NETL's NGCC Baseline Techno-economic Studies

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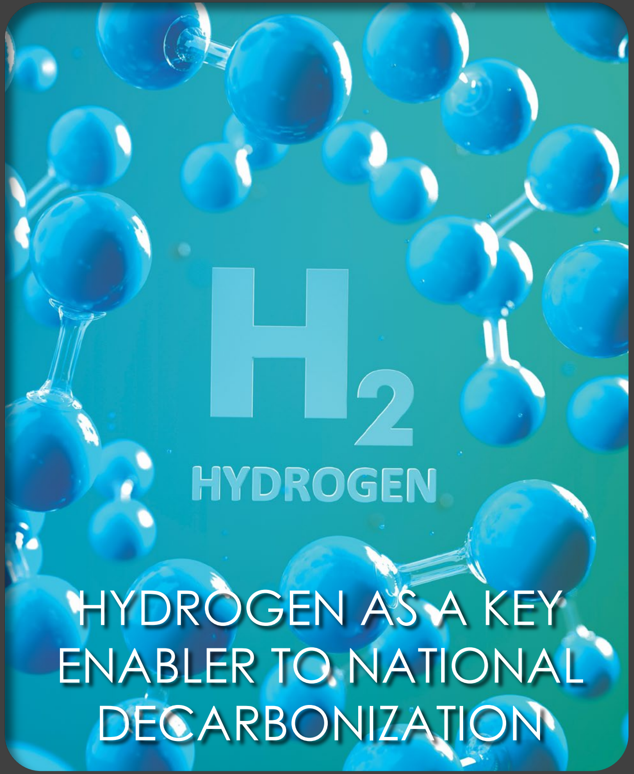

UTSR Project Review Meeting

September 25th, 2024

Overview

NETL has been performing transparent, authoritative techno-economic analyses for decades. Our analyses are used across DOE, as well as by EPA and other governing bodies

Briefly covered in today's presentation:

- Updated NGCC cases in the Fossil Energy Baseline Report
- Updated NGCC cases with EGR
- H-class 1x1 NGCC update
- Performance analysis of Natural Gas Electricity Generating Units for Flexible Operation

Other analyses of interest:

- H2/NG Blend NGCC study
- Insights from Post Combustion Carbon Capture FEED Studies

Fossil Energy Baseline (FEB) Revision 4a Update[1]

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Justification

- The vendor provided **updated quotes for the 90% capture system as well as updated quotes for higher rates of capture**. Due to differences in cost and performance than what is currently reported in the Fossil Energy Baseline Revision 4 (FEBR4), an update is necessary.

Outcomes

- **Characterized the cost and performance of PC and NGCC plants with 90% and higher capture systems**

Authors

Tommy Schmitt, Sarah Leptinsky, Marc Turner, Alex Zoelle

Approach

- Design basis is consistent with the assumptions made in FEBR4
- Cost results started with those reported in the FEBR4 which were developed using a combination of vendor data and scaled estimates

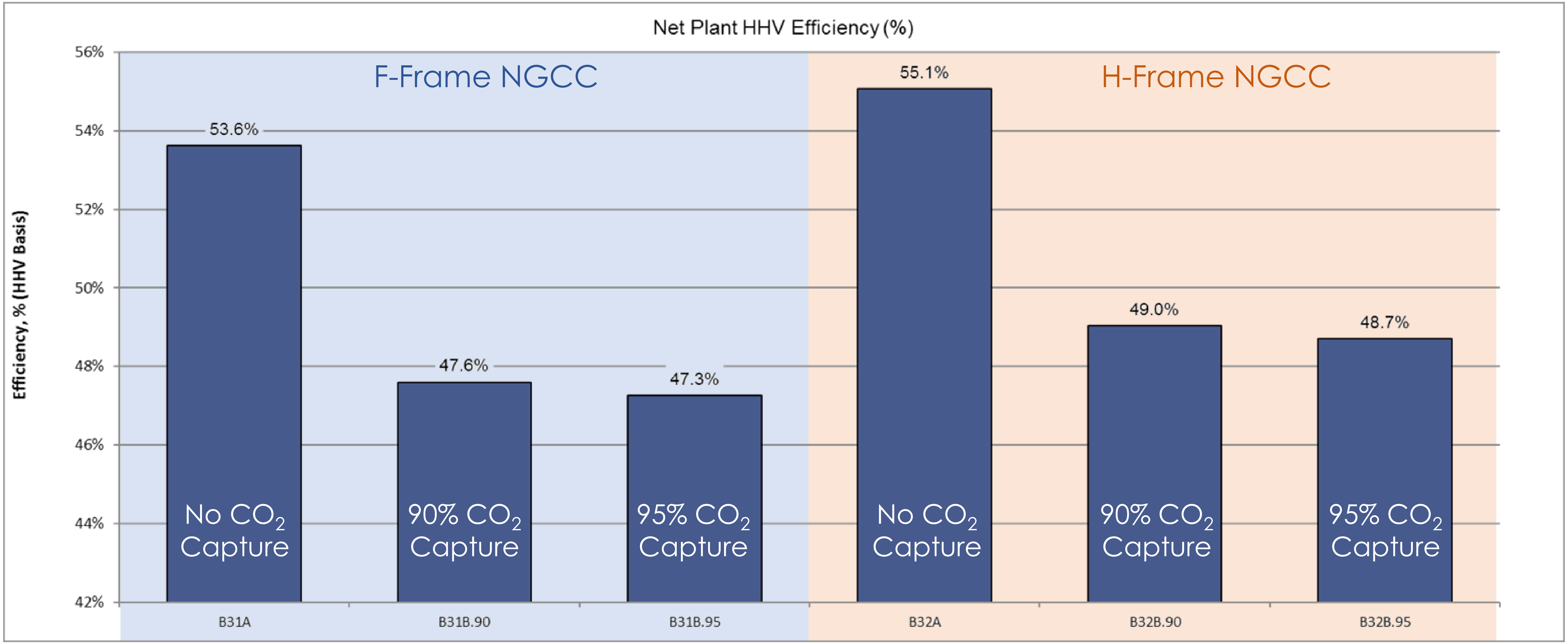
Highlights

- **The addition of capture to the NGCC cases increase the LCOE by 52–60 percent and decreases the relative efficiency by 11–12 percent**

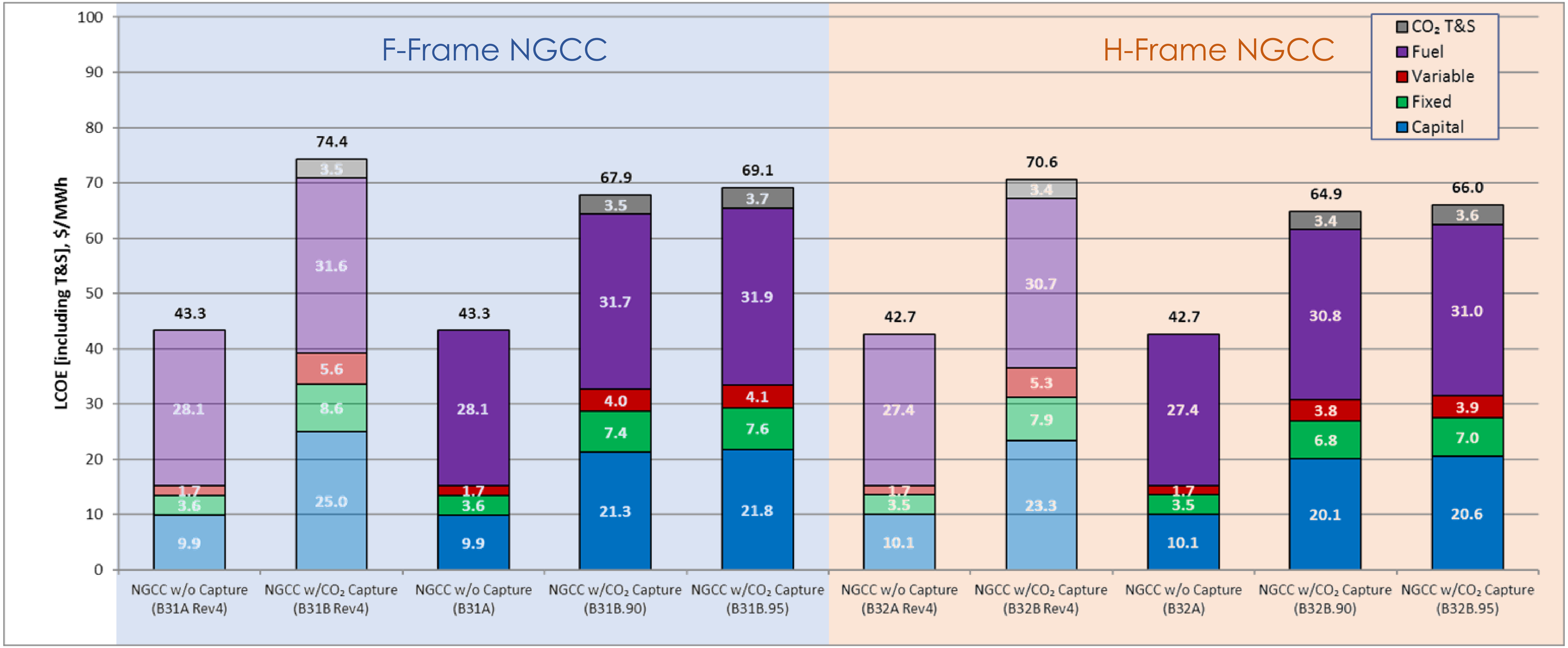
Case	Plant Type	Steam Cycle, psig/°F/°F	Combustion Turbine	Boiler Technology	CO_2 Separation	Capture Rate	Net Power Output (MW)
B31A	NGCC	2400/1085/1085	2 x State-of-the-art 2017 F-Class	HRSG	N/A	N/A	727
B31B.90					Cansolv	90%	645
B31B.95						95%	640
B32A		2700/1085/1045	2 x State-of-the-art 2017 H-Class		N/A	N/A	992
B32B.90					Cansolv	90%	883
B32B.95						95%	877

[1] T. Schmitt, S. Leptinsky, M. Turner, A. Zoelle, M. Woods, T. Shultz, and R. James "Fossil Energy Baseline Revision 4a," National Energy Technology Laboratory, Pittsburgh, October 14, 2022. https://netl.doe.gov/energy-analysis/details?id=e818549c-a565-4cbc-94db-442a1c2a70a9

NGCC Net Plant Efficiency



Levelized Cost of Electricity (LCOE) Breakdown



Capture:	0%	90%	0%	90%	95%	0%	90%	0%	90%	95%

Natural Gas Combined Cycle (NGCC) Power Plants with Carbon Capture and Exhaust Gas Recycle (EGR)

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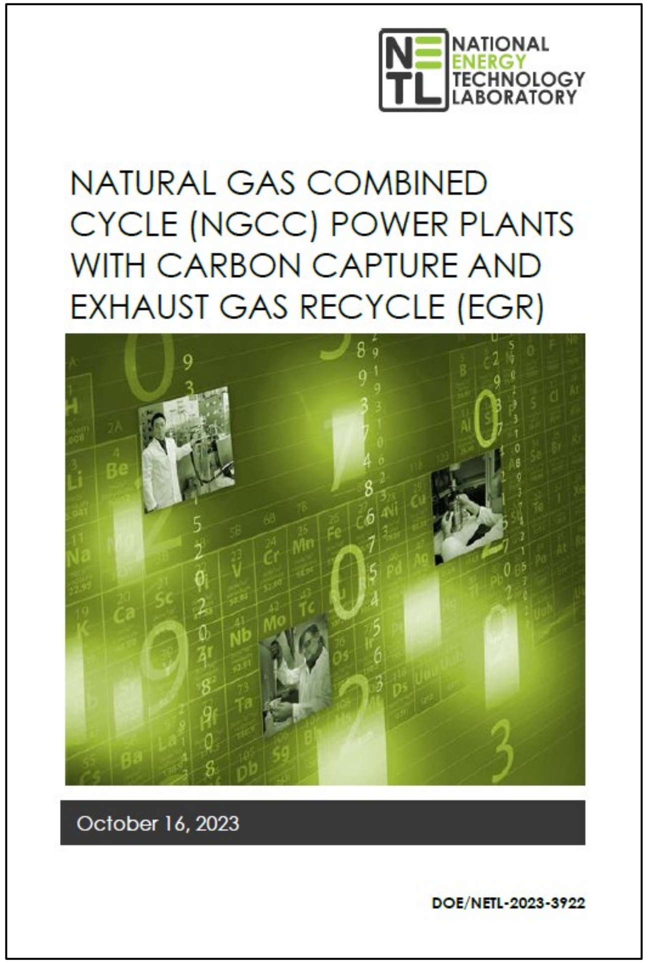
Objective

- Provides an update to a 2013 report on this topic
- Bottom Line Up Front:
  - Adding EGR to NGCC plants with CO_2 capture results in minimal improvement in the LCOE
  - Including the EGR ductwork and cooler in a greenfield plant design could still be prudent since there is some cost advantage to EGR
  - Adding EGR would allow more flexibility for taking advantage of future improvements in the technology.
- These results are consistent with the recently published report by the Electric Power Research Institute (EPRI).



Natural Gas Combined Cycle (NGCC) Power Plants with Carbon Capture and Exhaust Gas Recycle (EGR)

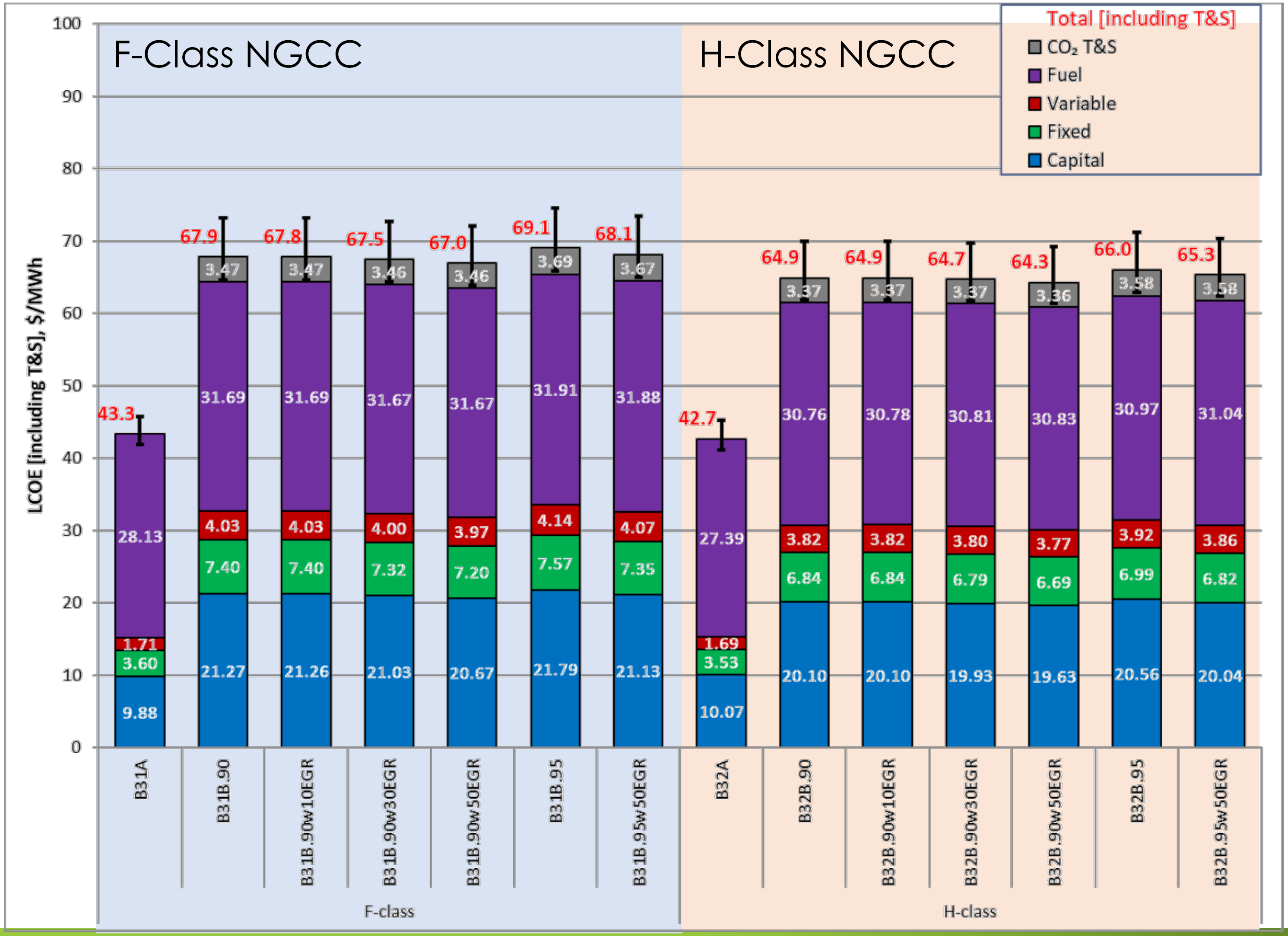
Case Matrix

Case[A]	Combustion Turbine	Recycle Type	% Recycle	CO_2 Separation[B]	% CO_2 in Feed to Capture System[C]
B31A	2 x State-of-the-art 2017 F-class	None	0%	None	N/A
B31B.90		None	0%	CANSOLV 90%	4.1%
B31B.90+10%EGR		EGR	10%	CANSOLV 90%	4.5%
B31B.90+30%EGR		EGR	30%	CANSOLV 90%	5.8%
B31B.90+50%EGR		EGR	50%	CANSOLV 90%	8.3%
B31B.95		None	0%	CANSOLV 95%	4.1%
B31B.95+50%EGR		EGR	50%	CANSOLV 95%	8.3%
B32A	2 x State-of-the-art 2017 H-class	None	0%	None	N/A
B32B.90		None	0%	CANSOLV 90%	4.1%
B32B.90+10%EGR		EGR	10%	CANSOLV 90%	4.5%
B32B.90+30%EGR		EGR	30%	CANSOLV 90%	5.8%
B32B.90+50%EGR		EGR	50%	CANSOLV 90%	8.3%
B32B.95		None	0%	CANSOLV 95%	4.1%
B32B.95+50%EGR		EGR	50%	CANSOLV 95%	8.3%

Natural Gas Combined Cycle (NGCC) Power Plants with Carbon Capture and Exhaust Gas Recycle (EGR)

LCOE Results

- Results show a $0.61 to $0.68/MWh decrease in the LCOE for the cases with the greatest EGR
  - Due primarily to the decrease in the flue gas volumetric flow rate to the capture system resulting in a smaller absorber and lower costs.
  - Reduction in CO2 capture plant costs is greater than the increase incurred in other capital cost accounts for adding the cooler, ductwork, and instrumentation and controls for the EGR
- Capital cost reduction only decreases the LCOE values by approximately 1.5%
  - Total capital costs for 50% EGR cases are up to 4 percent lower than for the base cases without EGR, but CapEx is less than 33% of the total LCOE



Cost and Performance Estimates for State-of-the-art and Advanced 1×1 H-class Natural Gas-fired Power Plants

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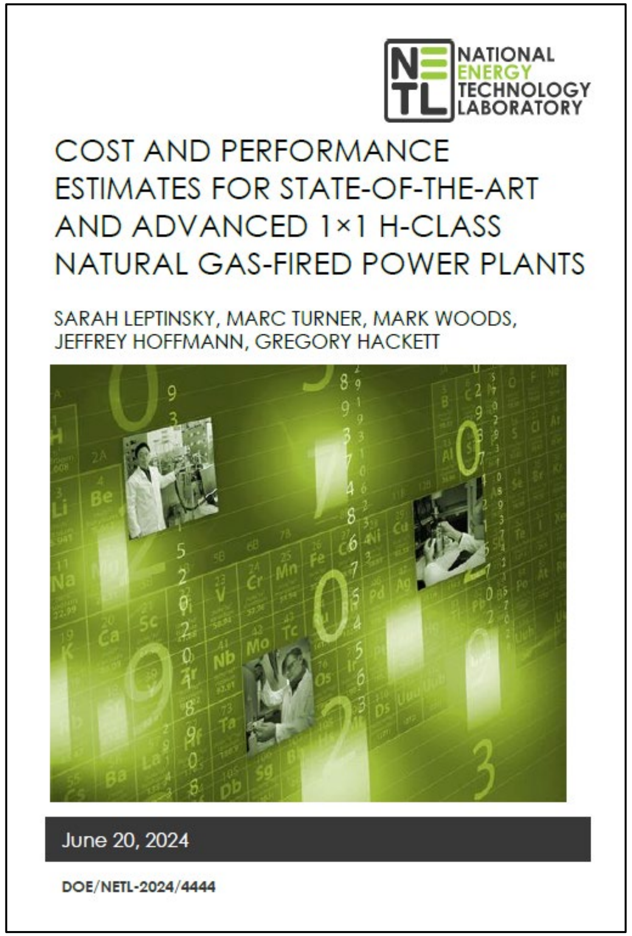
Objective

- NETL's Rev4a Fossil Energy Baseline included cases that used 2017 vintage H-Class combustion turbines in a 2×1 natural gas combined cycle (NGCC) configuration, and 2021 vintage CO2 capture.
- This study developed cost and performance estimates of NGCC cases analogous to NETL's Rev4a using a state-of-the-art 2023 vintage H-Class CT in a 1×1 configuration
  - A single CT and HRSG are coupled to a single ST on a common shaft.
- The 1×1 H-Class cases were used to develop cost and performance estimates of X-Class 1×1 NGCC cases with advanced performance characteristics
  - X-Class considers 3100 F firing temperature in an H-class frame
- These cases were used to support of the development of the NREL Annual Technology Baseline (most recently released in June 2024), which covers the gamut of electricity generating units.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COST AND PERFORMANCE ESTIMATES FOR STATE-OF-THE-ART AND ADVANCED 1×1 H-CLASS NATURAL GAS-FIRED POWER PLANTS

SARAH LEPTINSKY, MARC TURNER, MARK WOODS, JEFFREY HOFFMANN, GREGORY HACKETT

June 20, 2024

DOE/NETL-2024/4444

Methodology

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Advanced Capture System Assumptions

- **Five parameters are adjusted to reflect potential improvements of advanced carbon capture systems**

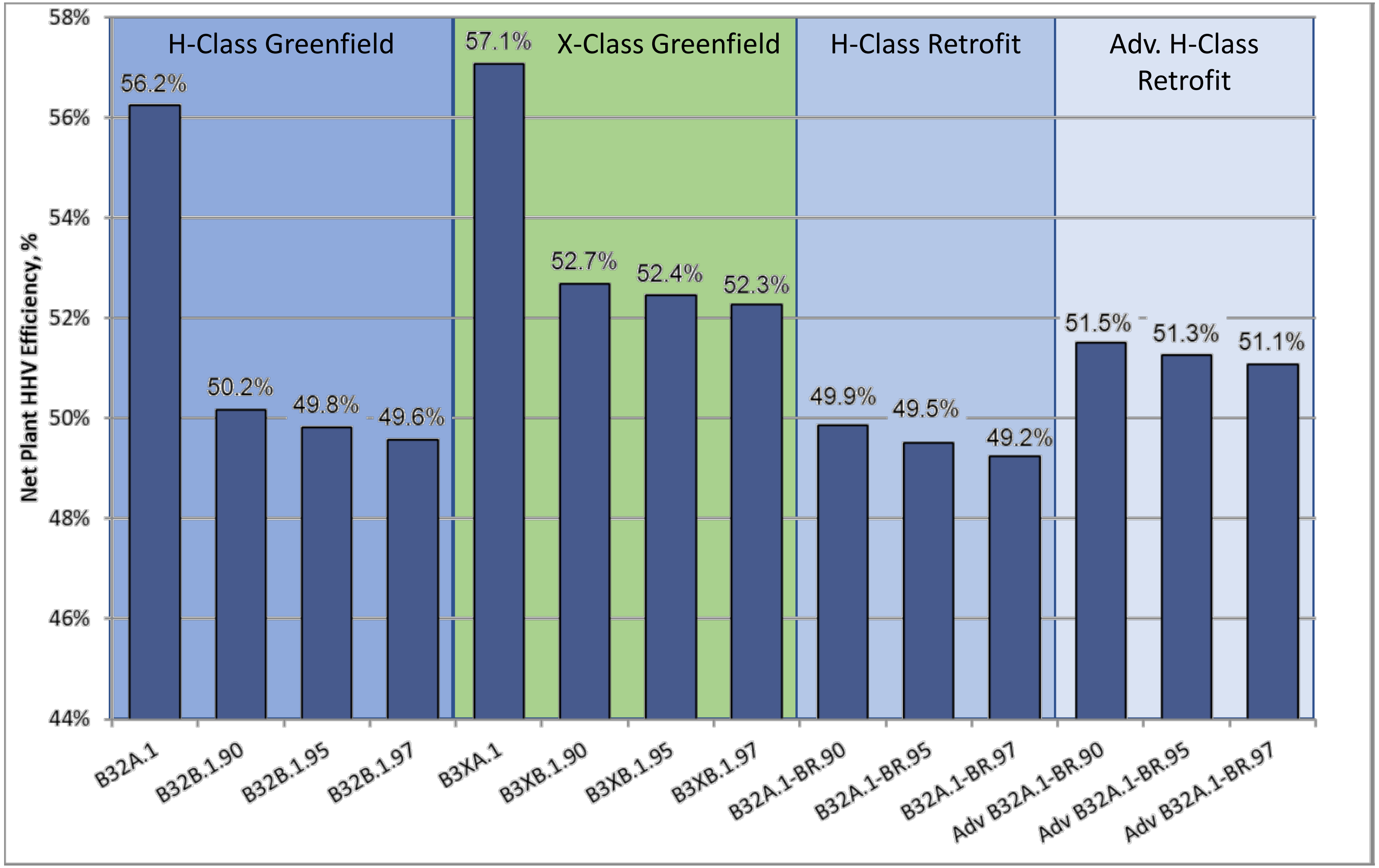
Parameter	Reduction from Current SOTA
Reboiler Duty, Btu/lb	30%
Capture System Auxiliary Load, kW/tph CO_2	65%
Total Plant Cost for the Capture System, $/kW	50%
Total Solvent Initial Fill Cost, $MM/y	50%
Total Solvent Makeup Cost, $MM/y	50%

- Limitation: Detailed, component-level modeling is outside the scope of this effort and the performance improvements were evaluated as cumulative parameter adjustments without consideration for process interdependences

NGCC 1x1 H-Class Updates

Net Plant Efficiency

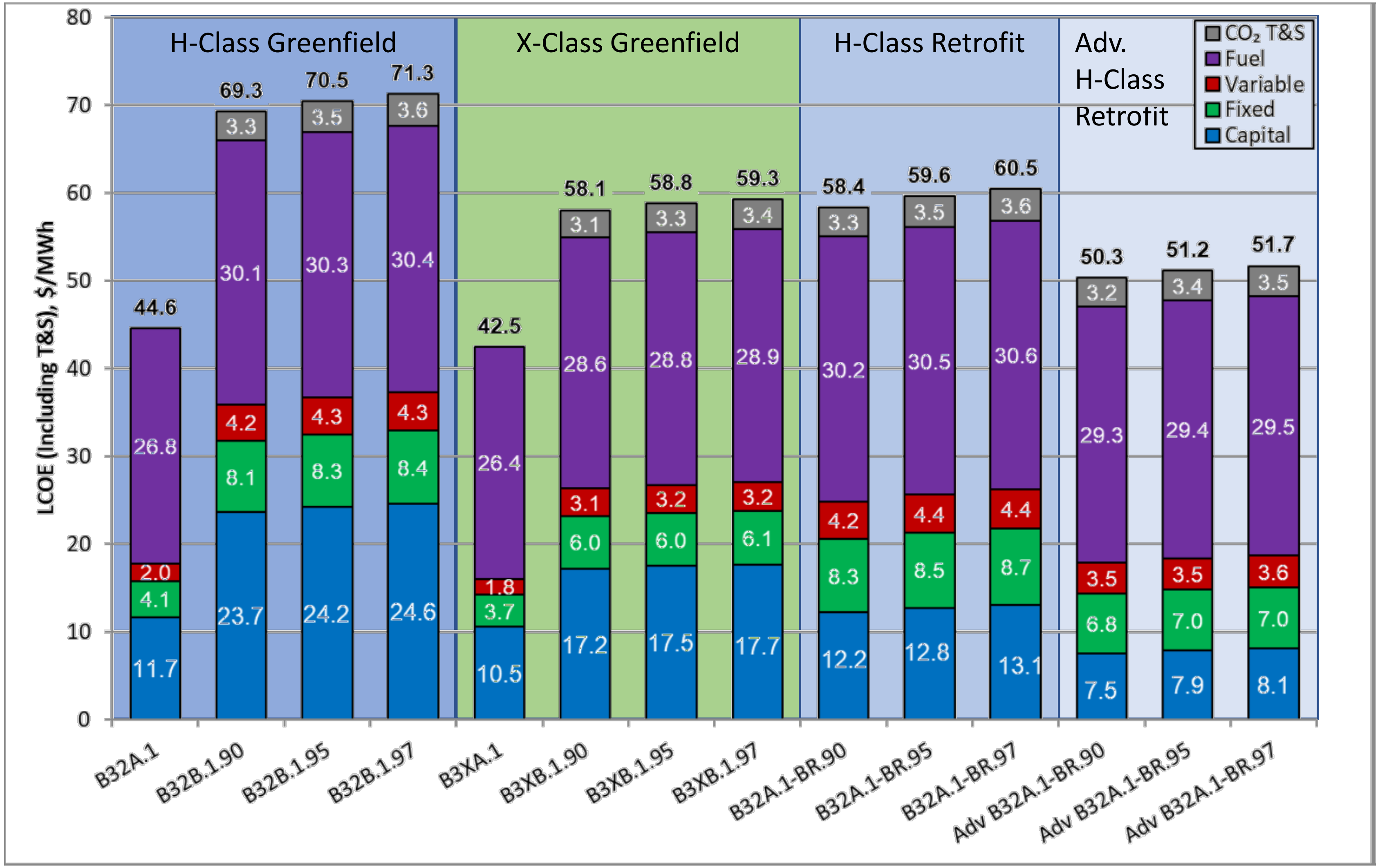
- Cases include 0%, 90%, 95% & 97% carbon capture
- X-class NGCCs offer ~2.5 percentage point efficiency improvements relative to H-class
- H-class retrofits are ~0.3% lower efficiency than greenfield
- Advanced capture systems yield 1.6-1.9% efficiency improvements



NGCC 1x1 H-Class Updates

Levelized Cost of Electricity (LCOE)

- The addition of 90% capture to greenfield NGCC cases increases the LCOE by 37-55%
  - Retrofit: 31% increase
- Greenfield 97% capture cases marginally increase LCOE 2.1-2.9% compared to 90% capture cases
  - Similar 2.7-3.6% increase for retrofit systems
- Advanced capture system retrofits:
  - About 14% lower LCOE
  - LCOE approaches that of non-capture greenfield installations



Fossil Energy Baseline, Volume 5 – Natural Gas Electricity Generating Units for Flexible Operation

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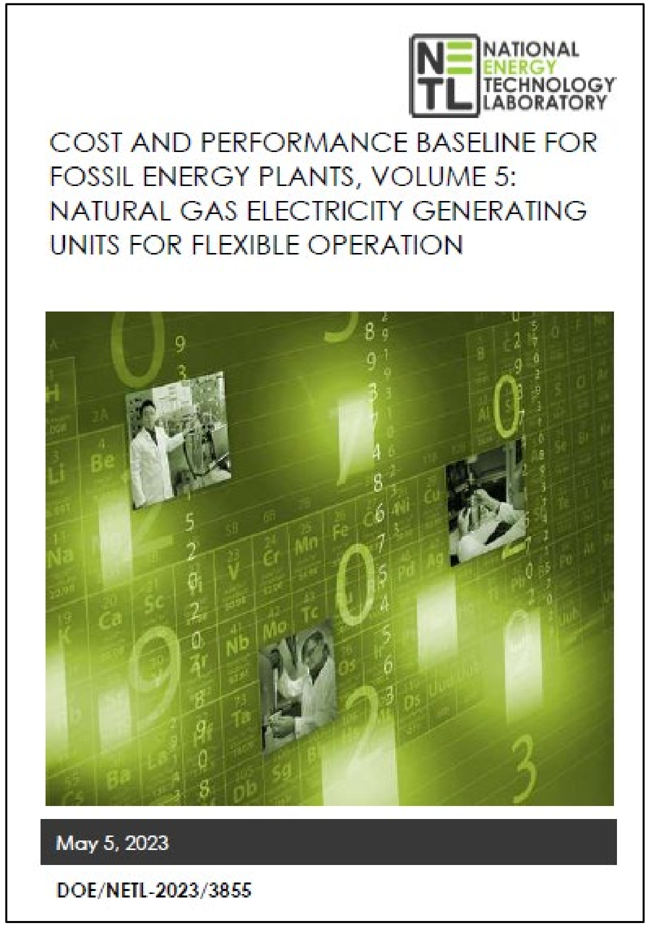
Study Overview

- Developed cost and performance estimates for several state-of-the-art, commercial, natural gas fired power plants without CO2 capture
  - 4 cases reciprocating internal combustion engines
  - 2 cases aeroderivative simple cycle combustion turbine generators (CTG)
  - 5 cases combined cycle CTGs
- Characterized the part load performance and flexibility metrics for each case
  - Natural gas options are inherently flexible—no specific options to increase flexibility were considered
- Assessed all technologies as fast starting, with one case showing a comparison to a conventional start
- Plants are market independent and not "capture ready"



M. Oakes, M. Turner, "Cost and Performance Baseline for Fossil Energy Plants, Volume 5: Natural Gas Electricity Generating Units for Flexible Operation," National Energy Technology Laboratory, Pittsburgh, May 5, 2023.

Case Configurations

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Case[A]	Plant Type	Steam Cycle, psia/°F/°F	Engine/Combustion Turbine	Boiler Technology	Notes
R6A-S	RICE	N/A	6 x State-of-the-art 18 MW RICE	N/A	Spinning Mode
R6A-E	RICE	N/A	6 x State-of-the-art 18 MW RICE	N/A	Efficiency Mode
R12A-S	RICE	N/A	12 x State-of-the-art 9 MW RICE	N/A	Spinning Mode
R12A-E	RICE	N/A	12 x State-of-the-art 9 MW RICE	N/A	Efficiency Mode
SC1A	NGSC	N/A	1 x State-of-the-art 100 MW Aero	N/A	Fast Start
SC2A	NGSC	N/A	2 x State-of-the-art 50 MW Aero	N/A	Fast Start
CC1A-F	NGCC	2,400/1,085/1,085	1 x State-of-the-art F-class	HRSG	Fast Start
CC1A-H	NGCC	2,400/1,085/1,085	1 x State-of-the-art H-class	HRSG	Fast Start
CC2A-F	NGCC	2,400/1,085/1,085	2 x State-of-the-art F-class	HRSG	Fast Start
CC2A-FC	NGCC	2,400/1,085/1,085	2 x State-of-the-art F-class	HRSG	Conventional Start
CC2A-H	NGCC	2,400/1,085/1,085	2 x State-of-the-art H-class	HRSG	Fast Start

- Spinning mode – All units operate and ramp simultaneously
- Efficiency mode – Minimum number of units operate, ramping units sequentially

Schematic of NGCC Startup

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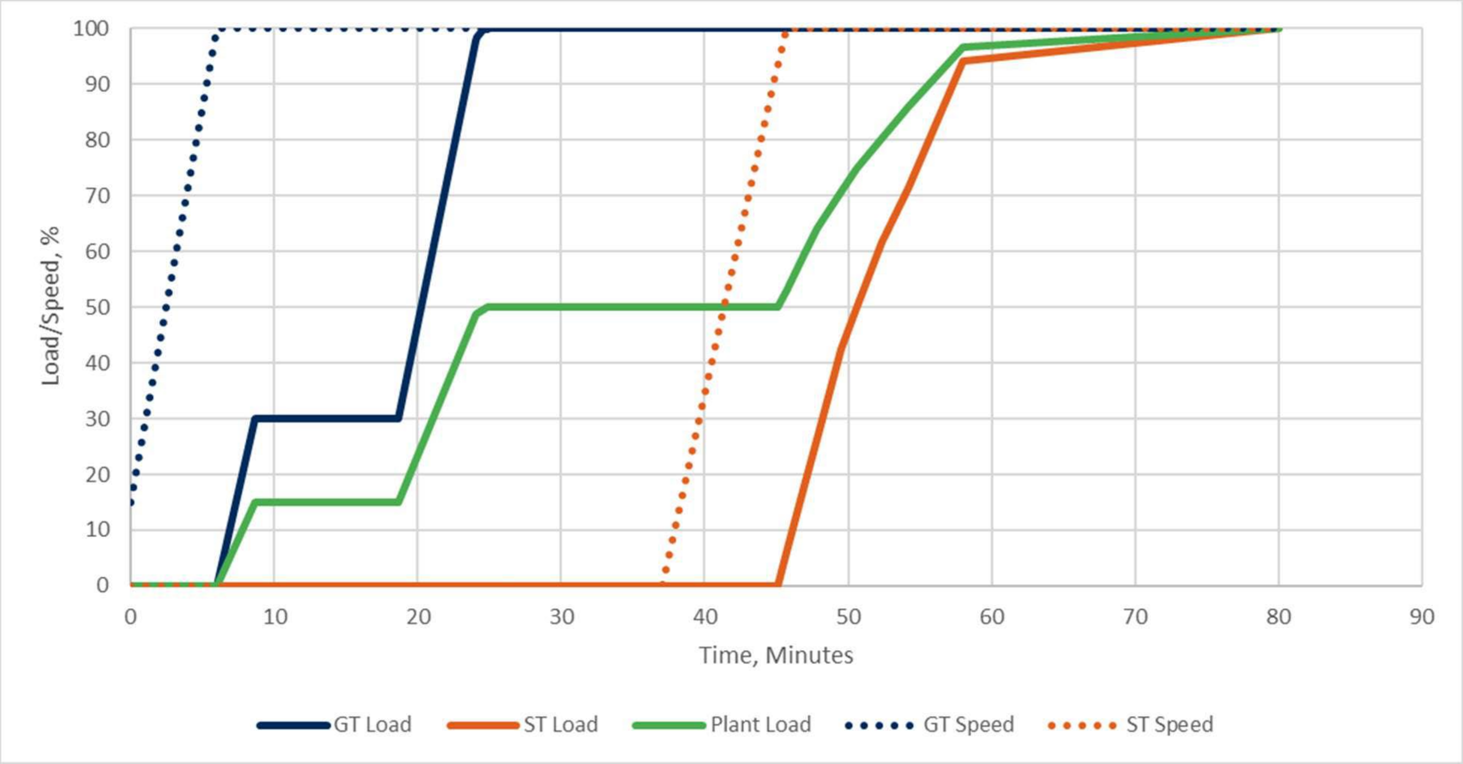
Example: Based on information from EPC firm



Time Parameter	Notification Time	Start Time	Soak Time	Run Time	
Event	*Commitment Instruction*	*Start Sequence Begins*	*First Breaker Closed*	*Dispatchable*	*Following Dispatch*

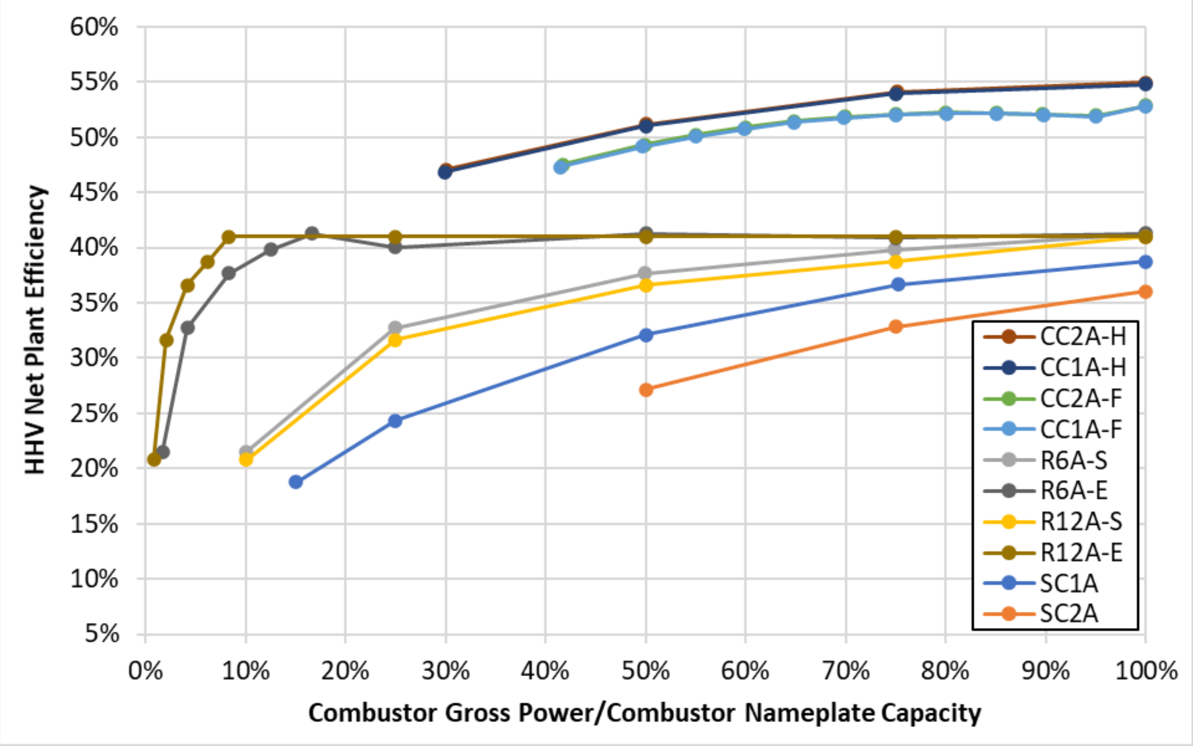
Natural Gas Electricity Generating Units for Flexible Operation

Results

- Combined cycle:
  - Pros: Highest net plant efficiencies and power output
  - Cons: Longest start times, lowest ramp rates, and highest minimum load
- Aeroderivatives:
  - Pros: High ramp rates, low minimum load, short start times
  - Cons: Lowest net plant efficiencies, low power output
- Reciprocating Engines:
  - Pros: High ramp rates, lowest minimum loads, short start times, mid net plant efficiencies
  - Cons: Low power output, requires multiple units

Limitations

- Part-load performance is estimated as a best-fit curve and may not exactly match vendor data
- Part-load performance is not dynamically estimated, rather the performance is estimated at various steady-state load points



Note: The values of the 2x1 configuration cases (CC2A-H and CC2A-F) overlap with their respective 1x1 configuration cases (CC1A-H and CC1A-F)

Suggested Follow-On Work

- Determine the impact of CO_2 capture on plant flexibility and part-load performance

	R6A-S	R6A-E	R12A-S	R12A-E	SC1A	SC2A	CC1A-F	CC1A-H	CC2A-F	CC2A-FC	CC2A-H
Nameplate Capacity, MWe	113	113	113	113	116	105	375	560	751	751	1,124
Cold Start, min	N/A	N/A	N/A	N/A	N/A	N/A	130	130	120	250	120
Warm Start, min	10	10	10	10	10	10	50	85	45	140	70
Hot Start, min	5	5	5	5	8	5	35	30	32	90	30
Ramp Rate, %/min	60.0	23.3	60.0	26.7	43.1	95.2	10.7	10.7	10.7	10.7	10.8
MECL[A], % of Full Load	9.7	0.8	9.7	0.8	16	50	49	38	50	50	38

[A] Minimum environmentally compliant load

Questions?

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Fossil Energy Baseline Overview

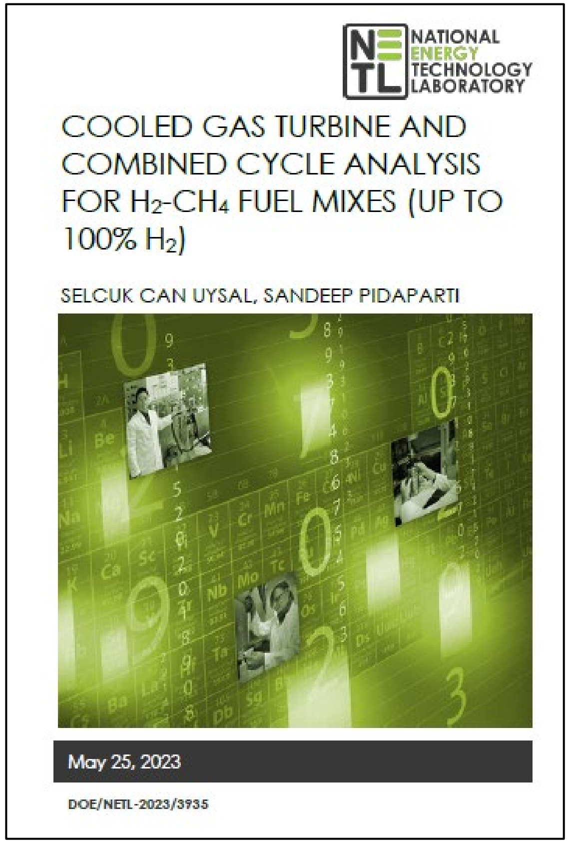
- Design basis is consistent with the assumptions made in FEBR4, including
  - Generic Midwest site location and ambient conditions
  - Cases configured to comply with FEBR4 air and water effluent regulation assumptions
  - Capital cost estimation[1] and scaling methodology,[2] fuel costs,[3] and CO_2 transport and storage (T&S)[4] prices reflect the current QGESS documents
  - Estimates were developed in 2018 year-dollars
  - Cases are modeled in Aspen Plus® v10.0 (Aspen)
- Cost Estimation Methodology
  - For the H-class NGCC cases, the vendor costs were adjusted based on the relationship of vendor cost to the B&V cost estimate for F-class cases previously reported in FEBR4
    - Vendor costs included those for the combustion turbine (CT), steam turbine (ST), and heat recovery steam generator (HRSG)

[1] NETL, "QGESS: Cost Estimation Methodology for NETL Assessments of Power Plant Performance," U.S. Department of Energy, Pittsburgh, PA, 2019.
[2] NETL, "QGESS: Capital Cost Scaling Methodology: Revision 4 Report," U.S. Department of Energy, Pittsburgh, PA, 2019.
[3] NETL, "QGESS: Fuel Prices for Selected Feedstocks in NETL Studies," U.S. Department of Energy, Pittsburgh, PA, 2019.
[4] NETL, "QGESS: Carbon Dioxide Transport and Storage Costs in NETL Studies," U.S. Department of Energy, Pittsburgh, PA, 2019.

Cooled Gas Turbine and Combined Cycle Analysis for H_2-CH_4 Fuel Blends

Objective

- Perform a cooled gas turbine (GT) analysis for a GT that uses H_2-CH_4 fuel blends up to 100% H_2
- Identify and study the required gas turbine technology developments in
  - Cooling system
  - GT design
  - Materials
- Calculate combined cycle performance with H_2-CH_4 fuel blends using the advanced GT design for flexible fuel operation
- Perform a techno-economic analysis (TEA) and calculate the impact of using H_2 fuel blends on levelized cost of electricity (LCOE)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COOLED GAS TURBINE AND COMBINED CYCLE ANALYSIS FOR H_2-CH_4 FUEL MIXES (UP TO 100% H_2)

SELCUK CAN UYSAL, SANDEEP PIDAPARTI

May 25, 2023

DOE/NETL-2023/3935

Cost Analysis for Hydrogen Combined Cycle

Fuel Price Sensitivity