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A Multi-Objective Evaluation of PC Plants with Aqueous Amine Carbon Capture Systems

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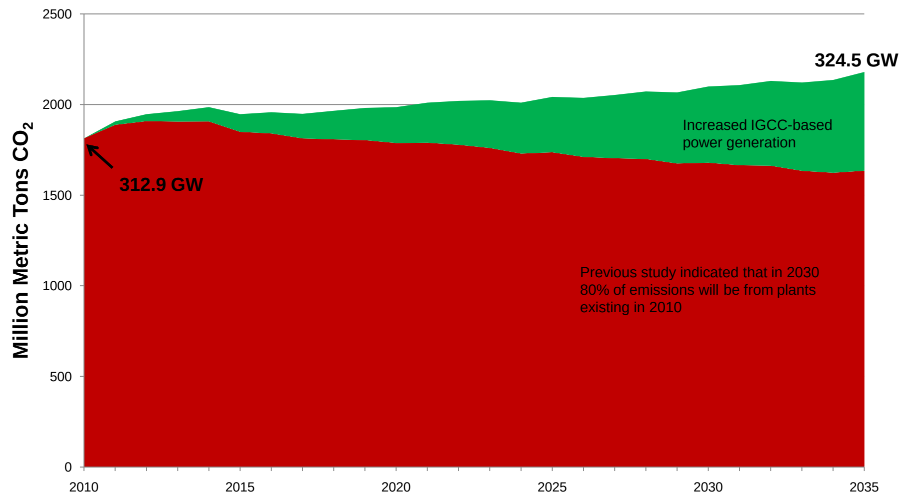
CO_2 Summit: Technology and Opportunity
7 June 2010

Outline

- **Motivation – CO_2 and Water**
- **Approach – Design & Optimization**
- **Model details**
  - PC Plant
  - MEA system
  - Compression system
- **Results & Discussion**
  - Capital cost
  - Water use
  - Power generation
- **Summary**

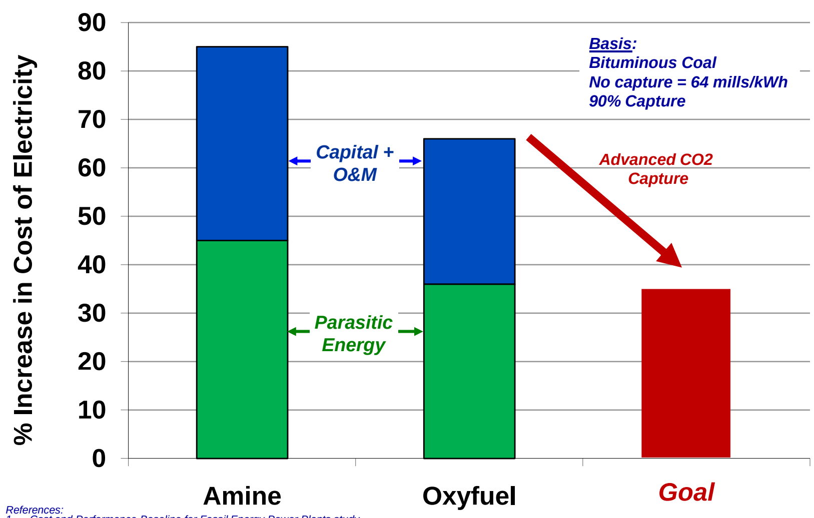
U.S. CO_2 Emissions from Coal Plants



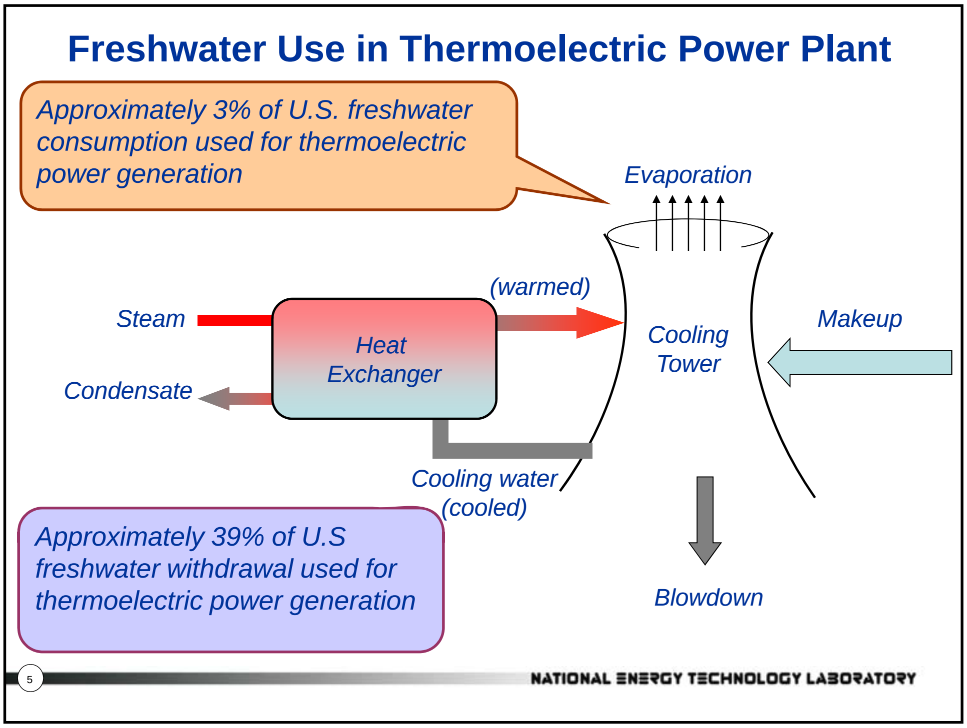
Source: EIA, Annual Energy Outlook 2010 Early Release, Dec. 2009

Post- and Oxy-combustion CO_2 Capture

Increase in COE



References:
1. *Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.*
2. *Pulverized Coal Oxycombustion Power Plants, Volume 1: Bituminous Coal to Electricity, U.S. DOE/NETL, Revised Final Report, August 2008*


Freshwater Use in Thermoelectric Power Plant
Approximately 3% of U.S. freshwater consumption used for thermoelectric power generation
Evaporation
(warmed)
Steam
Heat Exchanger
Condensate
Cooling Tower
Makeup
Cooling water (cooled)
Approximately 39% of U.S freshwater withdrawal used for thermoelectric power generation
Blowdown
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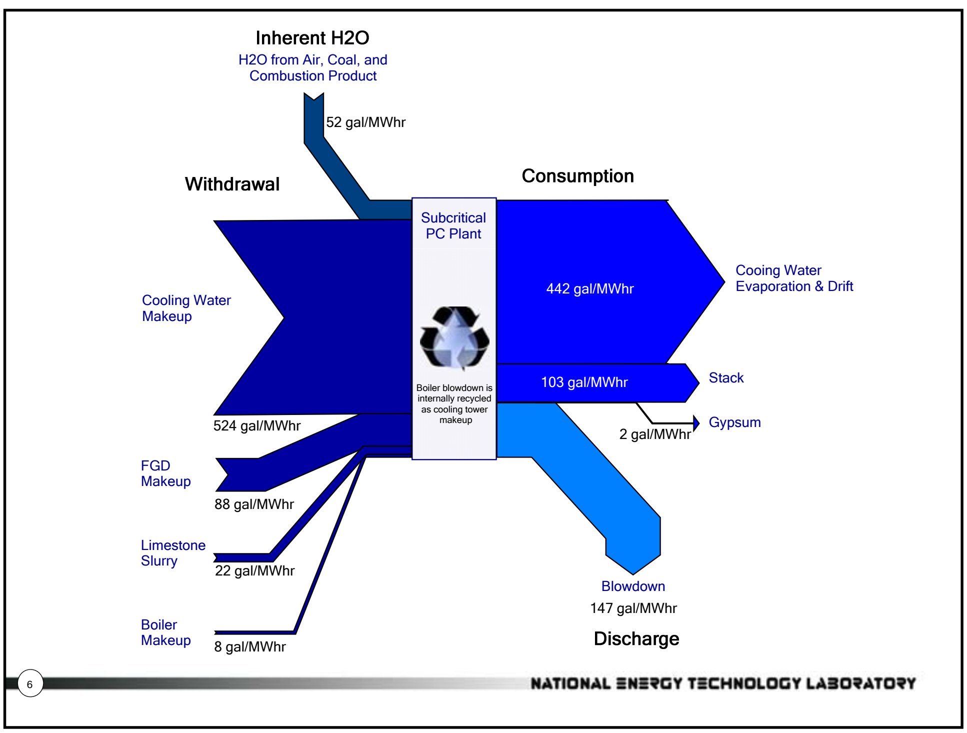
Inherent H2O
H2O from Air, Coal, and Combustion Product
52 gal/MWhr
Withdrawal
Consumption
Subcritical PC Plant
Cooling Water Makeup
442 gal/MWhr
Cooing Water Evaporation & Drift
103 gal/MWhr
Stack
Boiler blowdown is internally recycled as cooling tower makeup
524 gal/MWhr
2 gal/MWhr
Gypsum
FGD Makeup
88 gal/MWhr
Limestone Slurry
22 gal/MWhr
Boiler Makeup
8 gal/MWhr
Blowdown
147 gal/MWhr
Discharge
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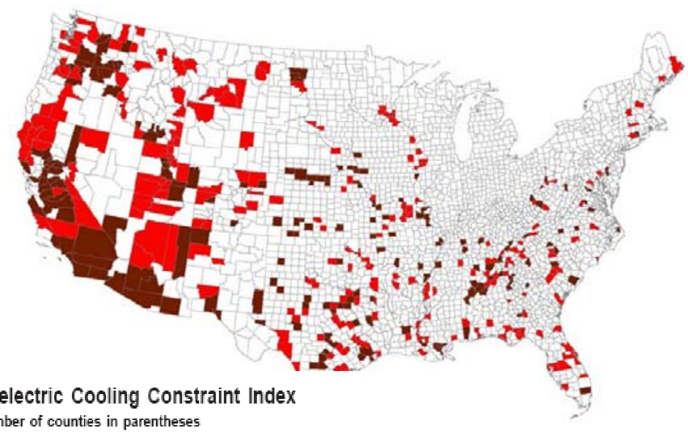
Expected Cooling Water Shortage in 2025



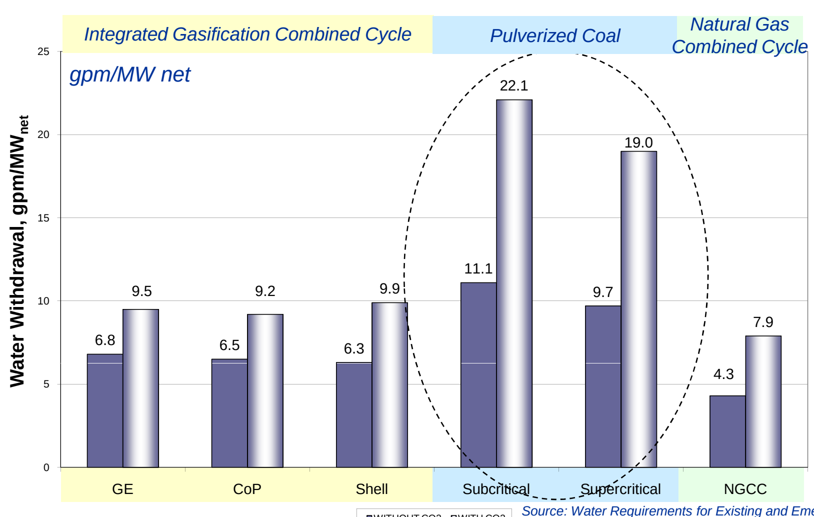
Thermoelectric Cooling Constraint Index
number of counties in parentheses

Highly constrained	(191)
Moderately constrained	(235)
No existing generation or constraints unlikely	(2685)

Source: Roy et al., (2003) A Survey of Water Use and Sustainability in the United States with a Focus on Power Generation. EPRI

Power Plant Water Withdrawal Requirements

with and without CO_2 capture



Source: Water Requirements for Existing and Emerging Thermoelectric Plant Technologies; NETL, August 2008

DOE/NETL Goals: CO_2 Capture

Minimum CO_2 Captured	Maximum Increase in COE
90%	35% for PC
	10% for IGCC

DOE/NETL Goals: Freshwater Minimization

- **Short-term goals (ready for commercial demonstration by 2015)**
  - Reduce freshwater withdrawal and consumption by > 50% for thermoelectric power plants equipped with wet recirculating cooling technology
  - Levelized cost savings > 25% compared to state-of-the-art dry cooling
- **Long-term goals (ready for commercial demonstration by 2020)**
  - Reduce freshwater withdrawal and consumption by > 70% for thermoelectric power plants equipped with wet recirculating cooling technology
  - Levelized cost savings > 50% compared to state-of-the-art dry cooling

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Challenges

- **Large-scale problem**
  - 2 billion tons CO_2 from coal by 2020 in US
  - Flue gas: 5 million lb/hr for 550MW PC plant
- **No existing economical solution**
- **No framework for developing & evaluating <u>optimized</u> designs**
- **Difficulty re-using existing models/simulations**
- **Approach**
  - Process synthesis & design
  - Process integration & optimization
  - Simulation-based optimization approaches
  - Water resource considerations
  - Interaction and potential synergy among subsections
  - Address multiple (conflicting) goals

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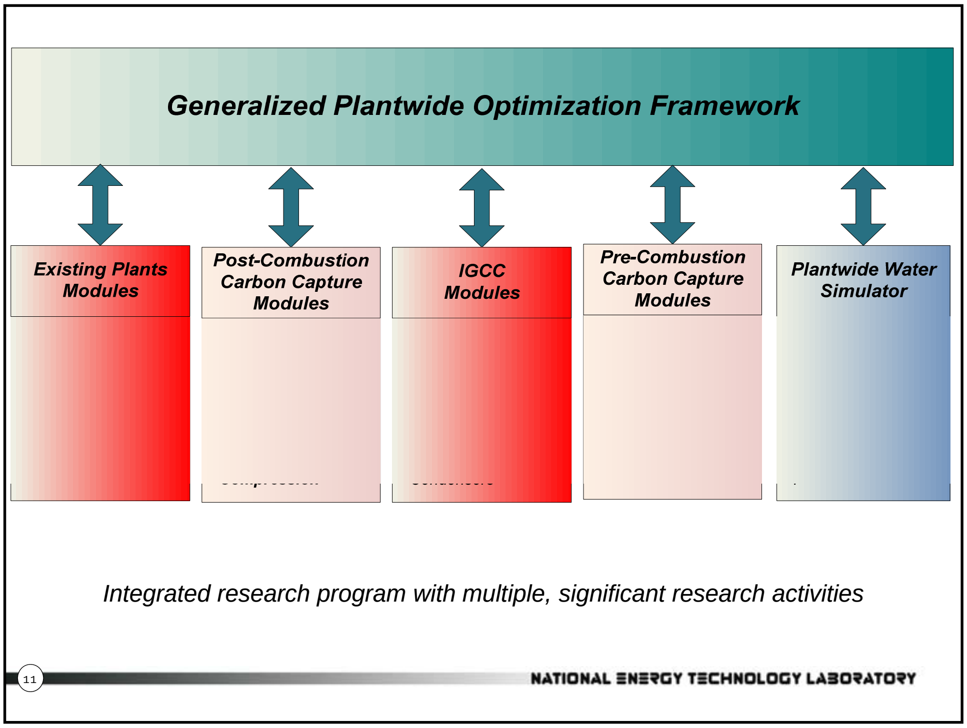
Generalized Plantwide Optimization Framework
Existing Plants Modules
Post-Combustion Carbon Capture Modules
IGCC Modules
Pre-Combustion Carbon Capture Modules
Plantwide Water Simulator
Integrated research program with multiple, significant research activities
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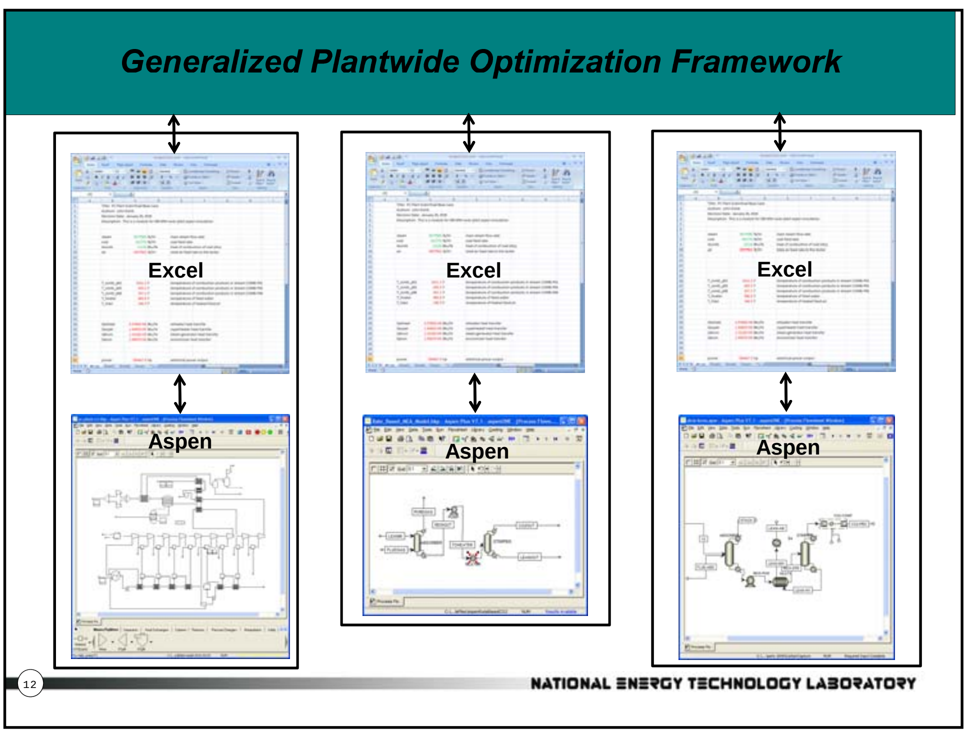
Generalized Plantwide Optimization Framework
Excel
Aspen
Excel
Aspen
Excel
Aspen
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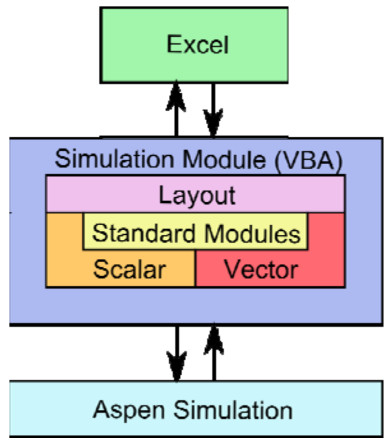
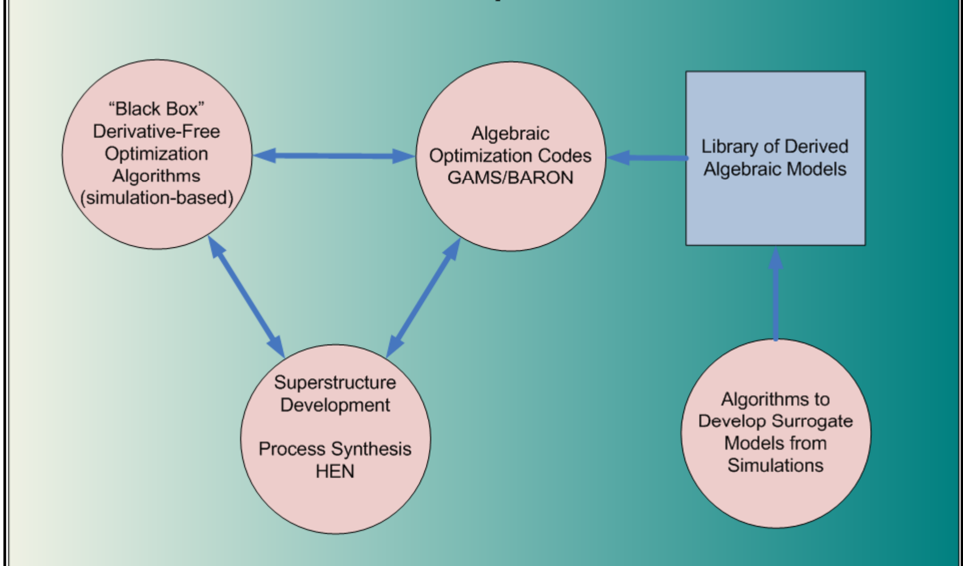
Simulation Interface

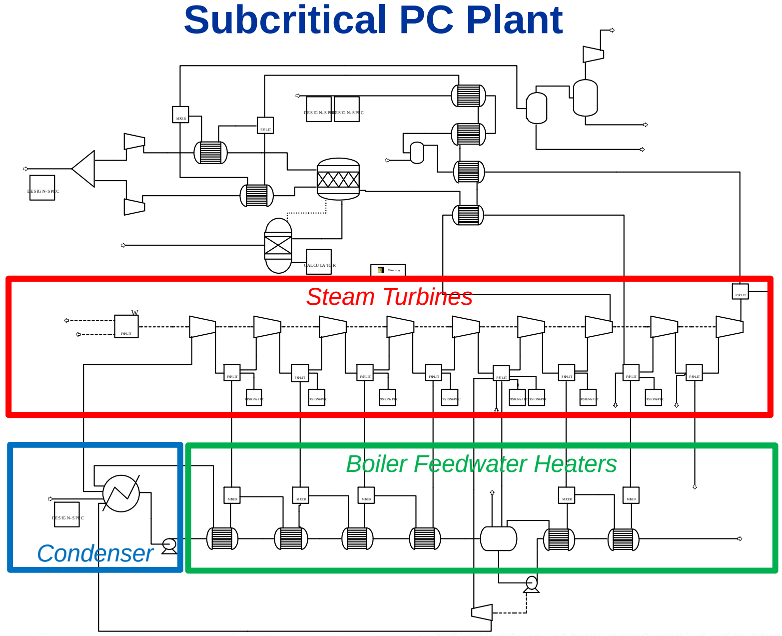
- Set simulation variables
- Supports structural changes
  - Feed stage
  - Number of stages
  - (not supported internally)
- Retrieves results
- Perform post-processing
  - Cost estimation
  - Objective function calculations



Generalized Plantwide Optimization Framework



Subcritical PC Plant

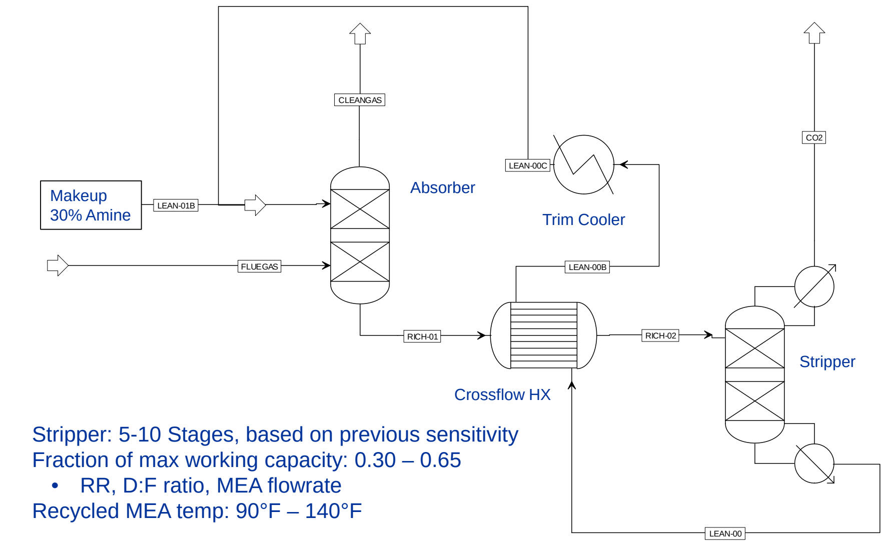


Steam Cycle Summary

	P (psia)	T (°F)	Power Generated (W/lb steam)	Power Lost extracting here (W/lb steam)	Heat Available Q (Btu/lb)
HP	2415.0	1050	43.70	195.20	773
IP-01	559.0	1000	16.26	151.50	1056
IP-02	363.0	885	23.47	135.24	1050
LP-01	182.0	705	29.58	111.77	1029
LP-02	65.4	500	24.08	82.19	1014
LP-03	24.0	320	19.71	58.11	993
LP-04	8.5	190	38.41	38.41	991

Q calculated for condensation at inlet pressure

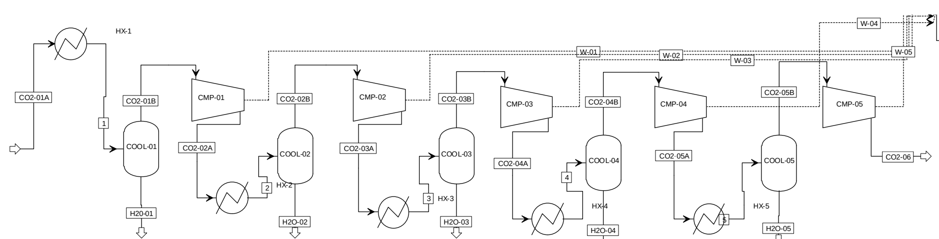
MEA



Stripper: 5-10 Stages, based on previous sensitivity
Fraction of max working capacity: 0.30 – 0.65
- RR, D:F ratio, MEA flowrate

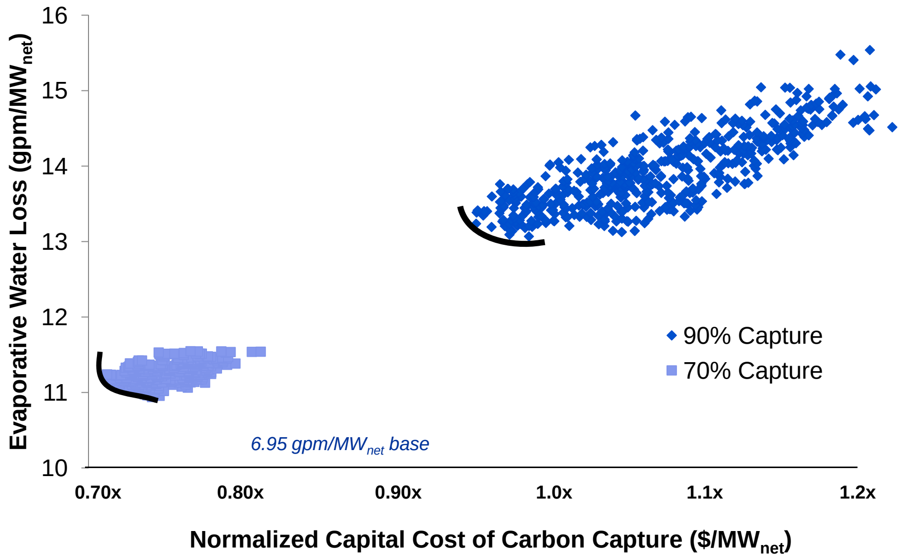
Recycled MEA temp: 90°F – 140°F

Compression

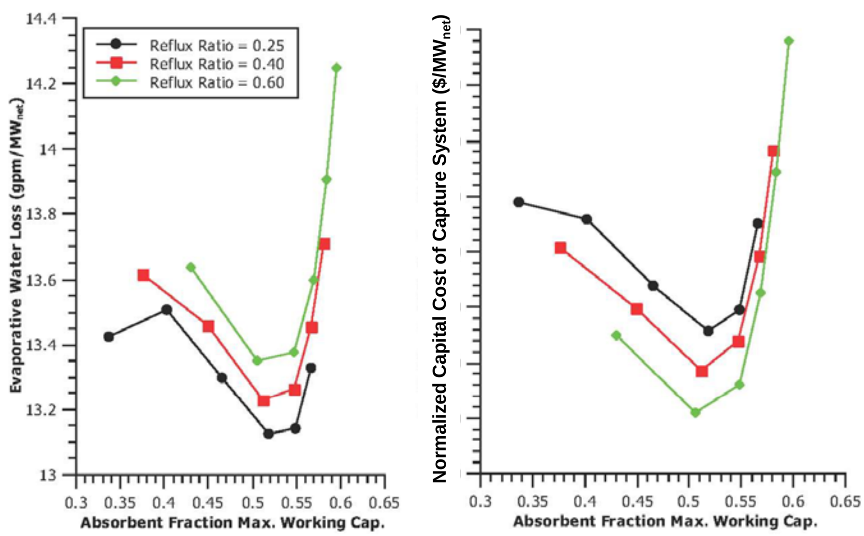


- **5 stage compression**
- **Intercoolers 285°F to 100°F**
- **Water returned to process**
- **Final pressure 2000 psia**

Pareto Curves



90% capture, 90°F absorbent, 10 stripper stages



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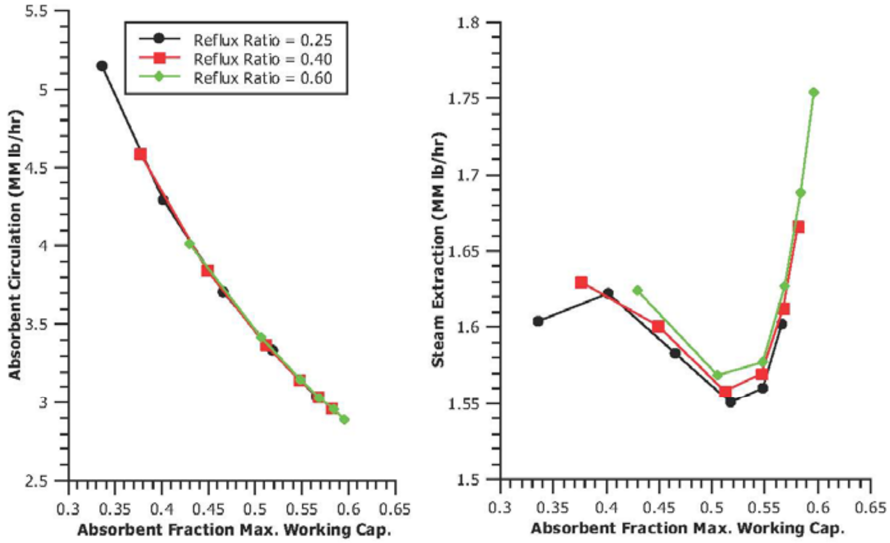

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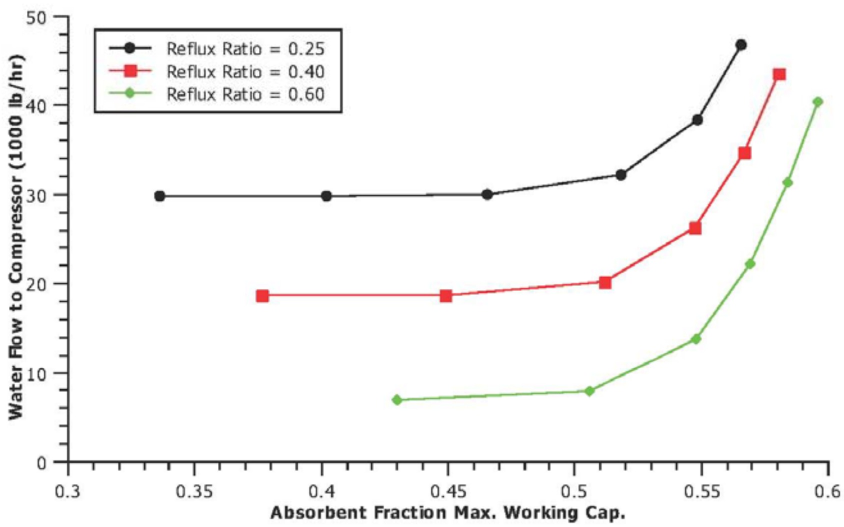
90% capture, 90°F absorbent, 10 stripper stages



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90% Capture Summary - Design

Base 543 MW	Best Water	Best Cost	Worst Case
Net Power(MW)	343	347	304
Number of Stripper Stages	10	10	6
Fraction of Max MEA capacity	0.550	0.515	0.543
MEA Circulation (MM lb/hr)	15.6	16.7	15.9
Steam Extraction (MM lb/hr)	1.56	1.55	1.86
Relative Capital Cost ($/MW$_{net}$)	0.97x	0.94x	1.18x

90% Capture Summary - Water

	Base	Best Water	Best Cost	Worst Case
Water Evap (gpm/MW$_{net}$)	7.0	13.1	13.2	15.0
Base PC Evap (gal/hr)	226,431	115,288	116,406	93,086
Capture Evap (gal/hr)		124,143	109,092	156,100
Abs. Evap. (gal/hr)		29,389	50,273	23,910
Total (gal/hr)	226,431	268,820	275,770	273,096

Conclusions

- **Important to consider plant integration**
- **Optimization needed to find best cases**
- **Tradeoff: Water use and capital cost**

- **Future work**
  - Dry cooling
  - Additional heat integration
  - Advanced column configurations
  - Nontraditional sources of water

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Acknowledgements: Research Team

- **Optimization and computational infrastructure**
  - ModeFrontier integration & multi-criteria, simulation-based optimization/DOE – NETL
  - Derivative-free "Blackbox" Optimization – CMU (Sahinidis/Cozad)
  - Surrogate model development – CMU (Sahinidis/Rios)
  - Simultaneous Superstructure-based Optimization – CMU (Grossmann/Yang)
  - Synthesis of Integrated IGCC Systems – CMU (Grossmann/Biegler/Kamath)
- **Module development**
  - Base plant modules
    - Predictive Plant Models (PC/IGCC) – NETL (Miller/Eslick)
    - Development of Predictive Turbine Models – NETL (Liese)
    - Oxycombustion Plant Model – NETL Albany (Summers/Oryshchyn/Harendra)
  - Carbon capture modules
    - Rate-based amine capture – NETL (Miller/Eslick)
    - Solid sorbent capture systems – NETL (Miller/Lee)
    - Membrane-based separation systems – NETL (Miller/Morinelly)
    - Compression system – NETL (Miller/Eslick)
    - Synthesis of Optimal PSA Cycles for CO2 Capture from Flue Gas – CMU (Biegler/Agarwal)
    - Synthesis of Optimal PSA Cycles for Hydrogen/CO2 Separation – CMU (Biegler/Vetukuri)
    - Cryogenic separation and hydrate-based separation – NETL (van Osdol)
  - Water-specific activities
    - Development of Predictive Models of Cooling Towers – WVU (Huebsch/Ogretim)
    - Treated Municipal Wastewater for Power Plant Cooling – CMU (Dzombak/Hsieh)
    - Modeling Nontraditional Sources of Power Plant Water – IIT (Abbasian/Arastoopour)
    - Water from Oxycombustion – NETL Albany (Summers/Oryshchyn/Harendra)

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