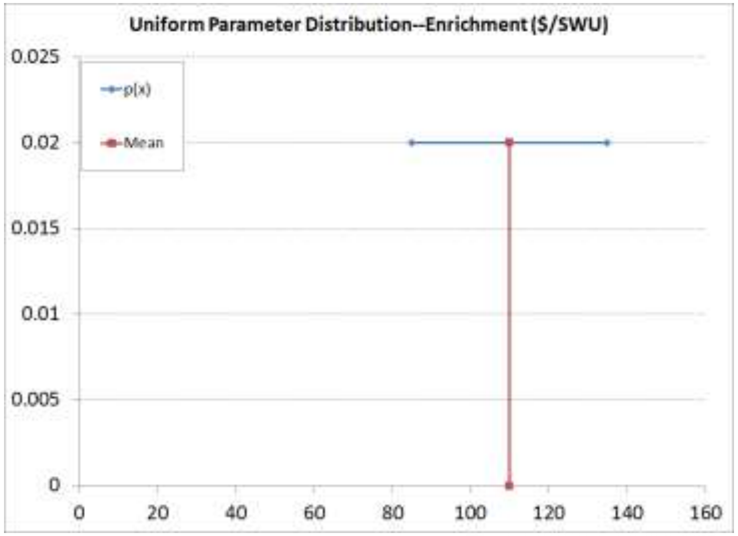
Conversion and enrichment follow a uniform distribution





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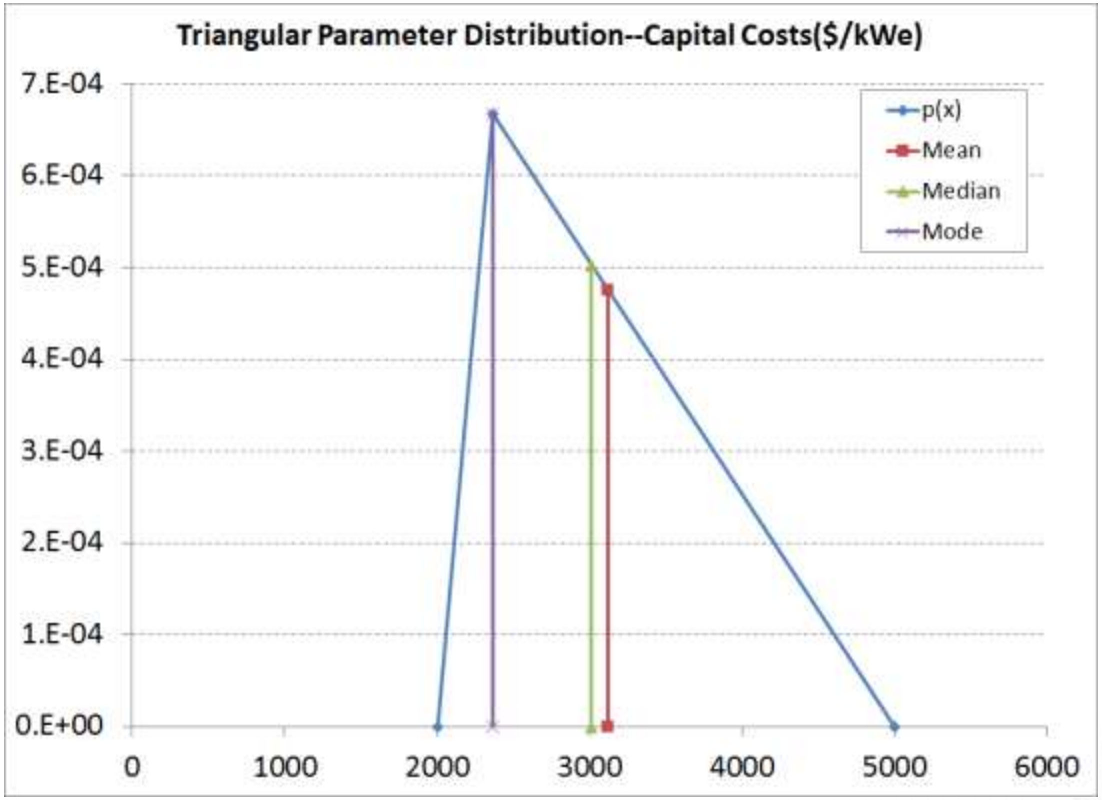
Given the input parameters, the capital cost is represented by a right-skewed triangular distribution



Capital cost drives ~74% of the total cost uncertainty, followed by interest during Operations at 22%

Parameter	Variance $(\$/MWeh)^2$	Contribution to Total Variance
Capital Cost	34.49	73.80%
Interest Rate During Operation	10.29	22.00%
Mining/Milling	0.94	2.00%
Interest Rate During Construction	0.47	1.00%
Capacity Factor	0.22	0.47%
O&M	0.17	0.36%
All Others	0.18	0.38%
Total	46.76→$6.84/MWeh standard deviation	

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The uncertainty distribution can account for extreme values while centralizing the most likely values

- Capital costs have some small probability of having both low-end and high-end values.
- The central estimate reflects the most likely case.
- Peaking the estimate near the low-end can hedge the estimate against potential high-end costs.

For example, the high-end of the capital cost range is reduced by $1000/kWe

Parameter	Low	Nominal	High
Natural U Mining/Milling	$30	$110/kgU	$260
Conversion	$5	$12/kgU	$15
Enrichment	$85	$100/SWU	$135
Fuel Fabrication	$200	$350/kgU	$500
DU Conversion	$2	$6/kgU	$50
Geologic Disposal		$1/MWeh	
Capital Cost*	$2000	$2366/kWe	**$4000**
O&M Costs	$8	$9.35/MWeh	$10
D&D Costs		21.55% of construction	

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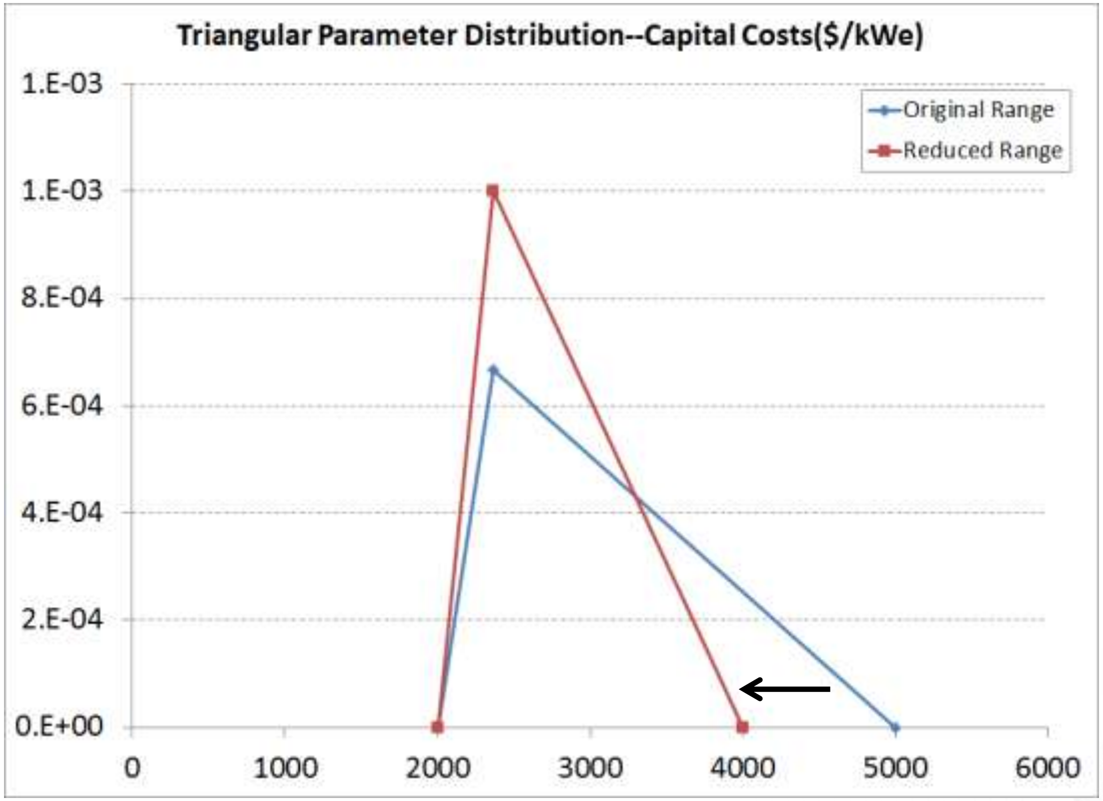
Reducing the high-range value of the Capital shifts the distribution to the left



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Reducing the Capital cost results in a decrease from ~74% to ~54% in the overall estimate standard deviation

Parameter	Variance ($/MWeh)^2	Percent of Total Variance
Capital Cost	14.6	54.3
Interest Rate During Operation	10.29	38.3
Mining/Milling	0.94	3.5
Interest Rate During Construction	0.47	1.8
Capacity Factor	0.22	0.8
O&M	0.17	0.63
All Others	0.18	0.67
Total	26.87→$5.18/MWeh standard deviation (~14%)	

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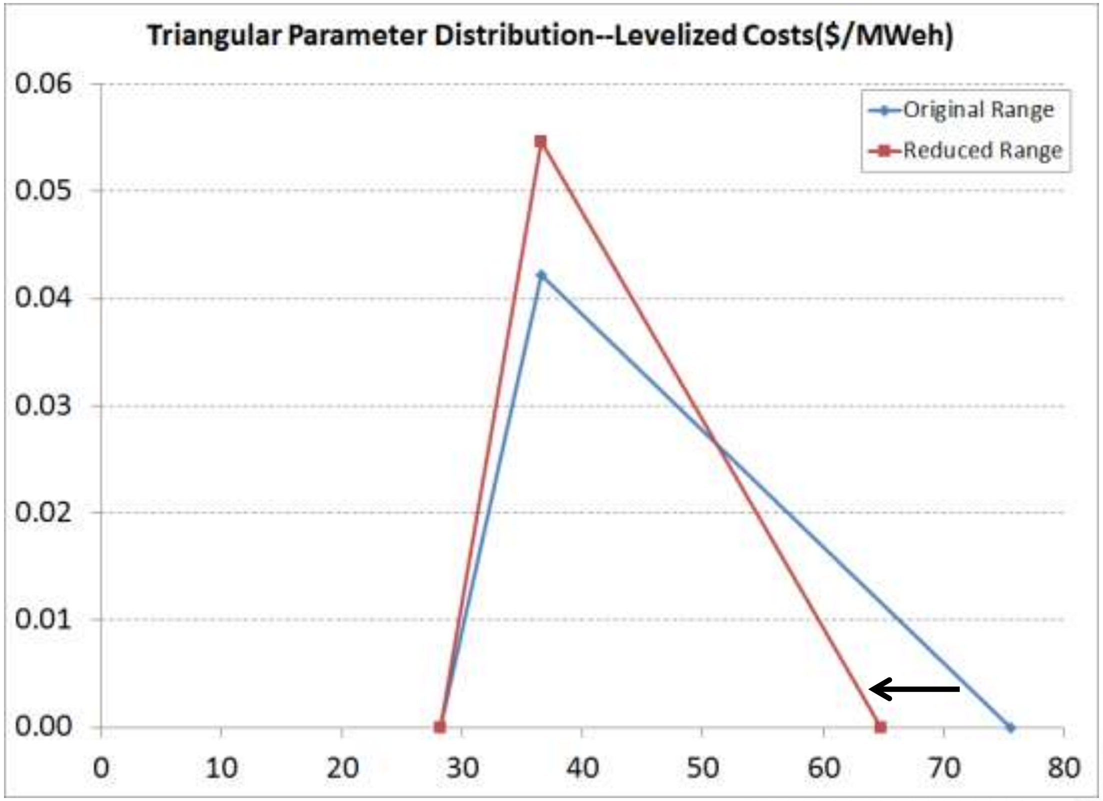
The overall cost distribution (LUEC) correlates with the shift of capital cost



Uncertainty analysis provides additional perspectives on the costs and potential risk of the investment

- Extending the end points of key cost parameters provides a means to account for contingency, but results in higher cost uncertainty
- Operational and commodity uncertainties are better understood and may be contained through best practices and supply chain efficiency
- Interest rate uncertainties have non-linear (compounding) effects but may be controlled by sovereign body policies (e.g., loan guarantees)

Conclusions

- The GIF Economic Modeling Working Group developed and continues to enhance G4ECONS
- The revised version of G4ECONS includes uncertainty analysis to allow analysts to understand what drives the overall cost
- However it is necessary to be mindful of how the uncertainty is quantified!