

The Cost of CCS for Natural Gas-Fired Power Plants

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Motivation

- Electric utilities again looking to natural gas combined cycle (NGCC) plants for new or replacement capacity in response to:
 - Recent decline in gas prices
 - Bullish outlook for new gas supplies
 - New environmental regulations for coal plants
 - New concerns about nuclear power after Fukushima
- Recent studies also show that many gas-fired plants must capture and sequester CO₂ to achieve large reductions in U.S. greenhouse gas emissions
- Most CCS cost studies have focused on coal-based power plants; relatively few on NGCC with CCS

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Some Questions of Interest

- What is the estimated cost of CCS for NGCC power plants?
- What is the uncertainty in current cost?
- What factors or assumptions contribute most to CCS cost and uncertainty?
- What carbon price or tax is needed to induce CCS use on NGCC plants?

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Recent Studies

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Recent CCS Cost Estimates for Natural Gas-Fired Power Plants

- 2007: Rubin, et al., *Energy Policy*
- 2007: DOE/NETL Baseline Report 2007/1281
- 2009: IEAGHG Report 2009/TR-3
- 2009: EPRI Report No 1017495
- 2009: CO2 Capture Project
- 2010: DOE/NETL Baseline Report 2010/1397
- 2010: US Interagency Task Force on CCS
- 2010: Southern California Edison
- 2010: UK DECC, Mott MacDonald Report
- 2011: DOE/EIA AEO 2011
- 2011: IEA Working Paper
- 2011: Global CCS Institute Update

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Results of Recent Studies: NGCC Power Plants (no CCS)

Parameter	NETL Baseline Rev 1 (2007)	NETL Baseline Rev 2 (2010)	U.S.Task Force on CCS (2010)	EPRI Update (2009)		EIA AEO (2011)
Turbine class/type	7FB	7FB		7FB	7FB	<i>H</i>
Net power output (MW)	560.4	555.1		550	550	400
Net plant efficiency, HHV (%)	50.8	50.2		46.7	42.3	53.1
Capacity factor	85%	85%		80%	40%	87%
Cost year	2007	2007	2009	2007	2007	2009
Inflation rate (0%=constant \$)	1.87%	3%	3%	0%	0%	
Fixed charge factor	0.164	0.105	0.150	-0.12	-0.12	
Levelization period (years)	20	30	30	30	30	30
NG price (\$/MBtu)	6.75	6.55		7.00	7.00	
Total plant cost (\$/kW)	554	584		800	800	
Total overnight cost (\$/kW)		718				1003
First-year COE (\$/MWh)		58.9				
Levelized COE (\$/MWh)	68.4	74.7	77	66.4	85.3	63.1

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Results of Recent Studies: NGCC Plants with CCS

Parameter	NETL Baseline Rev 1 (2007)	NETL Baseline Rev 2 (2010)	U.S.Task Force on CCS (2010)	EPRI Update (2009)		EIA AEO (2011)
				Econamine	Econamine	
Capture system	FG+	FG+	Amine	Econamine	Econamine	
CO ₂ capture efficiency	90%	90%	90%	90%	90%	
Net power output (MW)	481.9	473.6		467.5	467.5	340
Net plant efficiency, HHV (%)	43.7	42.8		39.7	35.9	45.4
Capacity factor	85%	85%		80%	40%	87%
Cost year	2007	2007	2009	2007	2007	2009
Inflation rate (0%=constant \$)	1.87%	3%	3%	0%	0%	
Fixed charge factor	0.175	0.111	0.157	~0.12	~0.12	
CCS T&S cost (\$/MWh)	2.9	3.2		4.1	4.5	
CCS T&S cost (\$/tonne CO ₂)				10	10	
Total plant cost (\$/kW)	1172	1226		1370	1370	
Total overnight cost (\$/kW)		1497				2060
First-year COE (\$/MWh)		85.9				
Levelized COE (\$/MWh)	97.4	108.9	121	91.2	121.1	89.3

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Results of Recent NGCC Studies: Added Cost for CCS

Cost Parameter (levelized 2007\$)	NETL Baseline Rev 1 (2007)	NETL Baseline Rev 2 (2010)	U.S.Task Force on CCS (2010)	EPRI Update (2009)		EIA AEO (2011)
Added COE for CCS (\$/MWh)	29	34	44*	25	36	26*
Cost of CO₂ Avoided (\$/tonne CO₂)	92	106	115*	74	95	<i>n/a</i>

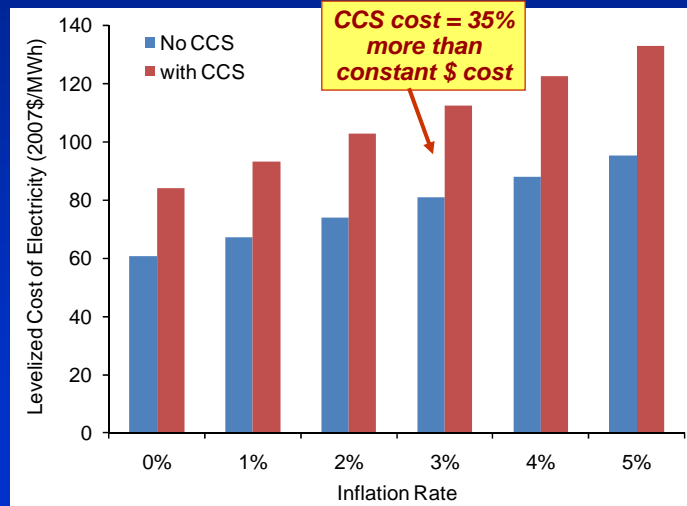
*2009 dollars

Recall that these results reflect different
technical, economic and financial assumptions

*The assumed inflation rate alone (constant vs. current dollars)
produces large differences in the cost of the same system!*

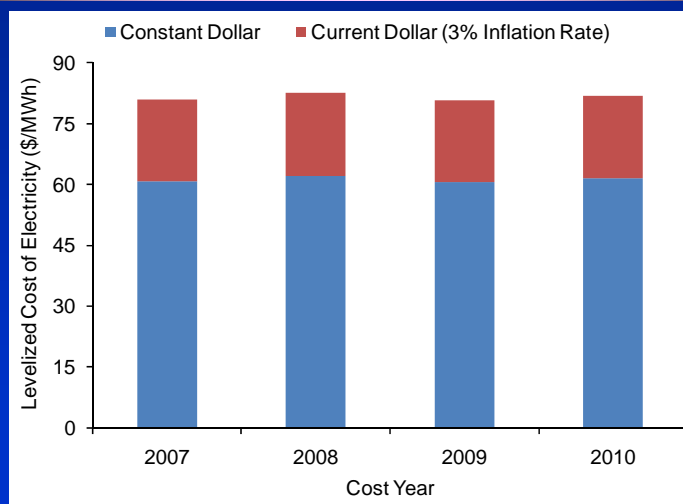
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Effect of Assumed Inflation Rate on LCOE (for the same system)



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Recent Cost-Year Changes are Small (Based on ChemE Plant Cost Index)



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U.S. Average Capacity Factors for NGCC Plants are Low

Year	Avg. CF
1998	34.2
1999	33.2
2000	37.1
2001	35.7
2002	38.2
2003	33.5
2004	35.5
2005	36.8
2006	38.8
2007	42.0
2008	40.6
2009	42.5

Source: EIA, 2011. Values thru 2002
include all NG-fired plants.

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A more systematic approach

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This Study . . .

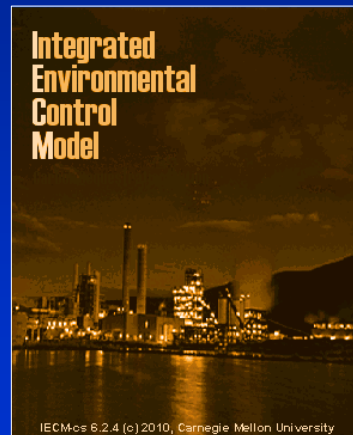
- Uses the IECM v.6.2.4 to analyze NGCC plant costs with and without post-combustion CCS
- Capital cost of NGCC base plant updated based on NETL 2010 Baseline Study; also assume NETL natural gas composition and price
- Reproduces NETL results for same assumptions
- Retain IECM default of constant dollar analysis and capacity factor for new baseload plants

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The IECM:

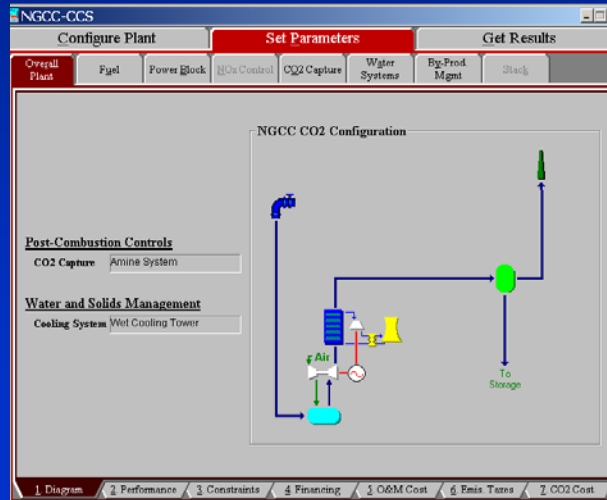
A power plant performance and cost model

- A desktop/laptop computer model developed for DOE/NETL; free and available at: www.iecm-online.com
- Provides systematic estimates of performance, emissions, costs and uncertainties using user-specified designs and parameter values for:
 - PC, IGCC and NGCC plants
 - All flue/fuel gas treatment systems
 - CO₂ capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)



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Configure Plant: NGCC Plant with CCS



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Set Parameters: Example Input Parameters

Performance Parameters

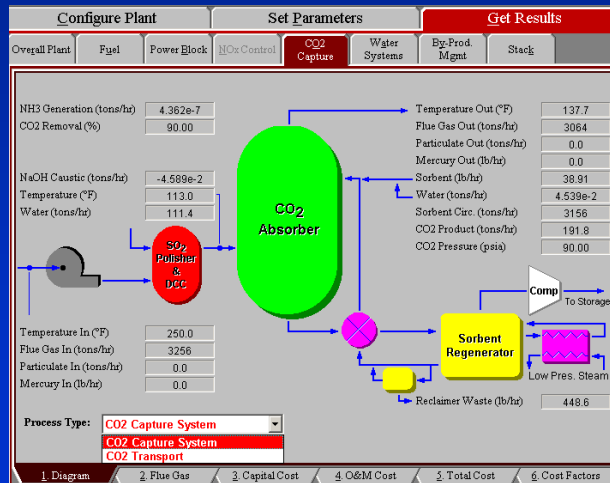
	Title	Units
1	Gas Turbine/Generator	
2	Gas Turbine Model	
3	No. of Gas Turbines	integer
4	Total Gas Turbine Output	MW _g
5		
6	Turbine Inlet Temperature	°F
7	Turbine Back Pressure	psia
8	Adiabatic Turbine Efficiency	%
9	Shaft/generator Efficiency	%
10		
11	Air Compressor	
12	Pressure Ratio (outlet/inlet)	ratio
13	Adiabatic Compressor Efficiency	%
14		
15	Combustor	
16	Combustor Pressure Drop	psia
17	Excess Air For Combustor	% stoich.
18	Combustor Inlet Pressure	psia
Process Type: <input type="text" value="Power Block"/>		
Gas Turbine 2. Steam Cycle 3. Emiss. Factors		

Capital Cost Parameters

	Title	Units
1	Construction Time	years
2		
3	General Facilities Capital	%PFC
4	Engineering & Home Office Fees	%PFC
5	Project Contingency Cost	%PFC
6	Process Contingency Cost	%PFC
7	Royalty Fees	%PFC
8		
9	Pre-Production Costs	
10	Months of Fixed O&M	months
11	Months of Variable O&M	months
12	Misc. Capital Cost	%TPI
13		
14	Inventory Capital	%TPC
15		
16		
17		
18	TCR Recovery Factor	%
Process Type: <input type="text" value="Power Block"/>		
Gas Turbine 2. Steam Cycle 3. Emiss. Factors		

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Get Results: Illustrative Results (Capture Unit)



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Base Case Assumptions & Results

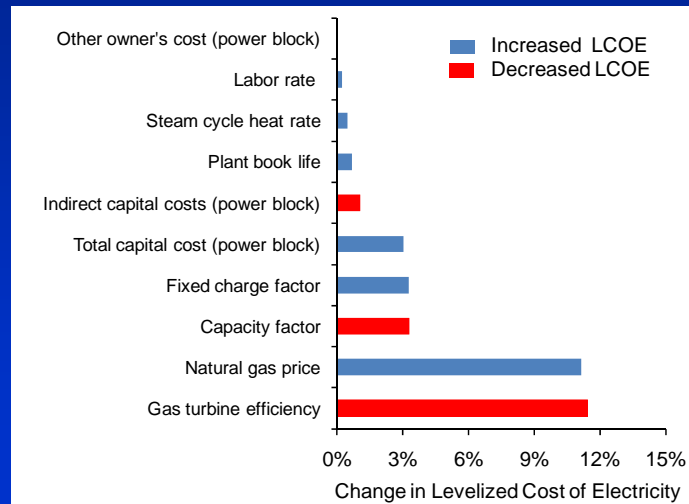
Parameter	Case 1: No CCS	Case 2: With CCS
Gas turbine model	GE 7FB	GE 7FB
Natural gas composition	NETL	NETL
CCS system	none	FG+ /saline aq.
CO ₂ capture efficiency	0%	90%
Net power output (MW)	527	449
Net plant efficiency, HHV (%)	50.0	42.6
Capacity factor (%)	75	75
Cost basis	Constant 2007\$	Constant 2007 \$
Fixed charge factor (fraction)	0.113	0.113
Natural gas cost (\$/MBtu)	6.55	6.55
Operating labor rate (\$/hr)	34.65	34.65
Total capital requirement (\$/kW)	760	1336
LCOE (mills/kWh)	60.8	84.2

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Sensitivity Analysis

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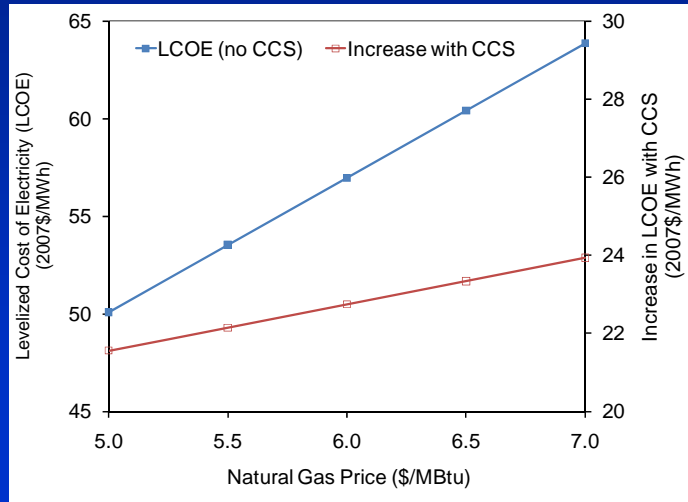
Effect on LCOE of a 15% Increase in Nominal Parameter Value



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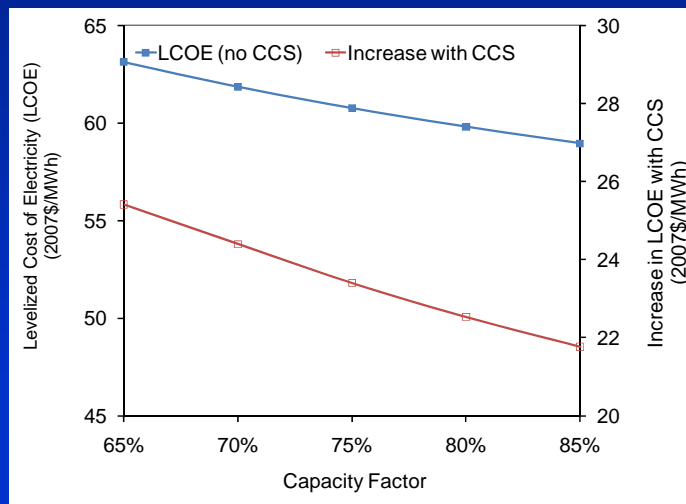
20

Effect of Natural Gas Price on LCOE and CCS Cost



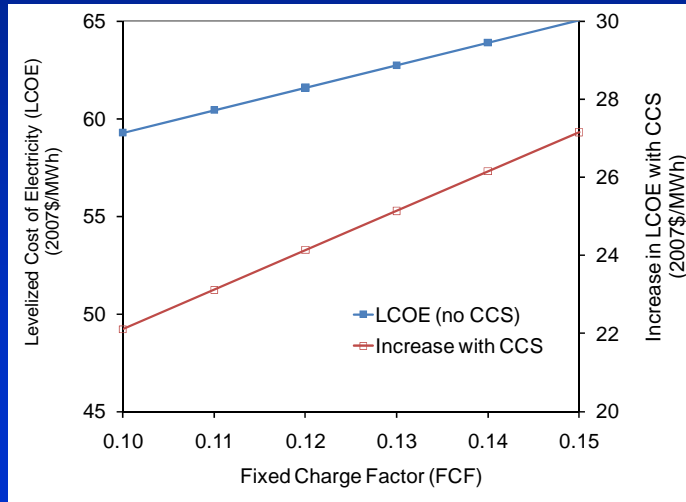
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Effect of Plant Capacity Factor on LCOE and CCS Cost



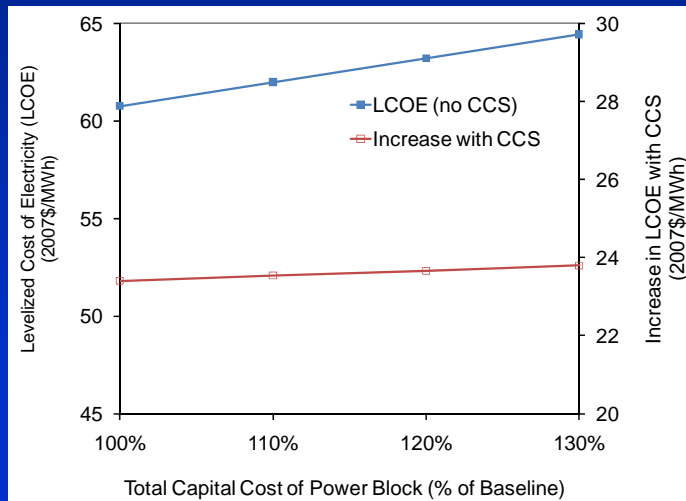
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Effect of Fixed Charge Factor on LCOE and CCS Cost



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Effect of Power Block Capital Cost on LCOE and CCS Cost



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Probabilistic Analysis

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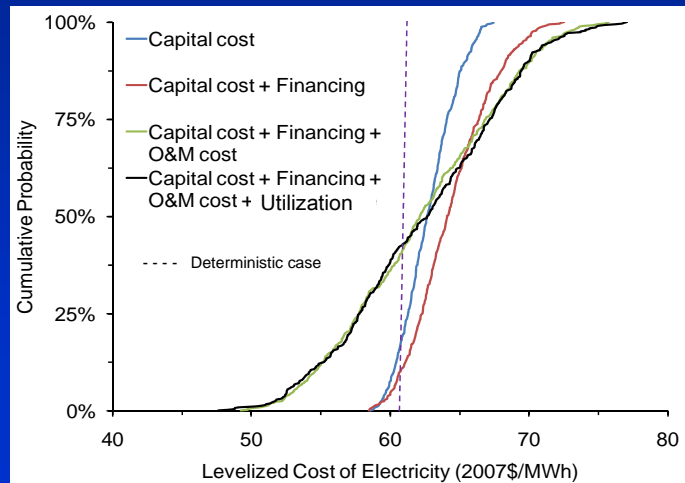
Assumed Distributions for NGCC Plant Uncertainty/Variability

Uncertainty Source	Parameter	Nominal Value	Min. Value	Max. Value	Distribution Function
Power block capital cost	Direct capital cost (% of baseline)	100	100	130	Uniform
	Indirect capital costs (total % of direct)	45.7	20	70	Uniform
	Misc. owner's cost (% total investment)	2	0	10	Uniform
Financing	Fixed charge factor	0.113	0.100	0.150	Uniform
	<i>high risk cases:</i>	<i>0.143</i>	<i>0.130</i>	<i>0.180</i>	
O&M costs	Natural gas price (\$/MBtu)	6.55	5.00	7.50	Uniform
	Labor rate (\$/hr)	34.65	30	40	Uniform
Plant utilization	Capacity factor (levelized)	75%	65%	85%	Uniform

Covers ranges in other recent cost studies

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Probabilistic Results for NGCC (Case 1: no CCS)



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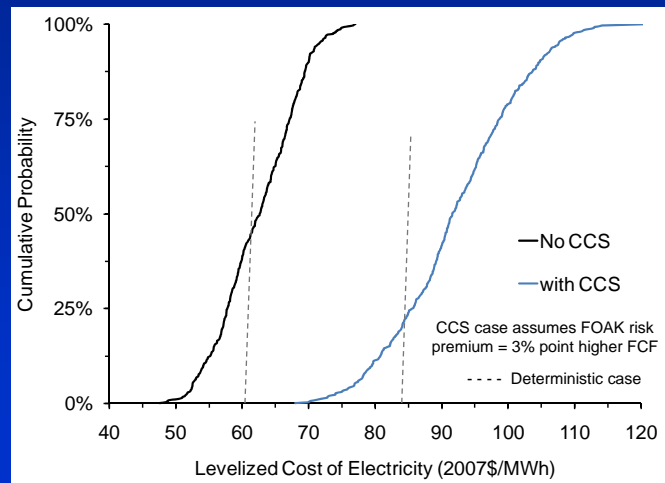
Uncertainty Distributions for CO₂ Capture System Parameters

Parameter	Units	Nominal Value	Distribution Function
ID fan efficiency	%	75	uniform (70,75)
Solvent pumping head	psia	30	triangular (5,30,36)
Pump efficiency	%	75	uniform (70,75)
Regeneration heat reqm't.	Btu/lb CO ₂	1712	uniform (1290, 2150)
System cooling duty	t H ₂ O/ t CO ₂	123	triangular (67, 123,162)
Nominal sorbent loss	lb/ton CO ₂	0.6	triangular (0.5, 0.6,3.1)
Captured CO ₂ purity	vol %	99.5	uniform (99.0, 99.8)
CO ₂ product pressure	psig	2000	uniform (1800, 2200)
CO ₂ compressor efficiency	%	80	uniform (75,85)
Total indirect capital costs	%	37.0	uniform (20,70)
Miscellaneous owner's costs	%	2	uniform (0,10)

Some CCS cases also assume a FOAK "high risk" premium of 3 percentage point increase in FCF over nominal (low risk, NOAK)

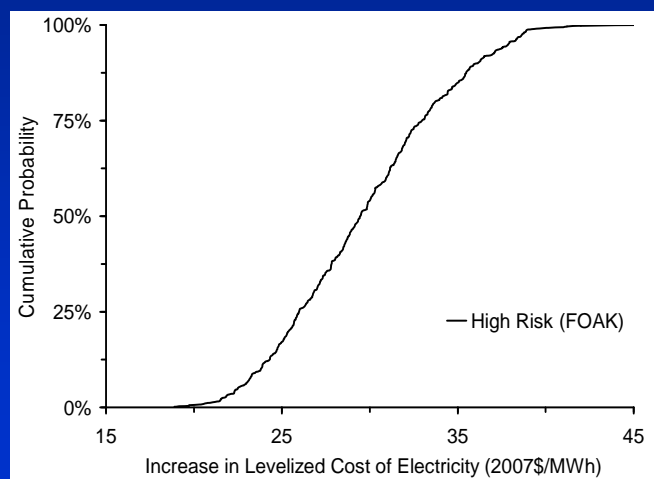
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Probabilistic Results for LCOE with and without CCS



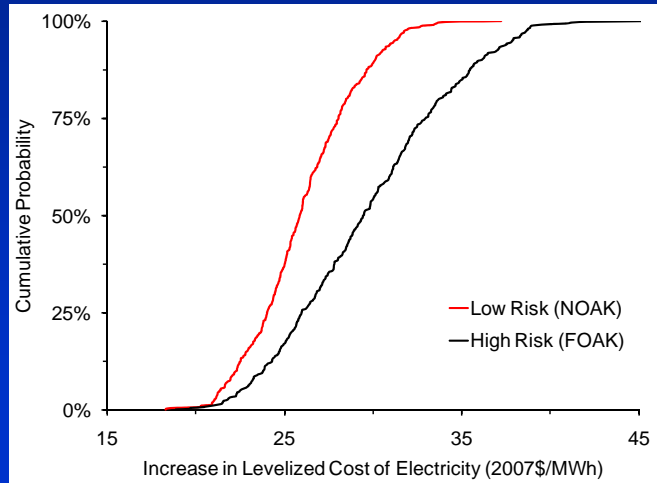
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Probabilistic Results for Added Cost for CCS



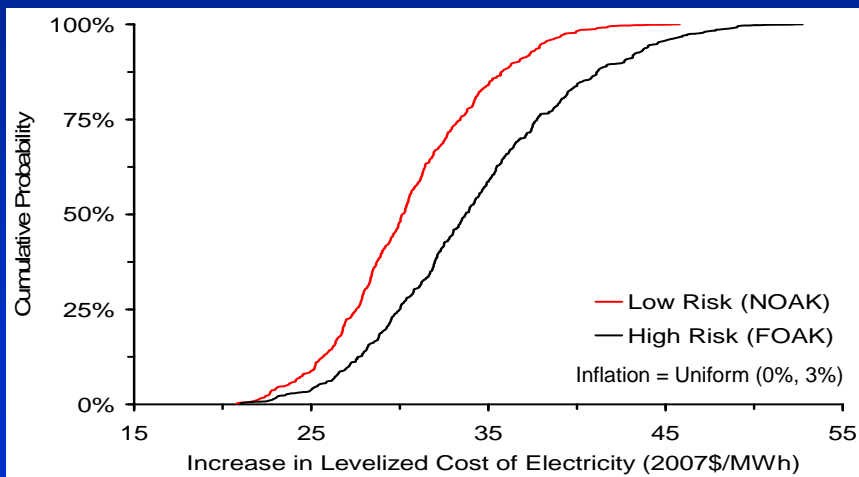
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Effect of Financing Assumption on Added Cost for CCS



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Effect of Inflation Assumption on Added Cost for CCS

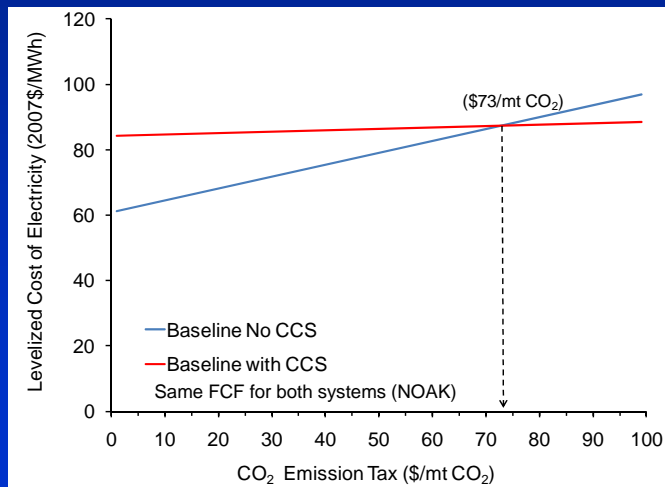


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What carbon price is needed?

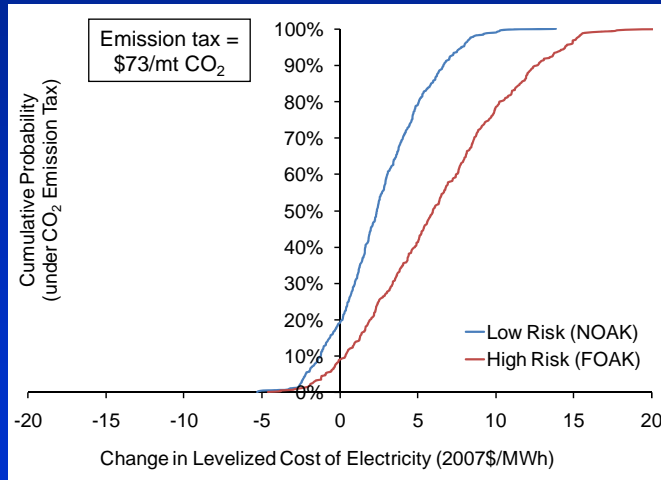
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Breakeven Carbon Price for Deterministic Cases



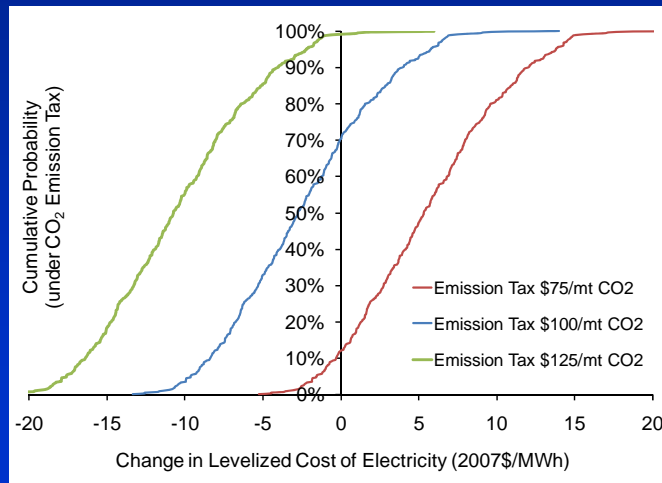
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Considering uncertainties the nominal CO₂ price is unlikely to induce CCS



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Likelihood of adopting CCS for different CO₂ emission charges



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Conclusions

- CCS for a new baseload NGCC power plant is likely to increase the LCOE by about \$20–35/MWh (in constant dollars), or about \$25–45/MWh in current dollars.
- While uncertainty in the cost of CCS technology contributes to this range, it is uncertainty in the future price of natural gas, the degree of plant utilization over its lifetime, and the financial terms for plant construction that contribute most to the overall variability of cost estimates.
- Given this variability, a policy intended to encourage CCS at NGCC plants solely via an emission tax or carbon price requires a higher than average price to be effective.
- Actual levelized capacity factors for NGCC plants have been far lower than assumed in most recent studies; thus, LCOE could be much higher than the values shown here for baseload plants.

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Thank You

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