Systems and Energy Analysis

Post-Combustion Capture Analysis Update

August 21, 2017

Presentation Outline

- SEA Organization & Purpose
- Process Analysis
- Markets & Infrastructure
- Tools

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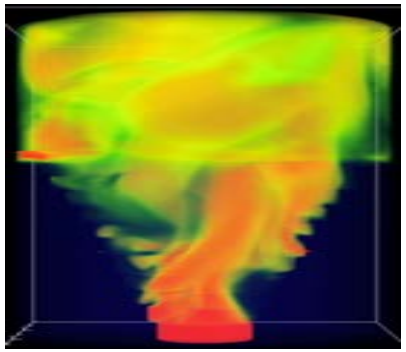
NETL Core Competencies

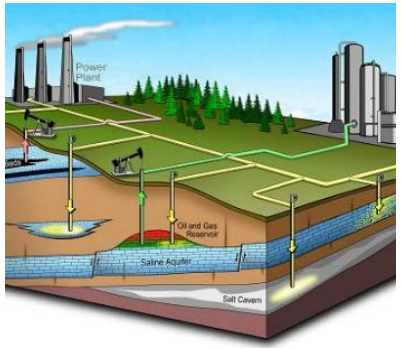


Computational Science & Engineering

- High Performance Computing
- Data Analytics

Materials Engineering & Manufacturing

- Structural & Functional
- Design, Synthesis, & Performance



Geological & Environmental Systems

- Air, Water & Geology
- Understanding & Mitigation

Energy Conversion Engineering

- Component & Device
- Design & Validation

Systems Engineering & Analysis

- Process & System
- Optimization, Validation, & Economics

Program Execution & Integration

- Technical Project Management
- Market & Regulatory Analysis

Effective Resource Development • Efficient Energy Conversion • Environmental Sustainability

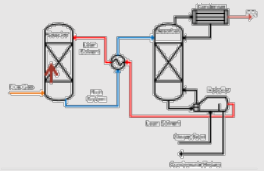
Systems Engineering & Analysis (SEA)

Teams and Scope

Energy Process Analysis

Energy Process Design, Analysis, and Cost Estimation

- Plant-level modeling, performance assessment
- Cost estimation for plant-level systems
- General plant-level technology evaluation and support



Advanced Technology Design & Cost Estimation

Energy Systems Analysis

Resource Availability and Cost Modeling

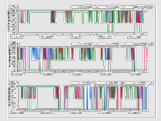
- CO_2 storage (saline and EOR)
- Fossil fuel extraction
- Rare earth elements
- General subsurface technology evaluation and support

Environmental Life Cycle Analysis

Energy Markets Analysis

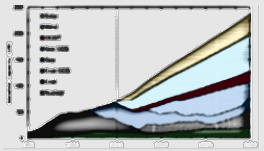
Energy Economy Modeling and Impact Assessment

- Enhanced fossil energy representation
- Multi-model scenario/policy analysis
- Infrastructure, energy-water



Grid, Infrastructure, & Energy Reliability

- Economic impact assessment
- General regulatory, market and financial expertise



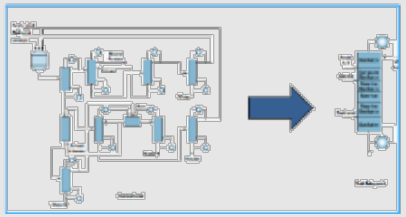
Regional & National Energy-Economy Model

Process Systems Engineering Research

- Process synthesis, design, optimization, intensification
- Steady state and dynamic process model development
- Uncertainty quantification
- Advanced process control

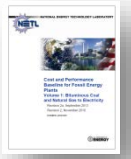
Design, optimization, and modeling framework to be expanded to all SEA "systems"

Advanced Energy Systems through Process Systems Engineering



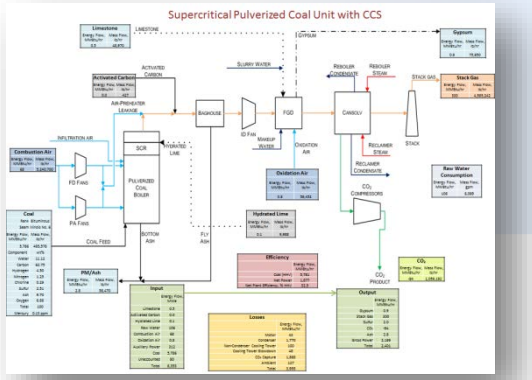
Systems Engineering and Analysis

Work Products and Tools of Note

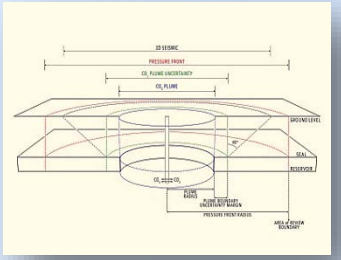


NETL Cost and Performance Baseline for Fossil Energy Plants

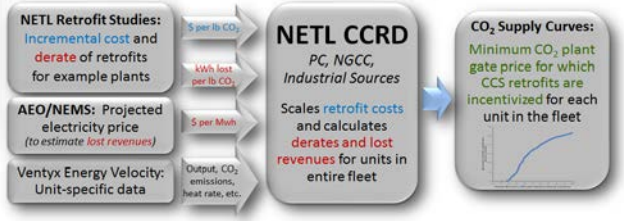
- *Detailed, transparent account of plant information*
- *Key resource for government, academia and industry*



NETL CO_2 Saline Storage Cost Model

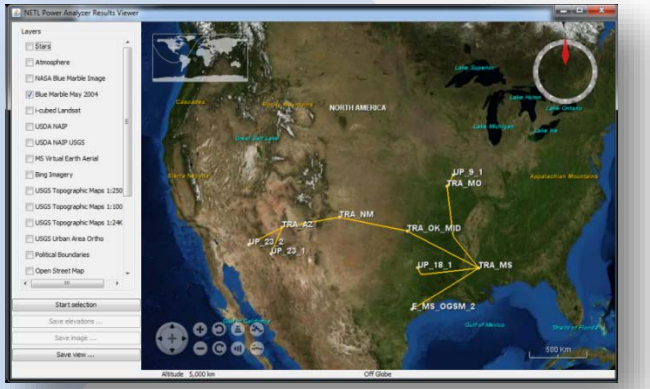


NETL Carbon Capture Retrofits Database (CCRD)



NETL CO_2 Capture, Transport, Utilization and Storage - National Energy Modeling System (CTUS-NEMS)

- *Adopted by EIA; first incorporated into AEO 2014*



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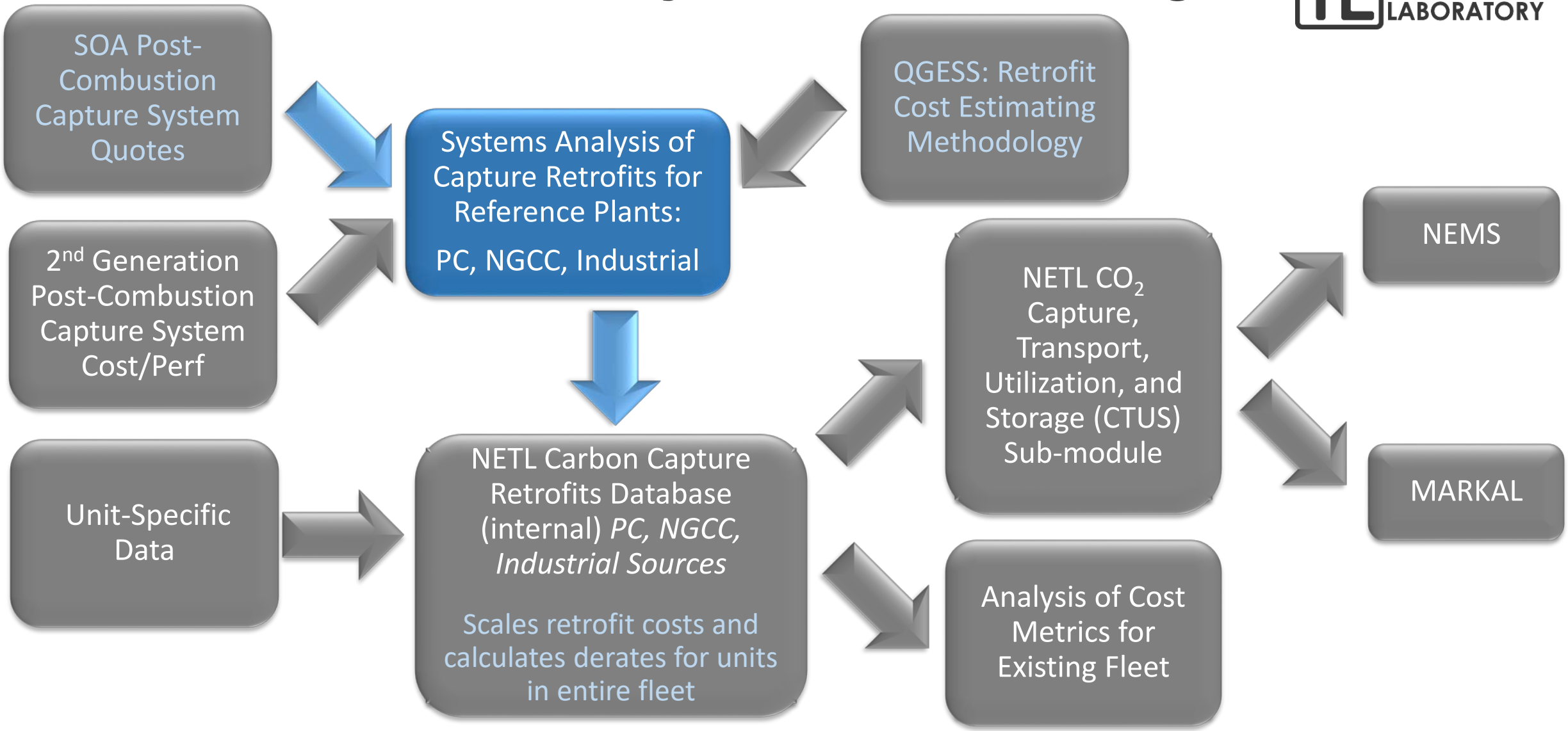
Cost and Performance Baseline for Fossil Energy Plants

Volume	Revision	Date	Fuel Types	Technology	Notes
1a	3	July 2015	Bituminous Coal, Natural Gas	PC, NGCC with and without CO_2 Capture	
1b	2b	July 2015	Bituminous Coal	IGCC with and without CO_2 capture	Year dollar update only
1 Supplement	0	June 2015	Bituminous Coal	PC and IGCC Partial CO_2 Capture	Sensitivity to CO_2 capture levels
3	0	Sept 2011	Sub-bituminous & Lignite Coal, Natural Gas	PC, IGCC, & NGCC with and without CO_2 capture	

Revision 4 Implementation

- Layout
  - Volume 1a and 1b being combined into Revision 4
- Performance
  - GT performance is being updated with vendor information, adding H-Class NGCC technology
  - CO_2 Capture system quotes on performance and economics are being updated
  - Emissions Limitations
    - Incorporating Effluent Limitation Guidelines (ELG) compliance (Zero Liquid Discharge [ZLD])
    - Adjusting operating conditions of CO_2 compression system
- Economics
  - Significant updates to capital costs for all cases is underway, with year dollar updates to 2016 or 2017
  - Updating feedstock prices, T&S costs, capital charge factor
  - Revisiting finance structure
- Final Report – Due in mid-to-late 2018

NETL CCS Retrofit Analysis and Modeling



Carbon Capture Retrofit Modeling Overview

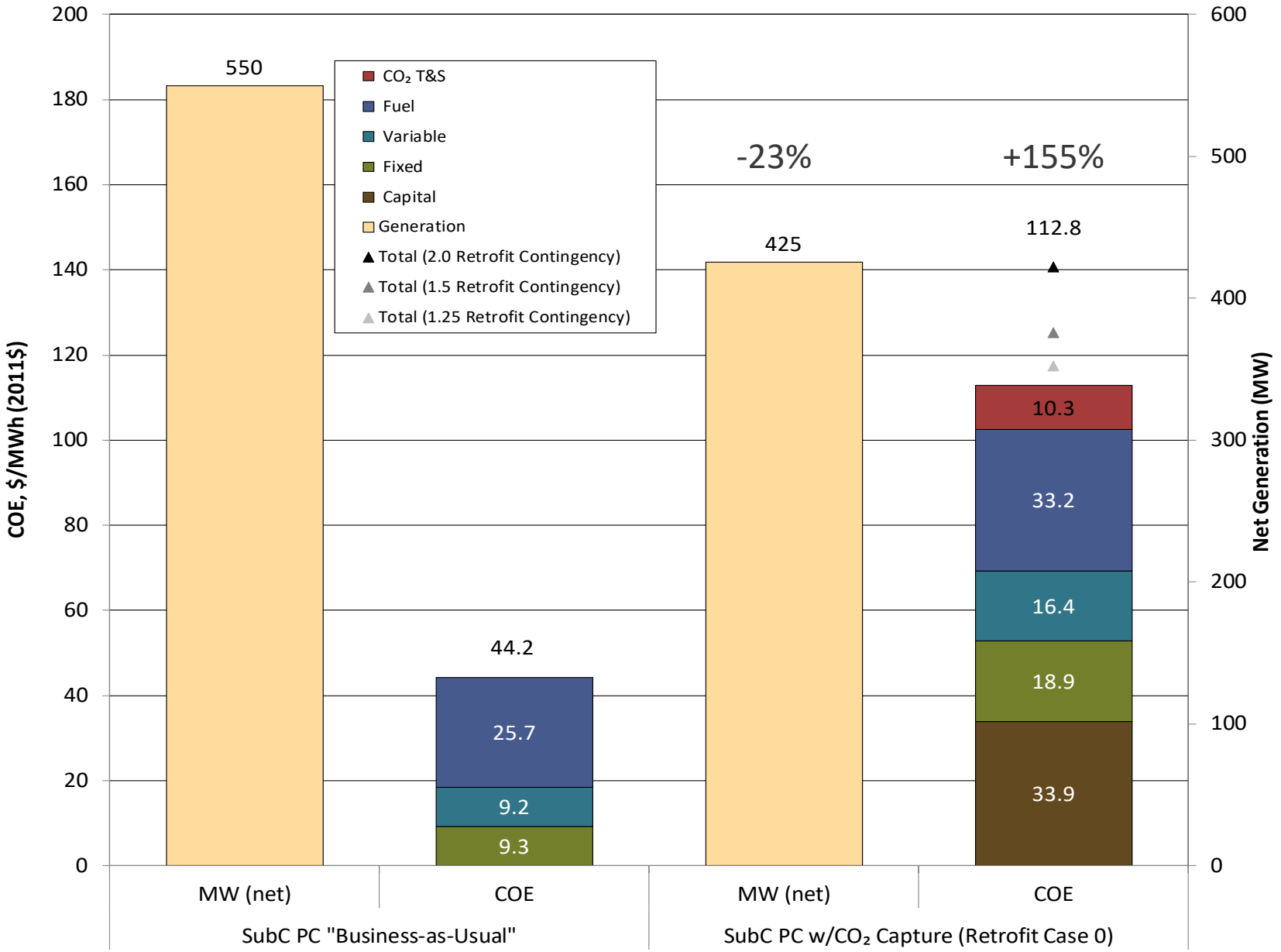
- 264 GW of existing coal and 242 GW of existing NGCC capacity in U.S.*
- CO_2 also available for capture from industrial sources; publicly available information from EPA's Greenhouse Gas Reporting Program
- Access to heat rate, nameplate capacity, O&M costs, CO_2 emissions, pollution controls, online date, other relevant data from which to estimate CCS retrofit costs
- Based on similar results of NETL studies, employ a factored approach to existing fleet to estimate cost, performance impact of CCS retrofits
- Determine sensitivity to capacity factor or financing assumptions, evaluate impact of advanced CCS R&D, assess benefits of EOR opportunities

*https://www.eia.gov/electricity/monthly/

Supporting Reports

- **PC**
  - "Eliminating the Derate of Carbon Capture Retrofits Study Update," Late 2017
- **NGCC**
  - "Cost and Performance of Retrofitting NGCC Units for Carbon Capture," Late 2017
- **Industrial**
  - "Cost of Capturing CO_2 from Industrial Sources," DOE/NETL-2013/1602, January 2014

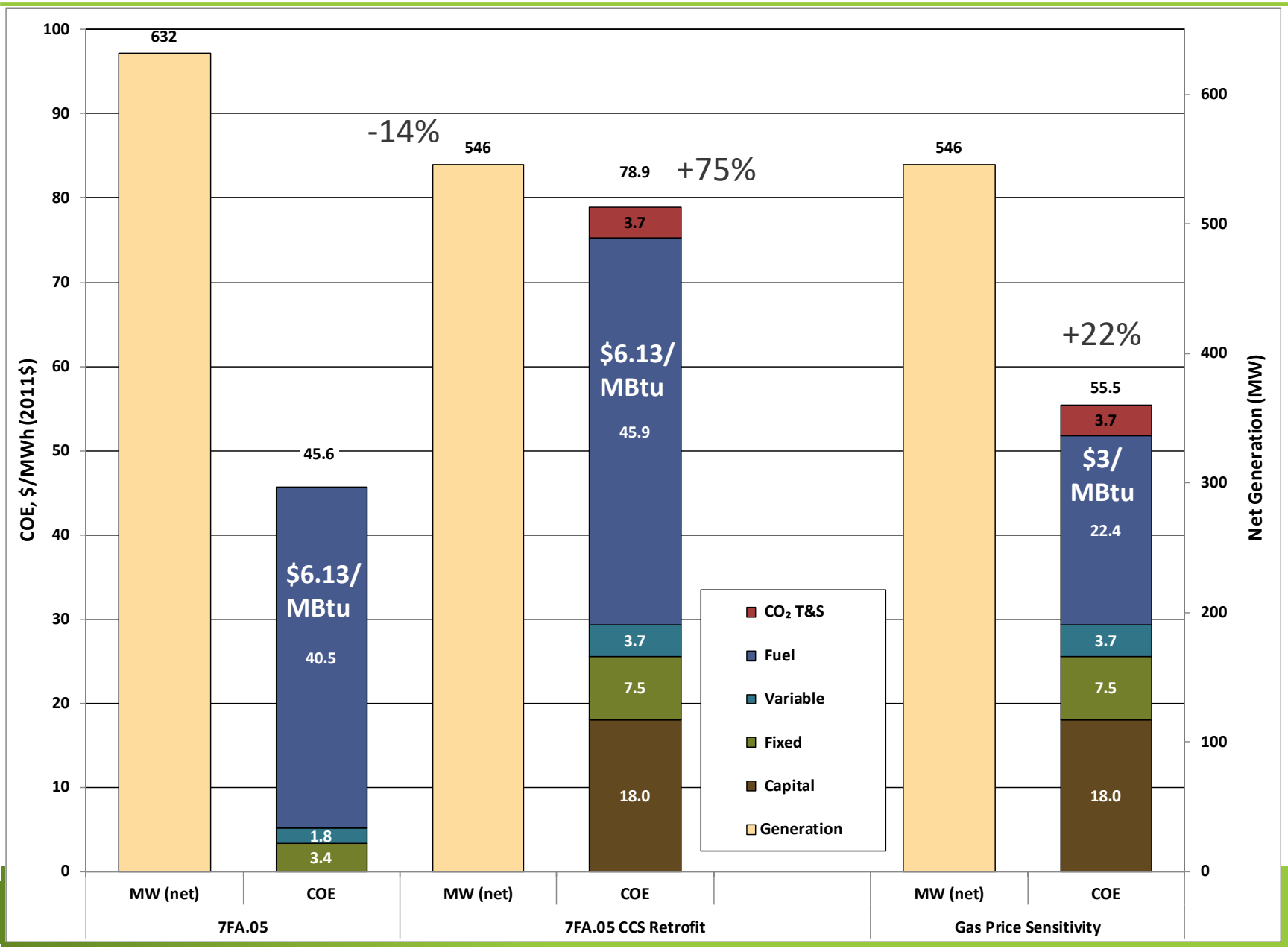
Subcritical PC Retrofit Results



Retrofit TPC	$726,600,000
Heat Rate (pre retrofit)	8,740 Btu/kWh
Heat Rate (post retrofit)	11,300 Btu/kWh
CO_2 Capture Rate	240,218 Lb CO_2/hr
Energy Penalty	≈0.14 kWh/Lb CO_2 captured
Incremental O&M	$18.8/MWh

TPC = Total Plant Cost

NGCC Retrofit Results



- NGCC cost of electricity highly sensitive to gas price!

Retrofit TPC	$647,300,000
Heat Rate (pre retrofit)	6,629 Btu/kWh
Heat Rate (post retrofit)	7,466 Btu/kWh
CO_2 Capture Rate	445,486 Lb CO_2/hr
Energy Penalty	≈0.19 kWh/Lb CO_2 captured
Incremental O&M	$6.15/MWh

TPC = Total Plant Cost

CO_2 Capture Retrofit Difficulty Factor

- Power plant retrofits typically space constrained
- A retrofit "difficulty factor" can be applied to capital costs to reflect site-specific challenges
- Factor only applied to capex, so impact on total cost of electricity can be easily assessed
- NETL Quality Guidelines for Energy System Studies – "Estimating Plant Costs Using Retrofit Difficulty Factors*"

* https://www.netl.doe.gov/energy-analyses/temp/QGESSRetrofitDifficultyFactors_083013.pdf

Incidental Retrofit Project Costs

- Existing coal units may require other environmental upgrades when adding CO_2 capture equipment

- Cost for NOx (SCR), SO_2 (FGD) upgrades should be considered to reflect all-in project cost

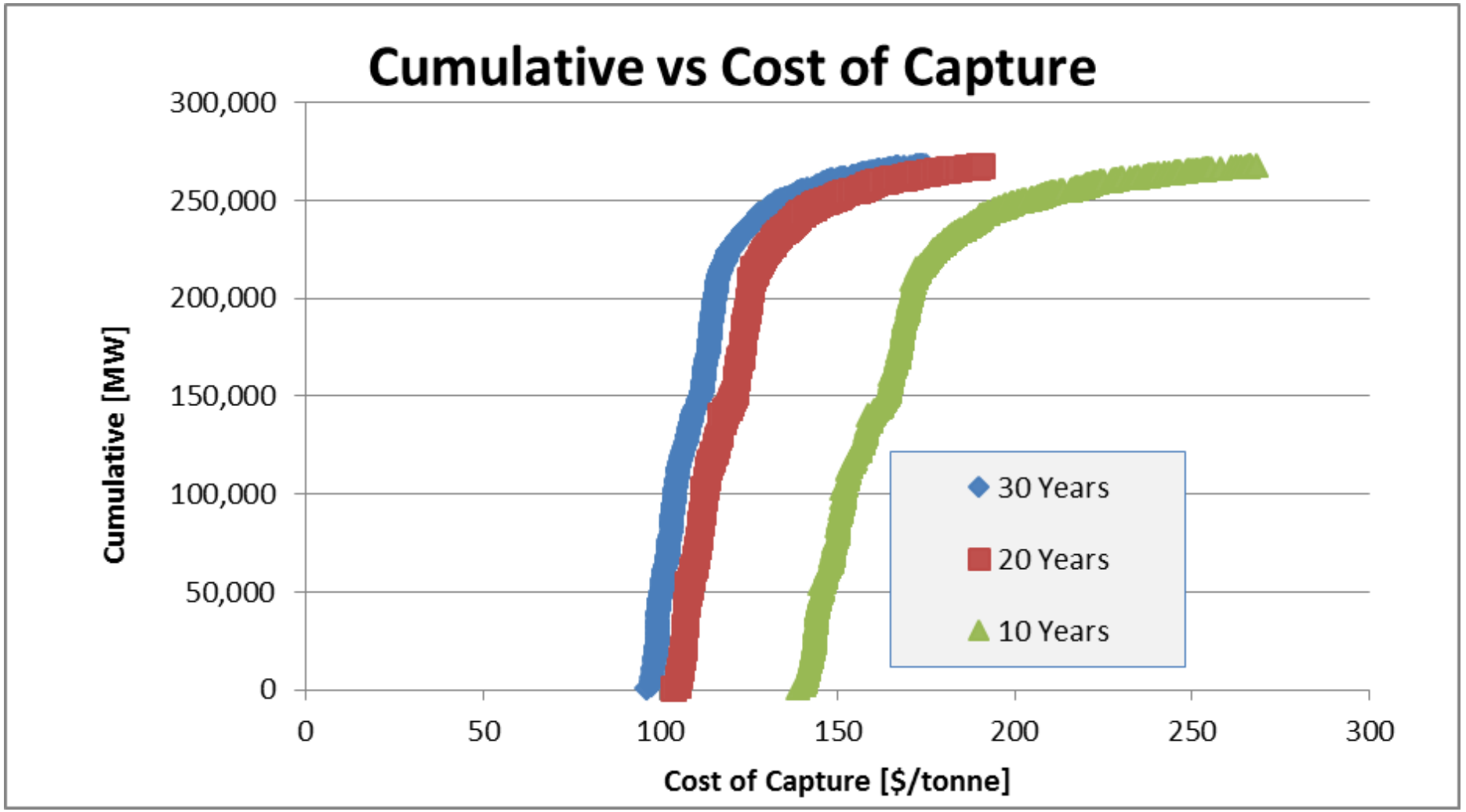
- CCS retrofit is a long-term bet on plant viability, may also want to consider cost for conversion from wet to dry cooling in certain regions (50% water consumption increase when capturing 90% CO_2)

Retrofit Financing Considerations

- NETL studies typically assume 30 year economic life (reflected in capital charge factor)
- What is expected remaining useful life of an existing coal unit retrofitted with CCS? Majority of existing coal fleet built in the 1970's.
- Financing assumptions needed to reflect scenarios shorter than 30-year default

Retrofit Financing Considerations

Impact of economic life on cost results

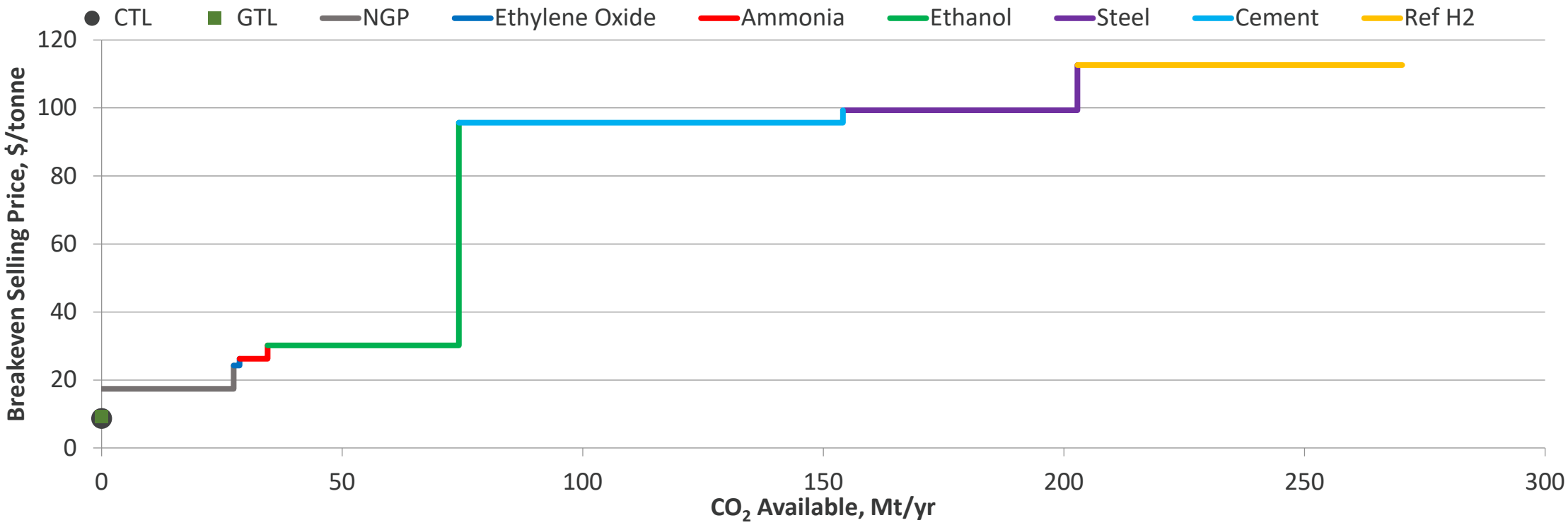


Industrial Source CO_2 Capture

Industrial Process	Reference Plant Capacity	CO_2 Source Stream	CO_2 to Product Ratio (tonne CO_2/tonne Product)	Source Stream CO_2 Concentration (mol%)	Source Stream CO_2 Partial Pressure (psia)	CO_2 Available for Capture (M tonnes CO_2/year)		Breakeven Cost of Capturing CO_2 ($/tonne CO_2)
						Reference Plant	All U.S. sources	
High Purity Sources								
Ethanol	*50 M gal/year*	Distillation gas	0.96	100	18.4	0.14	40	30
Ammonia	*907,000 tonnes/year*	Stripping vent	1.9	99	22.8	0.458	6	27
Natural Gas Processing	*500 MMscf/d*	CO_2 vent	N/A[1]	99	23.3	0.649	27	18
Ethylene Oxide	*364,500 tonnes/year*	AGR product stream	0.33	100	43.5	0.122	1	25
Coal-to-Liquids (CTL)	*50,000 bbl/d*	AGR product stream	N/A[2]	100	265	8.74	-	9
Gas-to-Liquids (GTL)	*50,000 bbl/d*	AGR product stream	N/A[2]	100	265	1.86	-	9
Low Purity Sources								
Refinery Hydrogen	*59,000 tonnes/year*	PSA tail gas	10.5	44.5	8.9	0.274	68	118
Iron/Steel	*2.54 M tonnes/year*	Plant Total COG PPS COG/BFG[3]	2.2	N/A 23.2 26.4	N/A 3.4 3.9	3.9 2.75 1.16	49	99 99 101
Cement *SCR/FGD Sensitivity*	*992,500 tonnes/year*	Kiln Off-gas	1.2	22.4	3.3	1.14	80	100 *127*
Coal-fired power plants	*550 MW*	*Flue Gas*	*NA*	*13.5*	*2.0*	*4.13*	*2,545[4]*	*77[56]*

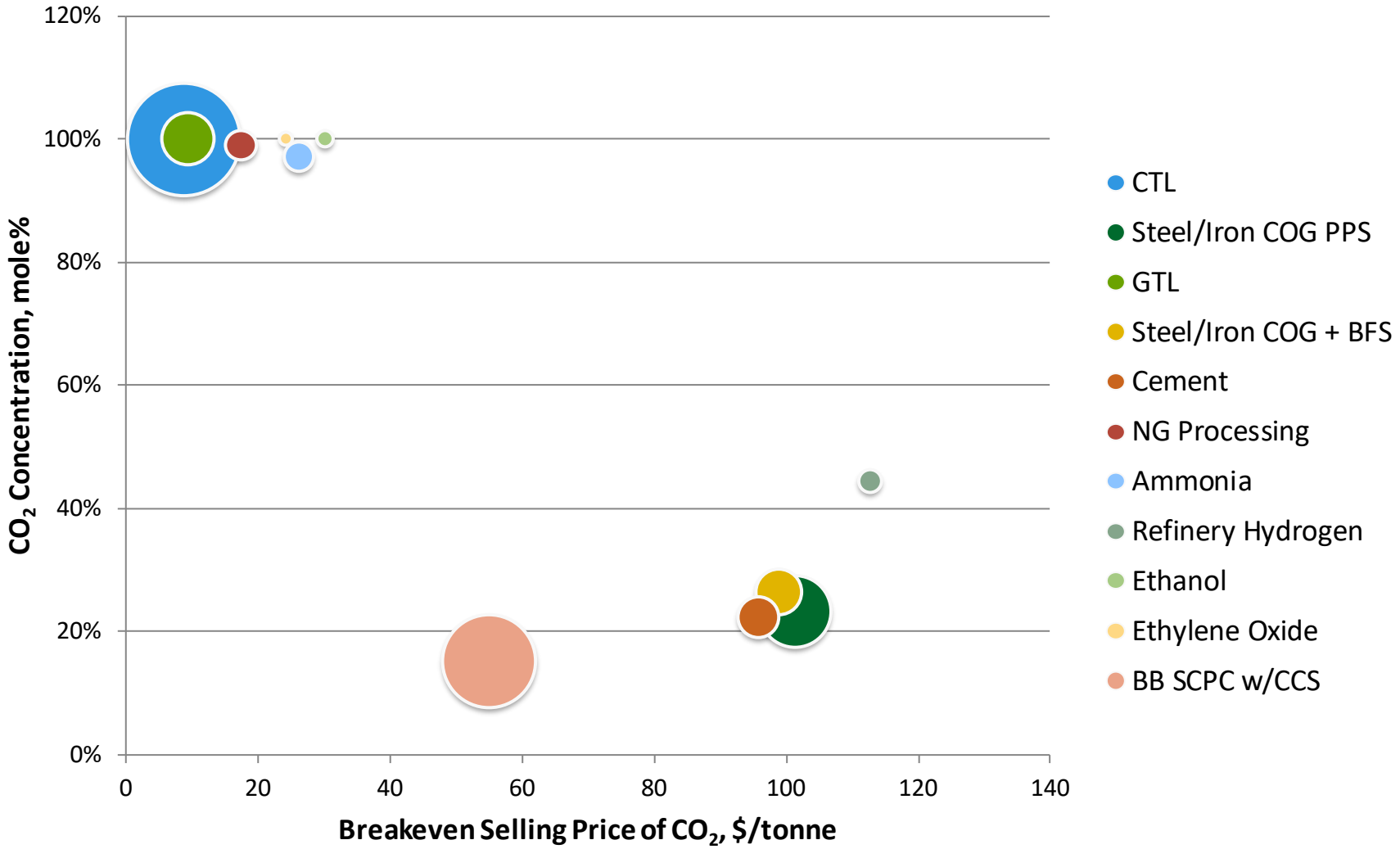
Capturing CO_2 from Industrial Sources

Incremental CO_2 Supply versus Breakeven Selling Price



Capturing CO_2 from Industrial Sources

Breakeven Selling Price as a Function of CO_2 Concentration



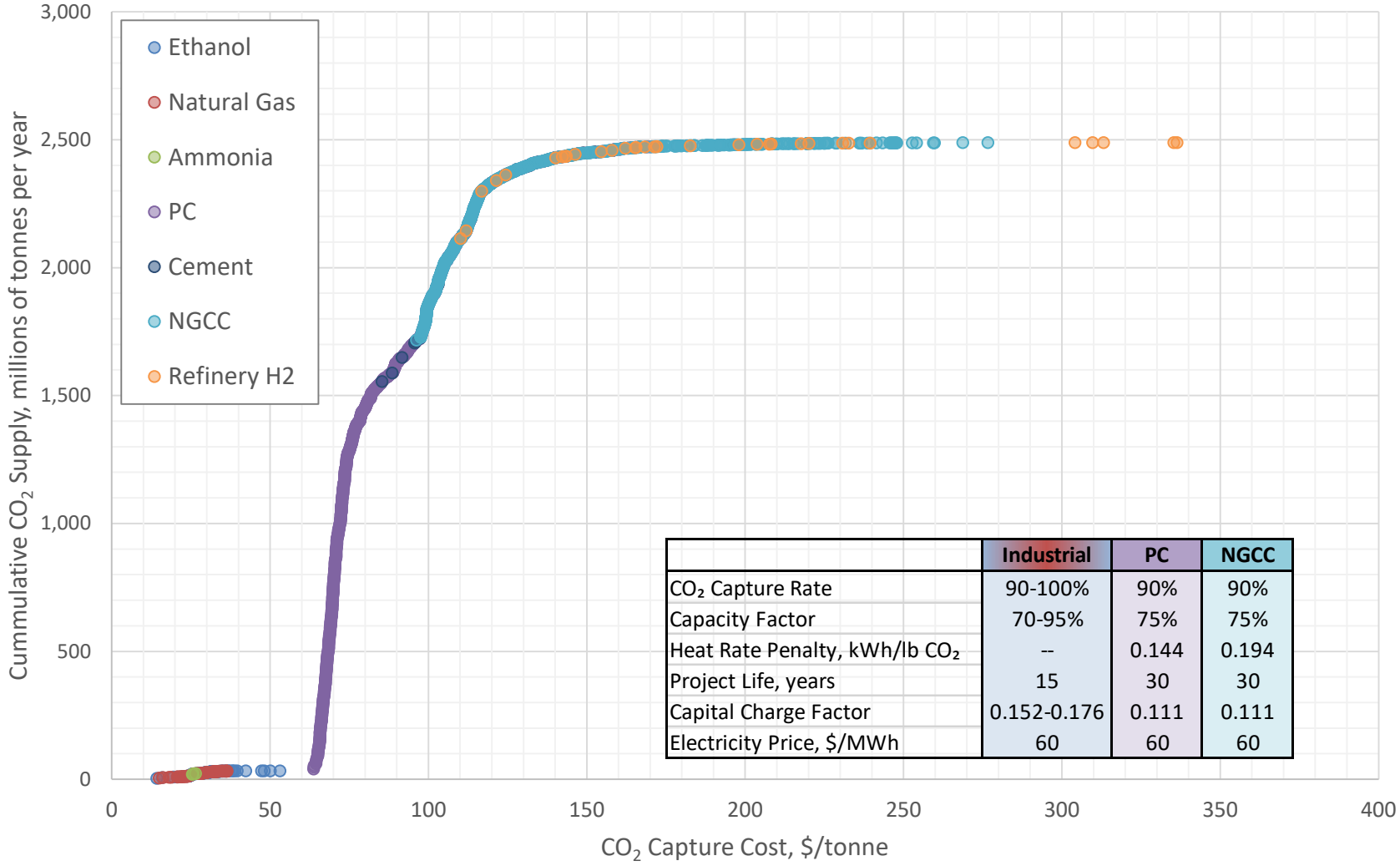
Industrial Source Retrofit Methodology

- Facility data for industrial sources based on EPA's Greenhouse Gas Reporting Program[1] and FLIGHT data[2]
- Plant capacity in report based on typical sizes, cost and performance post-retrofit based on source report, and applied using a scaled approach
- Key parameters of interest include payback period, financing structure, supplemental power or natural gas price

1. https://www.epa.gov/ghgreporting/ghgrp-reported-data
2. https://ghgdata.epa.gov/ghgp/main.do#

Cumulative CO_2 Supply

Large capacity available, at increasing cost of capture



	Industrial	PC	NGCC
CO_2 Capture Rate	90-100%	90%	90%
Capacity Factor	70-95%	75%	75%
Heat Rate Penalty, kWh/lb CO_2	--	0.144	0.194
Project Life, years	15	30	30
Capital Charge Factor	0.152-0.176	0.111	0.111
Electricity Price, $/MWh	60	60	60

Future Work

- Finalization of existing coal, NGCC retrofit source reports
- Continued development of internal version of retrofit model
- Development of public version of retrofit model

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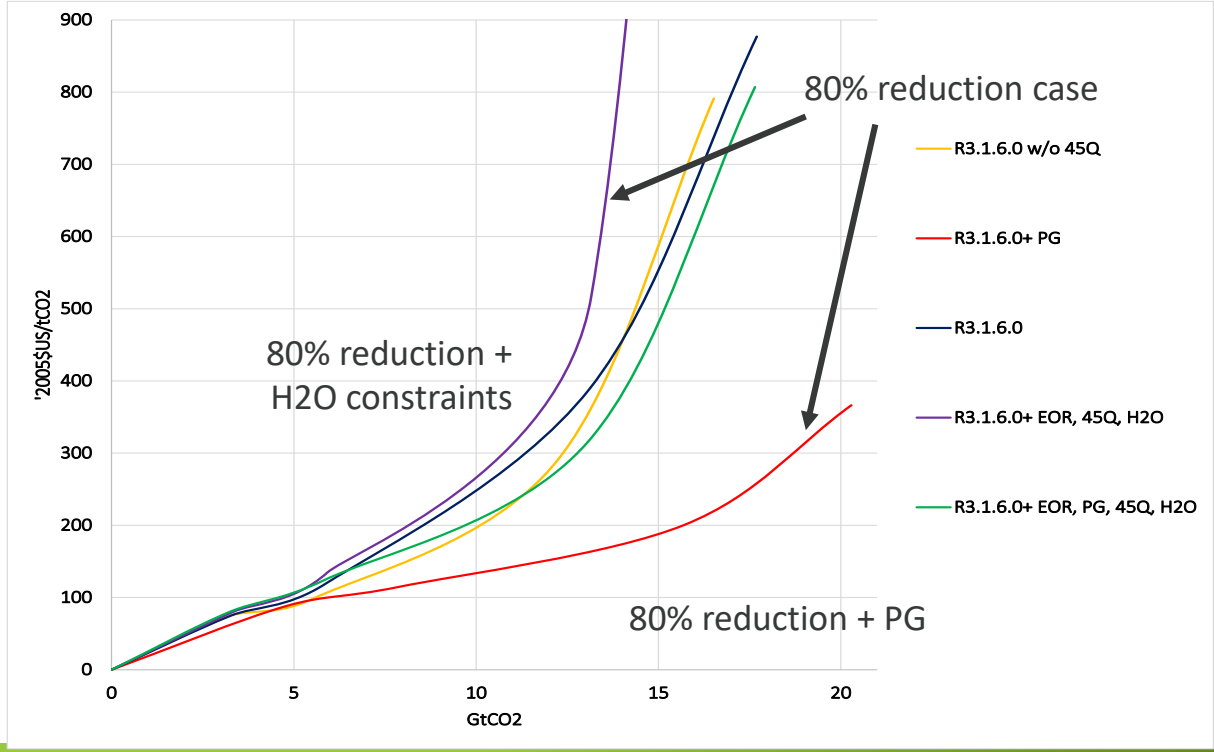
NEMS Modeling

National Energy Modeling System

- **Modeling system used to create EIA Annual Energy Outlook**
  - NETL aids in development of carbon capture related modules and utilizes NEMS for situational analysis
  - 2017 analyses have included carbon taxes, gas prices, carbon caps, and effects of achieving CCS program goals
- **Brief Summary Results**
  - Highest cumulative CO_2 reduction at lowest cost in scenario with CCS program goals
  - Water constraints increase costs in all scenarios
  - NGCC with carbon capture must be addressed



Other Studies

- **Scenario Analyses**
  - Evaluate retrofit/repowering potential for advanced technologies
  - Utilize PROMOD and cashflow models
    - NETL evaluates effect of incentives and market conditions on technology dispatch (capacity factors)
- **Infrastructure Analysis**
  - Currently evaluating CO_2 purity requirements for pipeline/storage
  - Deliverable - Update to CO_2 purity QGESS

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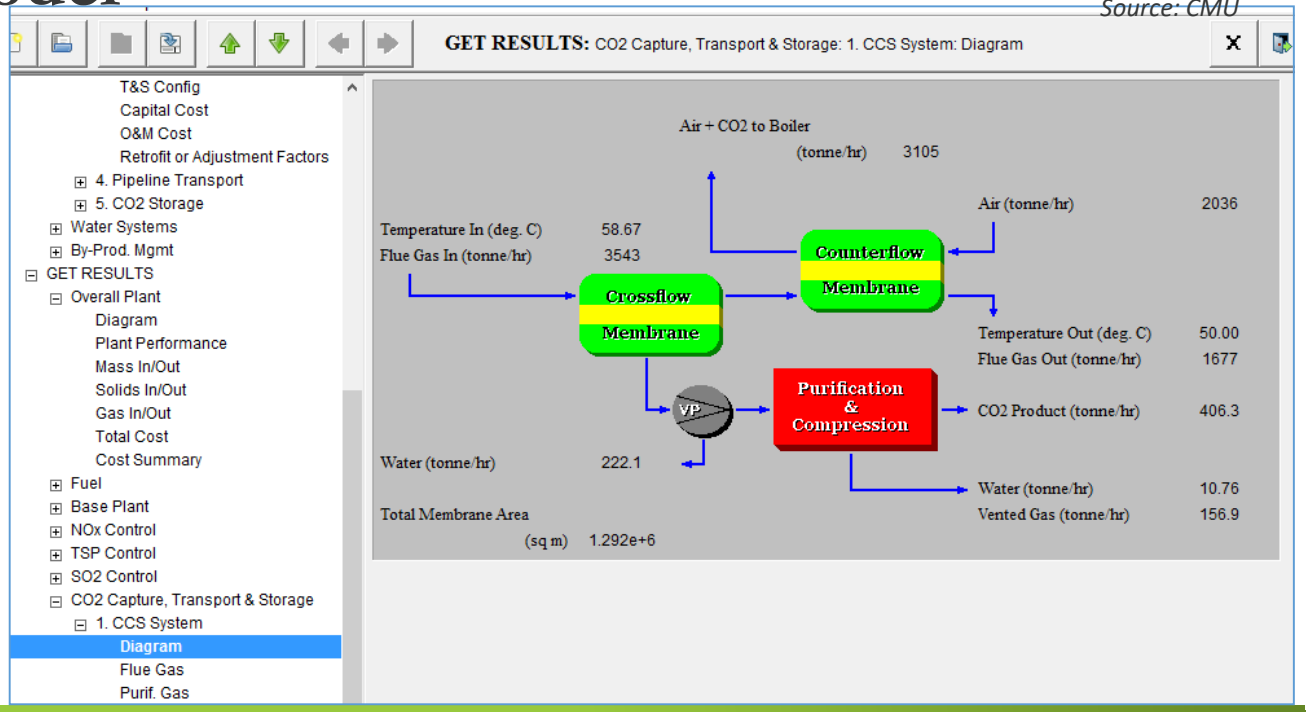
IECM Updates

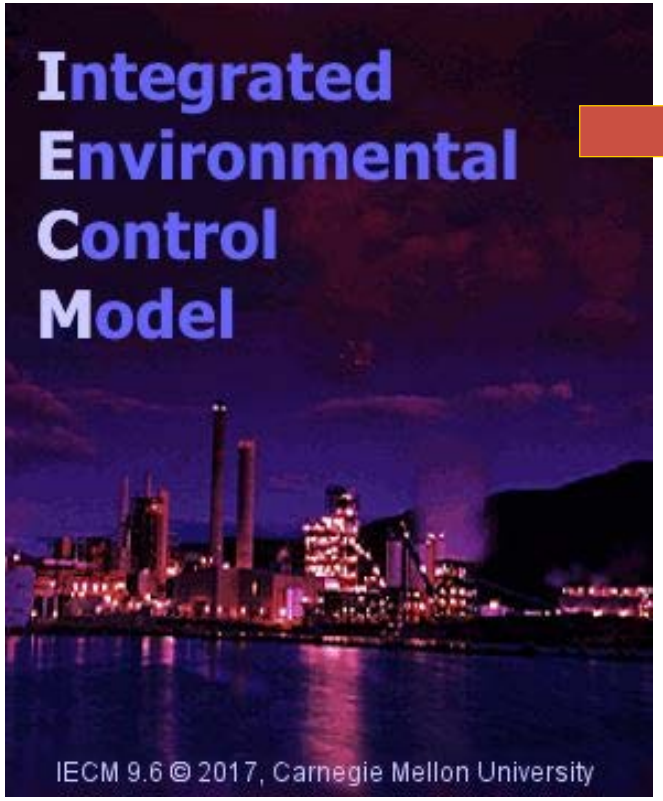
New Cases/Models

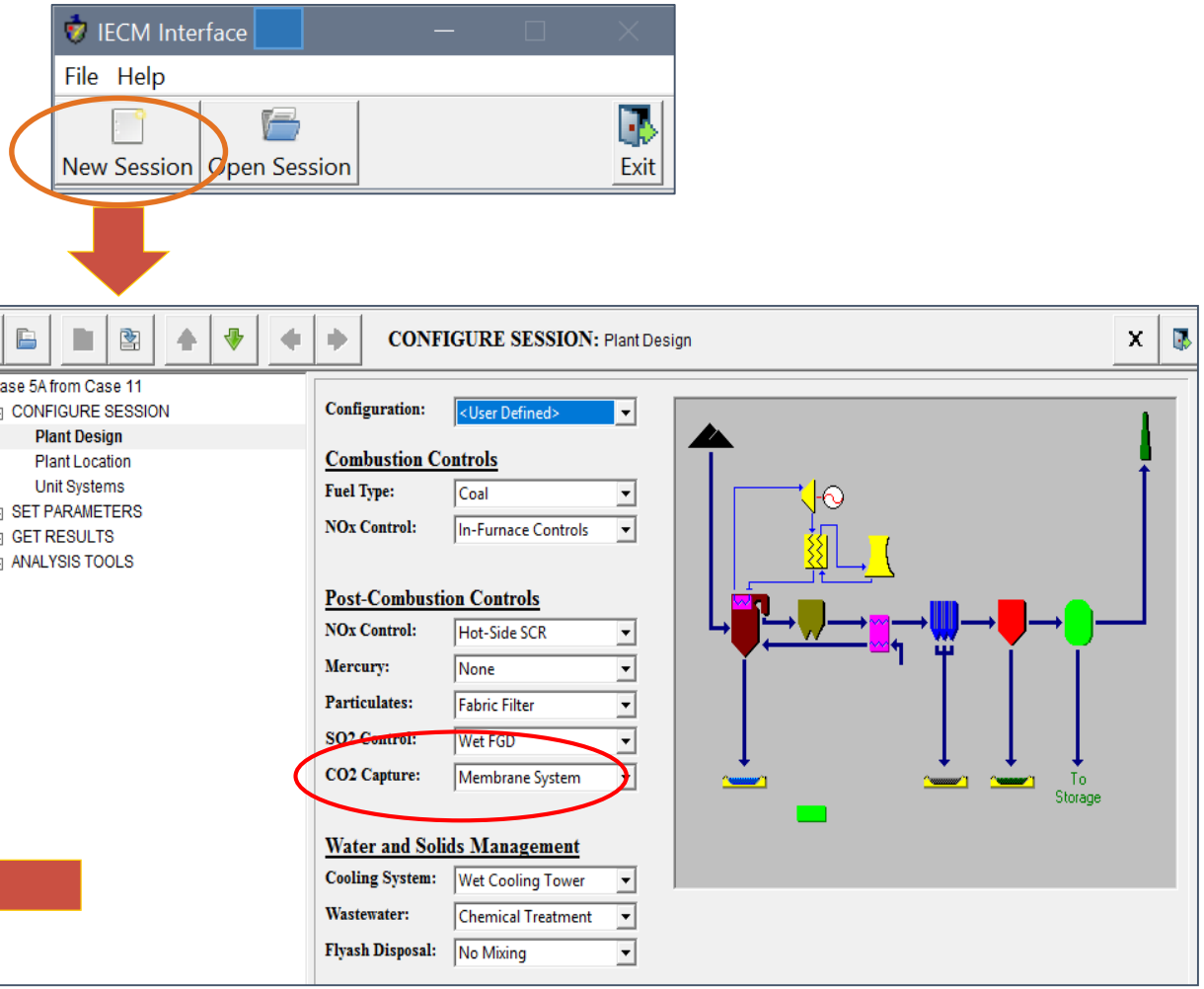
- Developed and Distributed by Carnegie Mellon University
- Advanced Membrane-based CO_2 Capture System Model
  - Incorporates air sweep option
- Enhanced CO_2 Purification Unit Model
- IECM 9.6 Released May 2017

Source: CMU



Implementation in IECM





Change or view model parameters and results. Use "Save as" to keep a copy of your session in a "New Database"

Source: CMU

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