

# Introducing ACAT:

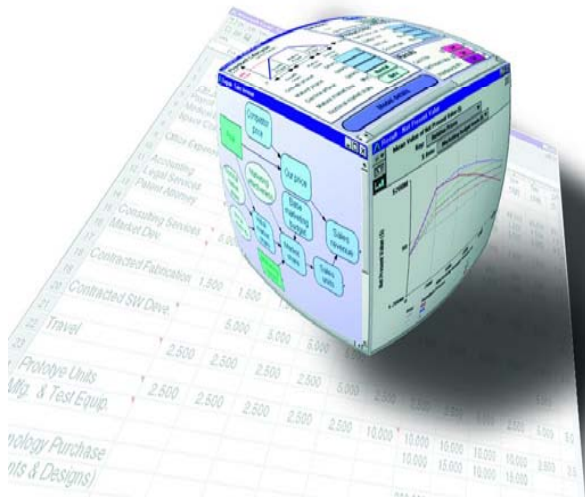
## Analytica COG Analysis Tool

for Sensitivity and uncertainty analysis  
on the Cost of Generation (COG) spreadsheet

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Los Gatos, California.

COG Workshop  
California Energy Commission  
March 7<sup>th</sup> 2013



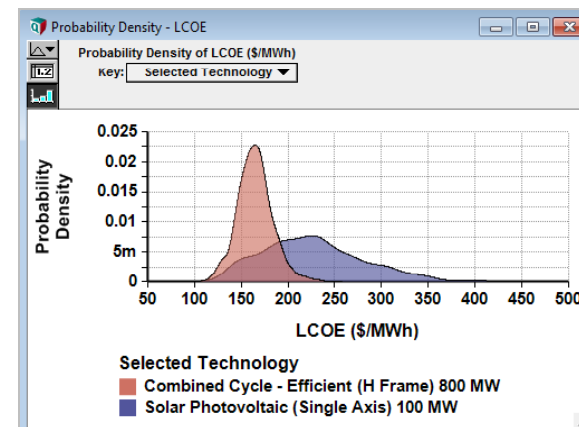
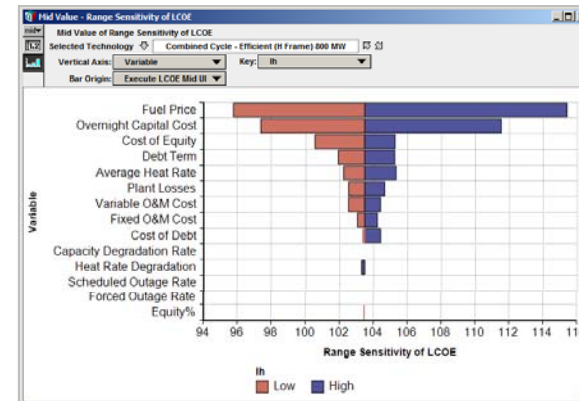
*Bringing clarity to  
green decisions*

# Purpose of ACAT:

## Analytica COG Analysis Tool

To perform rapid analysis of uncertainties with the Cost Of Generation (COG) spreadsheet, including:

- Range sensitivity analysis to calculate the effect of changing each uncertain parameter from low to high, holding others at their mid value.
- Monte Carlo (and Latin hypercube) simulation, to estimate probability distributions over LCOE



# Uncertainty in input parameters

- Uncertainty in each input parameter (for each technology type) is quantified by a low, mid, and high value:

Mid Value - Input variable ranges

mid

Mid Value of Input variable ranges (various)

Selected technologies Combined Cycle - Efficient (H Frame) 800 MW

UI Index

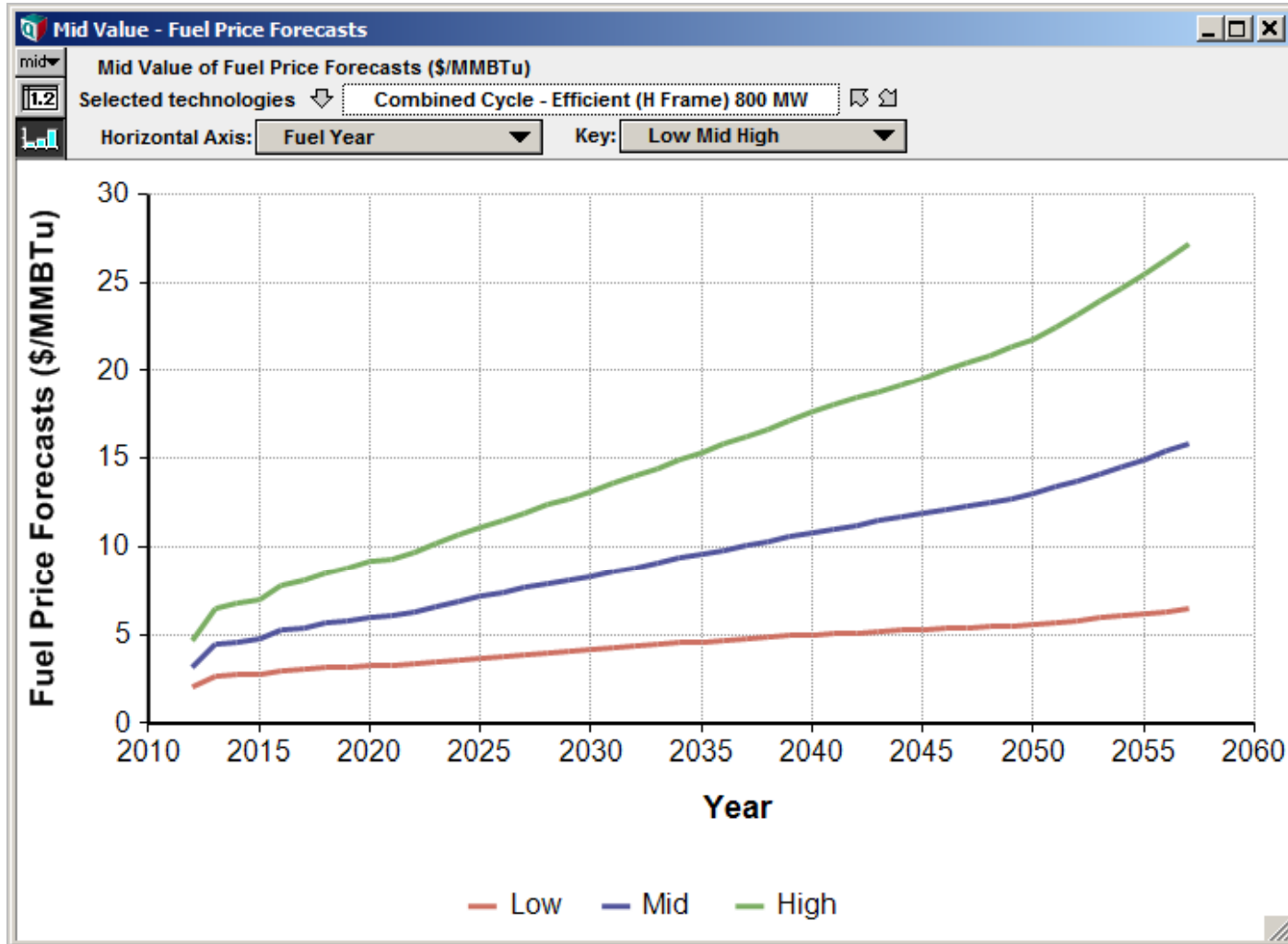
Totals

Low Mid High

Totals

	Low	Mid	High
Plant Losses (%)	2.00	2.90	4.00
Capacity Degradation Rate (%)	0.240	0.240	0.240
Debt Term (yr)	11.0	9.00	7.00
Average Heat Rate (Btu/kWh)	6310	6470	6710
Heat Rate Degradation (%)	0.200	0.240	0.200
Scheduled Outage Hours (%)	6.02	6.02	6.02
Forced Outage Rate (%)	2.24	2.24	2.24
Fixed O&M Cost (\$/kW-yr)	5.01	7.17	11.0
Variable O&M Cost (\$/MWh)	1.95	2.69	3.42
Overnight Capital Cost (\$/kW)	759	957	1220
Percent Equity (%)	20.0	20.0	20.0
Cost of Equity (%)	10.4	13.3	15.0
Cost of Debt (%)	4.03	4.40	7.19

# Uncertainty in natural gas prices



# Range Sensitivity for LCOE on PV

100MW Single-axis PV plant installed in 2020

Mid Value - Input variable ranges

Mid Value of Input variable ranges (various)

Selected technologies: Solar Photovoltaic (Single Axis) 100 MW

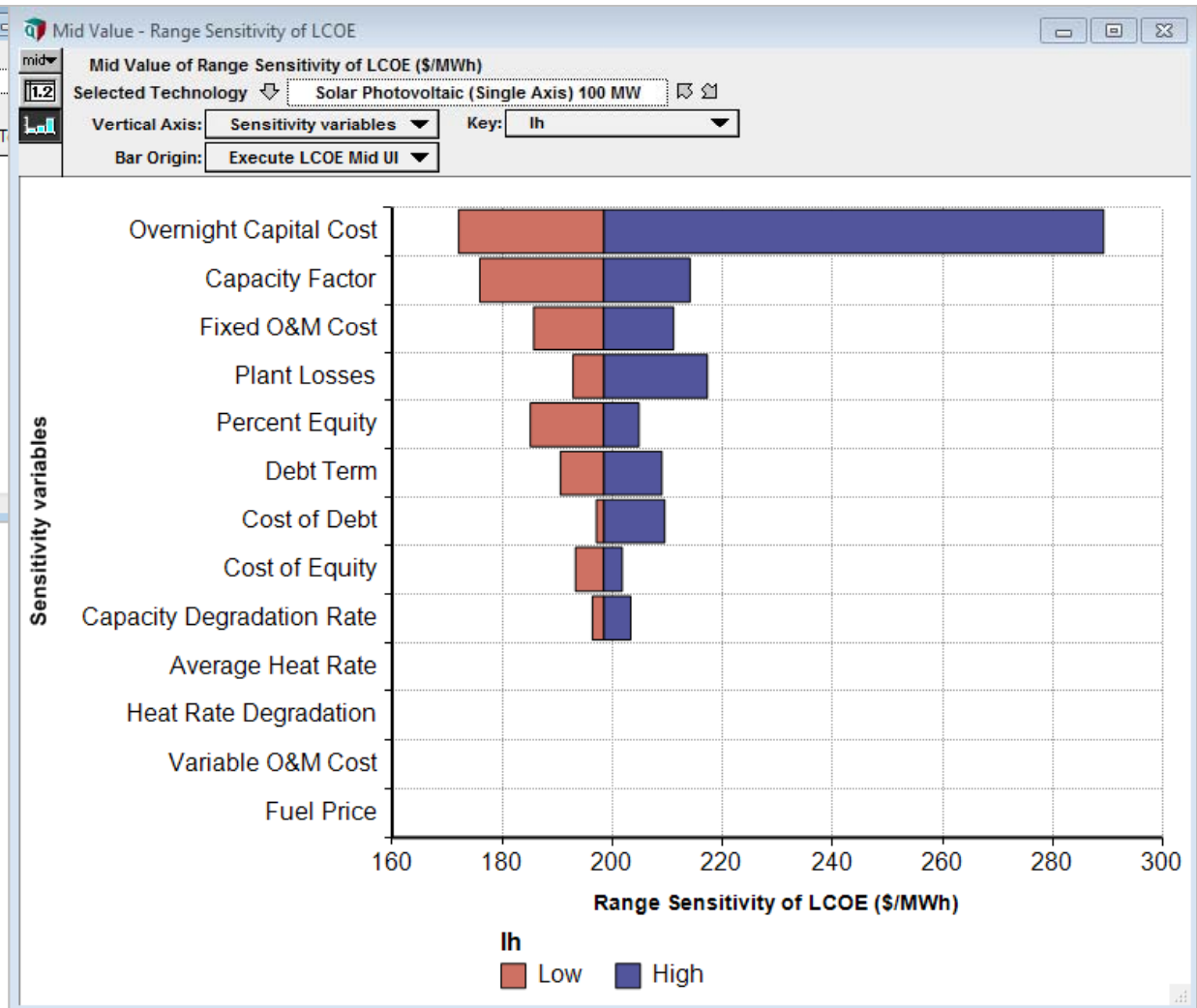
UI Index: [Dropdown]

Totals: [Dropdown]

Low Mid High [Dropdown]

	Low	Mid	High
Plant Losses (%)	11.0	13.5	21.0
Capacity Degradation Rate (%)	0.250	0.550	1.25
Debt Term (yr)	25.0	20.0	15.0
Average Heat Rate (Btu/kWh)	«null»	«null»	«null»
Heat Rate Degradation (%)	«null»	0.00	0.00
Capacity Factor (%)	31.5	26.6	24.0
Fixed O&M Cost (\$/kW-yr)	20.0	35.0	50.0
Variable O&M Cost (\$/MWh)	0.00	0.00	0.00
Overnight Capital Cost (\$/kW)	1250	1640	2950
Percent Equity (%)	9.55	25.5	31.8
Cost of Equity (%)	10.4	13.3	15.0
Cost of Debt (%)	5.54	5.91	8.70

- For each uncertain input assumption, it uses COG to calculate the effect on LCOE of changing that input over its range from low to high value, while keeping all other inputs at their mid values.



# Range Sensitivity

200MW Advanced natural gas turbine built in 2020

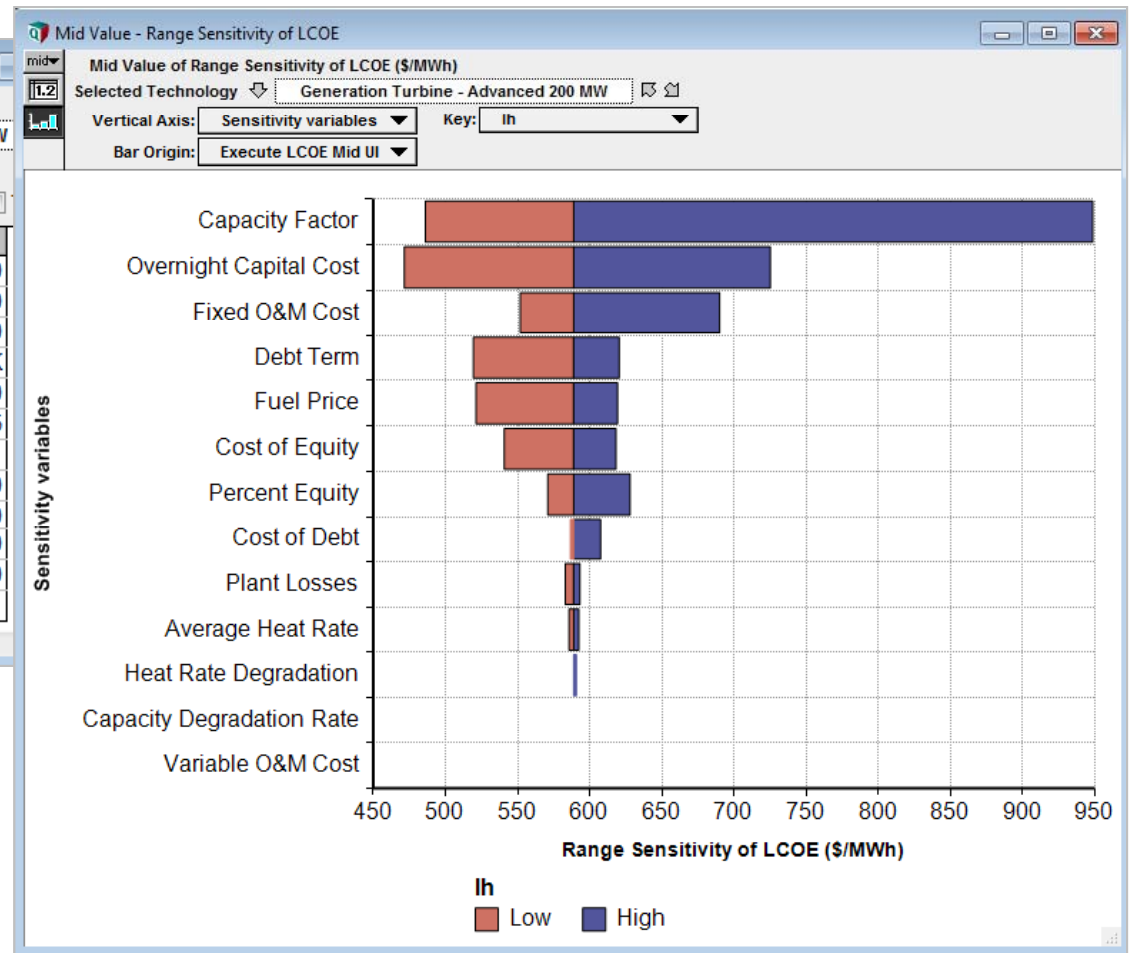
Mid Value - Input variable ranges

Mid Value of Input variable ranges (various)

Selected technologies: Generation Turbine - Advanced 200 MW

UI Index: ☐ Totals

	Low	Mid	High
Plant Losses (%)	2.30	3.40	4.20
Capacity Degradation Rate (%)	0.0500	0.0500	0.0500
Debt Term (yr)	20.0	10.0	7.00
Average Heat Rate (Btu/kWh)	9600	9880	10.2K
Heat Rate Degradation (%)	0.0500	0.0500	0.200
Capacity Factor (%)	10.5	7.50	3.75
Fixed O&M Cost (\$/kW-yr)	8.45	23.9	66.1
Variable O&M Cost (\$/MWh)	0.00	0.00	0.00
Overnight Capital Cost (\$/kW)	527	891	1310
Percent Equity (%)	20.0	33.0	60.0
Cost of Equity (%)	10.4	13.3	15.0
Cost of Debt (%)	4.15	4.52	7.31





# ACAT User Interface

**Diagram - Analytica COG Analysis Tool**  
Analytica COG Analysis Tool ▶

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**Analytica COG Analysis Tool (ACAT)**  
Range sensitivity and uncertainty analysis on CEC cost of generation (COG) spreadsheet

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**Set Options**

Plant type **Custom Set** ▼

Custom Plant Types **Edit Table** Start year **2012** ▼

Gas Price Forecast **SubTable** Owner Scenario **SubTable**

Tax loss **Tax Minimum Equals Zero** ▼

Other COG Inputs **Edit Table**

Input variable ranges (various) **Result** mid **Calc** mid

Fuel Price Forecasts (\$/MMBTu) **Result** mid **Calc** mid

Output: LCOE (\$/MWh) **Calc** mid

**Select spreadsheets**

Spreadsheet Name	
<b>COG</b>	CEC_COG_Model_Version_3_58_RMc 2-28-... mid
<b>Results</b>	ACAT_COG_Results_12182012.xlsx mid

**Model Details**

COG spreadsheet import/export ↔ Range Sensitivity Analysis ↔ COG Monte Carlo Analysis

**Range Sensitivity**

**Run sensitivity**

Range Sensitivity of LCOE (\$/MWh) **Result** mid

Notes

**Save to worksheet** **Refresh**

**Monte Carlo**

Distribution Shape **Triangular** ▼

Fitted Distributions **Calc** ↗

Serial correlation for gas price **0.8**

Set Sample Size **500** ▼

**Run Monte Carlo**

LCOE (\$/MWh) **Calc** ↗

LCOE Box Plot (\$/MWh) **Calc** mid

LCOE Importance **Calc** mid

Notes

**Save to worksheet** **Refresh**

Modeler Name **Evan Sherwin**

# ACAT architecture

## ACAT Analytica model

**Analytica COG Analysis Tool (ACAT)**  
Range sensitivity and uncertainty analysis on CEC cost of generation (COG) spreadsheet

**Set Options**  
Plant type: Custom Set  
Custom Plant Types: Edit Table  
Start year: 2012  
Gas Price Forecast: SubTable  
Owner Scenario: SubTable  
Tax loss: Tax Minimum Equals Zero  
Other COG Inputs: Edit Table  
Input variable ranges: (various) Result mid Calc mid  
Fuel Price Forecasts: (\$/MMBTu) Result mid Calc mid  
Output: LCOE (\$/MWh) Calc mid

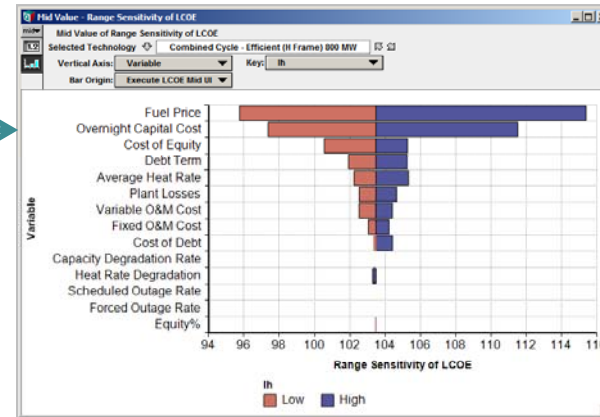
**Range Sensitivity**  
Run sensitivity  
Range Sensitivity of LCOE (\$/MWh) Result mid  
Notes: Save to worksheet Refresh  
Save to worksheet Refresh

**Monte Carlo**  
Distribution Shape: Triangular  
Fitted Distributions: Calc mid  
Serial correlation for gas price: 0.8  
Set Sample Size: 500  
Run Monte Carlo  
LCOE (\$/MWh) Calc mid  
LCOE Box Plot (\$/MWh) Calc mid  
LCOE Importance (\$/MWh) Calc mid  
Notes: Save to worksheet Refresh  
Model Name: Evan Sherwin

**Select spreadsheets**  
Spreadsheet Name  
COG: CEC\_COG\_Model\_Version\_3\_58\_RMCo 2-28-... mid  
Results: ACAT\_COG\_Results\_12182012.xlsx mid

**Model Details**  
COG spreadsheet import/export → Range Sensitivity Analysis → COG Monte Carlo Analysis

## Results



## COG spreadsheet

	A	B	C	D	E
1	Cost Of Generation				
2	Plant type	Wind-Class 3 50MW			
3	Input assumptions			Output result	
4	Plant losses (%)		15	Levelized cost of electricity (\$/kWh)	0.18
5	Debt Term (yr)		13		
6	Average Heat Rate (Btu/kWh)		130		
7	Overnight Capital Cost (\$/kW)		1800		
8					

## Results spreadsheet

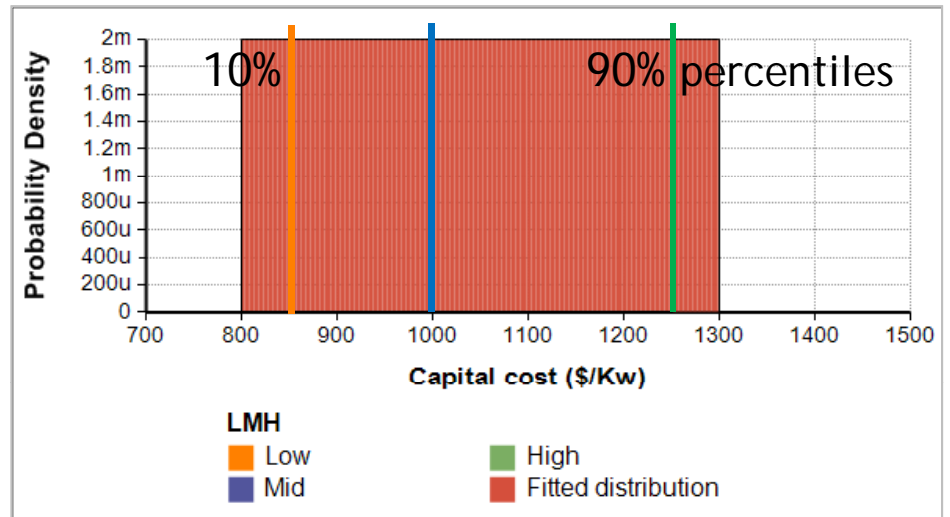
ACAT_COG_Results_12182012					
	A	B	C	D	E
1	Range Sensitivity Results from Analytica_COG_Analysis				
2	ACAT Filename	Analytica COG Analysis Tool			
3	Modeler Name				
4	Result Type	Range Sensitivity			
5	Method Description	Starts with LCOE from all mid values for each selected t			
6	Result Notes	Start year was 2011			
7	Date Saved	1/8/2013			
8					
9	Generation Turbine - Advanced 200 MW				
10	Variable Name	Unit	Input - Low	Input - Mid	Input - High
11	Total Overnight Cost	\$	693.00	801.00	919.00
12	Fixed O&M Cost	\$/kW-yr	6.27	16.33	39.82
13	Cost of Equity	%	10.11	12.75	15.00



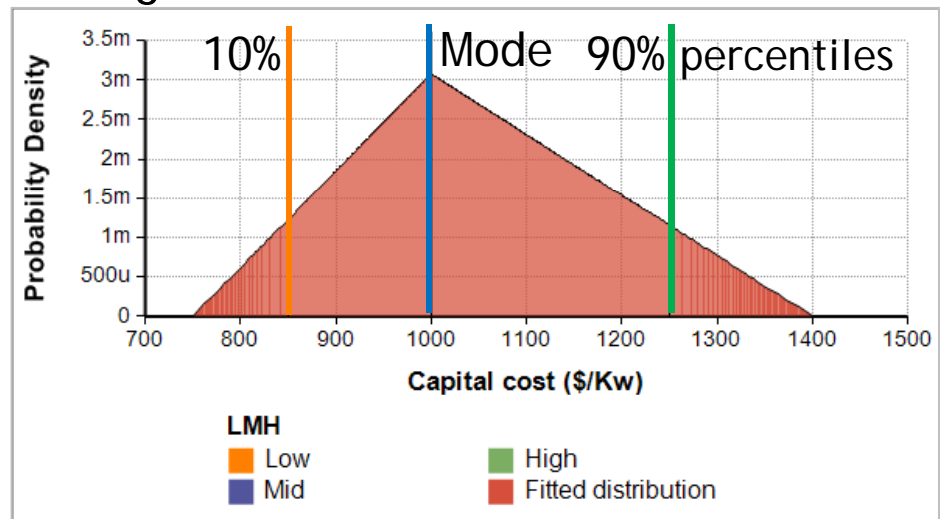
# Monte Carlo simulation

- It fits a probability distribution (uniform or triangular) to the low, mid, and high values for each input.
- It treats low and high as 10<sup>th</sup> percentile and 90<sup>th</sup> percentile of distributions.
- It truncates distributions at specified minimum (usually zero) and maximum.
- It selects  $n$  random samples from each input distribution.
- For each of the  $n$  samples, it sets the corresponding inputs in COG, and calculates the corresponding results LCOE.
- It estimates the corresponding distribution for LCOE.

## Uniform distribution



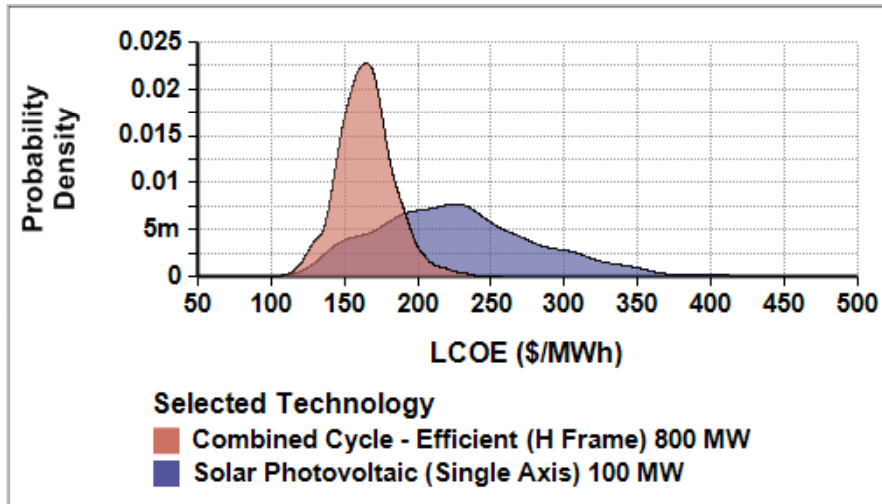
## Triangular distribution



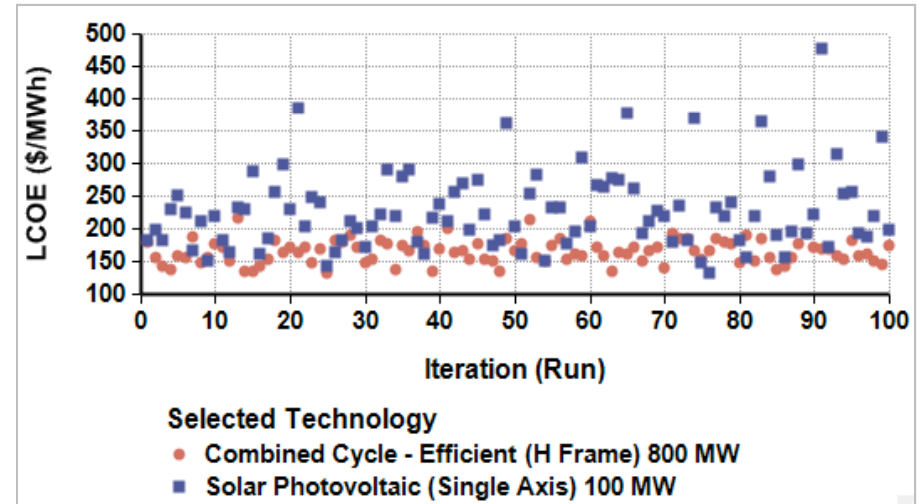
# Four ways to visualize uncertainty

Gas turbine combined cycle 800 MW and Solar PV single-axis 100MW, installed in 2020

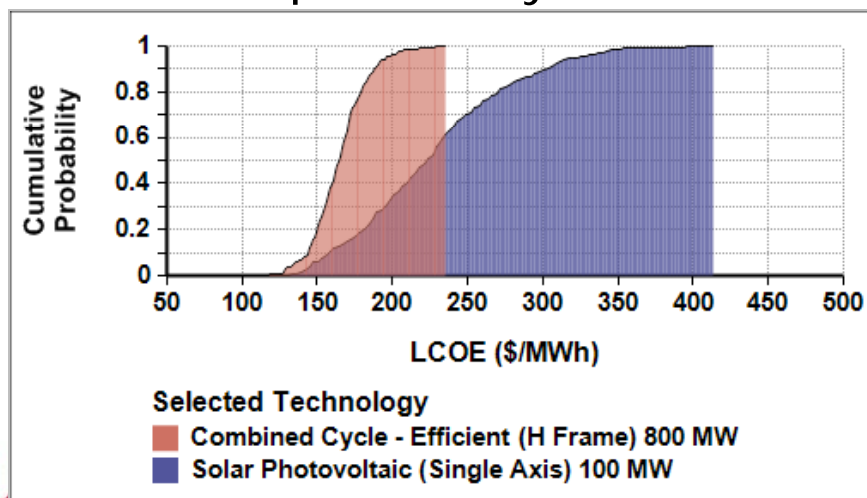
## Probability density functions



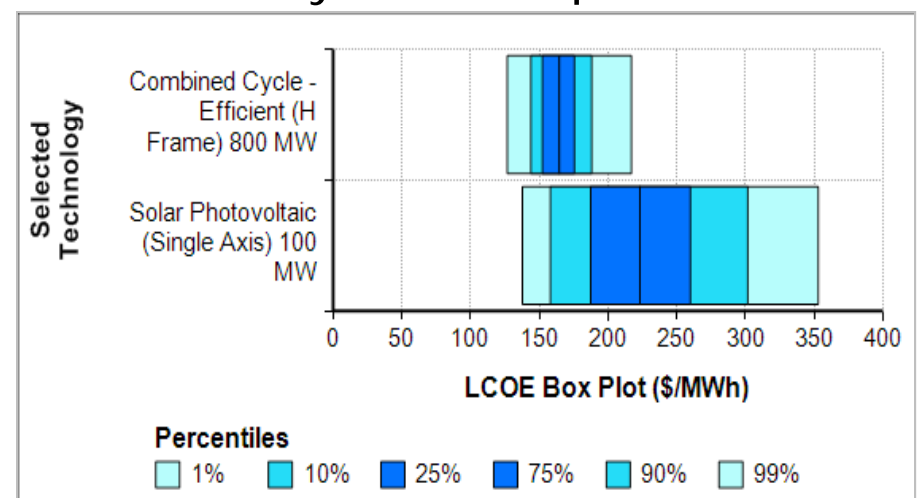
## Random sample values



## Cumulative probability distributions

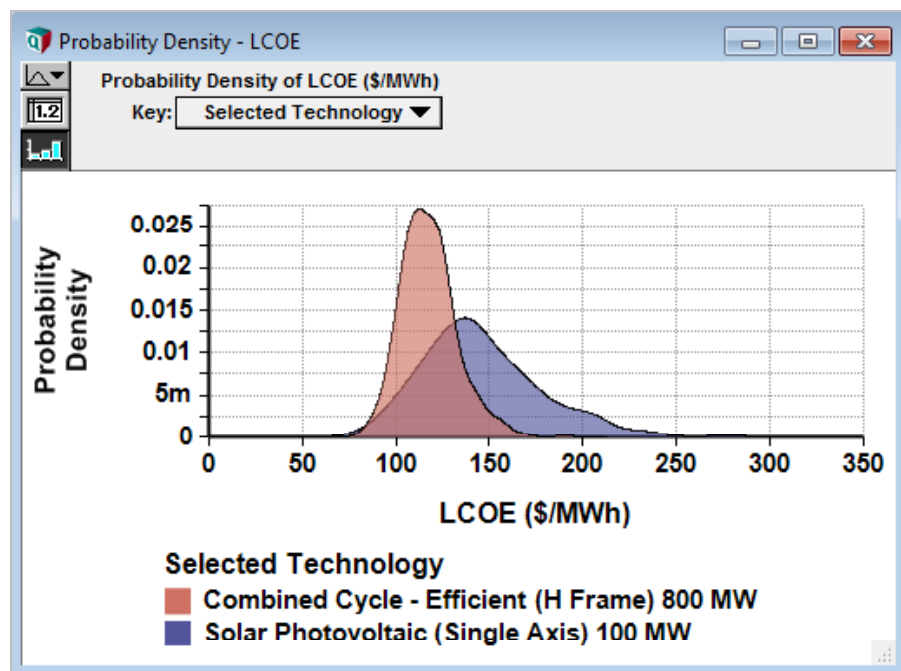


## Probability bands or percentiles

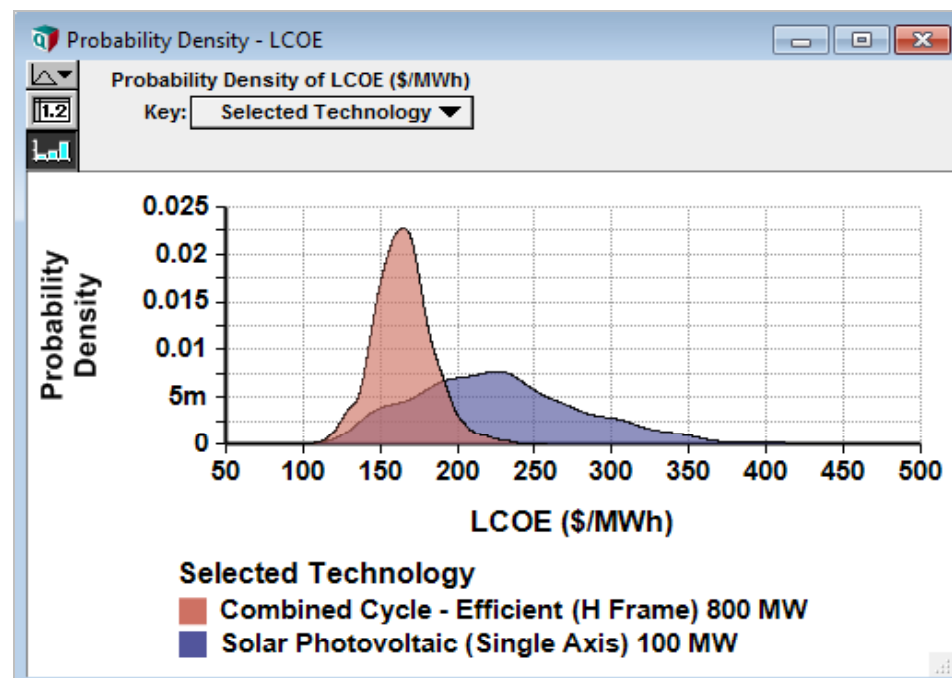


# Changes in LCOE from 2012 to 2020

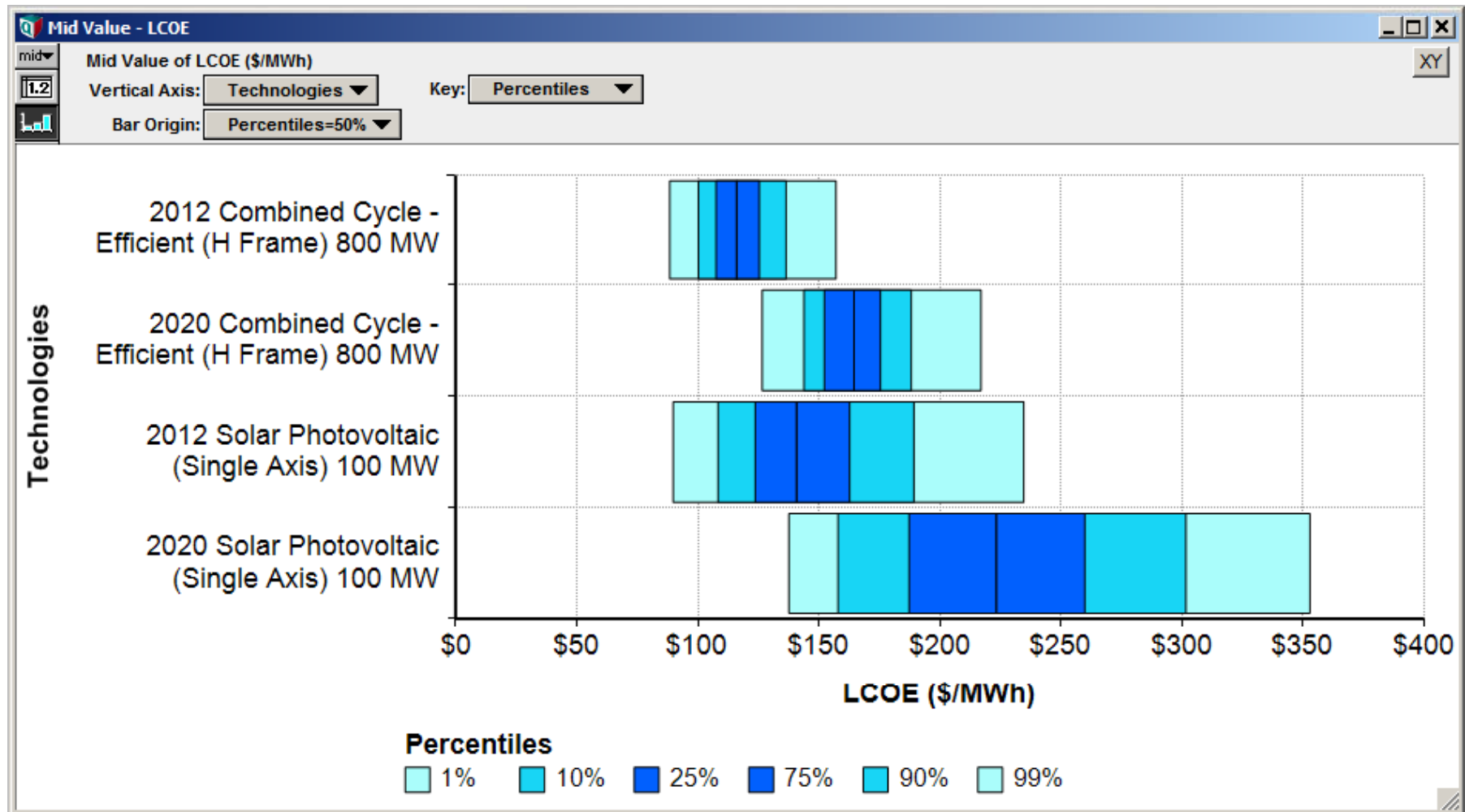
Installed in 2012



Installed in 2020



# Changes in LCOE from 2012 to 2020



Higher gas prices and ending of renewable tax credit  
Lead to increased costs. 2020 v. 2012