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
- Climate policy studies show that CO_2 capture and storage (CCS) is needed at gas-fired plants 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

Some Questions of Interest

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

Recent Studies

Recent CCS Cost Estimates for Natural Gas-Fired Power Plants

- 2007: Rubin, Chao, Rao, *Energy Policy*
- 2007: DOE/NETL Baseline Report 2007/1281
- 2009: IEAGHG Report 2009/TR-3
- 2009: EPRI Report No 1017495
- 2009: CO_2 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 for U.S. 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	*H*
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 for U.S. 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)
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%*
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*

Results of Recent NGCC Studies: Added Cost for CCS

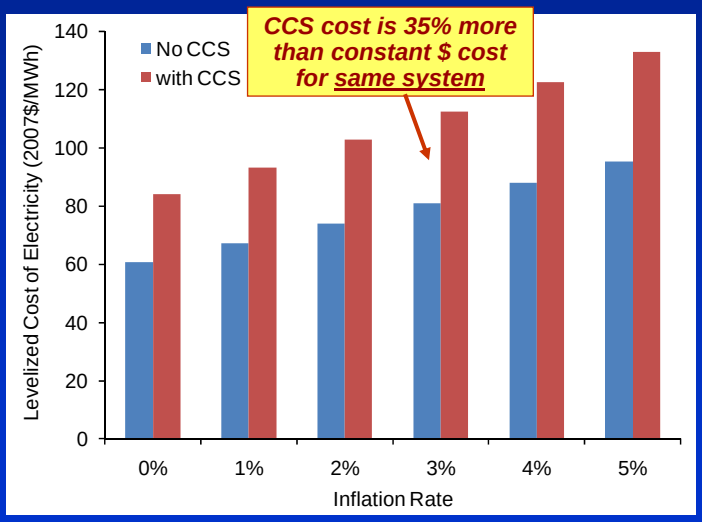
Cost Parameter (levelized 2007$)	NETL Baseline Rev 1 (2007)	NETL Baseline Rev 2 (2010)	US Task Force on CCS (2010)	EPRI Update (2009)		EIA AEO (2011)
Added COE for CCS ($/MWh)	**29**	**34**	**44***	**25**	**36**	***26****
Cost of CO_2 Avoided ($/tonne CO_2)	**92**	**106**	**115***	**74**	**95**	*n/a*

*2009 dollars

These results reflect different assumptions about key technical and economic parameters, especially:

- Plant efficiency
- Capacity factor
- Gas price
- Capital cost
- Inflation rate
- Fixed charge factor

Assumed Inflation Rate Alone has a Major Effect on Reported Costs



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U.S. Average Capacity Factors for NGCC Plants, 1998-2009

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.

Actual values currently are much lower than the levelized (baseload plant) values of 80-87% assumed in most recent studies

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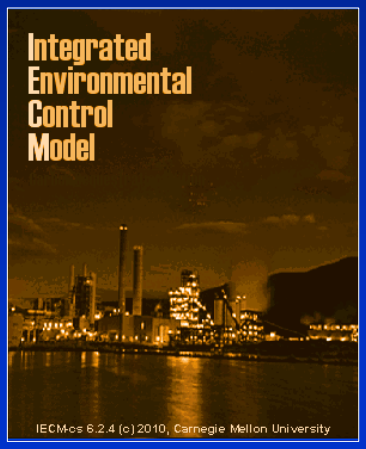
A more systematic approach

This Study . . .

- Uses the IECM v.6.2.4 to analyze NGCC plant costs with and without post-combustion CCS
- IECM reproduces NETL results for identical input assumptions, but allows users to employ different assumptions in an analysis

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
  - CO_2 capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)



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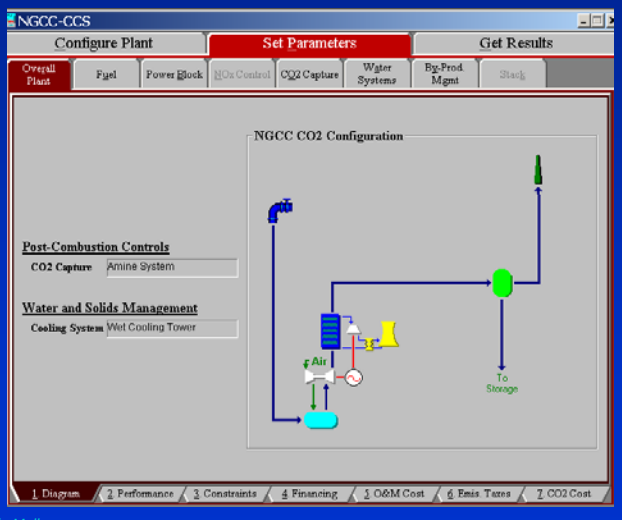
Configure Plant:
NGCC Plant with CCS



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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	MWg
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: Power Block

Gas Turbine | 2. Steam Cycle | 3. Emis. 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: Power Block

Gas Turbine | 2. Steam Cycle | 3. Emis. Factors

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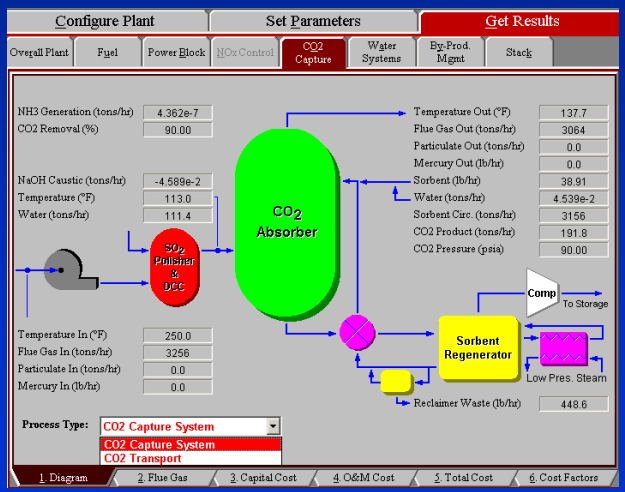
Get Results:
Illustrative Results (Capture Unit)



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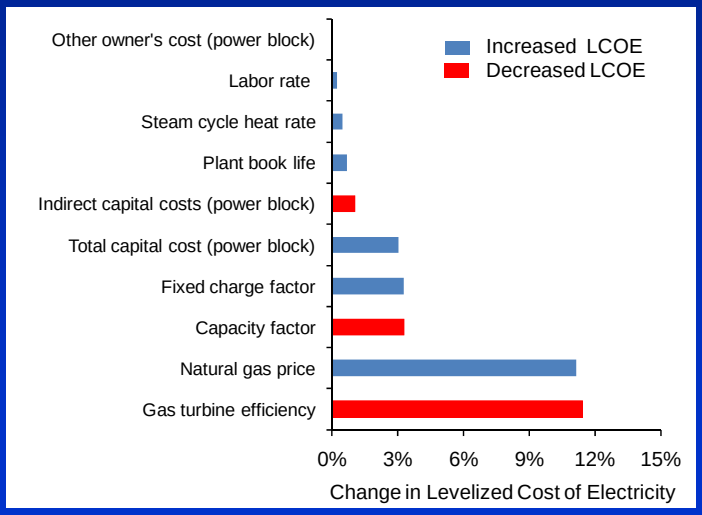
Effect on LCOE of a 15% Increase in Nominal Parameter Value



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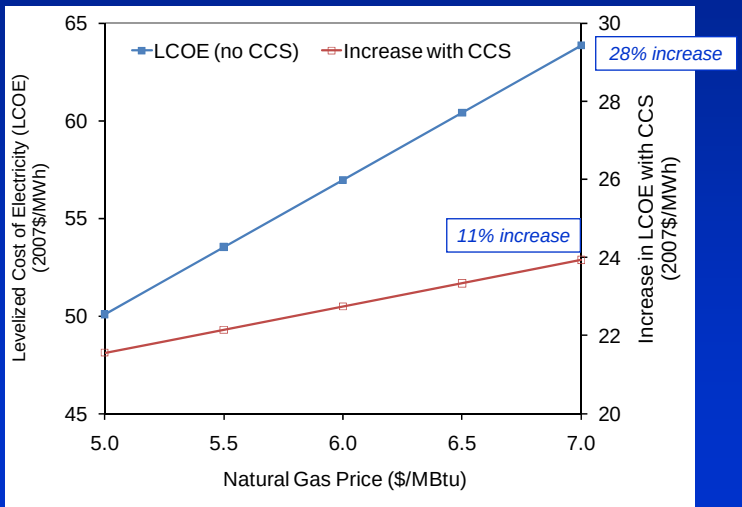
Effect of Natural Gas Price on LCOE and CCS Cost



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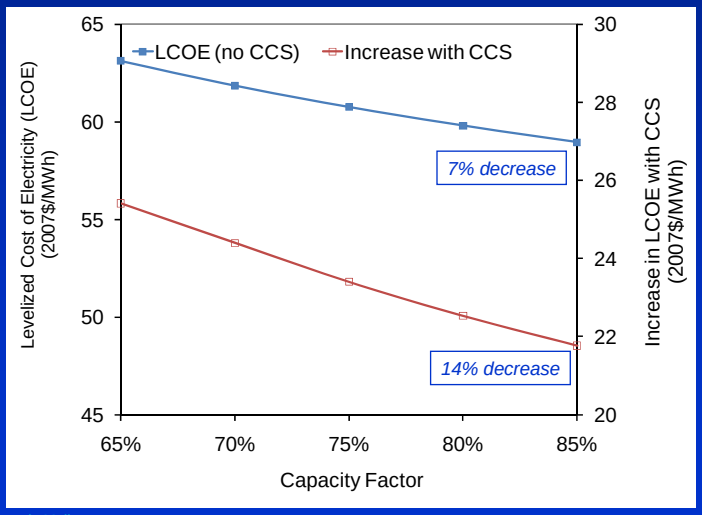
Effect of Plant Capacity Factor on LCOE and CCS Cost



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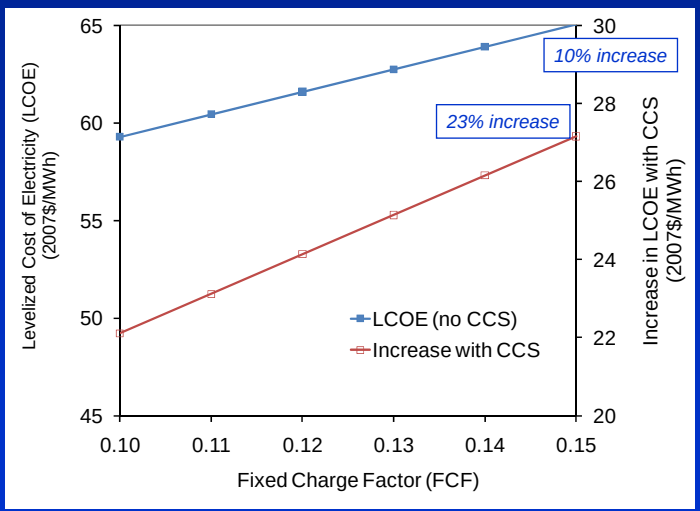
Effect of Fixed Charge Factor on LCOE and CCS Cost



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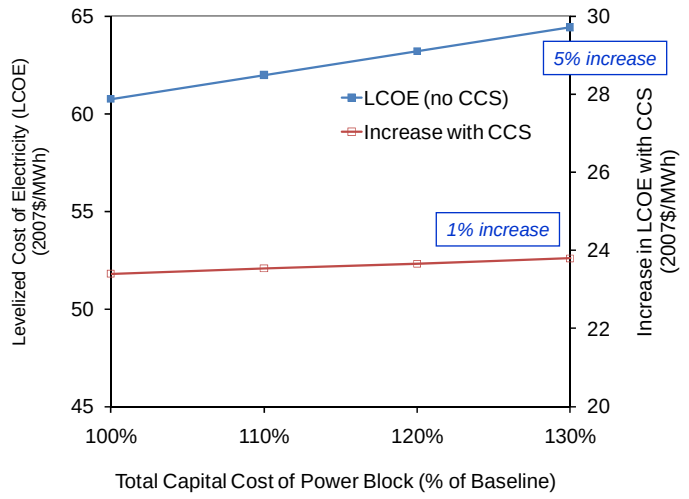
Effect of Power Block Capital Cost on LCOE and CCS Cost



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Probabilistic Analysis

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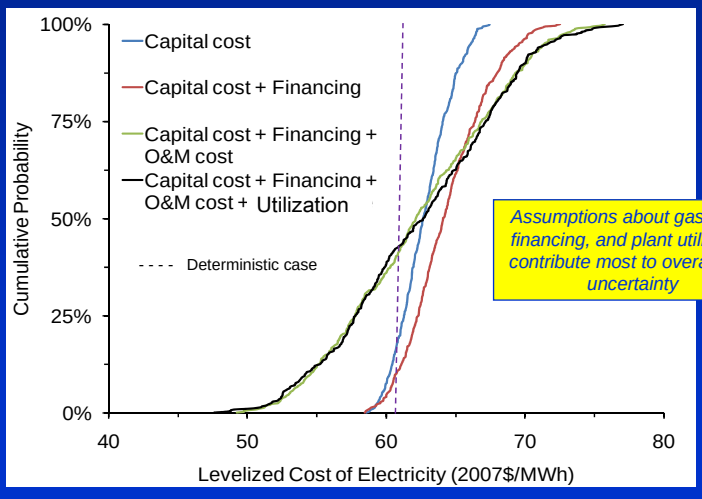
Assumed Uncertainty/Variability for NGCC Plant Parameters

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 *high risk cases:*	0.113 *0.143*	0.100 *0.130*	0.150 *0.180*	Uniform
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

Probabilistic Results for NGCC Reference Plant with no CCS



Assumptions about gas price, financing, and plant utilization contribute most to overall cost uncertainty

Uncertainty Distributions for CO_2 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_2O/ 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 assume a "high risk" premium of 3 percentage point increase in FCF for first of a kind (FOAK) plants (compared to "low risk" *Nth* of kind, NOAK)

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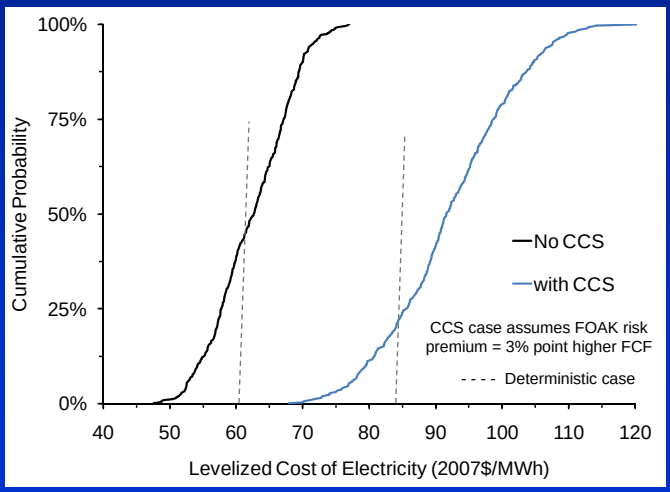
Probabilistic Results for LCOE with and without CCS



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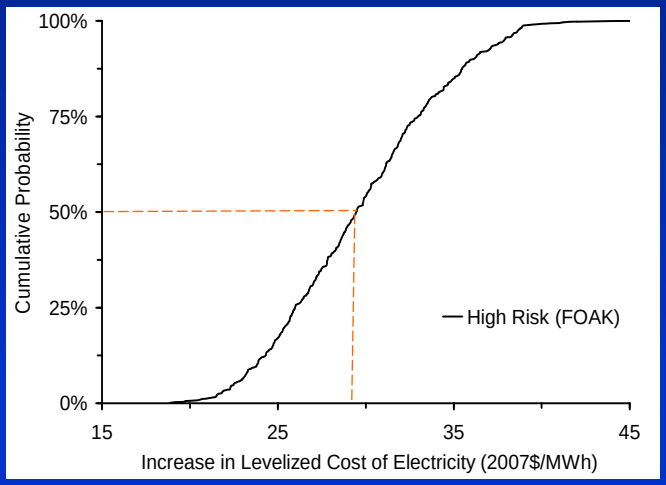
Probabilistic Results for the *Increase in LCOE* with CCS



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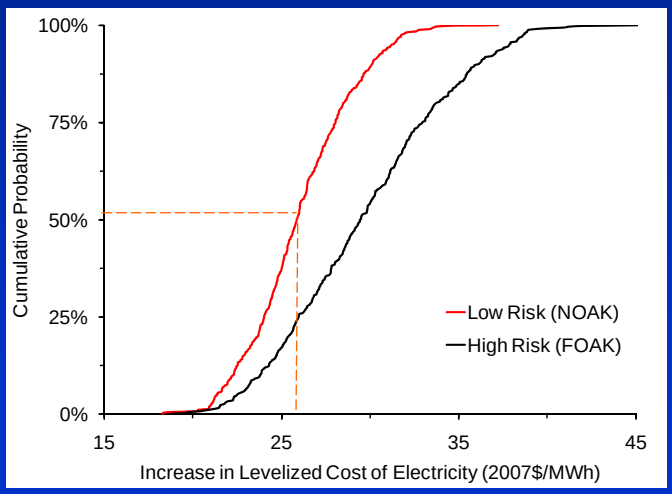
Effect of Financing Assumptions on the *Increase in Cost* with CCS



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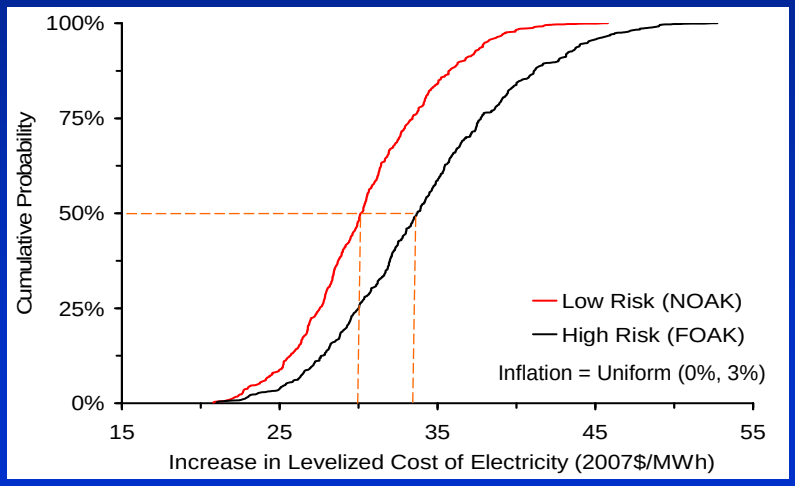
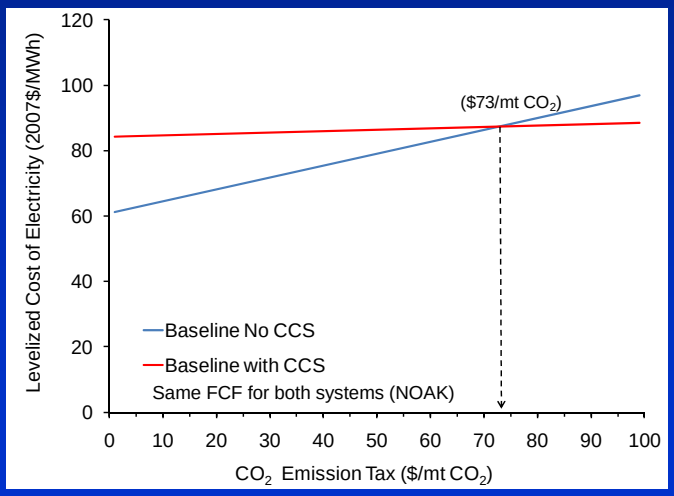
Effect of Inflation Assumption on the *Increase in Cost* with CCS



What carbon price is needed to encourage CCS?

Breakeven Carbon Price for Deterministic Cases



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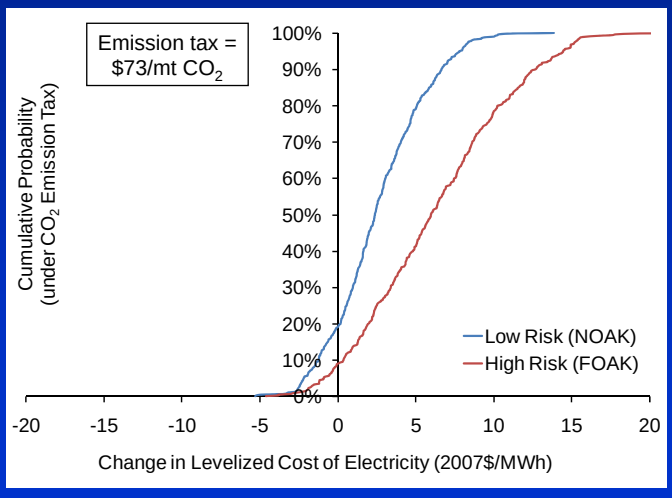
Considering uncertainties the nominal CO_2 price is unlikely to induce CCS



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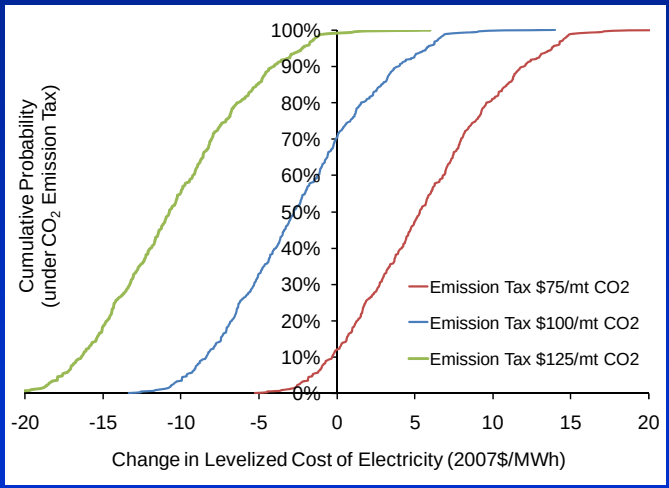
Likelihood of adopting CCS for different CO_2 emission charges



Conclusions *(1)*

- Adding current CCS to 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, based on current technology.
- Uncertainties in the terms of plant financing, the future price of natural gas, and the degree of plant utilization over its lifetime contribute most to the overall variability of current cost CCS estimates.

Conclusions *(2)*

- Because of cost uncertainties, a policy intended to encourage CCS at NGCC plants solely via an emissions tax or a carbon price requires a higher than average price to be effective.
- The levelized cost of NGCC plants with or without CCS will be higher than the values shown here if NGCC plants fail to operate under baseload conditions (as is currently the case).

*Thank You**

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