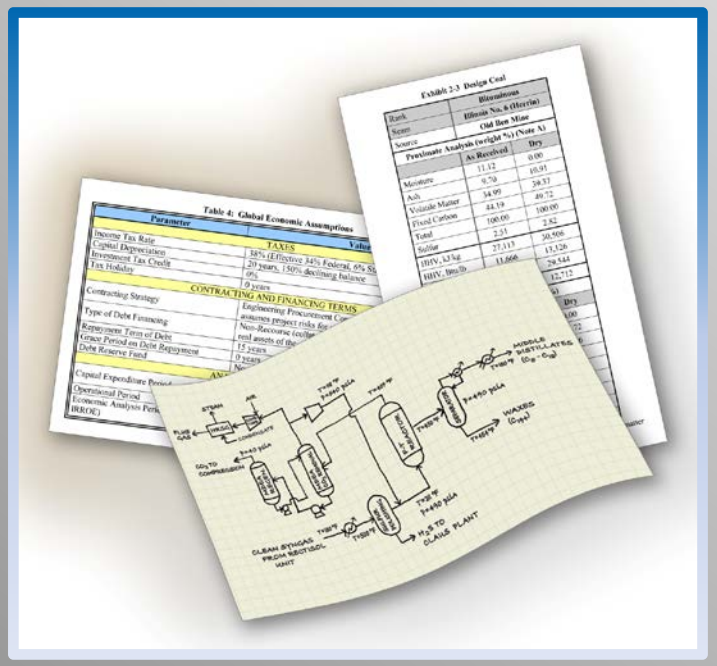

Techno-economic Evaluation of State-of-the-Art and Advanced Post-Combustion Capture Plants

Kristin Gerdes

Office of Program Performance and Benefits

July 29, 2014

- **Outline**
  - Bituminous Baseline Study Revision 3
  - Clean Coal Research Program Goal Review
  - NETL Advanced Capture Technology Assessments

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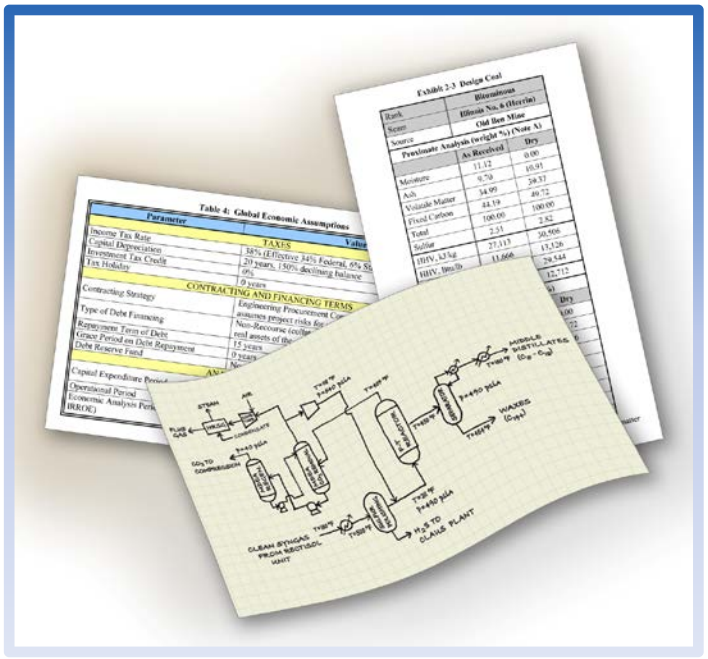

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BITUMINOUS BASELINE STUDY REVISION 3

Update to the Bituminous Baseline Study

Overview

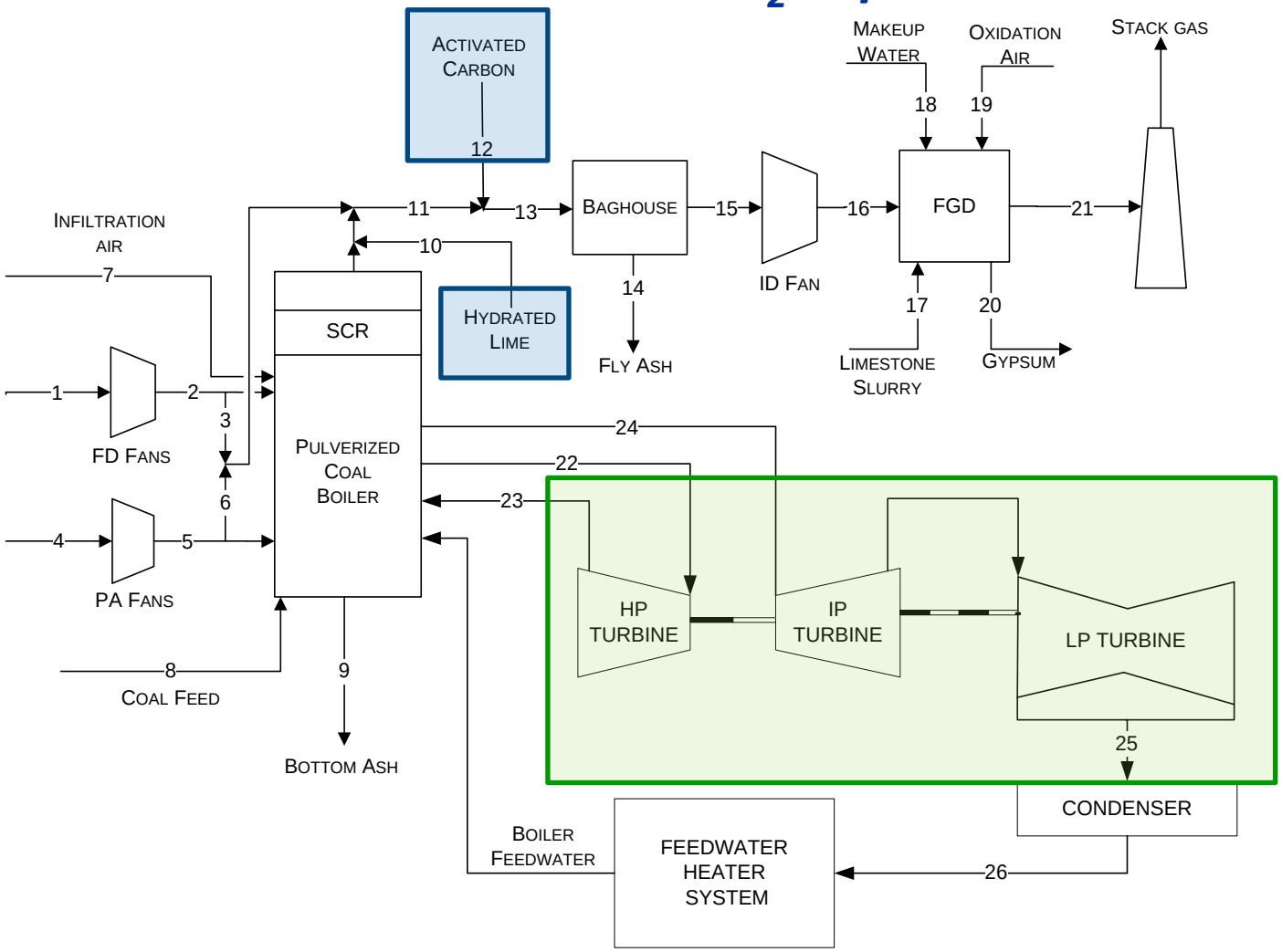
Full Title: ***Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity, Revision 3, Fall/Winter 2014***

Purpose: to provide a basis for evaluation of advanced technologies on a consistent set of technical and economic assumptions

- **Major change summary**
  - **Updated basis for performance and cost for CO_2 capture system, CO_2 compression, steam turbines, natural gas turbines**
  - **Update of all cases to 2011$**
  - **Updated environmental control train to address EPA regulations**
  - **Updated tables to include additional data**
  - **New case numbering system (conforms with Low Rank study)**
  - **Minimal changes to IGCC cases (further updates coming soon!!)**

Flowsheet Changes

B11A and B12A – No CO_2 Capture



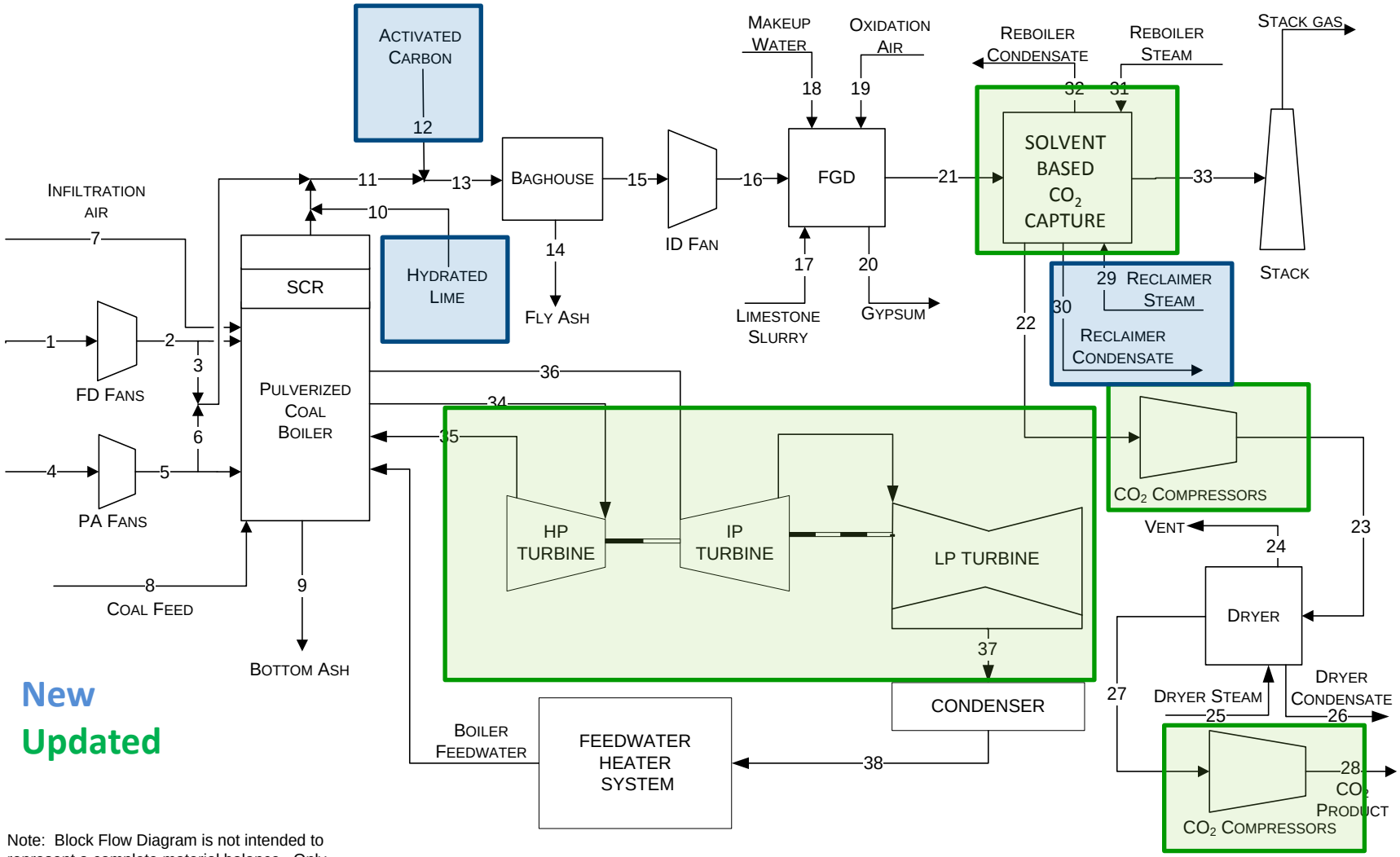
New

Updated

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

Flowsheet Changes

B11B and B12B – with CO_2 Capture

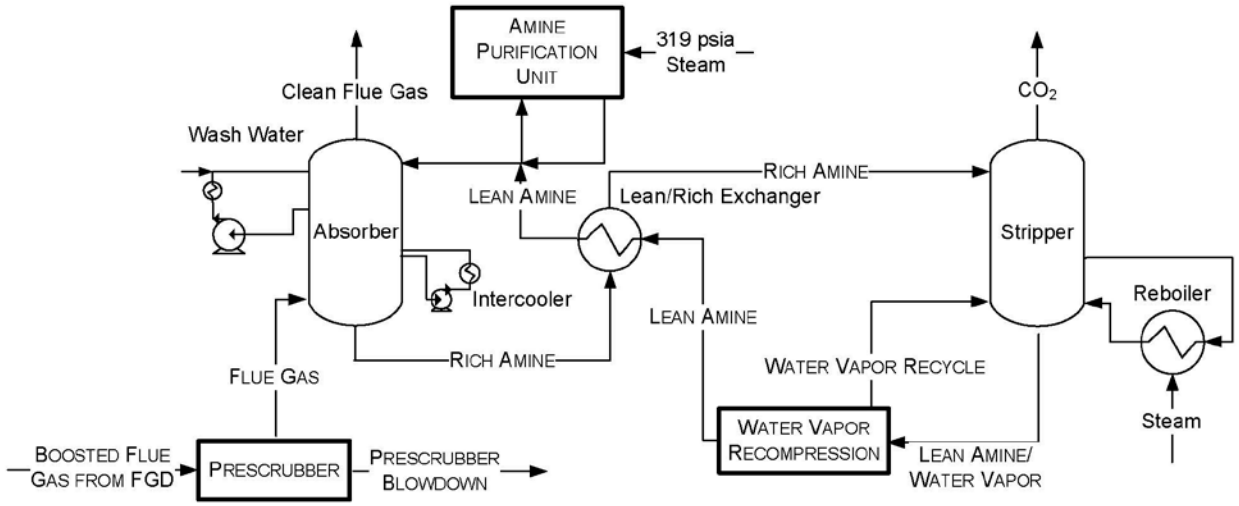


New

Updated

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

PC & NGCC Cases
CO_2 Capture System



Amine-based capture system

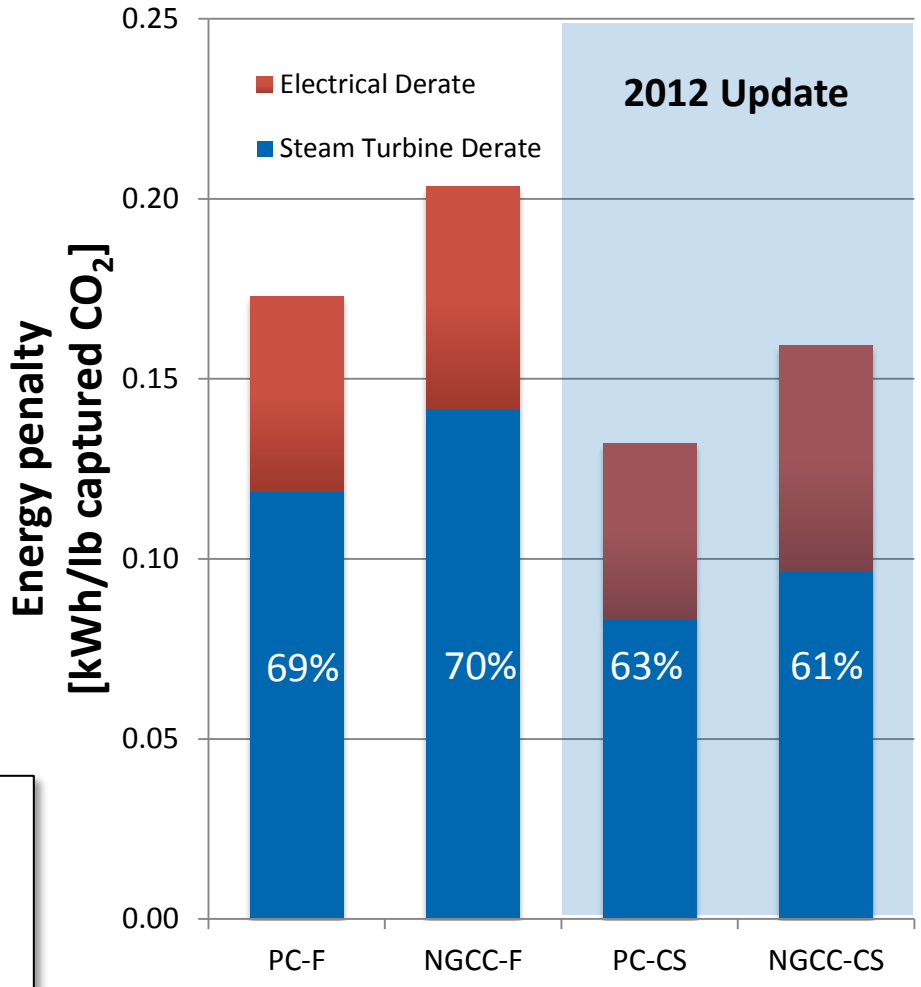
Features:
Absorber – acid brick lined concrete structure
90 % CO_2 Capture
Pre-scrubber used in coal cases only

Baseline Greenfield Capture and Compression Technology Update

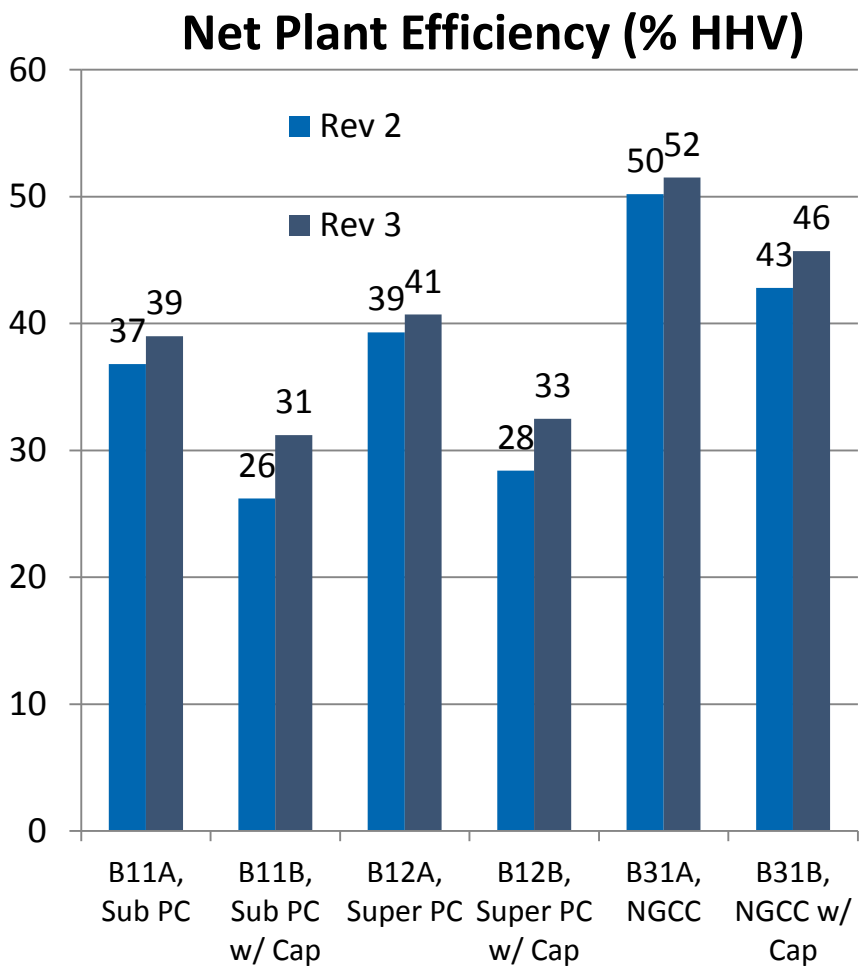
PC Plants	Quote Vintage	
Metric	2005	2012
Net Energy Penalty [kWhnet/lb CO_2 Captured]	0.17	0.13
Reference Capital Cost [$2011/tpd CO_2 Capt. @ full load]	$45,000	$47,900
CO_2 Capture Basis [tpd]	11,210	11,210

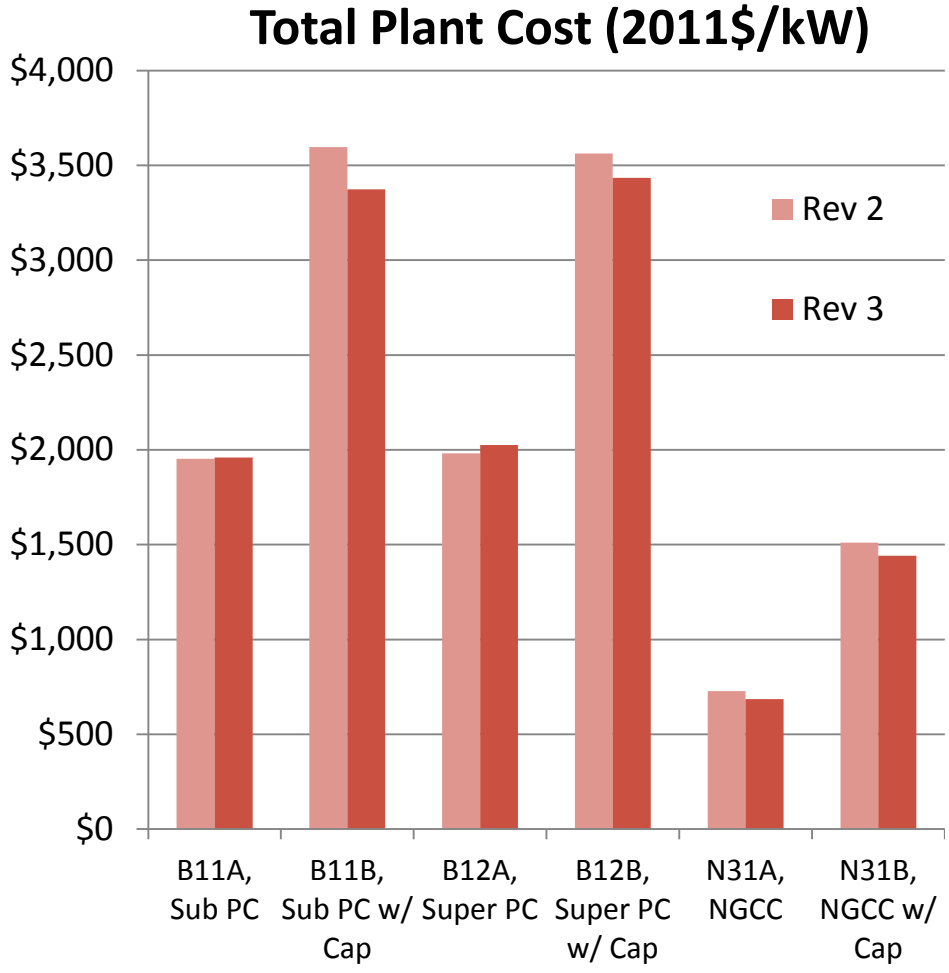
PC: ~25% reduction in regeneration energy penalty

NGCC: ~20% reduction in regeneration energy penalty

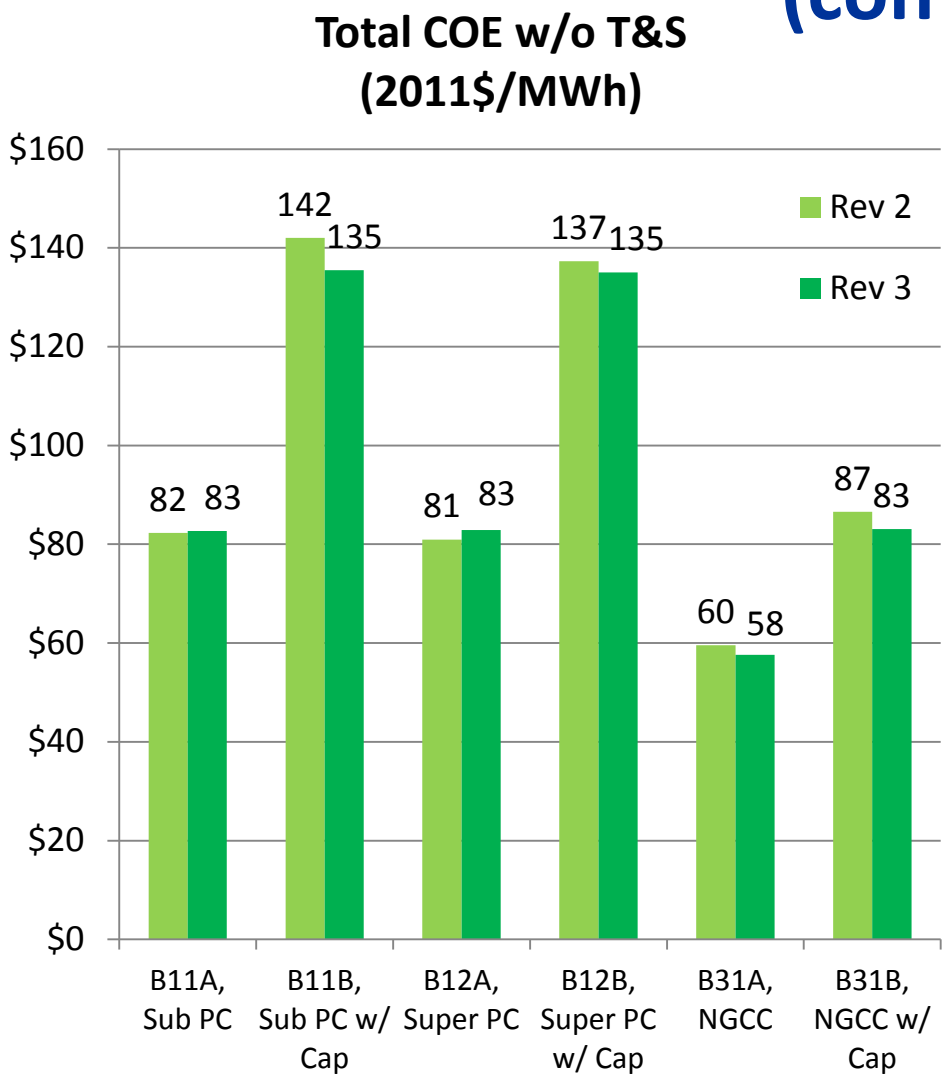


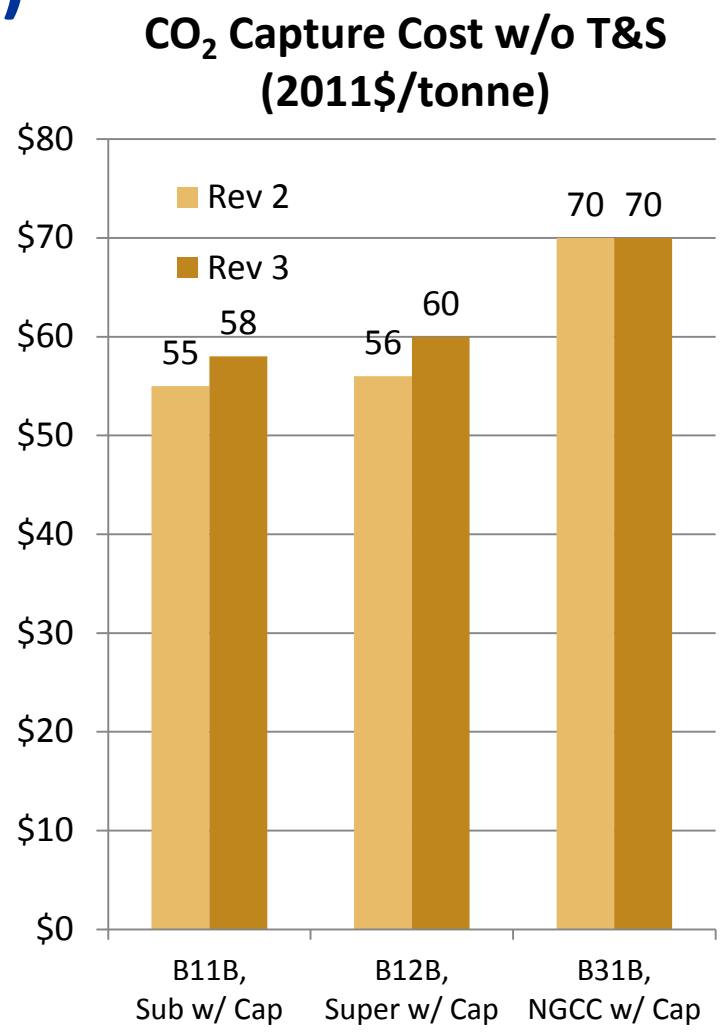
Bituminous Baseline Revision Comparisons



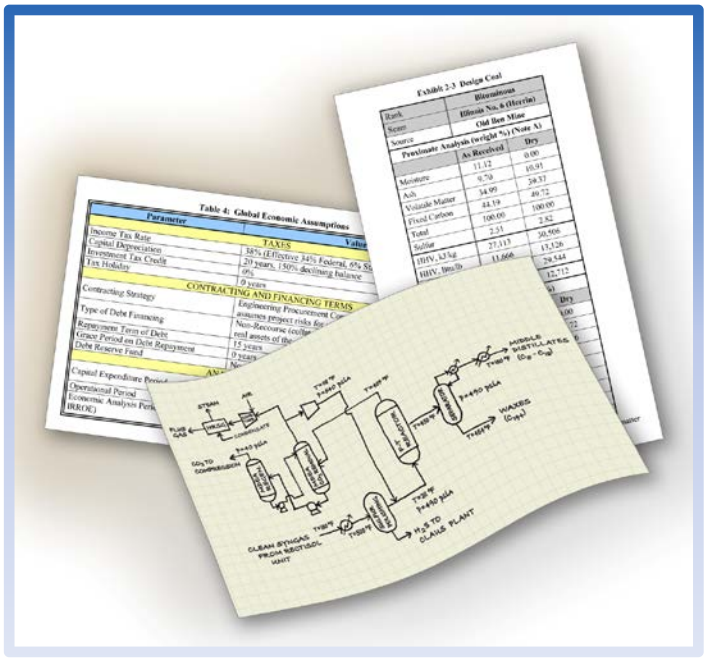


Bituminous Baseline Revision Comparisons (con't)





Capture cost calculated with SC baseline for Coal and NGCC for NG



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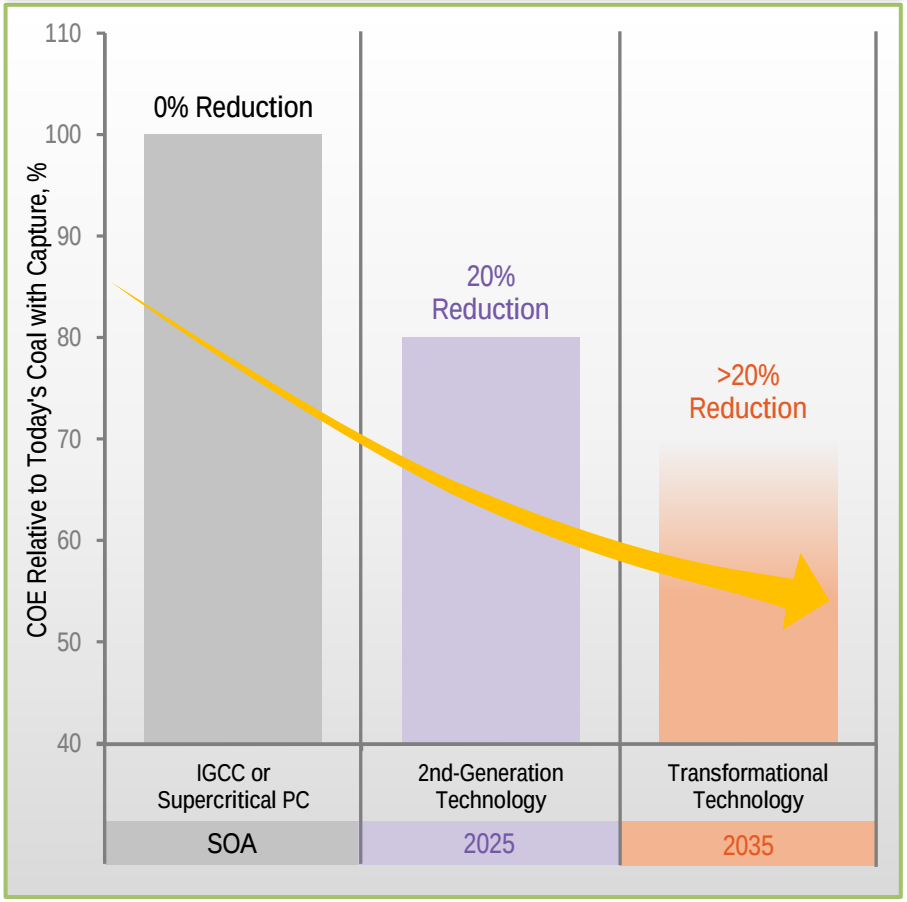
CLEAN COAL RESEARCH PROGRAM (CCRP) GOAL REVIEW

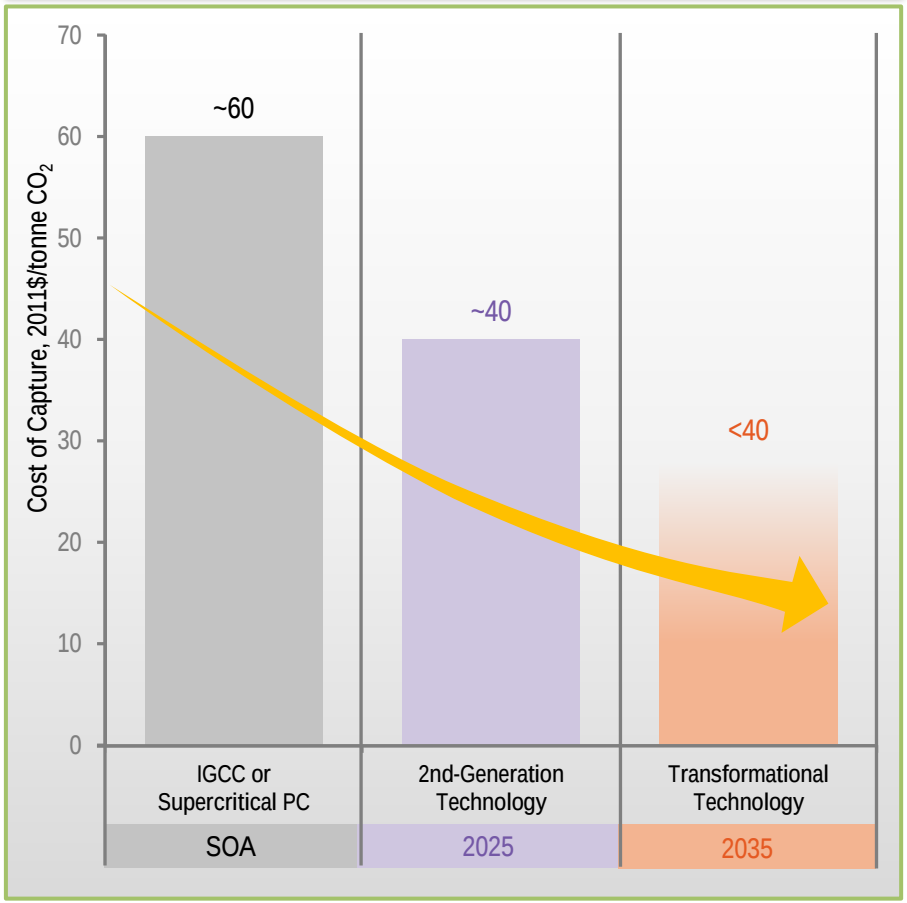
Clean Coal Research Program Goals

Driving Down the COE and Cost of CO_2 Capture of Coal Power with CCS

Cost of Electricity Reduction Targets



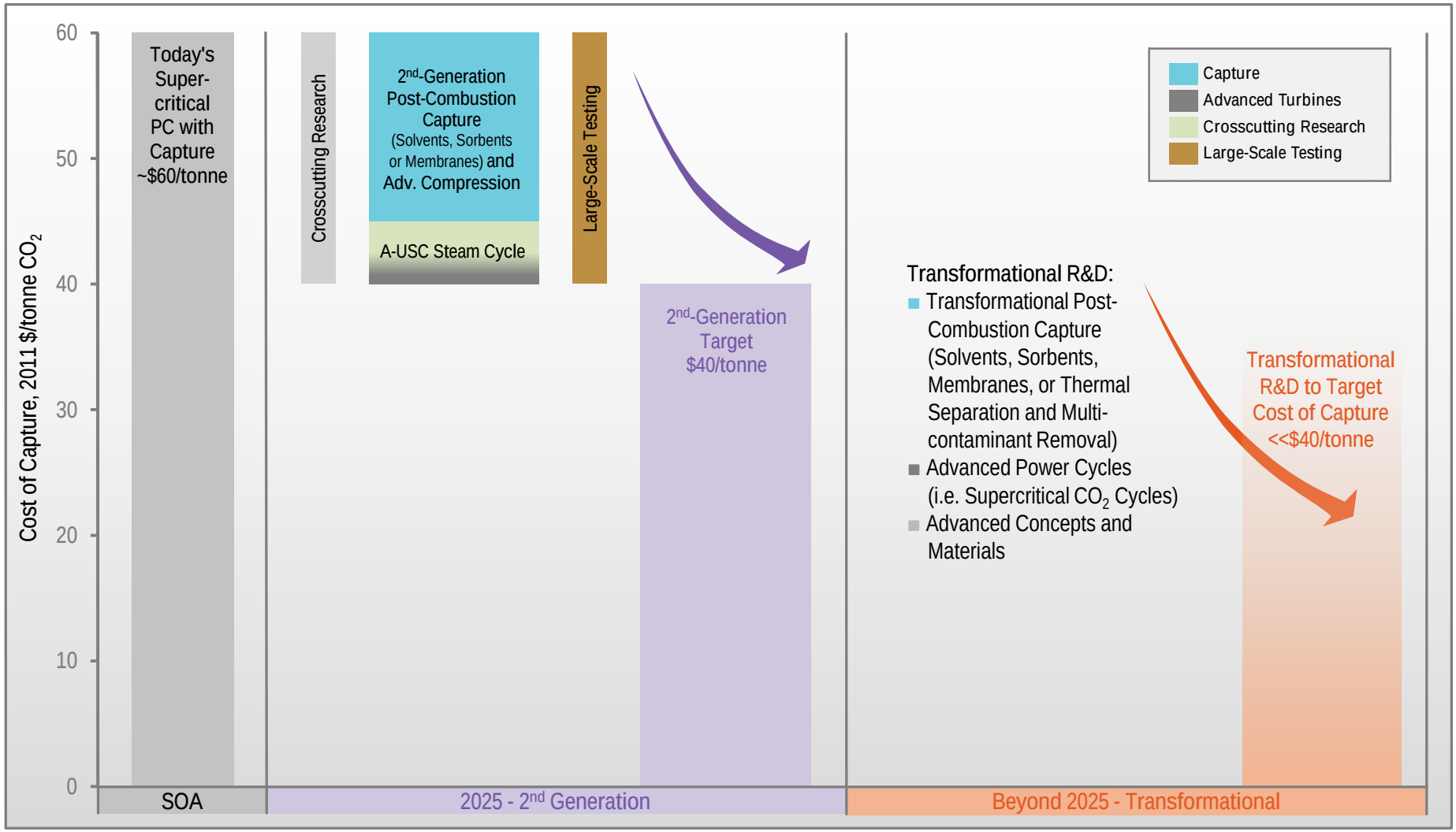
Corresponding Cost of CO_2 Capture Targets



Goals shown are for greenfield plants. Costs are nth-of-a-kind, are for the first year of plant operation, and include compression to 2215 psia but exclude CO_2 transport and storage costs. Today's capture costs are relative to Today's SCPC without CO_2 capture. 2025 and 2035 capture costs are relative to an A-USC PC without CO_2 capture.

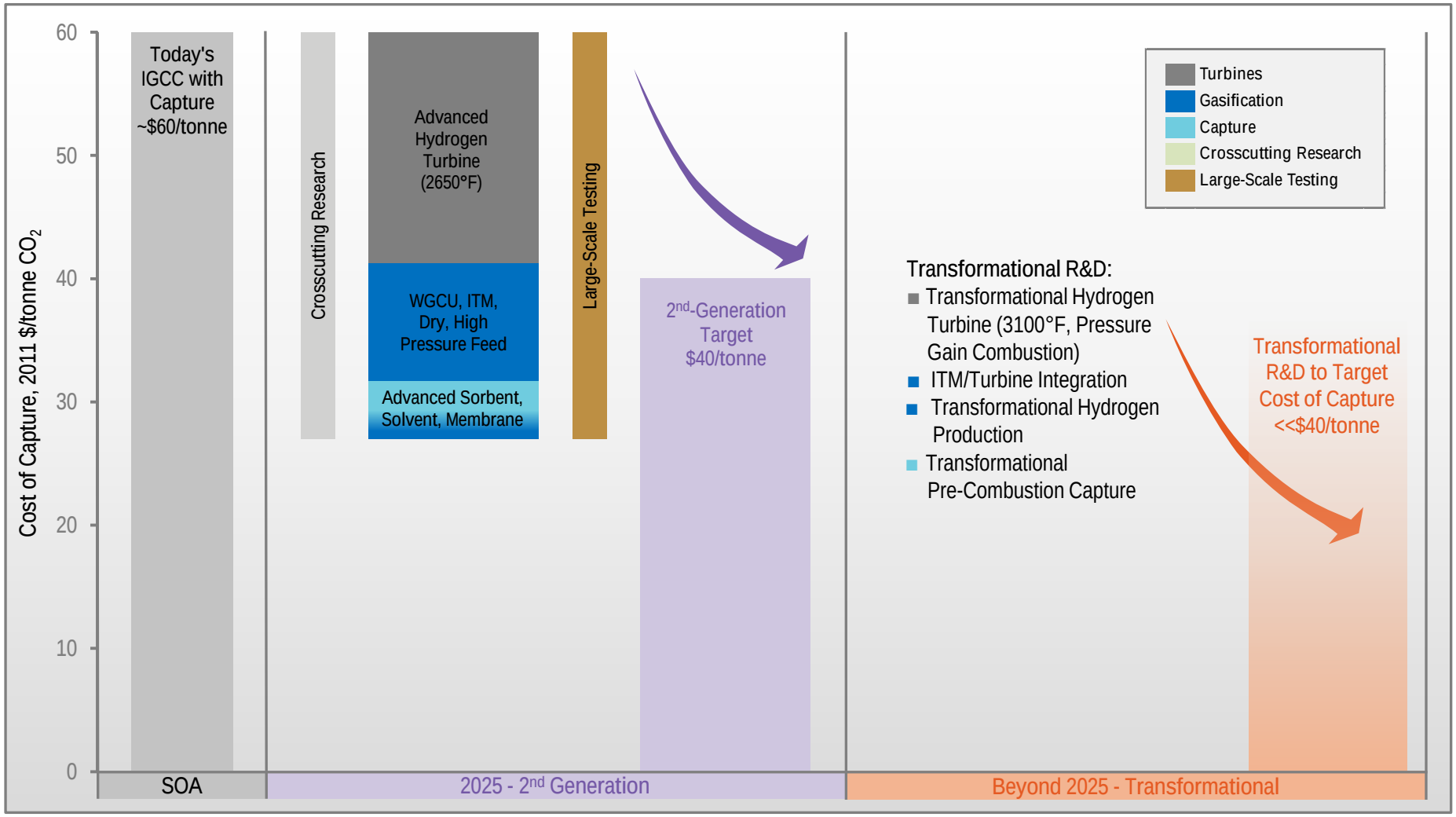
R&D Driving Down the Cost of CO_2 Capture

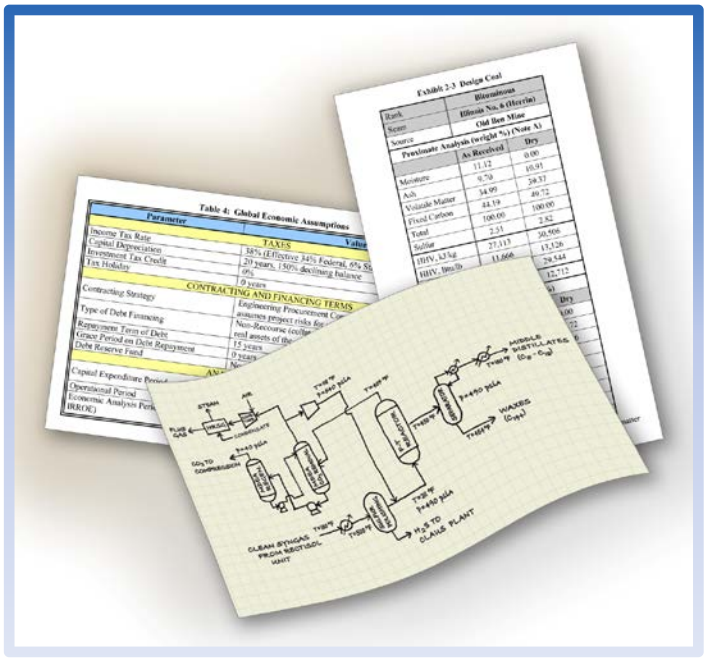
Greenfield Post-Combustion Capture Plants



R&D Driving Down the Cost of CO_2 Capture

IGCC with Pre-Combustion Capture





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ADVANCED CAPTURE TECHNOLOGY ASSESSMENTS

NETL/OPPB Advanced Capture Ongoing Analyses

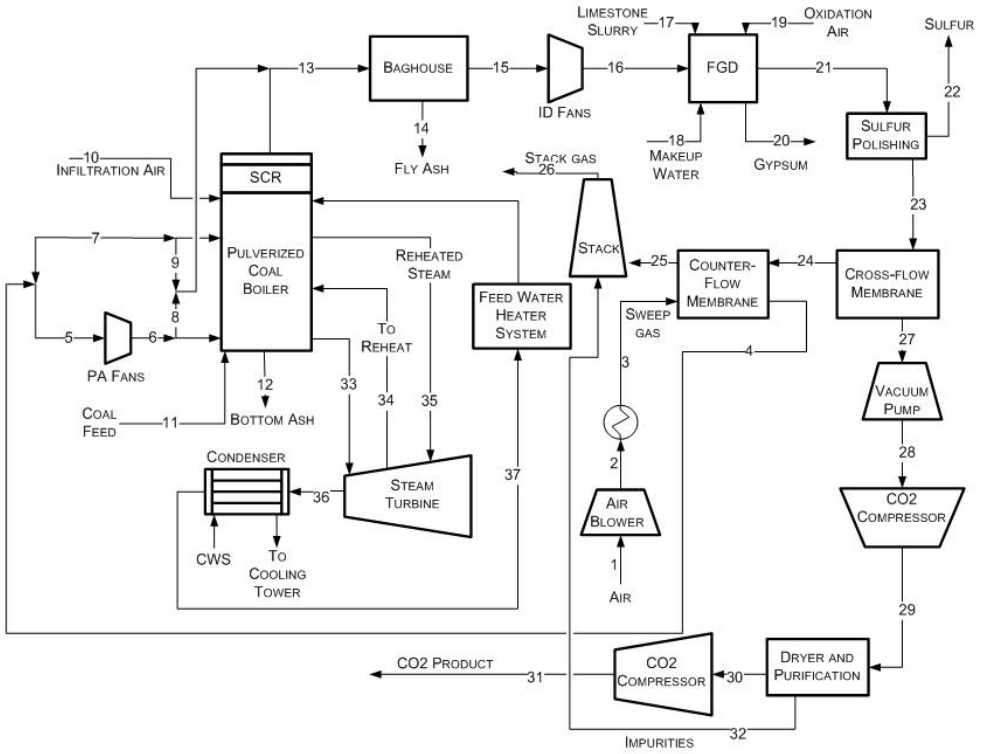
- **"Current and Future Technologies for Post-Combustion Capture" i.e. PCC Pathway Study**
  - Coal – Update to 2011 dollars; preliminary consideration of CO_2 purification
  - NGCC – In progress
- **Screening studies (pre- and post-combustion capture)**
  - Solvents
  - Sorbents
  - Membranes
  - Internal and external
- **R&D Guidance for Post-Combustion Capture Techno-Economic Evaluations**

PCC Pathway Study

Objectives & Scope

- **Objectives:**
  - Develop technology pathways that feature post-combustion CCS-enabled PC plants that achieve DOE goals
  - Utilize the pathway studies to inform technology development though identification of performance and cost targets
- **Technologies included:**
  - 2^{nd}-generation post-combustion CO_2 capture
  - Adv. Ultrasupercritical (A-USC steam) conditions (5000psig/1350F/1400F)
  - Advanced CO_2 compression
- **Scope:**
  - Pathway begins with 1^{st} generation supercritical PC plant with today's post-combustion capture technology
  - Emerging technologies added based on mature stage of development, thus simulating "n^{th}-of-a-kind" plant performance and cost
  - 2^{nd}-generation post-combustion CO_2 capture and compression cost and performance adjusted to meet program goals

PC with Adv. Membrane – Example to Meet Goals

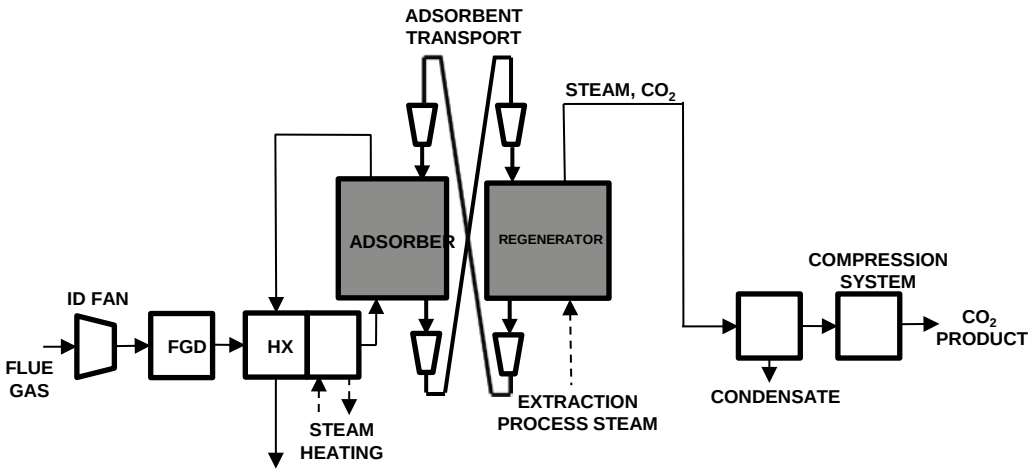


Key Membrane Parameter Assumptions

- **CO_2 and SO_2 Permeance: 3,500 gpu**
- N_2, O_2, Ar Permeance: 100 gpu
- H_2O Permeance: 5,000 gpu
- **Pressure drop: 1.0 psi (flue gas and sweep sides)**
- Vacuum pump achieves 0.2 bar pressure
- Membrane replacement time 5 years
- Membrane surface area: 1,500,000 m^2
- **Membrane installed cost \$127/m^2**
- Membrane replacement cost \$17/m^2

Capture/Compression Impact	Amine Quote Vintage		Adv. Membrane
Metric	2005	2012	
Net Energy Penalty [kWhnet/lb CO_2 Captured]	0.17	0.13	0.11
Reference Capital Cost [\$2011/tpd CO_2 Capt. @ full load]	\$45,000	\$47,900	\$39,100
CO_2 Capture Basis [tpd]	11,210	11,210	11,185

PC with Adv. Adsorbent – Example to Meet Goals



Source: NETL

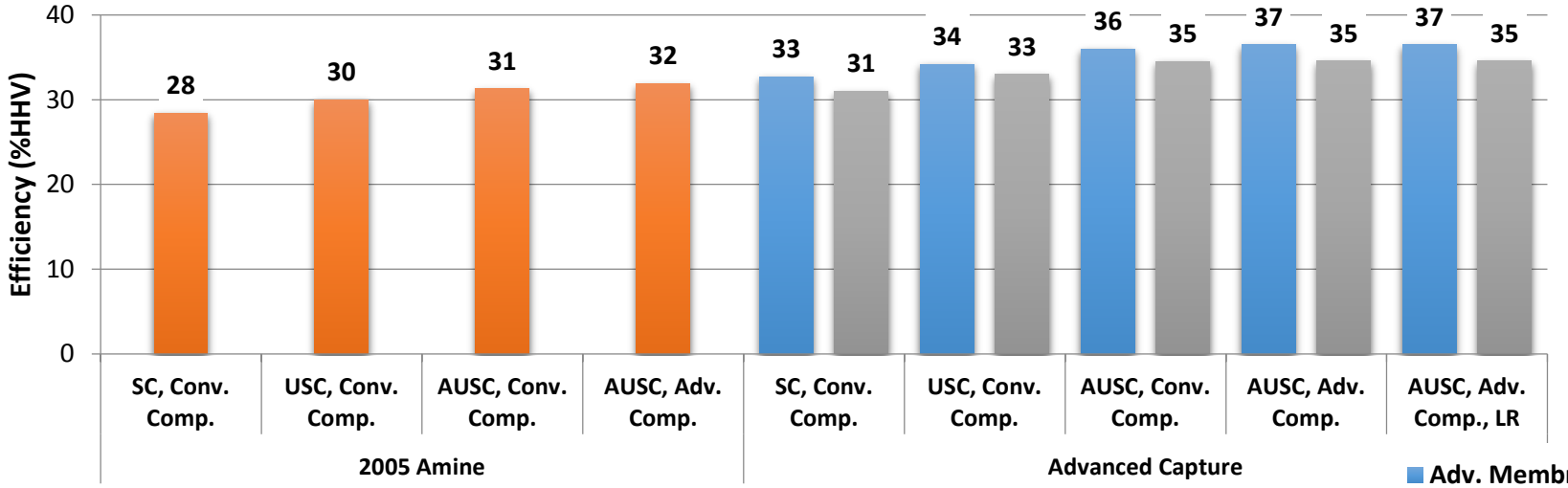
- **The adv. sorbent process requires considerable extraction steam consumption for flue gas heating and for adsorbent regeneration (> 1x10^6 lb/hr) and large BFW makeup treatment system**
- **The reaction vessels are very large and mechanical adsorbent circulation is used for the large adsorbent circulation rate required (> 31 x 10^6 lb/hr)**

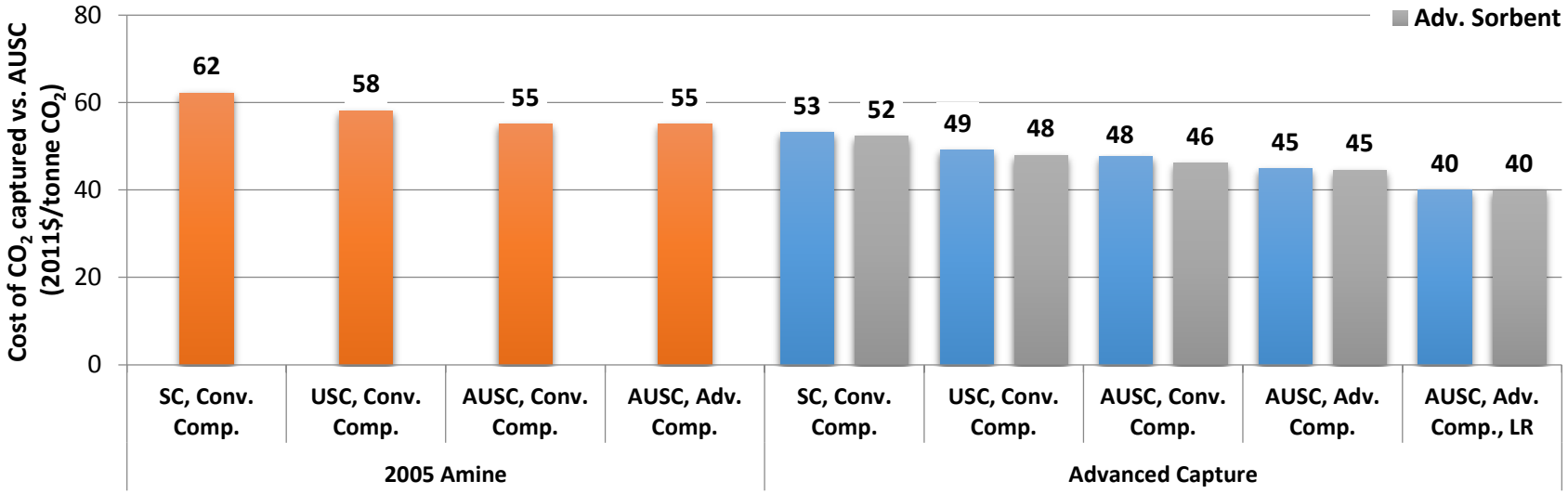
Key Adsorbent Parameter Assumptions

- Adsorbent: alkalized alumina; 3/8 inch diameter spheres
- Adsorbent cost: $5/lb
- **Sorbent CO_2 loading: 3.0%**
- Adsorber and regenerator temperature: 140°C
- Adsorber and regenerator pressure drop: 0.4 psi
- Adsorbent entrains 1.0 wt% of inlet N_2, O_2 and water vapor to the regenerator
- **Regenerator off-gas: 50 mole % CO_2**
- Adsorber-regenerator type: Moving bed
- Adsorbent transport: Bucket conveyor-elevators

Capture/Compression Impact	Amine Quote Vintage		Adv. Sorbent
Metric	2005	2012	
Net Energy Penalty [kWhnet/lb CO_2 Captured]	0.17	0.13	0.13
Reference Capital Cost [$2011/tpd CO_2 Capt. @ full load]	$45,000	$47,900	**$37,700**
CO_2 Capture Basis [tpd]	11,210	11,210	11,349

PCC Pathway Efficiency and Cost of Capture





NOTES:

- Amine-based cases are consistent with NETL Bituminous Baseline Rev. 2 Report
- All membrane and sorbent-based cases utilize enhanced performance and cost parameters

CO_2 Purification

- Purification of the CO_2 product stream will likely be necessary for most end-uses
- Preliminary evaluation of refining CO_2 purification to PCC Pathway cases
  - CO_2 purity prior to purification: 92-97%
  - Impact using external refrigeration cycles
    - Efficiency reduction ~2% points
    - COE increase 8-10%
- Other potential purification options:
  - Auto-refrigeration cycles
  - Membranes
  - Other capture process optimizations

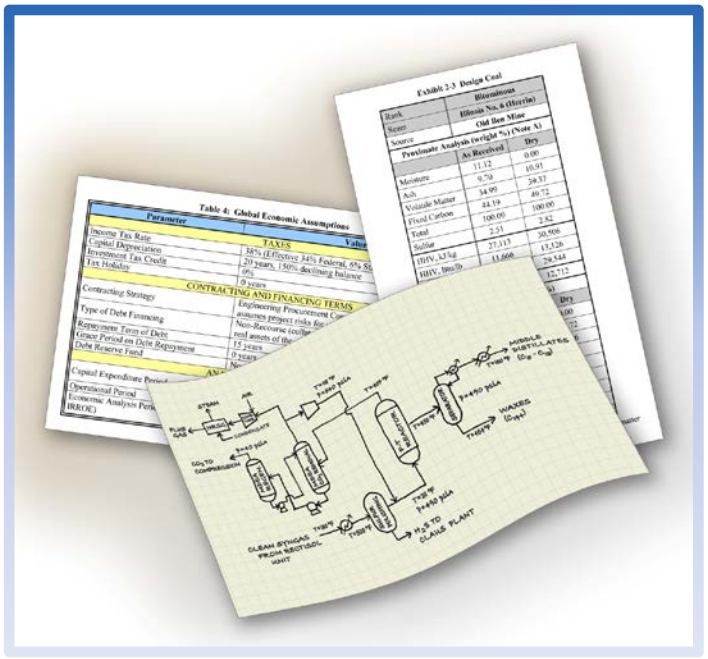
Purity Specifications	
CO_2	≥ 95 vol%
O_2	10 – 100 ppmv
H_2O	500 ppm
N_2, Ar, CH_4, H_2	1 – 4 vol%
CO	35 ppm
H_2S	75 – 100 ppmv
SO_2	50 – 100 ppmv
…etc.	

Current and Future Technologies for Post-Combustion Capture: NGCC

- **Objective: Evaluate impact of advanced CO_2 capture technologies in an NGCC plant**
- **Preliminary conclusions:**
  - Sorbents and membranes more sensitive to lower CO_2 concentration of NGCC flue gas (~4% vs. ~14% for PC) than solvents
  - Exhaust gas recirculation (EGR) key to increase CO_2 concentration in flue gas for sorbents and membranes

Advanced Capture Technology Screening Studies

- **Post-combustion capture solvents:**
  - Model/predict process improvements that are applicable to many capture technologies:
    - L/R exchanger temperature approach
    - CO_2 Stripper regen pressure
    - Advanced heat integration schemes
  - Forecast potential of combining advanced capture technologies with advanced processes
- **Pairing of post-combustion capture technologies**
  - e.g. solvents and membranes
- **Pre-combustion capture sorbents/membranes:**
  - Pairing with advanced gas cleanup systems and CO_2 purification systems
- **NETL may contact you with requests for details about your project (i.e., design and/or performance aspects)**



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QUESTIONS?