Updated Costs for Carbon Capture Retrofits

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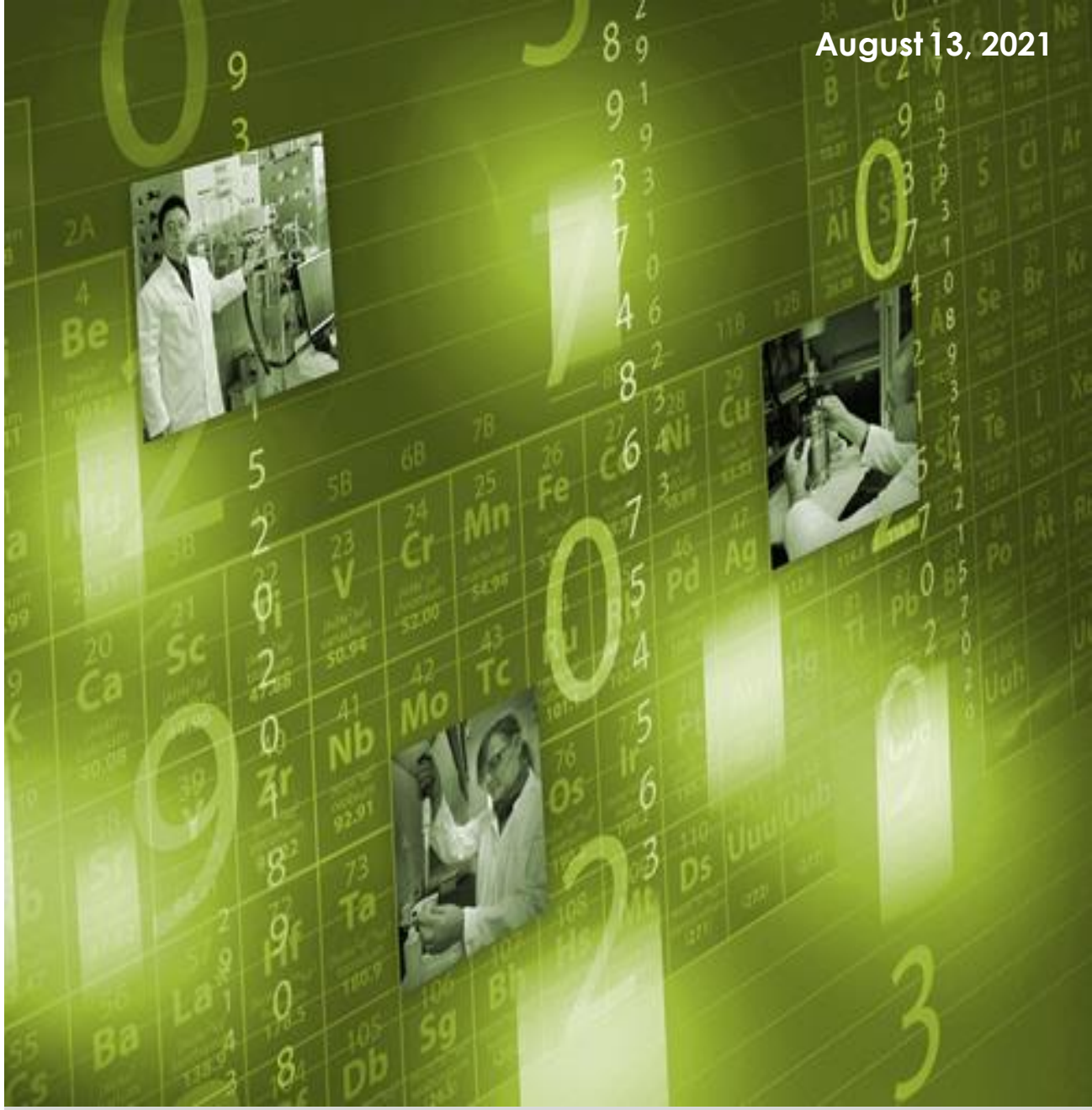
Preliminary Results – Subject to Revision

August 13, 2021



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Agenda

- **Natural Gas Retrofit Updates**
  - Design Basis
  - Performance Results
  - Cost Results
  - Sensitivities

Design Basis

Basis for Model and Cost Development

- **QGESS for Carbon Capture Retrofit (in process)**
- **QGESS for Capital Cost Estimation Methodology[1]**
- **Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal (PC) and Natural Gas to Electricity (2019) – Rev 4[2]**
  - Cases B31A/B (NGCC)
  - H-class supplement – Cases B32A/B (in process)
- **Aspen Plus v10**
  - Previous revisions of the NGCC retrofit report were developed in GTPro
  - Development of F(retrofit)- and H-frame cases

1 - https://netl.doe.gov/projects/files/QGESSCostEstMethodforNETLAssessmentsofPowerPlantPerformance_022621.pdf
2 - https://netl.doe.gov/projects/files/CostAndPerformanceBaselineForFossilEnergyPlantsVol1BitumCoalAndNGtoElectBBRRev4-1_092419.pdf

Site Characteristics

Parameter	Value
Location	Greenfield, Midwestern U.S.
Topography	Level
Size (NGCC), acres	100
Transportation	Rail or Highway
Water	50% Municipal and 50% Ground Water

Parameter	Value
Elevation, m (ft)	0 (0)
Barometric Pressure, MPa (psia)	0.101 (14.696)
Average Ambient Dry Bulb Temperature, °C (°F)	15 (59)
Average Ambient Wet Bulb Temperature, °C (°F)	10.8 (51.5)
Design Ambient Relative Humidity, %	60
Cooling Water Temperature, °C (°F)[A]	15.6 (60)
Air composition based on published psychrometric data, mass %	
N_2	75.055
O_2	22.998
Ar	1.280
H_2O	0.616
CO_2	0.050
Total	100.00

[A]The cooling water temperature is the cooling tower cooling water exit temperature. This is set to 4.8°C (8.5 °F) above ambient wet bulb conditions in ISO cases.

Fuel Characteristics

Component		Volume Percentage
Methane	CH_4	93.1
Ethane	C_2H_6	3.2
Propane	C_3H_8	0.7
n-Butane	C_4H_{10}	0.4
Carbon Dioxide	CO_2	1.0
Nitrogen	N_2	1.6
Methanethiol[A]	CH_4S	$5.75x10^{-6}$
	Total	100.0

	LHV	HHV
kJ/kg (Btu/lb)	47,201 (20,293)	52,295 (22,483)
MJ/scm (Btu/scf)	34.52 (927)	38.25 (1,027)

[A]The sulfur content of natural gas is primarily composed of added Mercaptan (methanethiol [CH_4S]) with trace levels of hydrogen sulfide (H_2S)

Emission Limits

- **Air Emissions: All cases are compliant with the current utility Mercury and Air Toxics Standards (MATS) and New Source Performance Standards (NSPS)**
  - CO_2 emission limit for NGCC technology is 1,000 lb CO_2/MWh-gross
  - B31A has a CO_2 emission rate of 741 lb/MWh-gross

Pollutant[A]	NGCC (lb/MWh-gross)
SO_2	0.90
NOx	0.43
PM (Filterable)	N/A
Hg	N/A
HCl	N/A

[A] Carbon monoxide (CO) emissions will be reported as 1 ppm

- **Water Emissions: Based on the global plant assumptions made for NGCC cases in Revision 4 of the Bituminous Baseline report, there were no water streams that required treatment to attain compliance with the effluent limitation guidelines**
  - H-frame cases will apply the same set of plant assumptions, and thus, are compliant without additional treatment technology

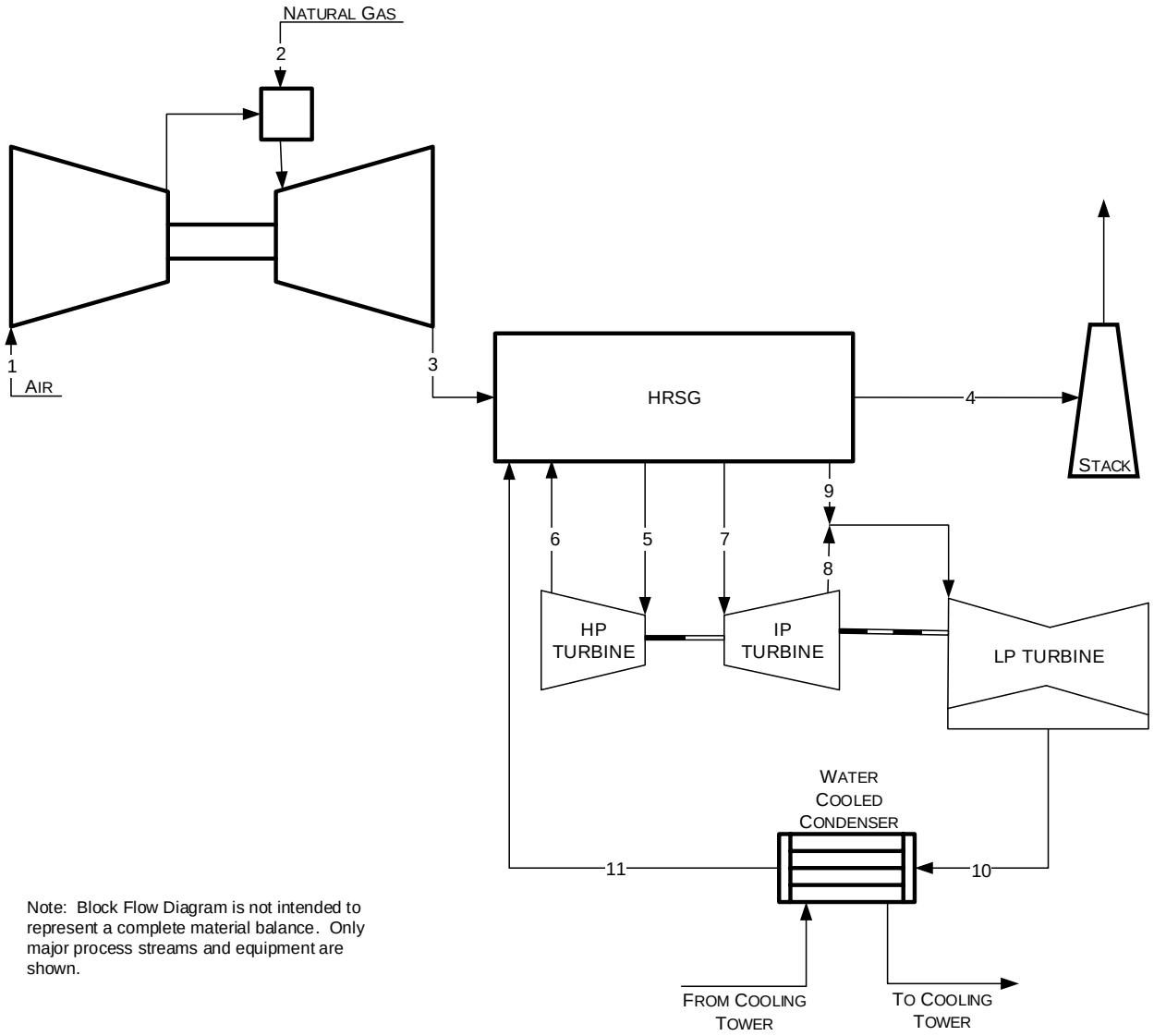
Case List

Case[A]	Unit Cycle	Steam Cycle, psig/°F/°F	Combustion Turbine	Heat Recovery	Oxidant	NOx Control	CO_2 Separation	Capture Rate	Plant Type	Process Water Treatment
B31A	NGCC	2400/1085/1085	2 x State-of-the-art 2017 F-Class	Heat Recovery Steam Generator (HRSG)	Air	Low NOx Burner and Selective Catalytic Reduction	N/A	N/A	Greenfield	N/A
B31B							Cansolv	90%	Greenfield	
B31A-BR							Cansolv	90%	Brownfield (retrofit)	
B32A		2700/1085/1045	2 x State-of-the-art 2017 H-Class				N/A	N/A	Greenfield	
B32B							Cansolv	90%	Greenfield	
B32A-BR							Cansolv	90%	Brownfield (retrofit)	

[A] Natural Gas feed flow rate is the same amongst similar frames types.

Block Flow Diagram

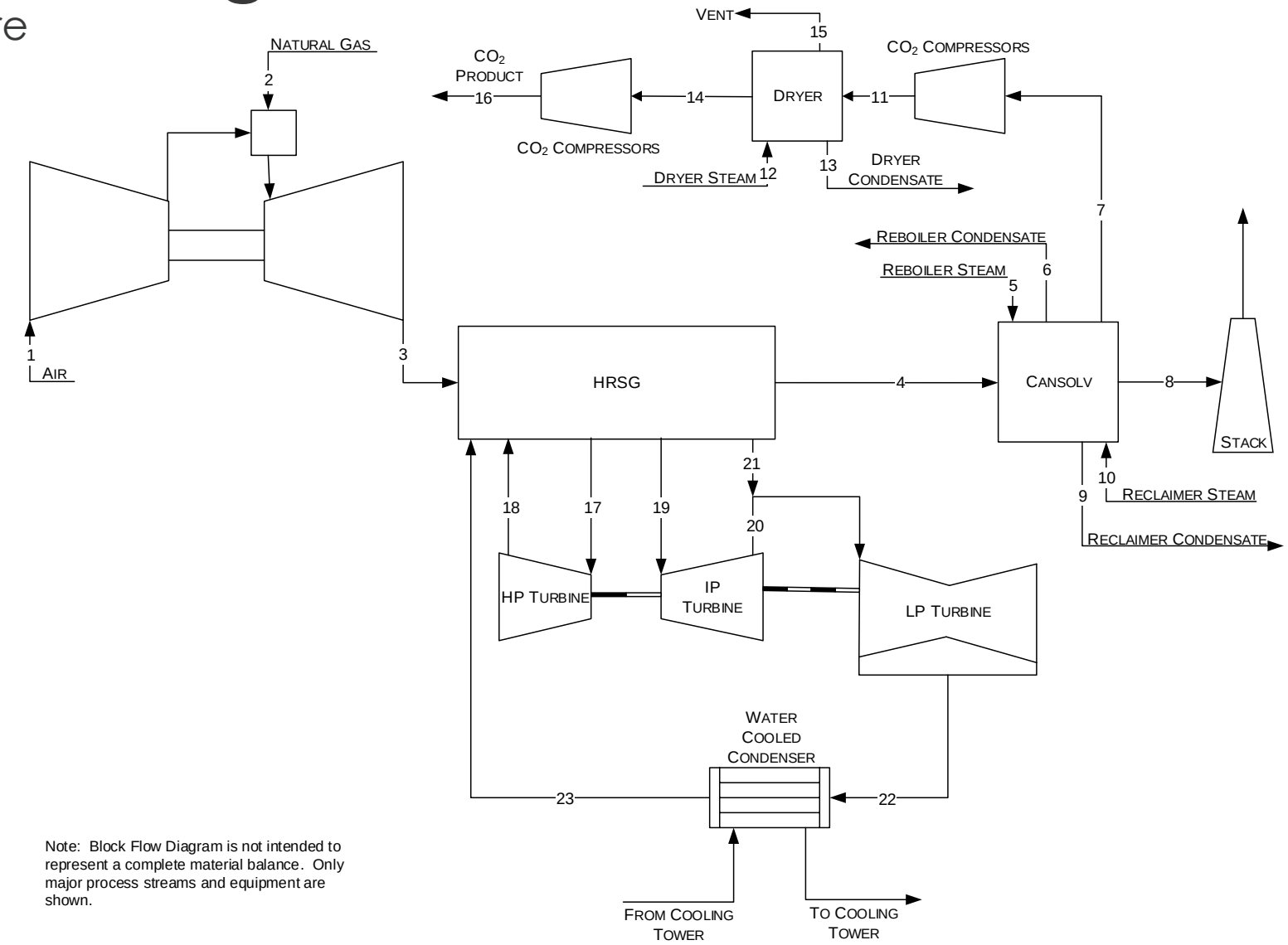
NGCC w/o Capture



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Block Flow Diagram

NGCC w/ Capture



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Derate Considerations

- **Retrofit plants are assumed to be capture ready**
  - The IP/LP crossover pressure of 73.5 psia pre-retrofit is suitable for Cansolv applications
  - In addition to the reduction in output from redirected steam flow prior to the LP turbine, additional derate due to off-design steam turbine flow was considered
- **Derate calculations were performed in the Aspen Plus models**
  - The derate is calculated as a ~2% decrease from the gross steam turbine power (reference study is Lucquiaud et al.)

M. Lucquiaud and J. Gibbins, "Retrofitting CO2 Capture Ready Fossil Plants with Post-combustion Capture Part 1: Requirements for Supercritical Pulverized Coal Plants Using Solvent-based Flue Gas Scrubbing," *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. doi: 10.1243/09576509JPE661. Mechanical Engineering Department, Imperial College London, South Kensington Campus, London, UK.,* vol. 223, pp. 213-226, January 2009

Cost Estimation

- **Assumptions for retrofit cases**
  - Existing units are assumed to be fully paid off
  - The only capital outlays required are for the carbon capture processes (including the removal technology process equipment, a CO_2 compression train, and any modification to the existing plant required for the retrofitted technology)
  - Ongoing fuel costs, as well as fixed and variable O&M, and additional consumables are included in the levelized cost of electricity calculations

Cost Estimation

$$SC = RC * \left(\frac{SP}{RP}\right)^{Exp}$$

$$FRC = RDF * SC = RDF * RC * \left(\frac{SP}{RP}\right)^{Exp}$$

SC – greenfield equivalent of the scaled cost for the retrofit technology
RC – item reference cost
SP – process scaling parameter for the retrofit equipment
RP – process reference parameter for the reference plant equipment
Exp – scaling exponent
RDF – retrofit difficulty factor
FRC – factored retrofit cost

- **The retrofit difficulty factor was applied at the total TPC level**
  - RDF = 1.09 for NGCC cases
  - RDF varies from 1 to 1.3 depending on difficulty of retrofit, type of equipment and labor productivity
  - Value use represents an overall average

Cost Estimation

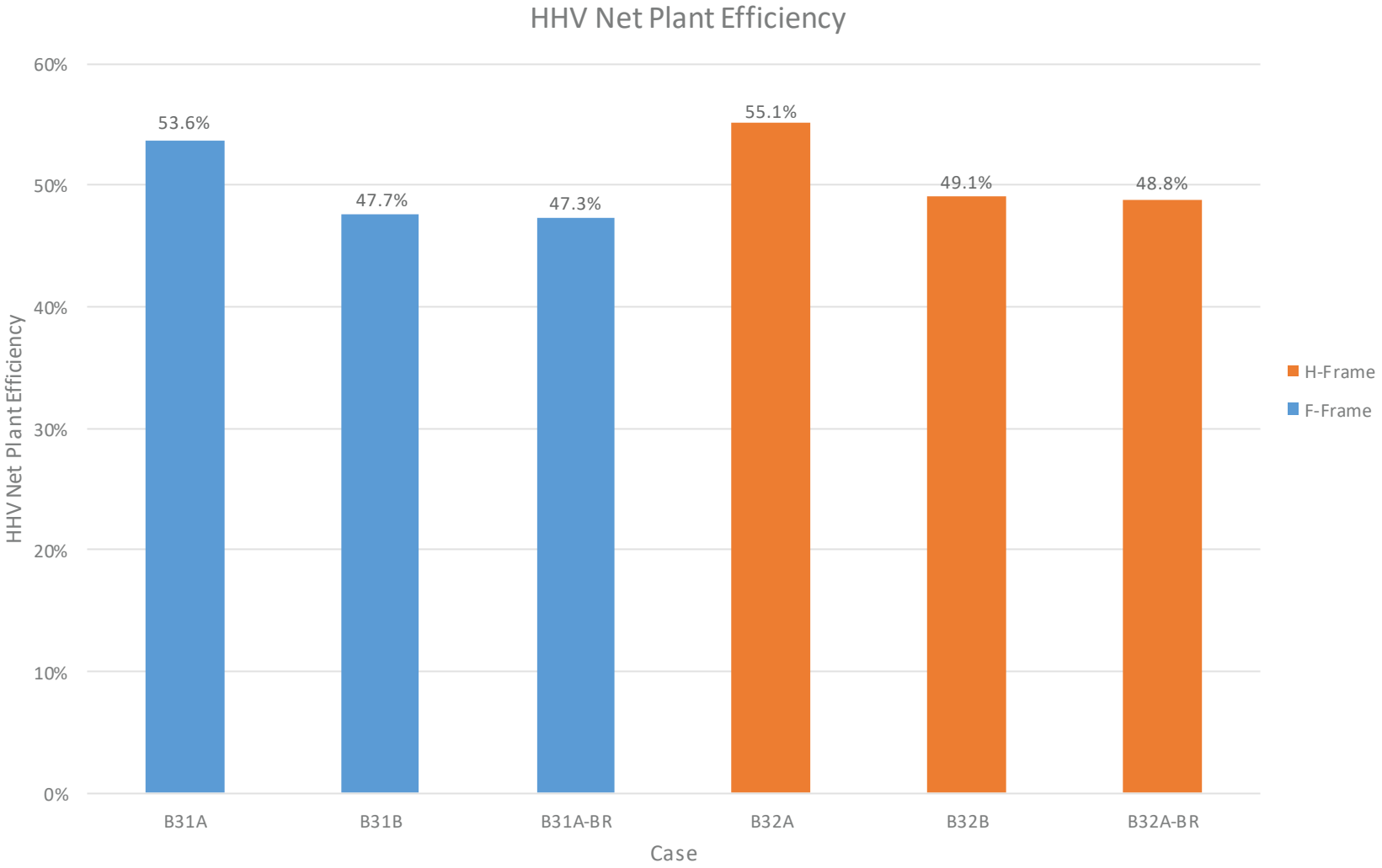
- **Financial Parameters**
  - The prior study/QGESS method had financial structures for low risk (NGCC w/o capture) and high risk (NGCC w/ capture); both were three-year construction periods.
    - The updated QGESS* only includes differentiators for three versus five-year construction periods.
  - The existing three-year construction period timeframe/financial structure was used as is.
- **A make-up power cost (MPC) of $30/MWh was added to retrofit cases to bring to net plant power back to pre-retrofit levels**

*https://netl.doe.gov/projects/files/QGESSCostEstMethodforNETLAssessmentsofPowerPlantPerformance_022621.pdf

Performance Results

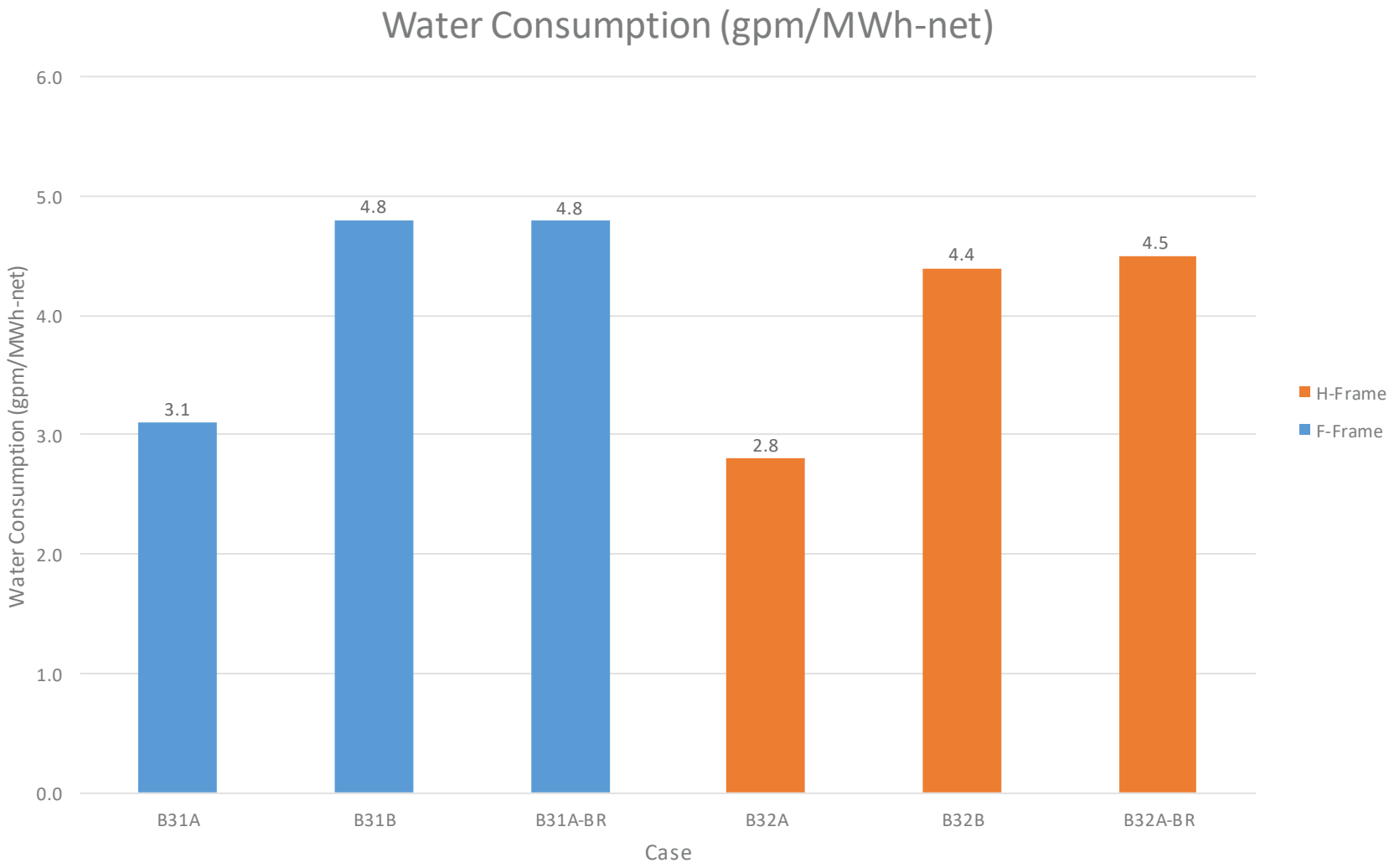
Performance Summary

HHV Net Plant Efficiency



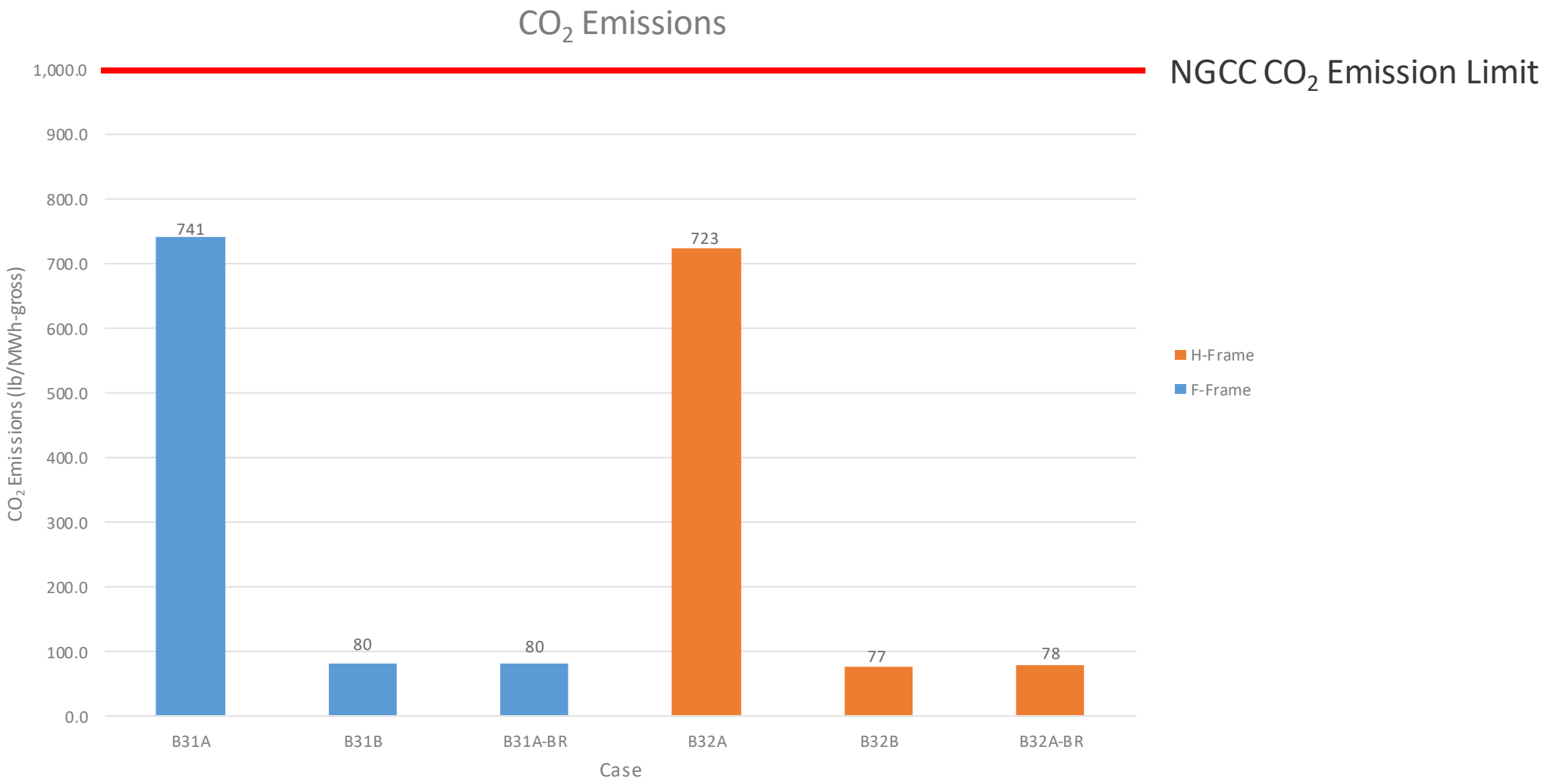
Performance Summary

Water Usage



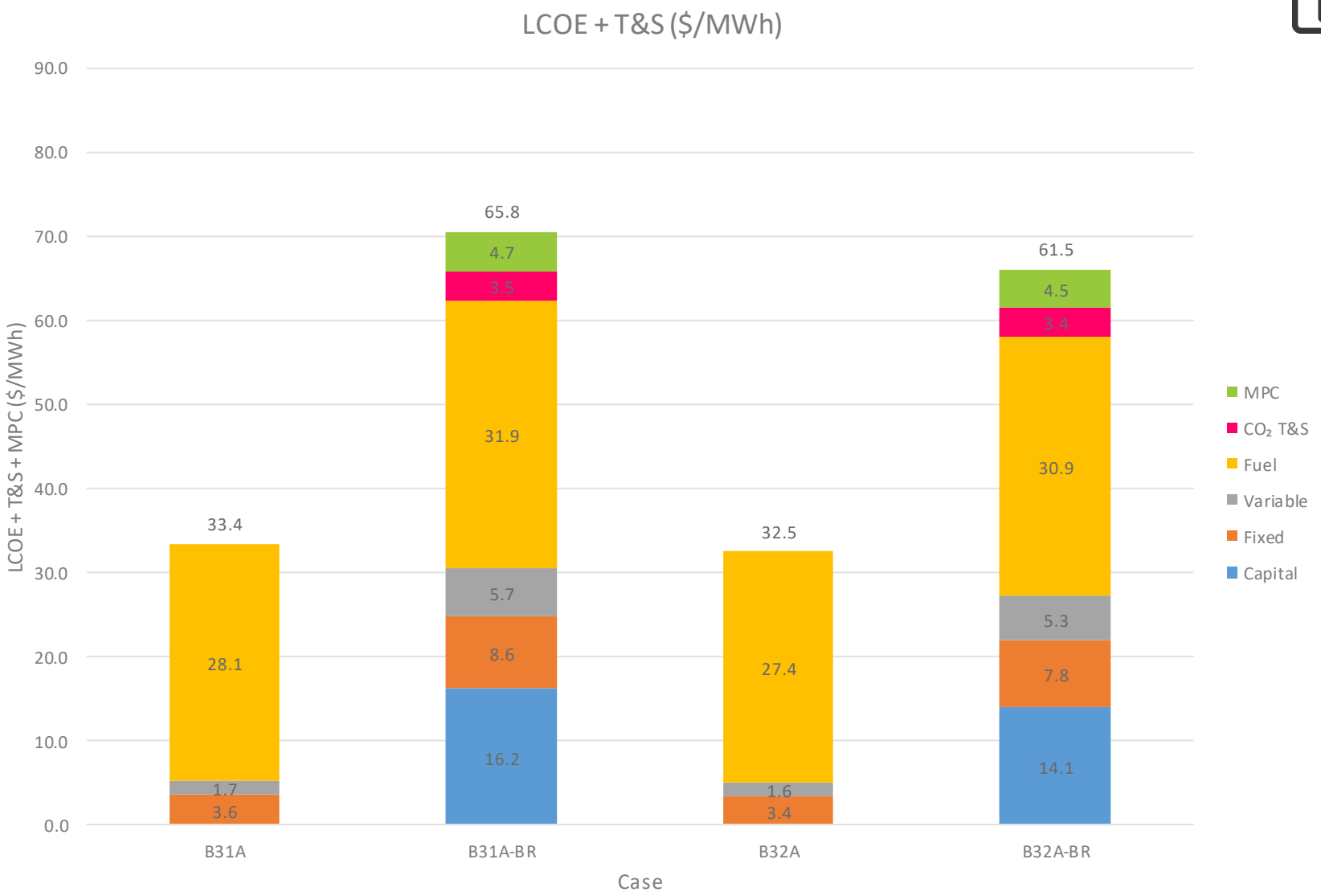
Performance Summary

CO_2 Emissions

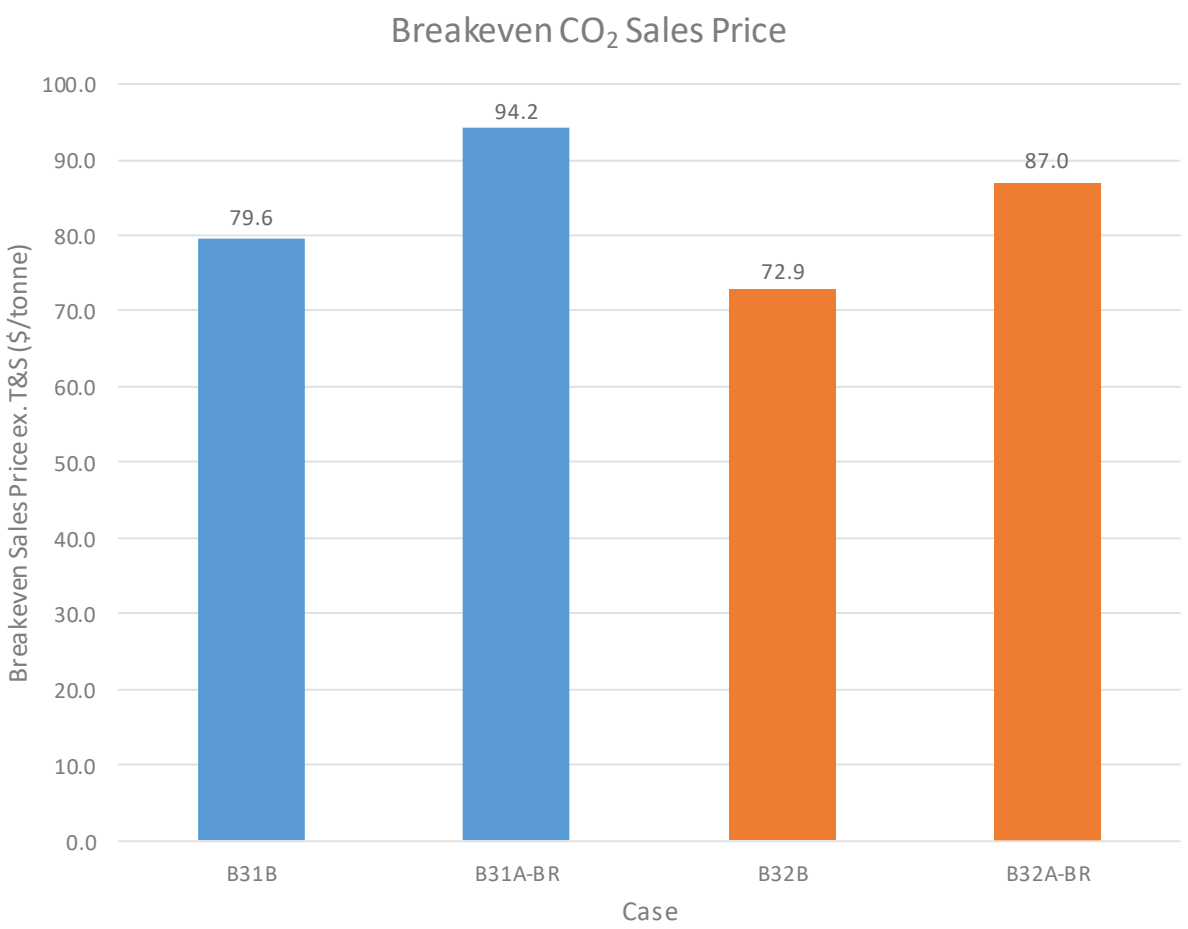


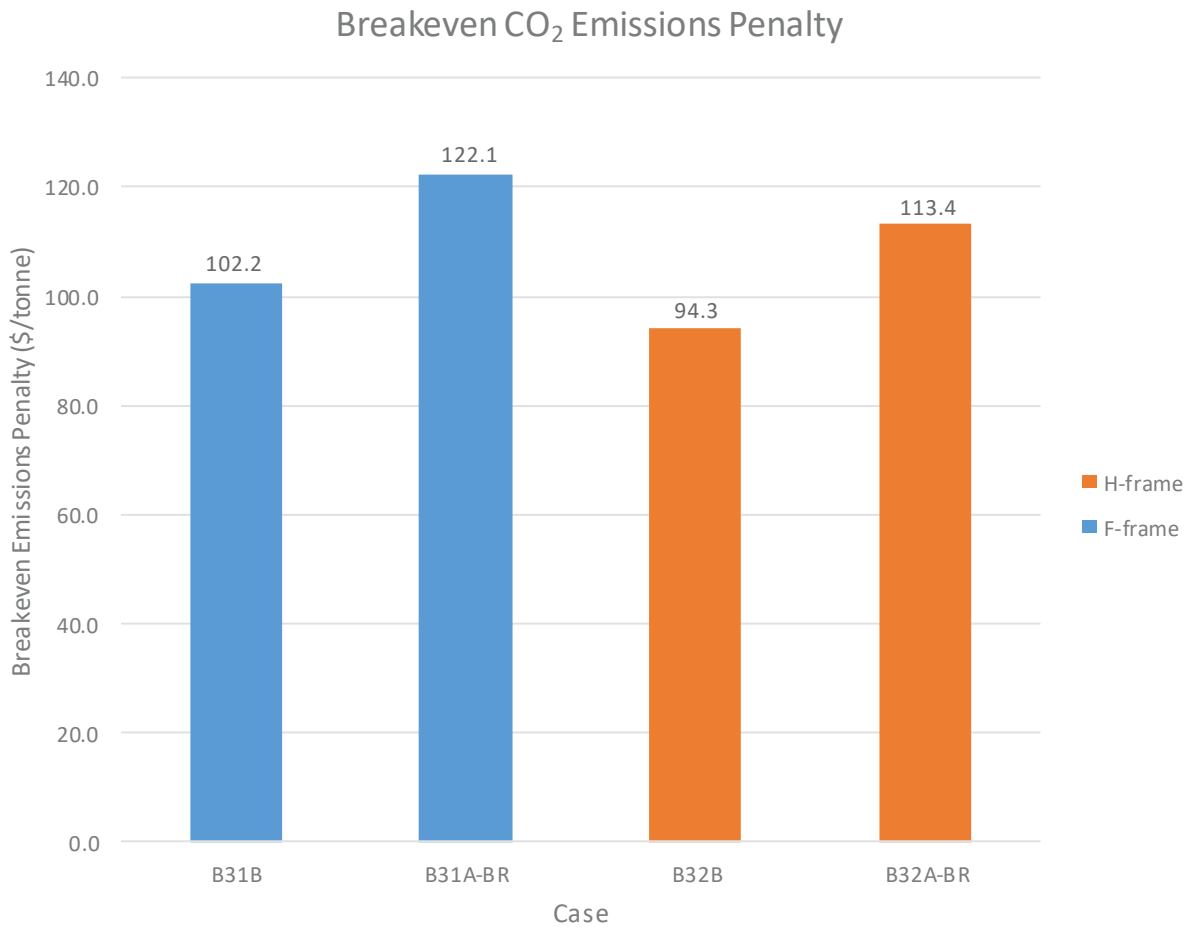
Cost Results

Levelized Cost of Electricity



CO_2 Breakeven Point





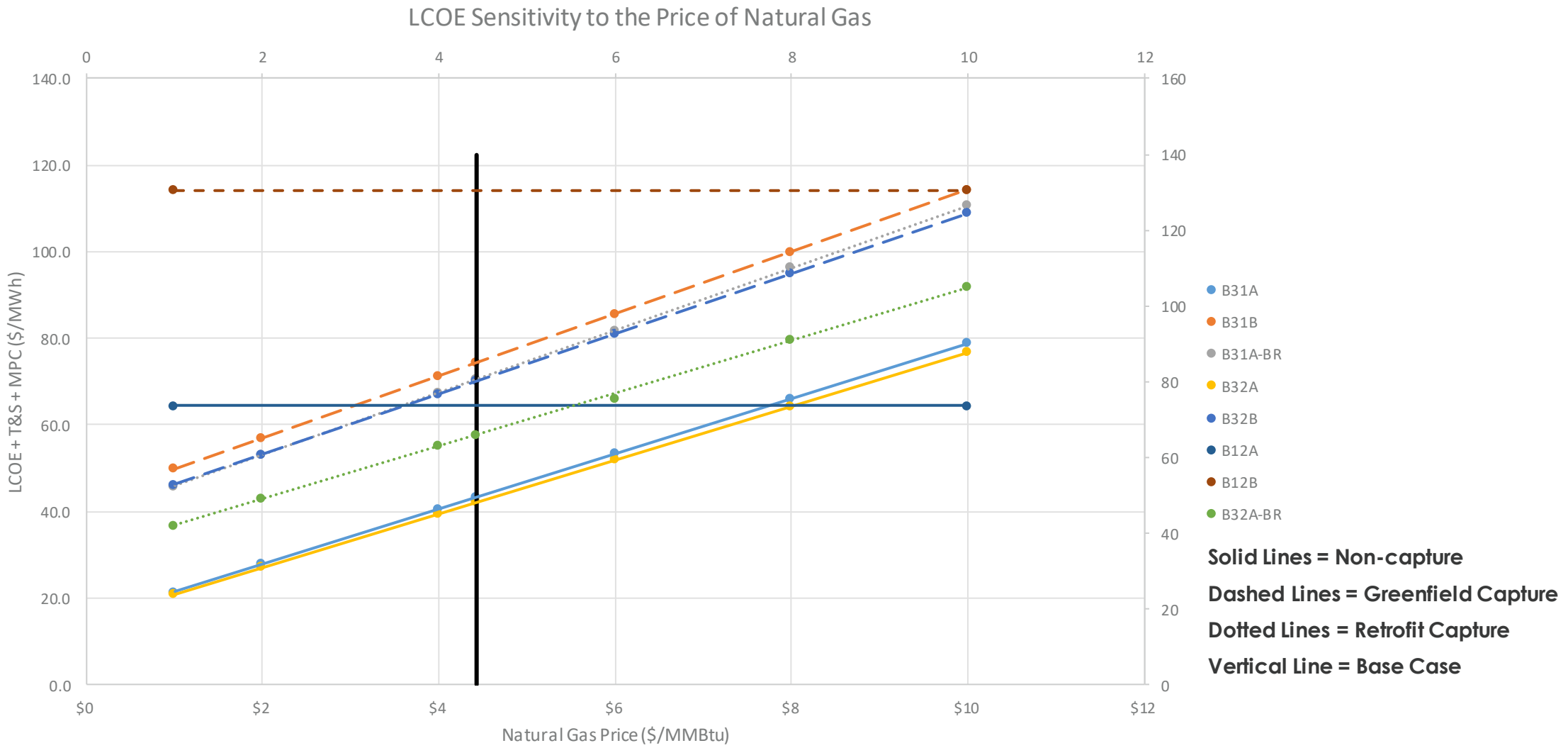
Preliminary Results – Subject to Revision

Sensitivities

- **Price of Natural Gas**
  - $1-10/MMBtu
- **Capacity Factor**
  - 30 to 100 percent
- **Make-up Power Cost**
  - $0/MWh - $100/MWh

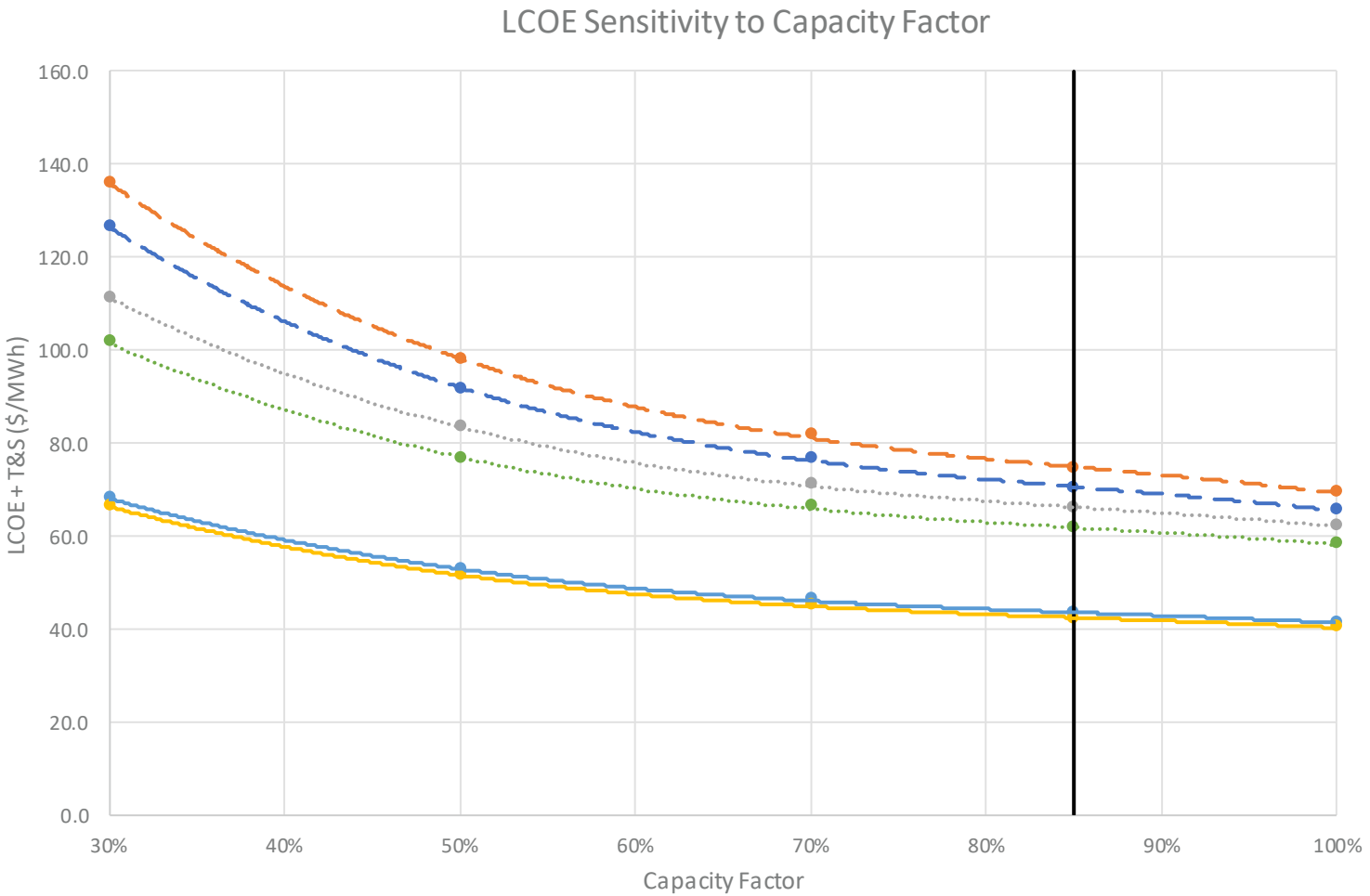
Sensitivities

Price of Natural Gas



Sensitivities

Capacity Factor

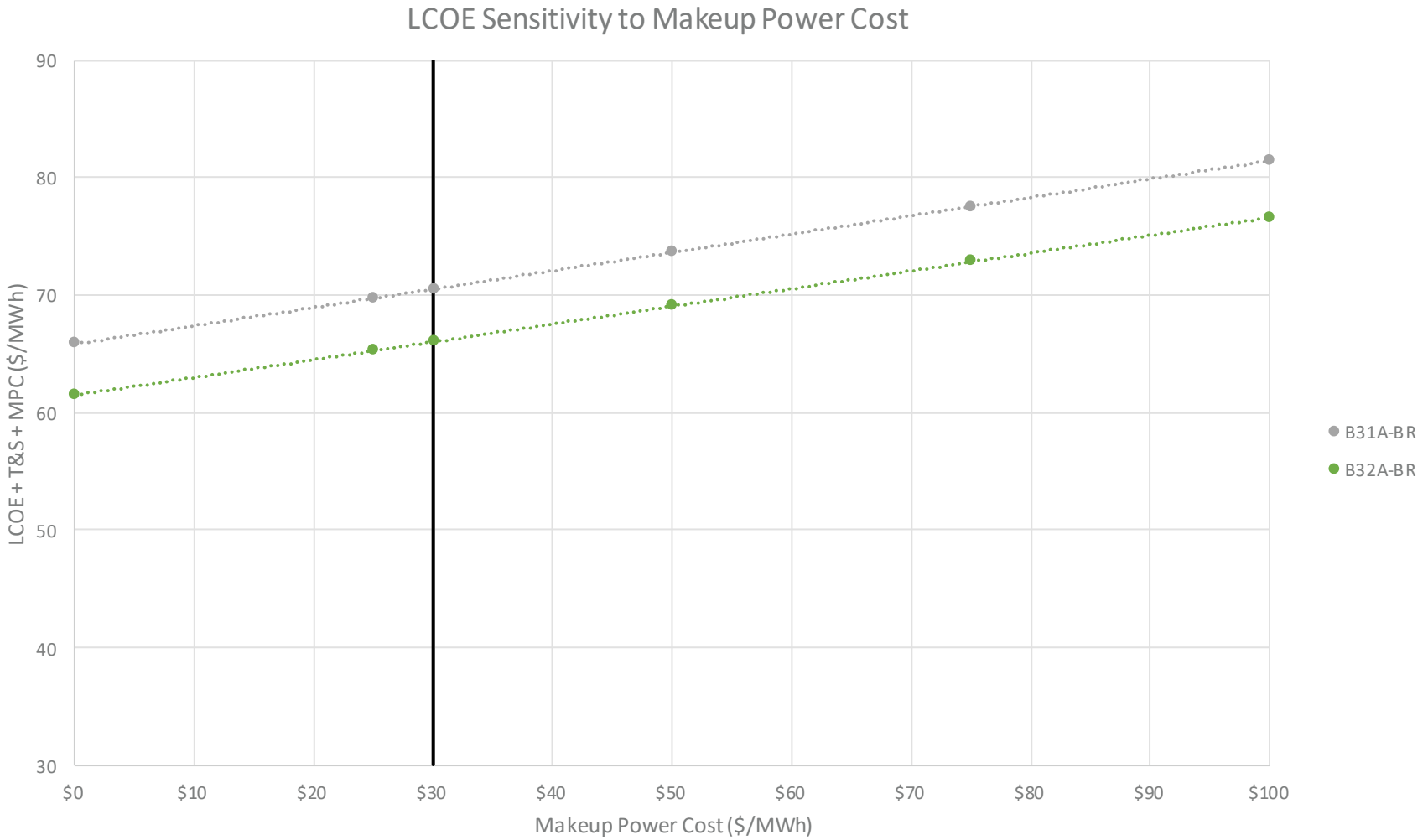


MPC Not Included

Vertical Line = Base Case

Sensitivities

Makeup Power Cost



Current work

- **Updating Carbon Capture Retrofit Database to reflect this report**
  - Incudes update to NGCC, PC and Industrial Database
- **Analogous retrofit reports for Industrial and PC under review/development**

Acknowledgements

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