# Economic and Environmental Assessment of Natural Gas Plants with Carbon Capture and Storage (NGCC-CCS)


**Samaneh Babaee (ORISE) and Dan Loughlin**

**U.S. EPA Office of Research and Development**

**Research Triangle Park, NC**



34th USAEE/IAEE North American Conference

October 23-26, 2016 – Tulsa, Oklahoma

# Outline

1. Motivation
2. Objectives
3. Approach
4. Preliminary results
5. Lessons learned

Disclaimer

- The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

# Motivation

- **Natural gas combined-cycle (NG) plants are promoted as a clean technology and a bridge to a low carbon future.**
- **NG plants have a number of advantages:**
  - Compared to new coal and nuclear plants
    - Relatively low investment cost
    - Easier to site and shorter build time
  - Lower NG prices in recent years due to the technological advancements in U.S. shale gas exploration
  - NG combined-cycle turbines (NGCC) can be retrofitted at a later date with carbon capture and sequestration (CCS)

# Motivation

- **NG plants have a number of challenges:**
  - Methane ($CH_4$) leakage in the NG extraction, processing, transmission and distribution processes
  - Carbon dioxide ($CO_2$) capture and sequestration results in a higher cost and energy penalty
  - The low $CO_2$ content of gas from conventional NGCC plants yield difficulties in capture
  - Stringent $CO_2$ reduction targets may make natural gas plants less attractive, even with CCS
- **The competitiveness of NGCC-CCS technologies may be affected by regional variations in fuel prices and access to renewables, as well as the presence and stringency of a $CO_2$ cap.**

# Objectives

- How do various factors affect the competiveness of NGCC-CCS and its potential role in climate change mitigation?
  - e.g., NGCC cost and efficiency, $CO_2$ capture cost and capture rate, fuel prices, methane leakage rate, stringency of greenhouse gas (GHG) reduction targets, nuclear hurdle rates, …
- Do results change when we use a regional model?
  - Are there important underlying stories when we examine NGCC-CCS penetration at the regional level?

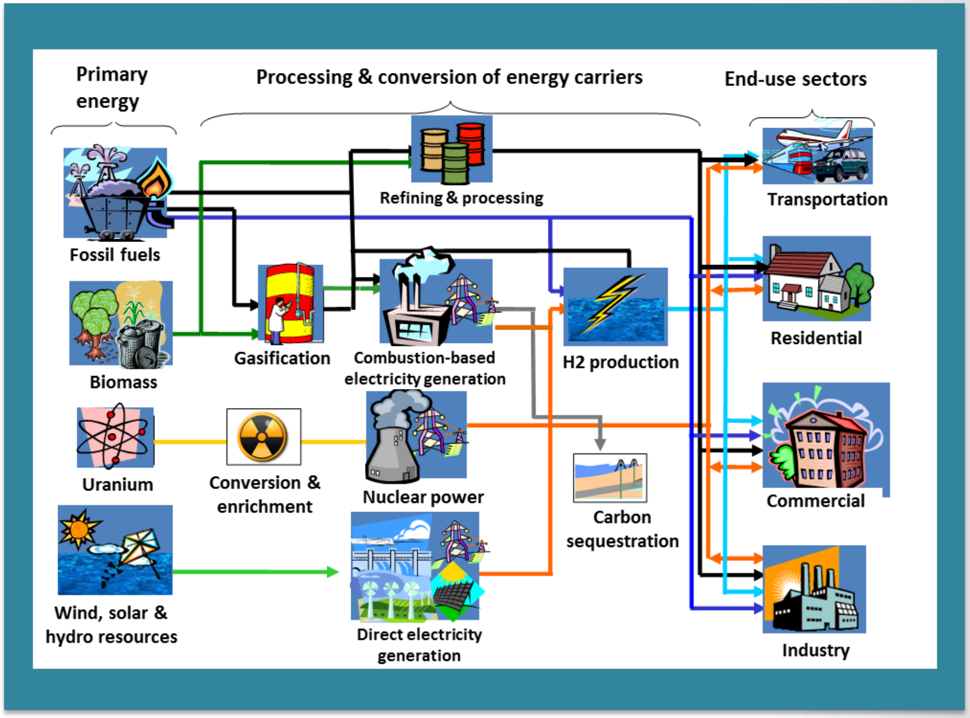
# Approach

- Used MARKet ALlocation (MARKAL) energy system model along with U.S. 9-region EPA database (EPAUS9r-2014), which can capture regional deployment of NGCC-CCS.
- Performed sensitivity analysis to explore conditions in which NGCC-CCS can compete with other power plants in each region through 2050 in response to:
  - 30% and 40% system-wide GHG cap
  - 50% system-wide GHG cap:
    - with variations in CCS retrofit characteristics (costs, capture rate, hurdle rate, efficiency penalty), NG prices, renewables availability and storage level, nuclear lifetime and cost, leakage rates… → 45 sensitivity runs
- Quantified energy consumption and $CO_2$ emissions as well as air pollutant emissions (nitrogen oxides (NOx), sulfur dioxide ($SO_2$),…) for each region and scenario.

# Approach
# Energy system model: MARKAL

- **Bottom-up, technology-rich, and capture the full energy system:**
  - Technologies cost and performance estimates (efficiency, emission factors,…)
  - Technologies are connected via flow of energy commodities
  - End-use demands
  - Constraints (energy/emission regulations and policies, …)

- **Optimization**
  - Identify the least-cost way to satisfy end-use demands over the model time horizon from 2005 to 2055




- **Model output**
  - Optimal installed capacity and utilization by technology
  - Marginal fuel prices
  - Emissions

# Approach
# Sensitivity parameters

**Contextual parameters:**

- No lifetime extension on existing coal
- No lifetime extension on existing nuclear
- Hurdle rate for nuclear plant
- Natural gas price
- Methane leakage rate
- Maximum electrification of LDVs
- Wind and solar availability
- Battery storage capacity for renewables
- Electricity storage cost
- No CCS gas retrofit
- No gasification technologies
- No biomass gasification with CCS (BioIGCC-CCS)
- Hurdle rate for BioIGCC-CCS

## NGCC-CCS parameters:

**Cost**

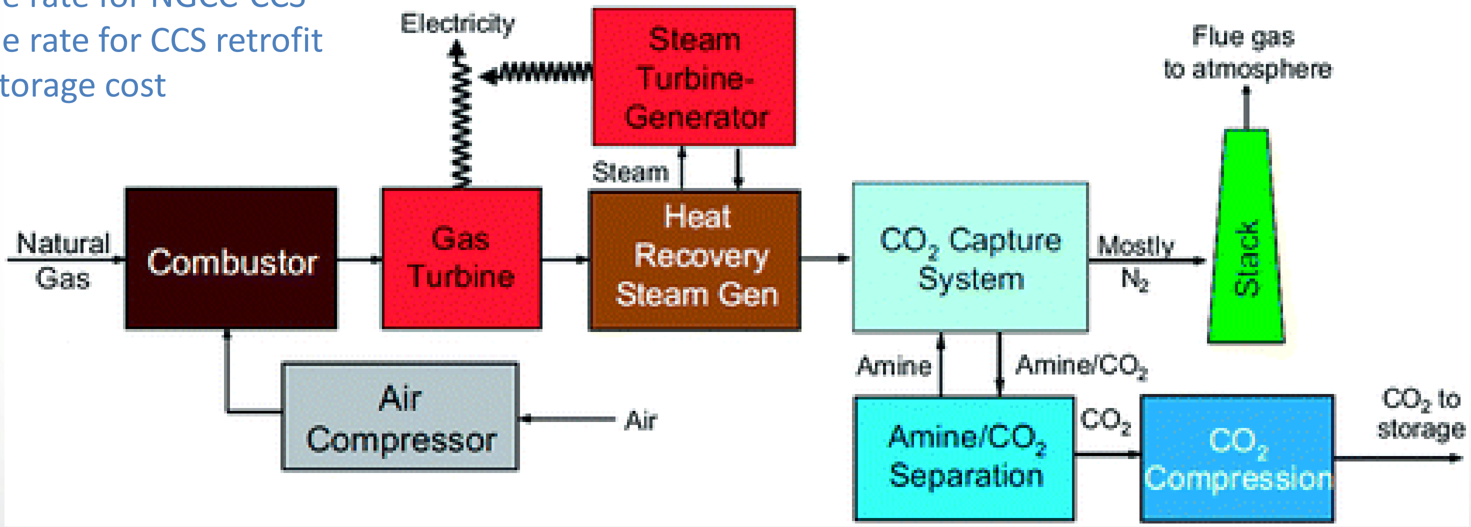
- Investment cost for NGCC-CCS
- CCS retrofit cost
- Hurdle rate for NGCC-CCS
- Hurdle rate for CCS retrofit
- $CO_2$ storage cost

**Performance: Efficiency**

- Efficiency penalty for NGCC-CCS
- Efficiency penalty for CCS retrofit

**Performance: $CO_2$ capture rate**

- $CO_2$ capture rate for NGCC-CCS
- $CO_2$ capture rate for CCS retrofit




*Source: Kenarsari et al. (2013)*

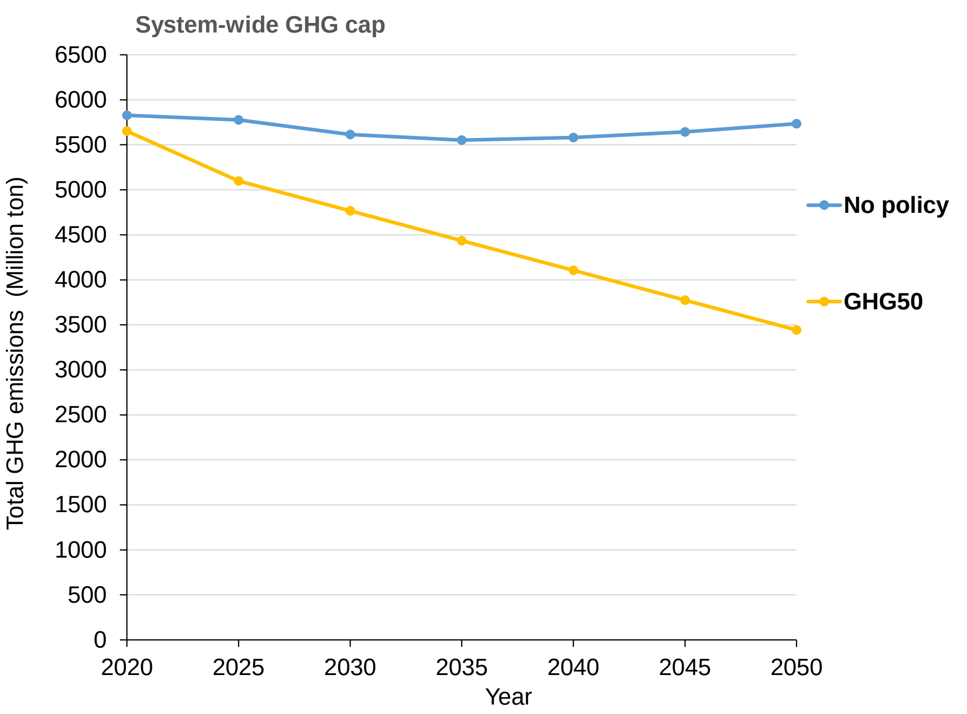
# Assumptions

Baseline and all GHG mitigation scenarios include:

- Cross-State Air Pollution Rule (CSAPR), Clean Power Plan (CPP) (regional caps derived from IPM mass-based analysis), and Corporate Average Fuel Efficiency (CAFE) standards for light duty vehicles
- Updated solar PV costs from the EPA's Integrated Planning Model (IPM)
- Simplified hurdle rates for power plants (new nuclear:15%, coal and nuclear extension: 5%, and other new power plants: 10%)
- Upper bound capacity on new nuclear electricity generation is 5GW in 2020, which can grow up to 5% per year until 2055 (Max: 28GW new nuclear is built by 2055).
- The maximum share of electricity generation from wind and solar photovoltaics (PV) is limited to 50% of system-wide electricity production from 2010 through 2055.

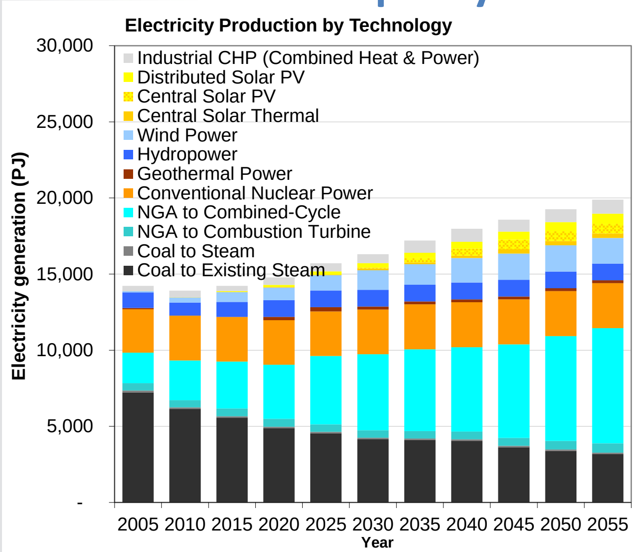
# Assumptions

- Sensitivity analysis on 20 model parameters yielded a total of 45 MARKAL scenarios
- Discretized each parameter into very low, low, high, very high
- Ran MARKAL for individual parametric sensitivity
- For discussion purposes, focus on the results for:
  - No GHG policy
  - 50% GHG energy system-wide reduction by 2050, relative to 2005 (GHG50)



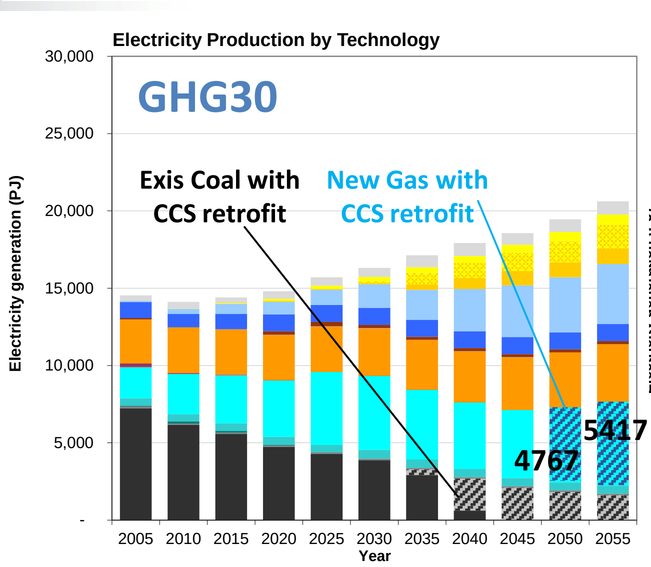
# Preliminary results
# Electricity generation

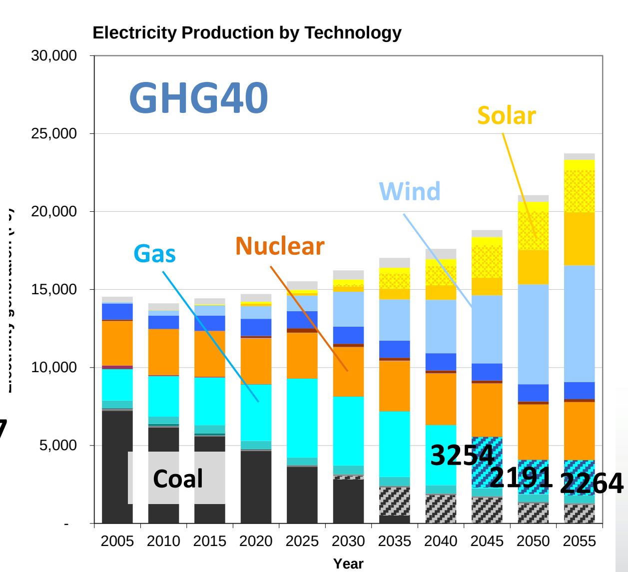
## Baseline: No policy

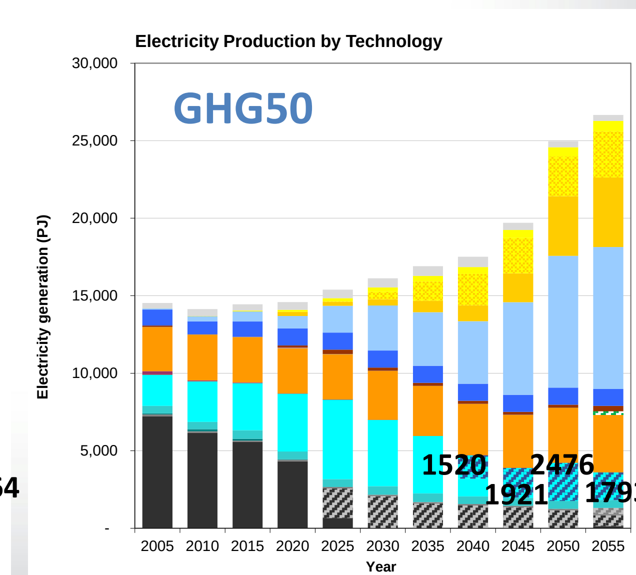



## Electricity generation from natural gas power plants (PJ)

| Scenario | 2015 | 2030 | 2050 |
|---|---|---|---|
| No Policy | 3600 | 5480 | 7540 |
| GHG30 | 3710 | 5370 | 5390 |
| GHG40 | 3710 | 4990 | 2710 |
| GHG50 | 3710 | 4830 | 2970 |

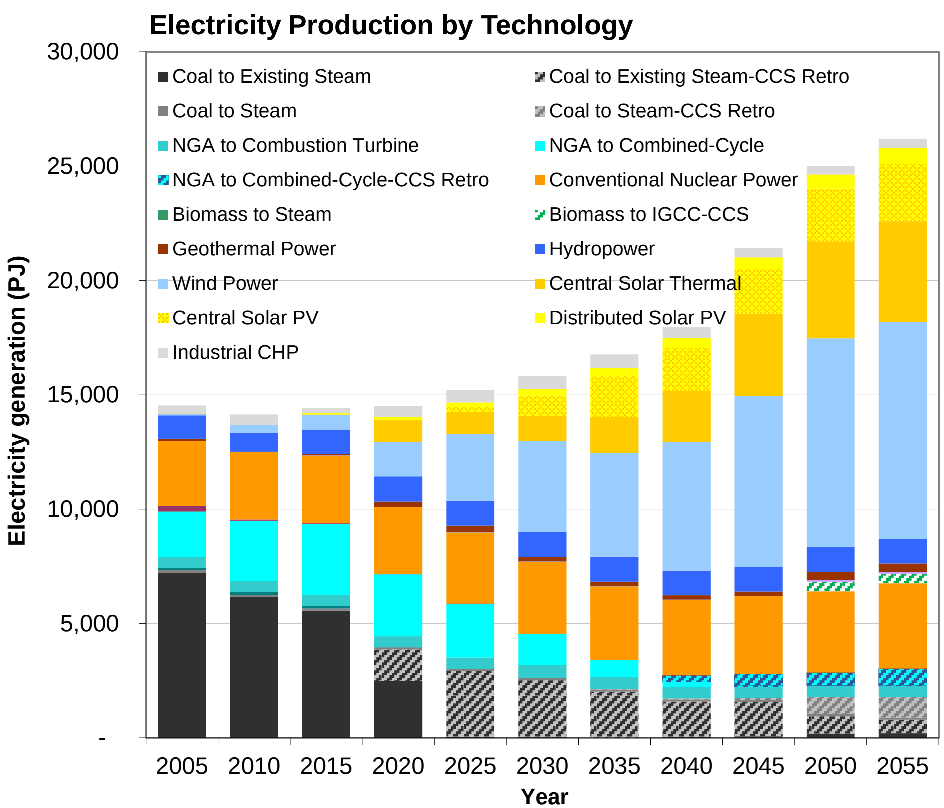


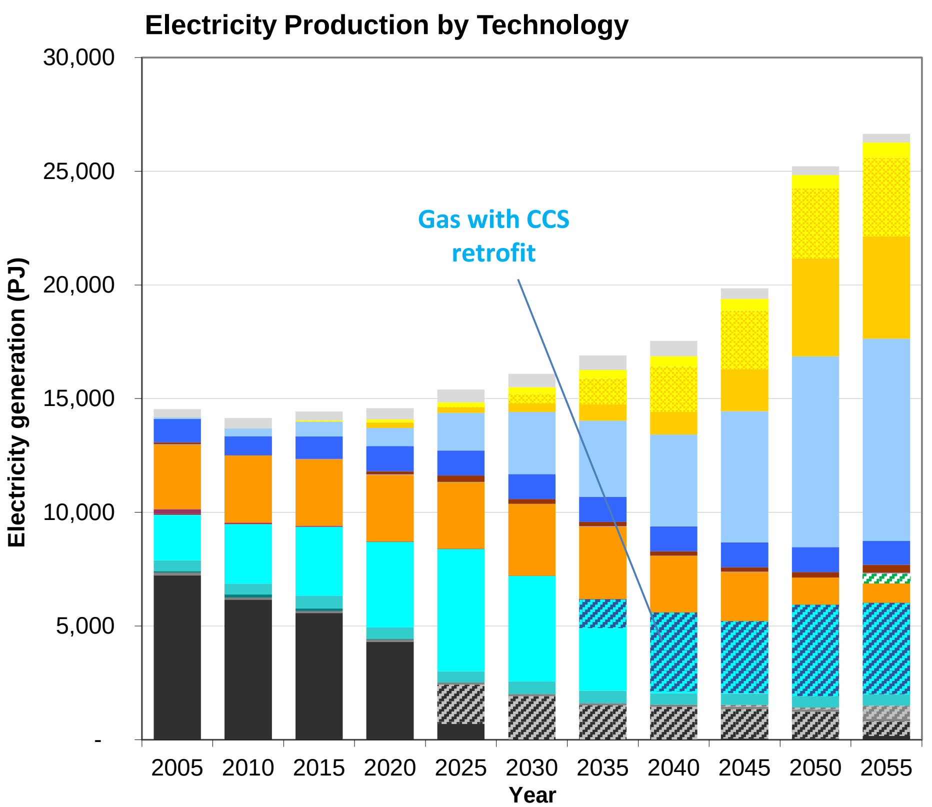



# Preliminary results
## Electricity generation under 50% GHG cap

**Lowest NGCC-CCS deployment: Very high natural gas price + GHG50**

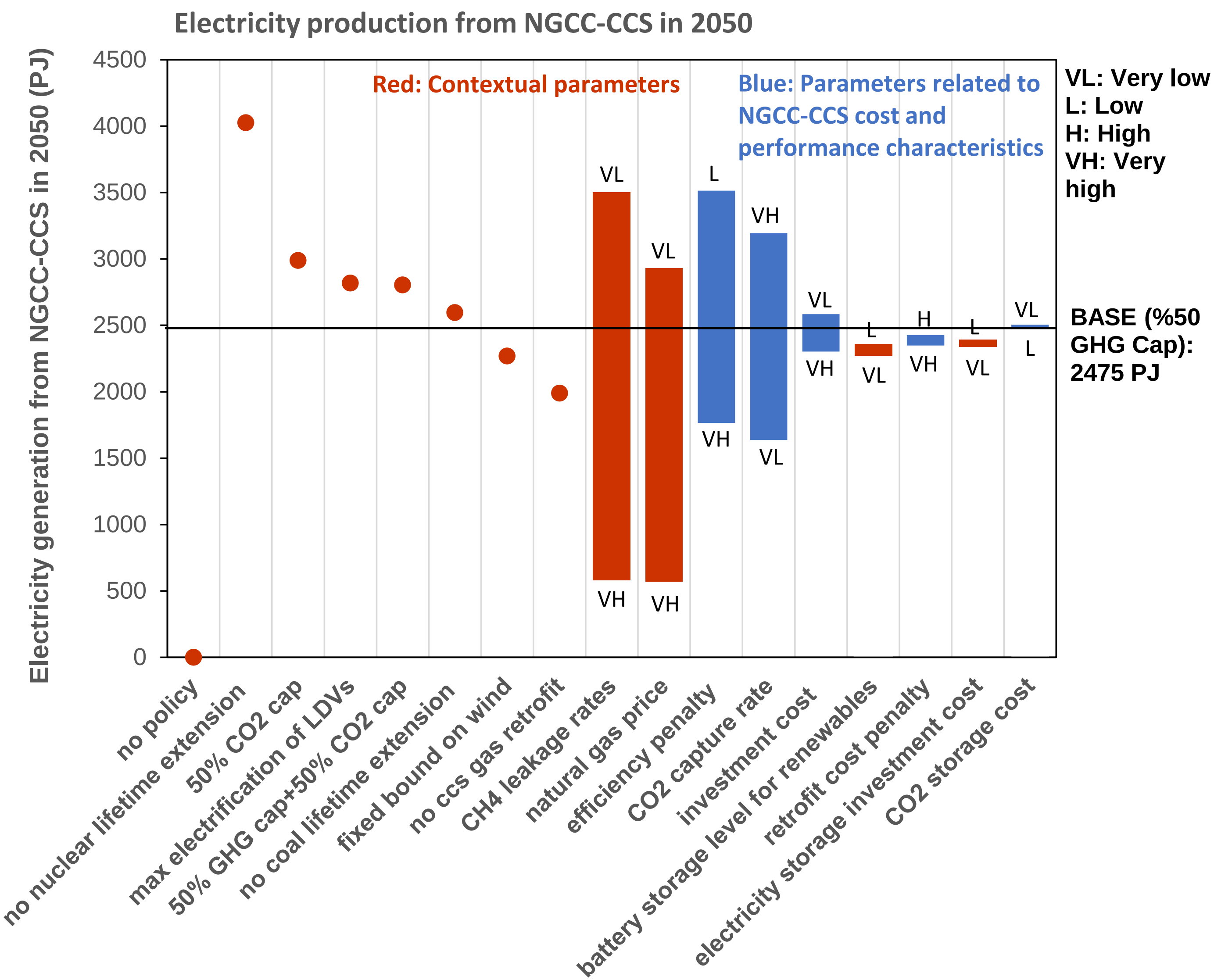



**Highest NGCC-CCS deployment: No nuclear lifetime extension + GHG50**




- In low NGCC-CCS deployment: Higher coal with CCS, wind, solar thermal, and nuclear post 2040
- In High NGCC-CCS deployment: Higher central solar PV, NGCC (with CCS retrofit starting 2035)

# Preliminary results
## Electricity generation from NGCC-CCS under GHG50



# Preliminary results
# GHG cap vs. methane leakage rate in 2050

- As GHG cap and CH4 leakage rate increase, NGCC-CCS deployment, NOx and $CO_2$ emissions, and NG consumption decrease, but solar and wind deployment increases, nuclear is fixed.

- As GHG cap increases, coal deployment, PM health damages, and $SO_2$ emissions decrease.

**NGCC-CCS deployment (PJ)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 3910 | 3440 | 2920 | 1230 |
| GHG40 | 3830 | 2690 | 1660 | 1290 |
| GHG50 | 3500 | 2990 | 1430 | 580 |

**Nuclear deployment (PJ)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 3550 | 3550 | 3550 | 3550 |
| GHG40 | 3550 | 3550 | 3550 | 3550 |
| GHG50 | 3550 | 3550 | 3550 | 3550 |

**Coal deployment (PJ)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 2030 | 2020 | 1830 | 1760 |
| GHG40 | 1510 | 1450 | 1490 | 1780 |
| GHG50 | 1060 | 1140 | 1580 | 1790 |

**Solar and wind deployment (PJ)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 5280 | 5800 | 8450 | 10980 |
| GHG40 | 8740 | 10270 | 13390 | 15320 |
| GHG50 | 13680 | 14410 | 16210 | 16310 |

**Water consumption (trillion gallon)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 1460 | 1470 | 1310 | 1190 |
| GHG40 | 1360 | 1260 | 1220 | 1290 |
| GHG50 | 1290 | 1290 | 1350 | 1530 |

**PM-related health damages (billion $)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 1130 | 1130 | 1120 | 1100 |
| GHG40 | 1050 | 1040 | 1000 | 1000 |
| GHG50 | 980 | 980 | 980 | 1000 |

**Total NOx (Kt)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 6340 | 6330 | 6200 | 5940 |
| GHG40 | 5980 | 5880 | 5530 | 5270 |
| GHG50 | 5080 | 5020 | 4980 | 4810 |

**Total $SO_2$ (Kt)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 2140 | 2150 | 1980 | 1800 |
| GHG40 | 1430 | 1360 | 1240 | 1310 |
| GHG50 | 1180 | 1200 | 1200 | 1300 |

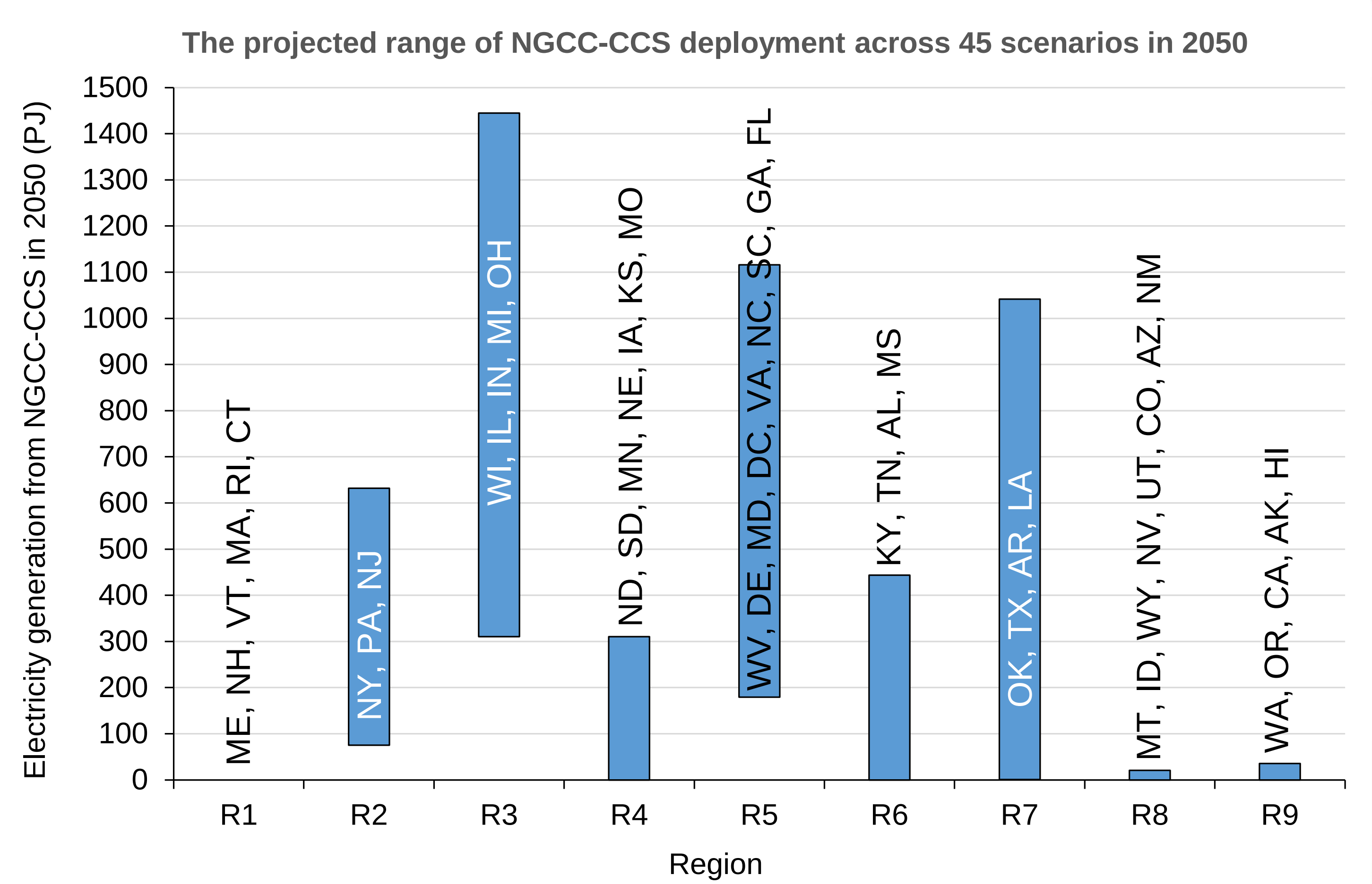
**Total $CO_2$ (Mt)**

| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 4210 | 4090 | 3740 | 3550 |
| GHG40 | 3610 | 3520 | 3260 | 3070 |
| GHG50 | 3170 | 3090 | 2870 | 2710 |

**Total natural gas consumption (PJ)**

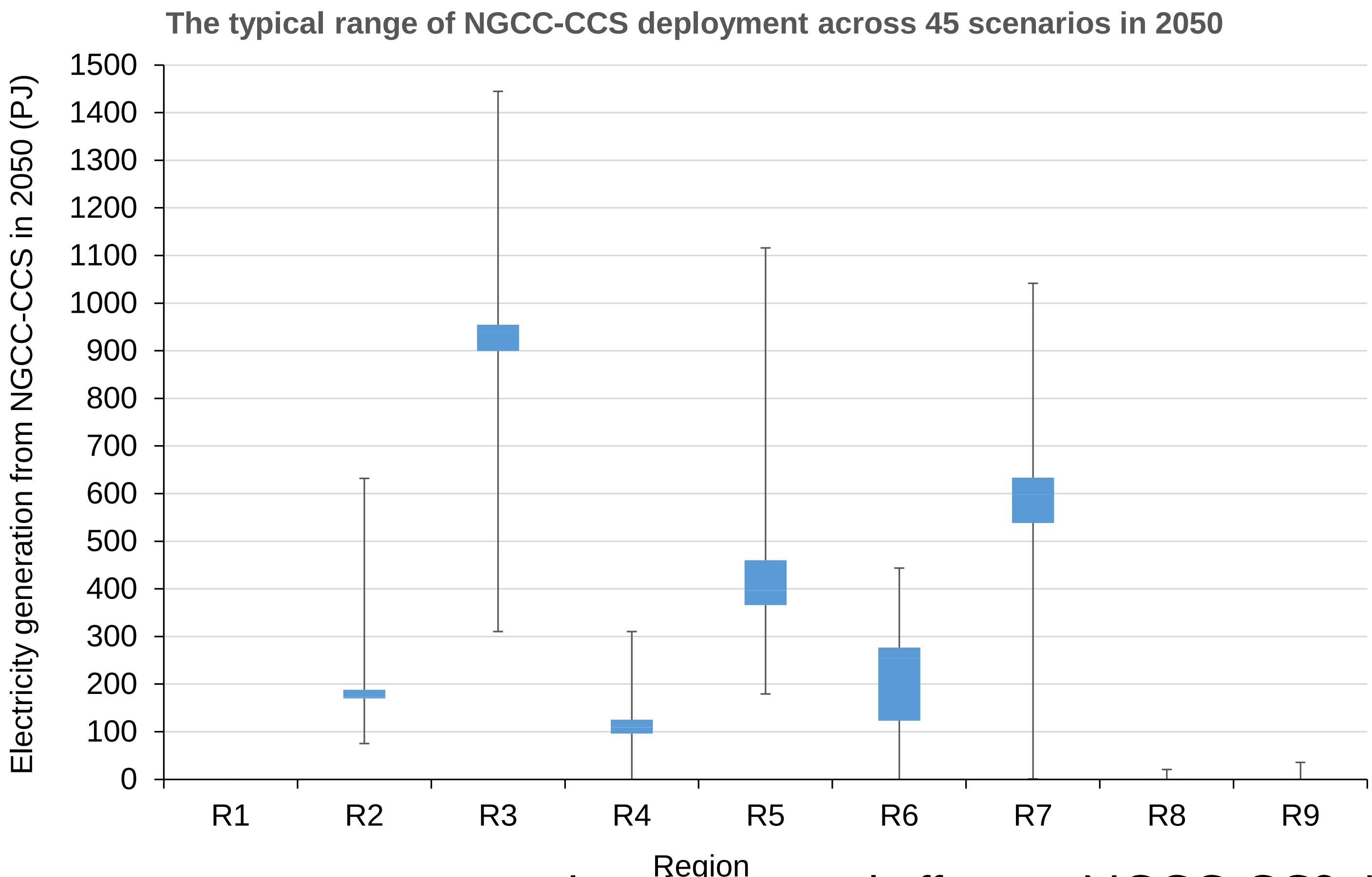
| GHG cap | Methane Leakage rate | | | |
|---|---|---|---|---|
| | 0.25% | 1.00% | 4.00% | 7.00% |
| GHG30 | 29140 | 28260 | 23400 | 19140 |
| GHG40 | 25170 | 22450 | 18180 | 15290 |
| GHG50 | 20370 | 19100 | 15840 | 13640 |

# Preliminary results
# Regional NGCC-CCS adoption under GHG50




- R3 has the widest range of NGCC-CCS adoption with very low influence from different scenario parameters.
- The NGCC-CCS deployment in R1, R8, and R9 is negligible.

# Preliminary results
# Regional NGCC-CCS adoption under GHG50




- Variation in scenarios parameters has the minimal effect on NGCC-CCS deployment in R2 and R4.
- R5 has higher NGCC-CCS deployment than R7, but the typical range of NGCC-CCS adoption is higher in R7.

# Lessons learned

- Mild GHG cap leads to higher NGCC-CCS deployment in later time periods, while stringent GHG cap results in lower NGCC-CCS deployment starting earlier in the model time horizon.
- Under 50% GHG cap and at the national level in 2050:
  - Highest NGCC-CCS deployment scenario: no nuclear lifetime extension
  - Lowest NGCC-CCS deployment scenario: very high NG price
    - The main trade-off is between nuclear and NGCC-CCS plants
  - Uncertainty in $CH_4$ leakage rates result in the largest range of NGCC-CCS adoption.
- Increased GHG cap and methane leakage rate result in:
  - Decrease in NGCC-CCS deployment, NOx and $CO_2$ emissions, and NG consumption
  - Increase in electricity generation from renewables
  - Fixed electricity production from nuclear power plants
- At the regional level, the minimum deployment of NGCC-CCS is seen in R1, R8, and R9; the widest range of NGCC-CCS adoption is associated with R3; NGCC-CCS deployment in R2 and R4 is the least responsive to variations in scenario parameters.

# Next steps

- Add other scenario parameters:
  - Change the methane leakage rate over time
  - $CO_2$ leakage from $CO_2$ storage sites
  - Assume NGCC with CCS retrofit as a baseload power plant
- Examine the effects of including emissions associated with $CO_2$ transport through pipelines, trucks (gasoline, diesel, natural gas, … )
- Examine the role of NET Power gas plant in our analysis
- Develop nested sensitivity analysis

# Questions?

Contact information:

Samaneh Babaee, Ph.D.

ORISE Postdoctoral Fellow at the U.S. EPA

Babaee.Samaneh@epa.gov