The Role of Natural Gas Power Plants with Carbon Capture and Storage in a Low-Carbon Future

Samaneh Babaee *ORISE Postdoctoral Fellow, U.S. Environmental Protection Agency, Research Triangle Park, NC*

Daniel H. Loughlin *Senior Scientist, U.S. Environmental Protection Agency, Research Triangle Park, NC*

Introduction

Natural gas combined-cycle (NGCC) with carbon capture and storage (CCS) has the potential to be a major source of low-carbon electricity over the coming decades. However, a number of factors may negatively affect the long-term role of NGCC-CCS:

- **Methane** emissions associated with natural gas production, transmission, and distribution can offset some of the climate benefits relative to coal
- Some carbon dioxide (CO_2) inevitably escapes capture, hurting **competitiveness with zero-carbon technologies** such as wind and solar power
- Significant **cost and efficiency penalties** are associated with capturing and compressing CO_2
- The **low CO_2 content** of natural gas relative to coal may make economically capturing CO_2 more difficult

Objectives

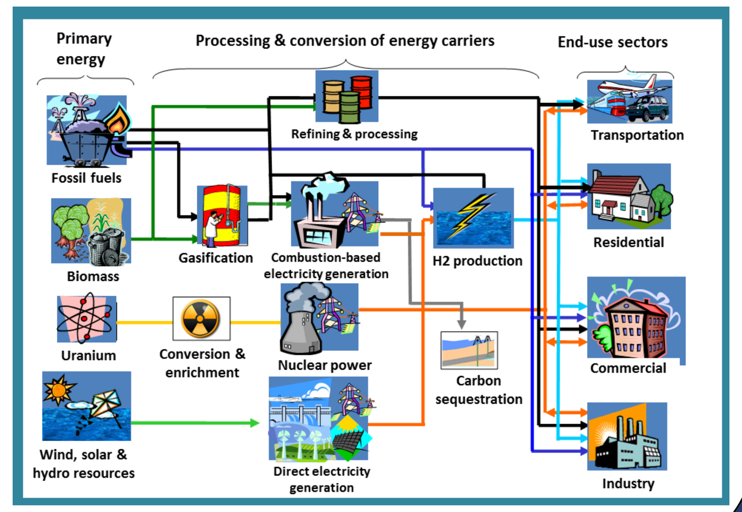
This study is aimed to address the following questions:

- How is the competitiveness of NGCC -CCS affected by technology, fuel, and emission assumptions?
- Is NGCC-CCS more competitive in some parts of the country than others?

Methods

Model and Database:

Used MARKet ALlocation (MARKAL) energy system model, coupled to the EPA U.S. nine-region database (EPAUS9r)



Experimental Design:

- Examine electricity production for Business-As-Usual (BAU) and three greenhouse gas (GHG) reduction trajectories
- Conduct a parametric sensitivity analysis on NGCC-CCS adoption in response to various technological and contextual assumptions under 50% GHG mitigation scenario (GHG50)

Parametric assumptions for sensitivity analyses under GHG50

	Factor	Very low	Low	Default	High	Very high
1	Hurdle rate on biomass with CCS power plant	-	-	10%	-	44%
2	Natural gas price ($/thousand m^3)	173	-	308	-	438
3	Hurdle rate* on nuclear	-	10%	15%	25%	44%
4	Investment cost for NGCC-CCS (M$/GW)	1255	1325	1428	1782	2133
	CO_2 retrofit cost for NGCC ($/KWh)	0.027	0.031	0.041	0.054	0.072
5	CO_2 capture rate for NGCC-CCS and CCS retrofit in NGCC	66%	70%	85%	90%	95%
6	NGCC-CCS efficiency (energy out/energy in)	40%	43%	45%	49%	-
	CCS retrofit efficiency	75%	80%	84%	91%	-
7	CCS retrofit cost for NGCC ($/KWh)	-	-	0.041	0.049	0.066
8	Hurdle rate* for NGCC-CCS	-	5%	10%	25%	45%
	Hurdle rate* for CCS retrofit in NGCC	-	5%	10%	15%	20%
9	Battery storage requirement for renewables (GW storage per GW of variable renewables)	0%	7%	14%	-	-
10	CO_2 storage cost ($/t$CO_2$)	4.90	7.30	9.70	12.1	14.5
11	Electricity storage investment cost (M$/GW)	1000	2000	4623	-	-
12	Methane leakage rate during extraction	0.25%	1.00%	2.30%	4.00%	7.00%
		No range				
13	Max electrification of light duty vehicles (LDVs)	Fixed 99% of LDV fleet purchases				
	Battery electric vehicles	49%				
	Plug-in electric vehicles	50%				
14	Max wind and solar	No upper bound on solar + 27,778 billion KWh upper bound on wind + 2,083 billion Kwh lower bound on total wind and solar electricity generation				
15	No biomass with CCS power plant	No biomass with CCS plant option				
16	No CCS gas retrofit	No CCS retrofit option for natural gas combined cycle plants				
17	No lifetime extension on existing coal	No investment option to extend 50-year lifetime of existing coal plants				
18	No gasification technologies	No biomass- and coal-IGCC plant options				
19	No lifetime extension on existing nuclear	No investment option to extend 40-year lifetime of existing nuclear plants				
20	High nuclear output	833 billion KWh lower bound limit on electricity from nuclear plants				

*Hurdle rate is a technology-specific discount rate replacing the 5% global discount rate used by the model when amortizing capital cost over the technology lifetime. Hurdle rates are used to partially capture non-market factors that may affect technology deployment (e.g., investment risk, technology maturity, uncertainty in future policies and regulations, public opinion and acceptance of a particular technology).

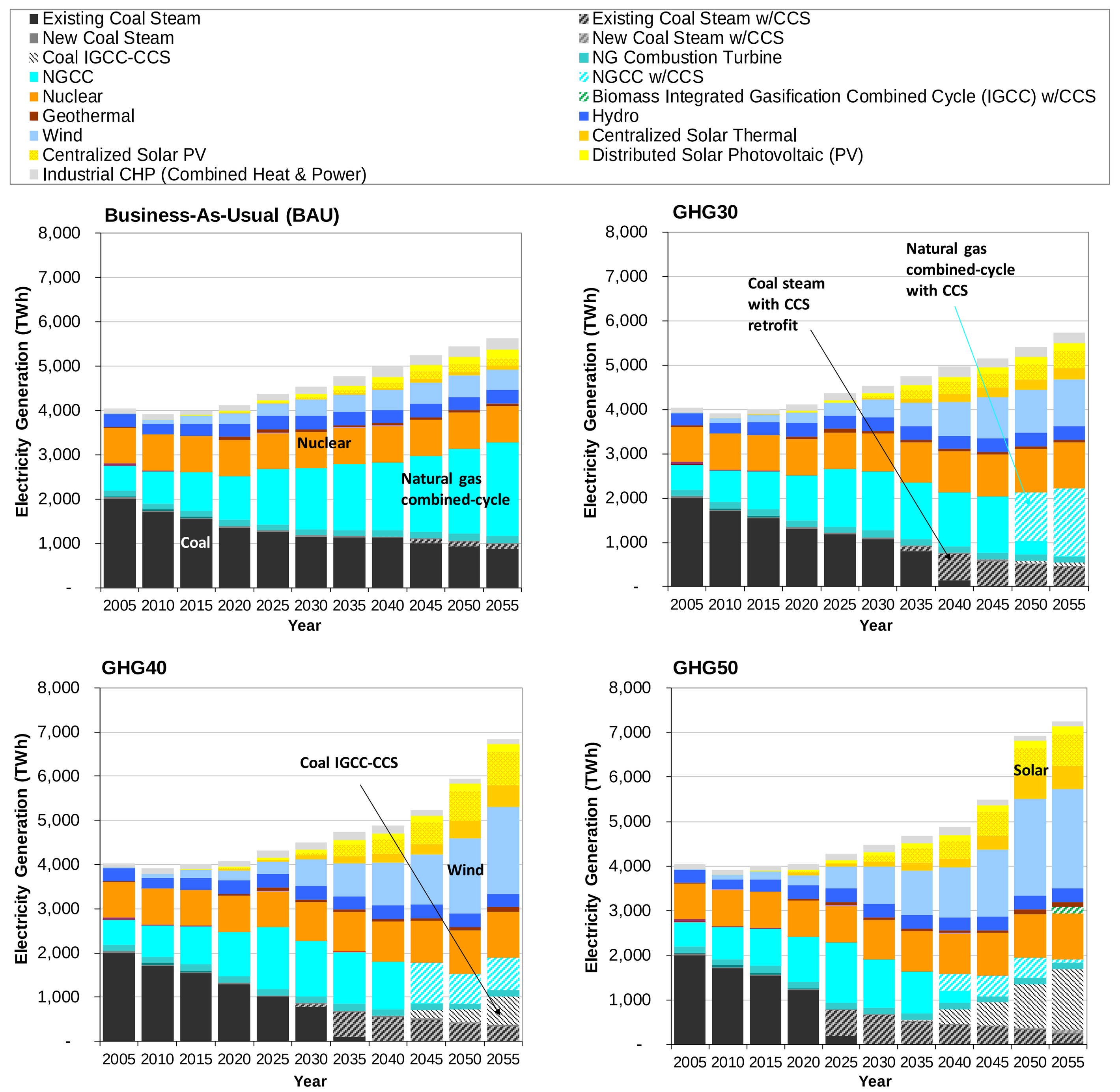
With the combination of GHG50 and every assumption related to 20 parameters

44 Sensitivity runs characteristics

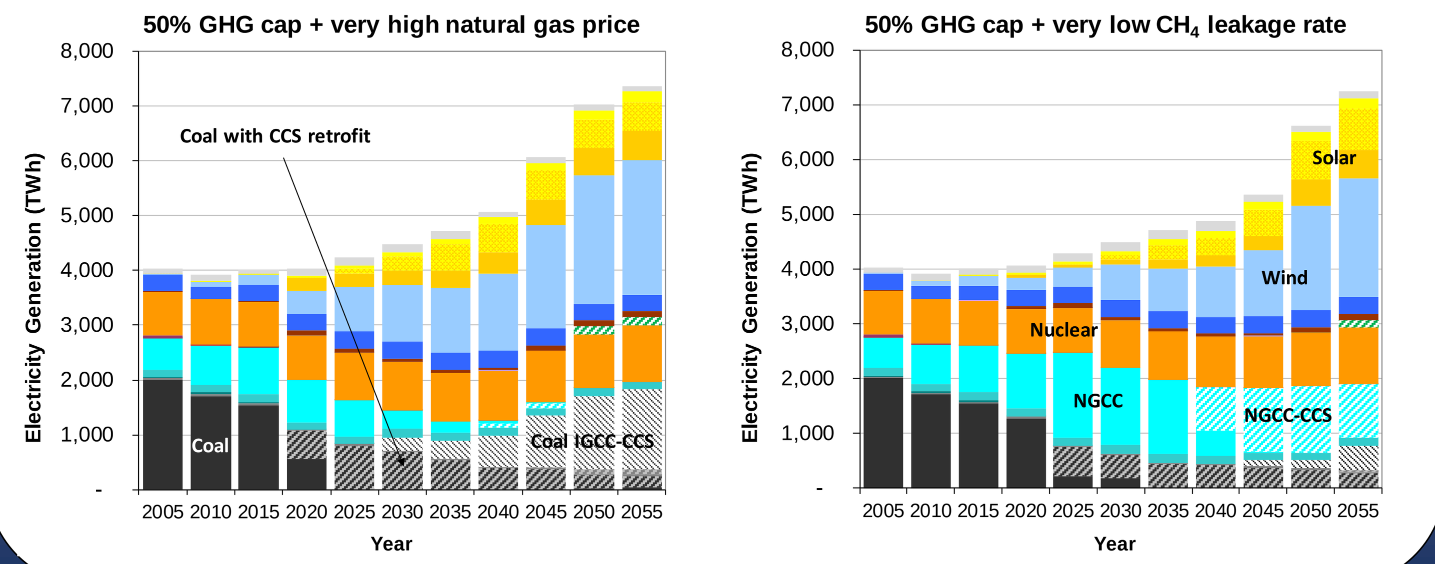
Sensitivity run	Very low	Low	High	Very high
1 GHG50+Natural gas price	X	-	-	-
2 GHG50+Natural gas price	-	-	-	X
3 GHG50+ CO_2 storage cost	X	-	-	-
4 GHG50+ CO_2 storage cost	-	X	-	-
5 GHG50+ CO_2 storage cost	-	-	X	-
6 GHG50+ CO_2 storage cost	-	-	-	X
.				
.				
.				
43 GHG50+Max electrification of LDVs	GHG50+Fixed 99% of LDV fleet purchases			
44 GHG50+No biomass with CCS	GHG50+No biomass with CCS plant option			

Results

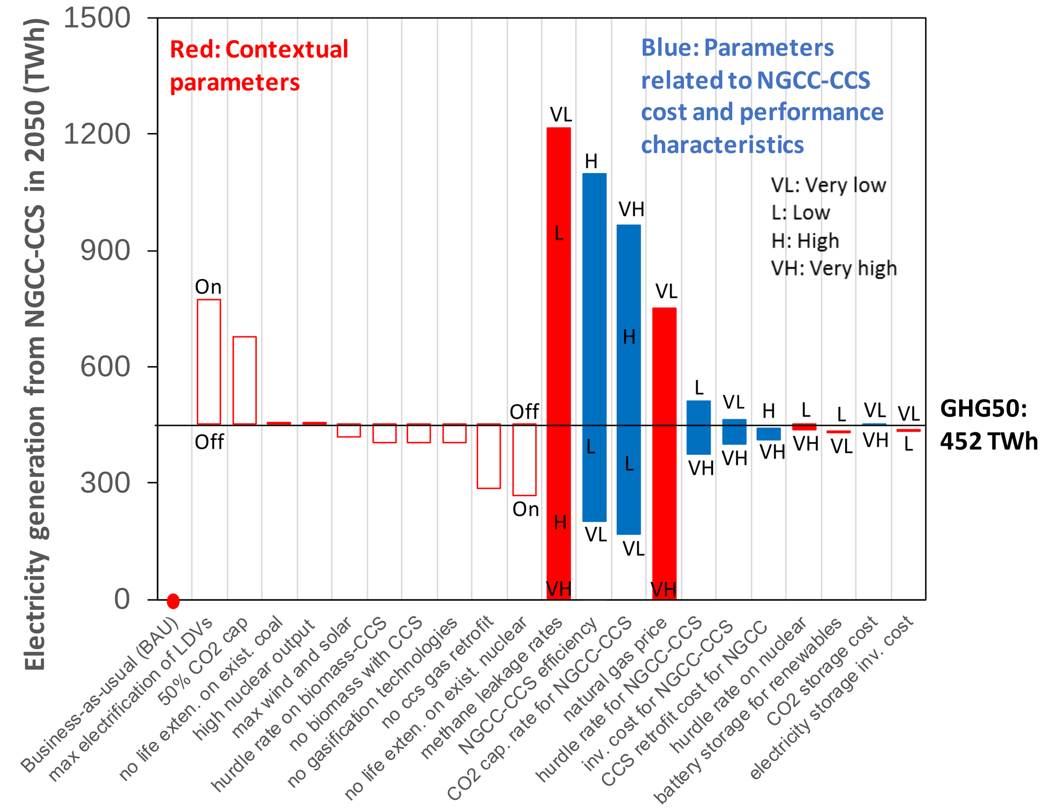
Electricity generation by aggregated technology for BAU, 30%, 40%, and 50% GHG reductions in 2050 relative to the 2005 level



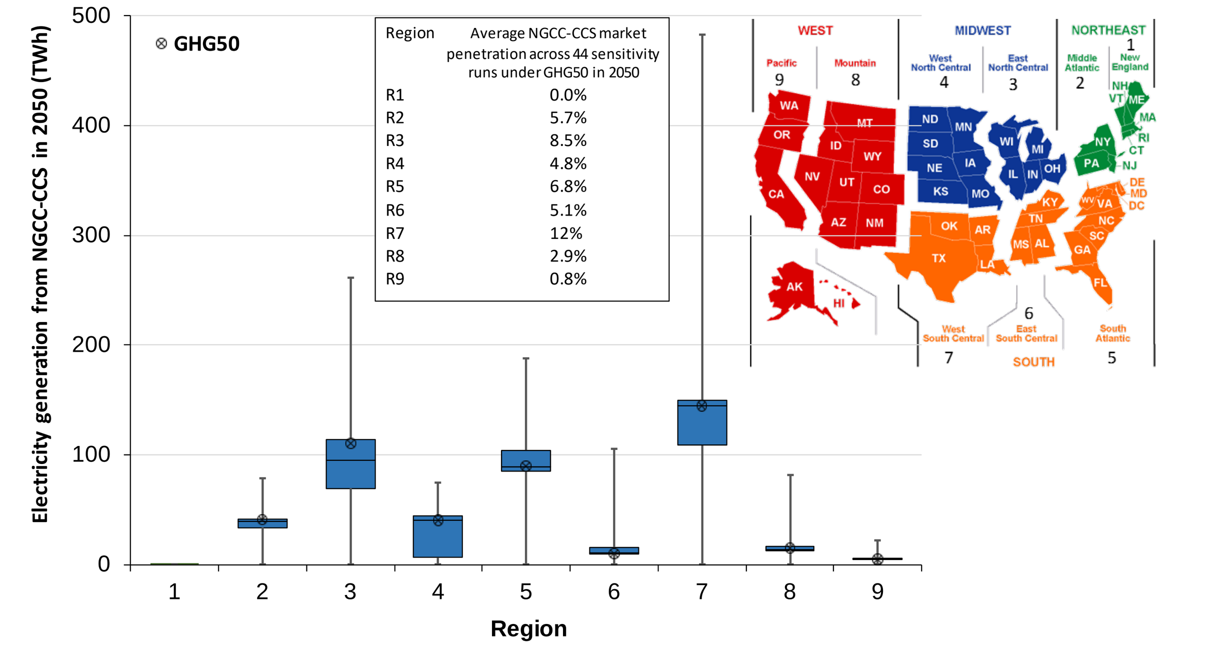
Electricity generation for the lowest NGCC-CCS deployment scenario (left) and the highest NGCC-CCS deployment scenario (right)



The estimated range of electricity production from NGCC-CCS in 2050 across BAU and 44 sensitivity runs under GHG50



NGCC-CCS adoption range across sensitivity runs in each region



Conclusions

- NGCC-CCS was a component of nearly all strategies for achieving 50% energy system-wide GHG reduction target.
- NGCC-CCS plays a greater role in GHG30 than in GHG50. For GHG50, market share is limited by upstream methane emissions and the fraction of emissions that are not captured.
- However, NGCC-CCS never achieved more than 20% of U.S. electricity production. While promising, NGCC-CCS will need to be accompanied by other measures, such as renewables, coal with CCS, or nuclear.