Advancing Cleaner Energy

OPTIMIZING THE COSTS OF SOLID SORBENT-BASED CO_2 CAPTURE PROCESS THROUGH HEAT INTEGRATION

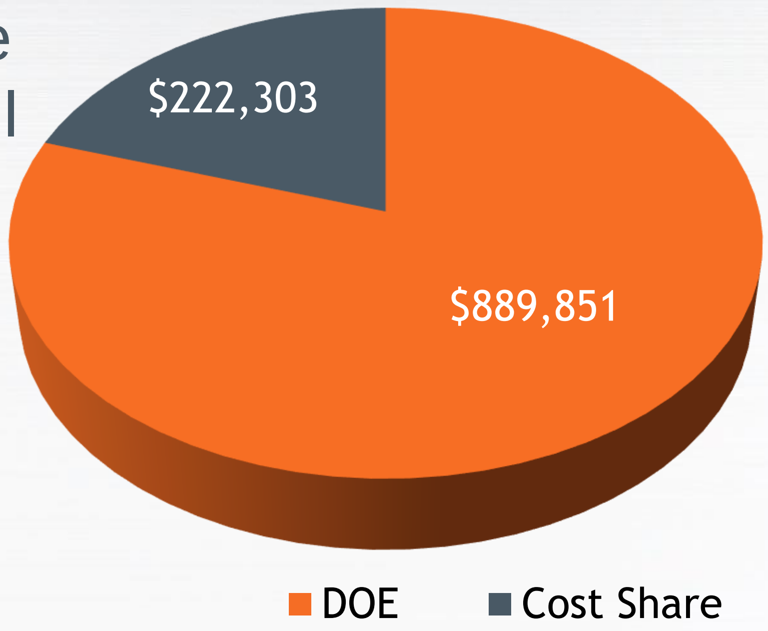
ADA-ES, Inc. NETL Contractor's Meeting

June 25, 2015

DE-FE0012914

Project Funding, Objective, and Timeline

- The overall objective: reduce the energy penalty and/or the overall levelized cost for solid sorbent-based CO_2 capture
- Outcome: progress towards meeting the overall DOE Carbon Capture Program performance goals



Cooperative Agreement (Award No. DEFE001291)

Administered by DOE-NETL: Project Manager Bruce Lani

Project Duration: Nov 2014 – Dec 2015

Project Team

- **DOE – NETL**
  - Project Sponsor
- **ADA-ES, Inc.**
  - Project Management
  - Technology Selection and Integration
  - Techno-Economic Assessment
  - Project Cost Share
- **Technip Stone and Webster Process Technology with Dorr Oliver Division**
  - Conceptual Process
  - Detailed Engineering, Design, and Costing
  - Experience w/ multiple types of FB reactor designs (single, multibed, heat exchanger)
- **Solex Thermal Science**
  - Experience w/ Moving Bed Heating and Cooling
  - Thermal Modelling & Costing
  - 400 Installations in 23 countries
  - Project Cost Share
- **Lehigh University Energy Research Center**
  - Broad Process Modelling Capabilities w/ ASPEN
  - Conceptual Process Design
  - Techno-Economic Assessment
  - Project Cost Share

Project Scope

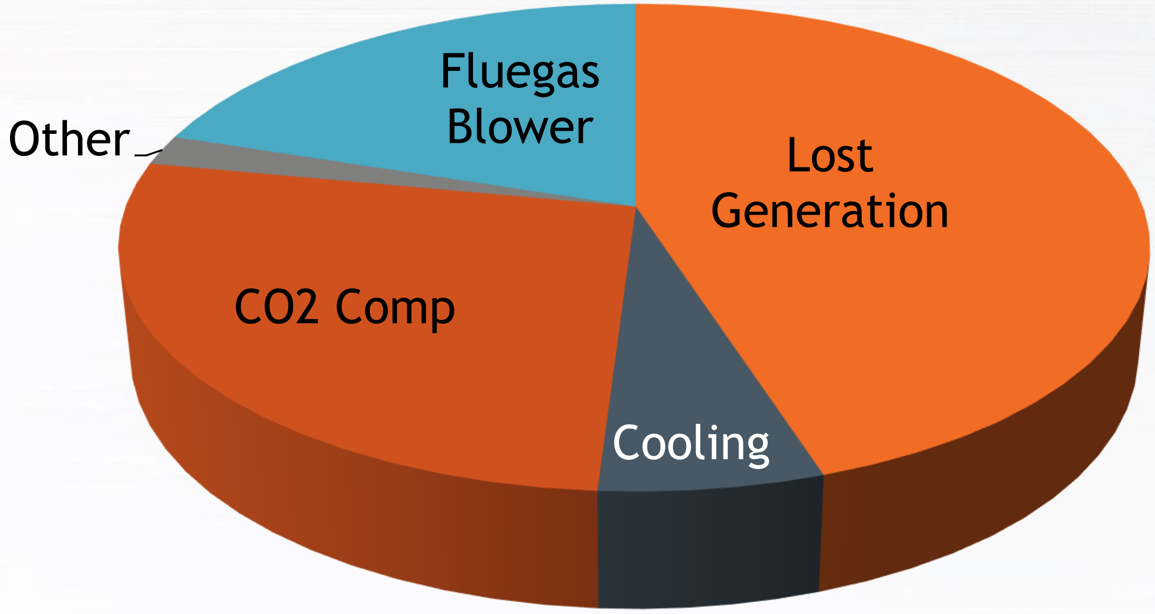
- Evaluate options to reduce plant heat rate and LCOE associated with ADAsorb™ implementation through:
  - Heat integration with plant
  - Cross heat exchanger
- Assess two cross heat exchanger designs
  - Laboratory testing
  - Preliminary design
  - Preliminary techno-economics

Project Schedule

Task Description	Schedule
Bench Scale Testing: Moving Bed	April-July 2014
Modeling: Moving Bed	July 2014
Design Integration: Fluidized Bed	July 2015
Heat Integration and Optimization: Economic Sensitivity Analysis	Feb ‘14 – August‘15
Techno-Economic Assessment	July – Dec 2015

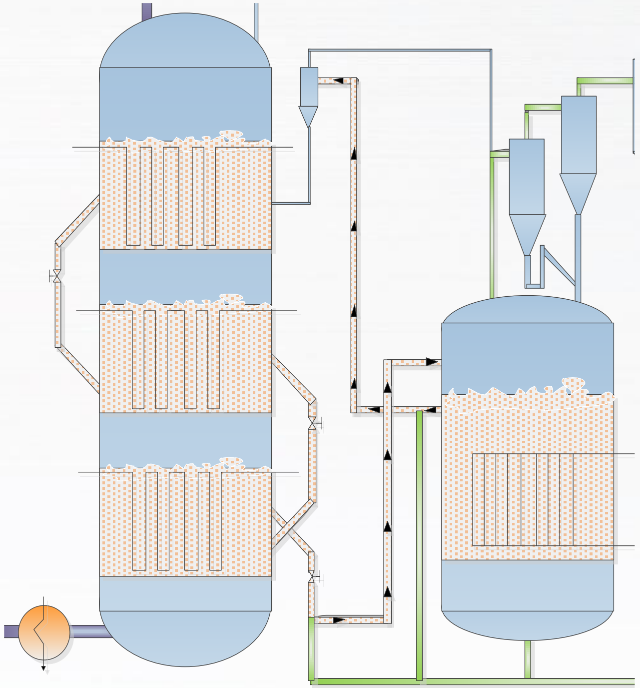
Breakdown of Estimated Parasitic Load

DOE Case 10 Analysis, ADAsorb™ without heat integration



ADASorb™ System Adsorber-Regen

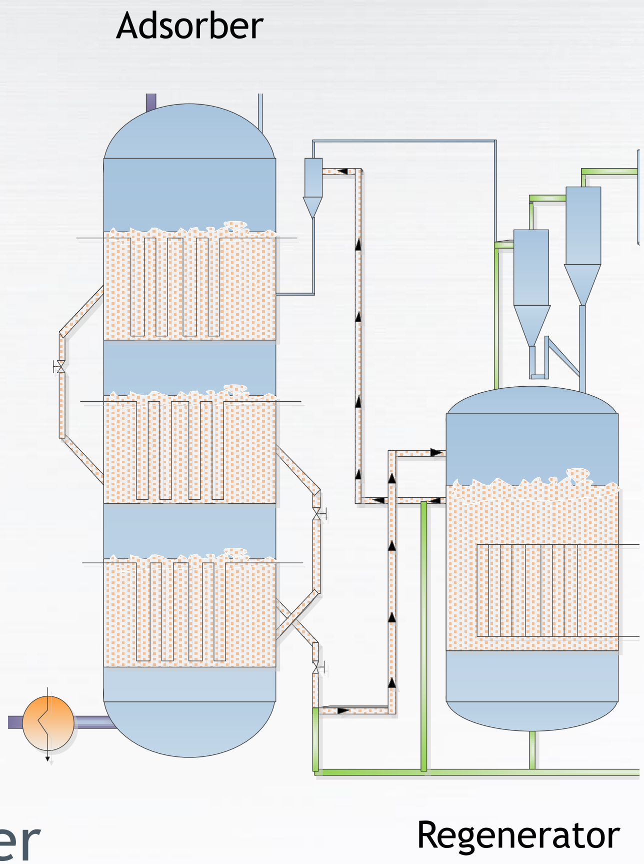
Adsorber



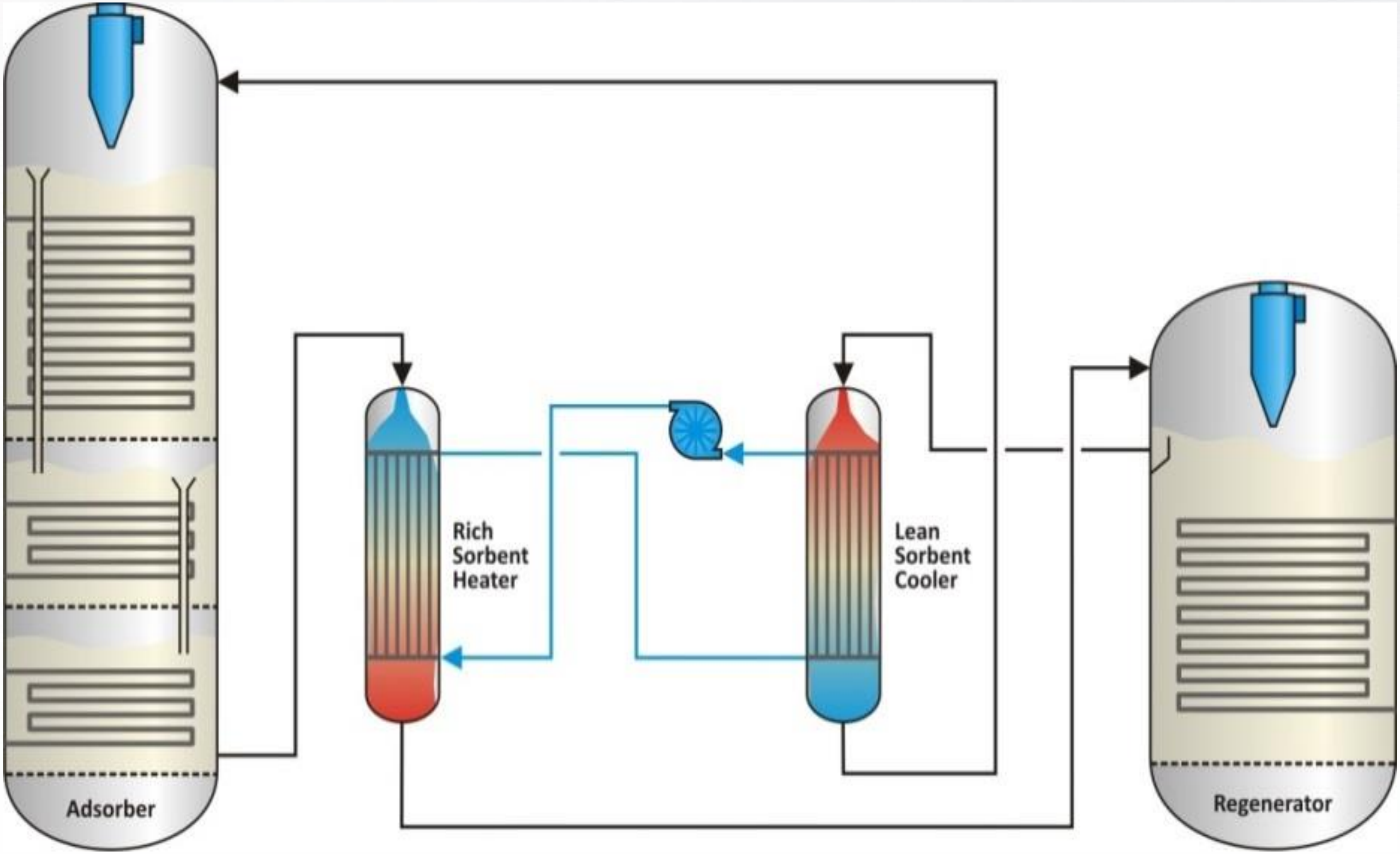
Regenerator

Benefits of Incorporating a Cross Heat Exchanger

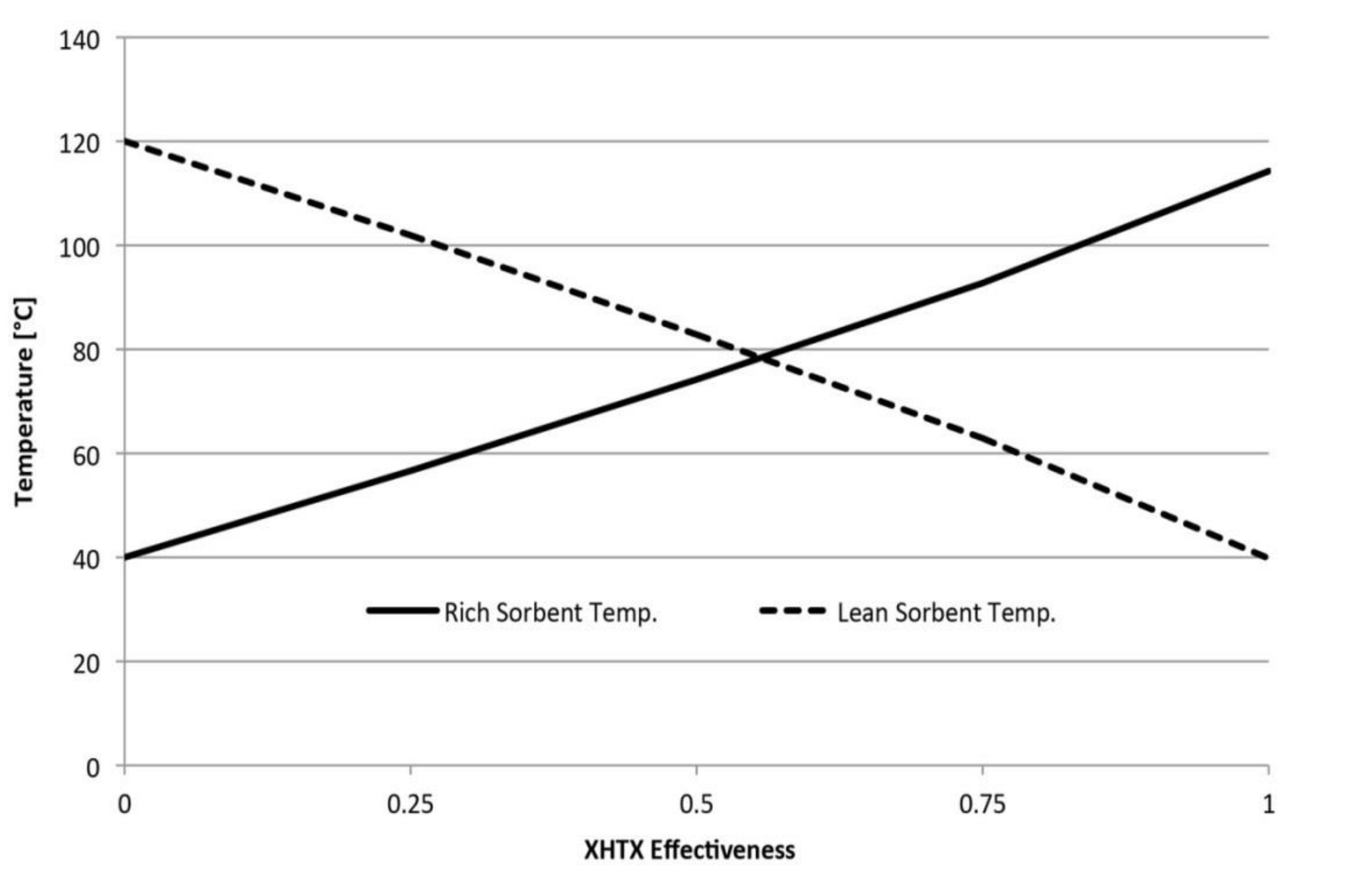
- Sensible Heat Recovery
- Reduced Adsorber Pressure Drop
  - Sorbent is currently cooled in top adsorber bed
  - Reduced cooling requirements → smaller bed → reduced flue gas blower power → reduced thermal regeneration input & cooling duty
- Reduced Regenerator Pressure Drop
  - Sorbent enters regenerator at higher temperature. Less heat transfer surface required



Cross Heater Exchanger Concept



Cross Heat Exchanger Effectiveness (Actual Heat transfer/Max Heat transfer)

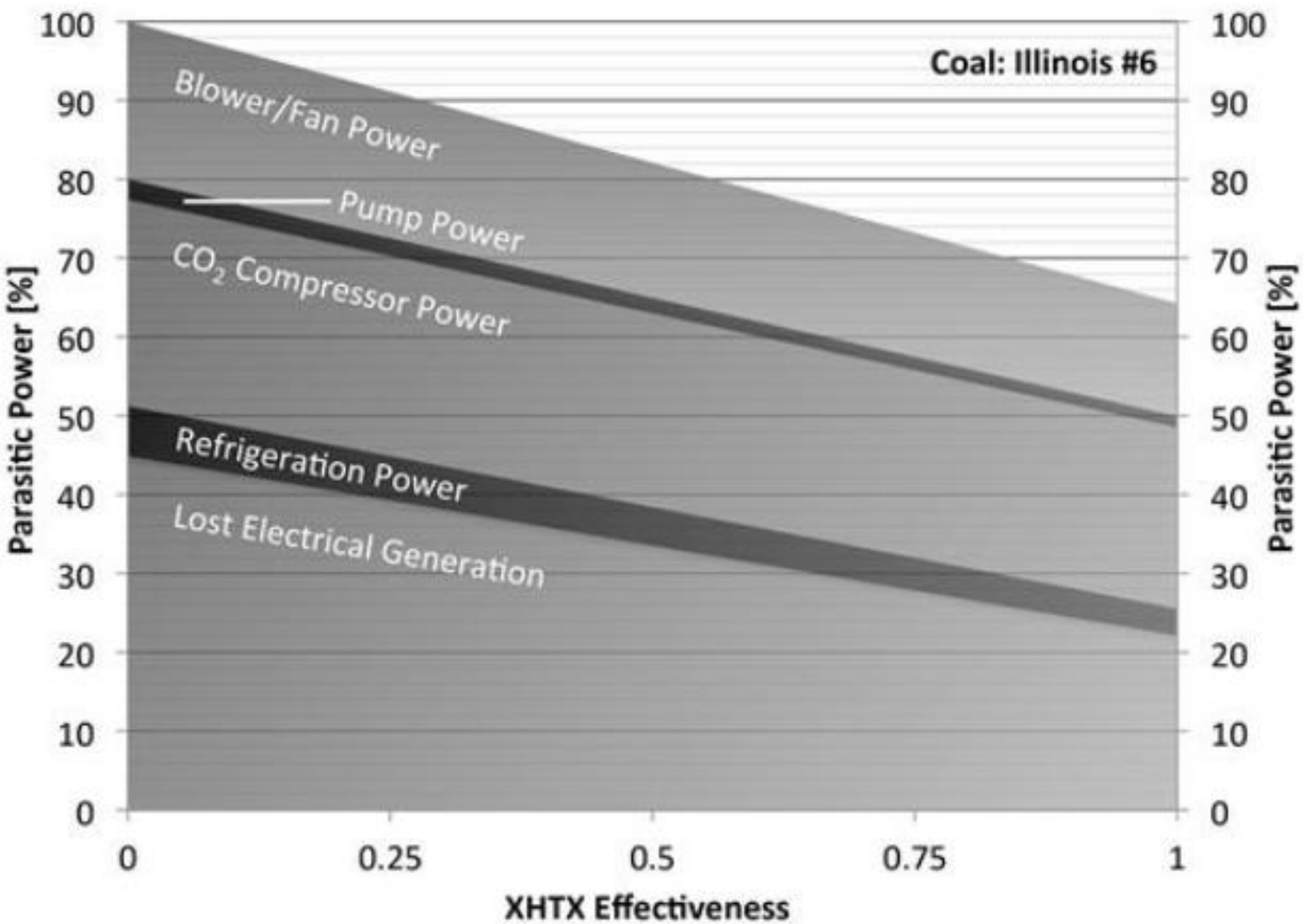


Heat Rate vs Efficiency

- Power Plant Efficiency = Power Out/Fuel In
- Heat Rate = Fuel In/Power Out
- Heat Rate = 1/Efficiency

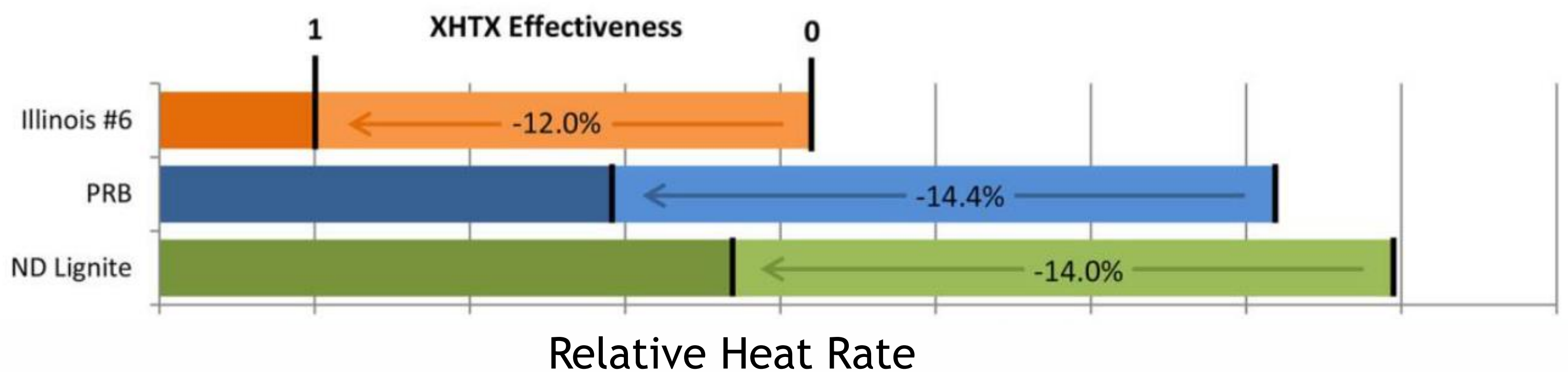
Reduction of Net Unit Heat Rate as Function of Effectiveness of an Idealized Cross Heat Exchanger

Effect of Cross Heat Exchanger Effectiveness on Parasitic Power Losses



Impact of Cross Heat Exchanger

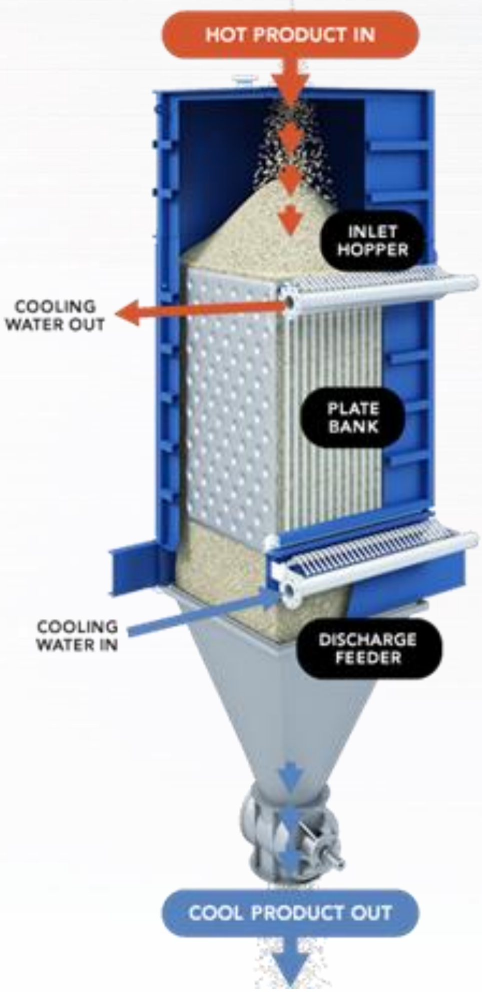
- Significant improvements in process efficiency can be achieved.
- Pressure drop reduction of approximately 1.3 psi may be realized reducing the blower requirements for the adsorber.
- Total CO_2 capture (mass) is reduced
- Gross/Net generation ratio is substantially improved



Lehigh Model Results

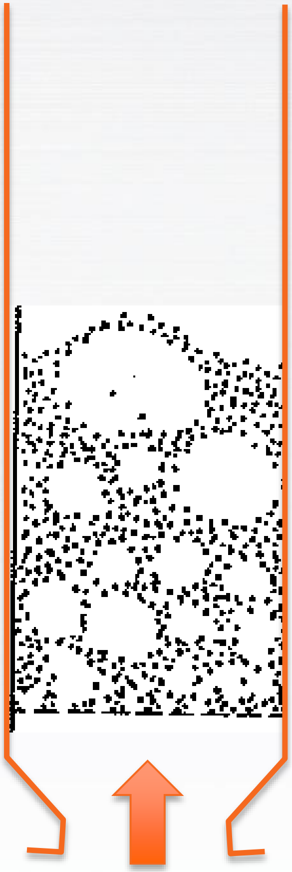
Cross Heat Exchanger Design Options

Moving Bed



Courtesy of Solex

Fluidized Bed



Moving Bed Advantages

- Reduced blower requirements: little or no fluidizing gas is necessary
- Counter-Current flow between solids and heat transfer media
  → possible to achieve an aggressive approach temperature and high heat recovery using only two moving beds per CO_2 capture train (one moving bed for heating and one for cooling)
- *Note: Heat transfer coefficient of a sorbent in a moving bed will be lower than that of the same sorbent in a fluidized bed*

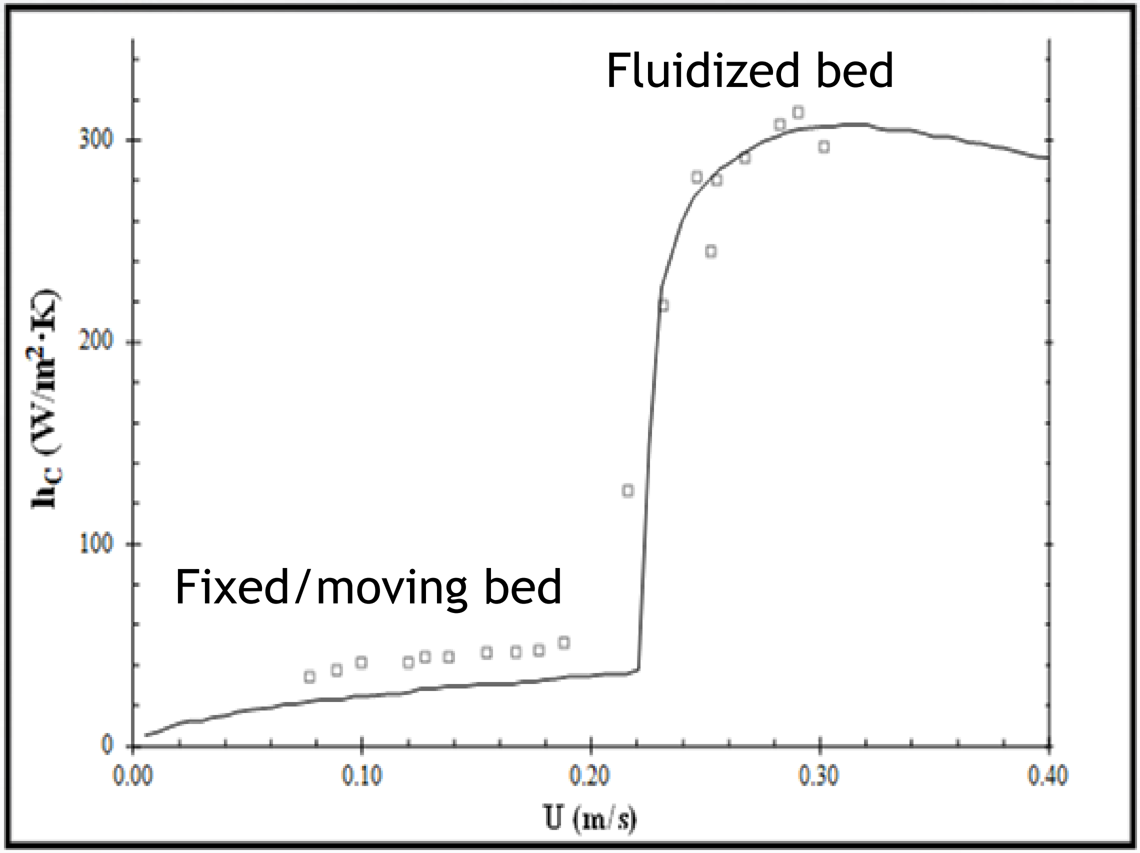
ADA and Solex Bench Scale Testing Results

Successful Bench Scale Test

- Sorbent heated and cooled with the heat exchanger through process range (40-120^{0}C)
- Sorbent flow smooth and consistent, no bridging between plates observed
- Minor bridging observed at the outlet of the exchanger. Proved to be manageable

Benefits of Fluidized Beds

- Good heat and mass transfer
- Equipment components have been demonstrated successfully on the required scale
- Industry process scalability knowledge



But . . .

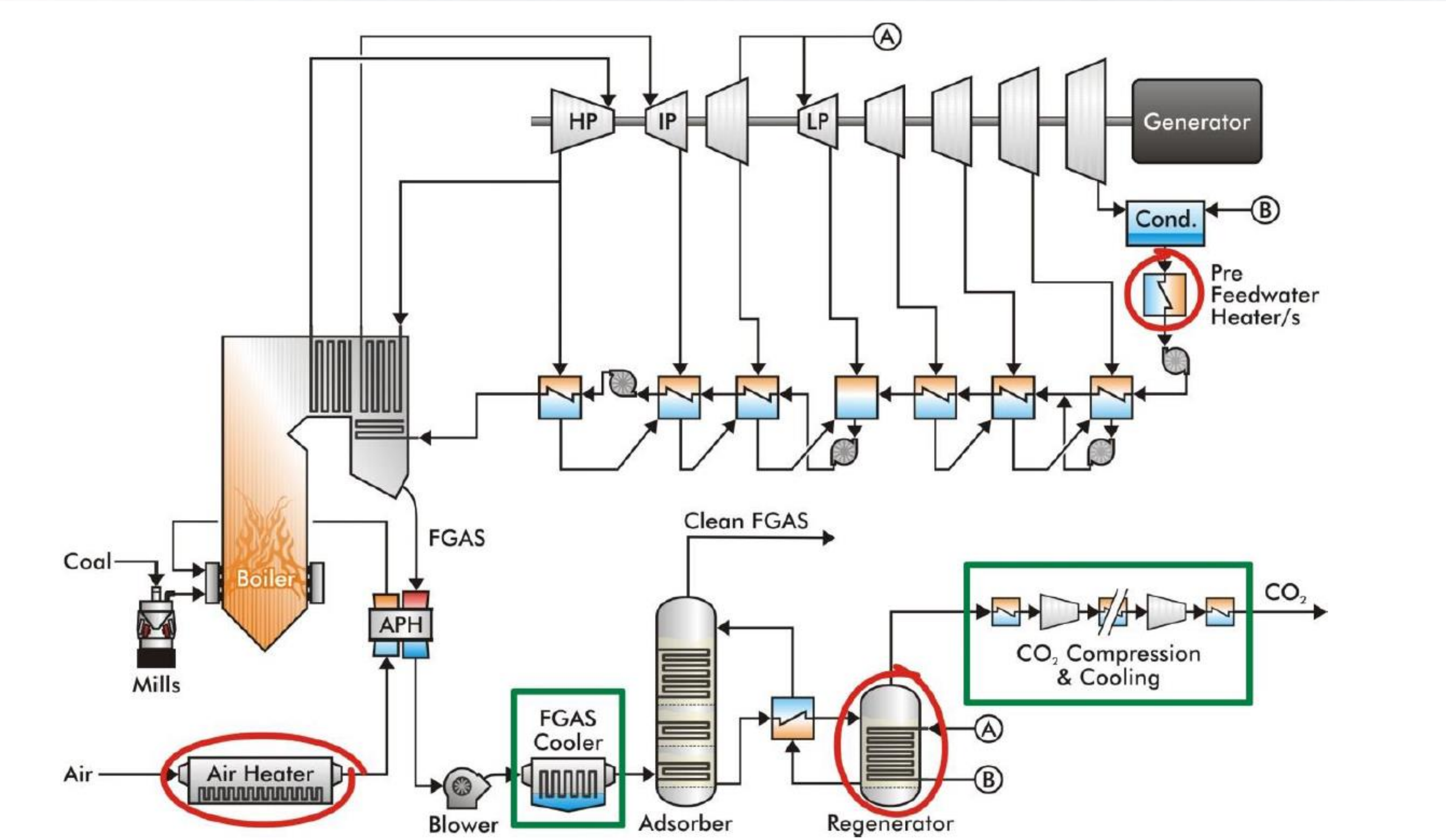
- Higher pressure drop
- More complicated operation

J.F. Davidson, "Fluidization" 1985

Cross Heat Exchanger Preliminary Assessment

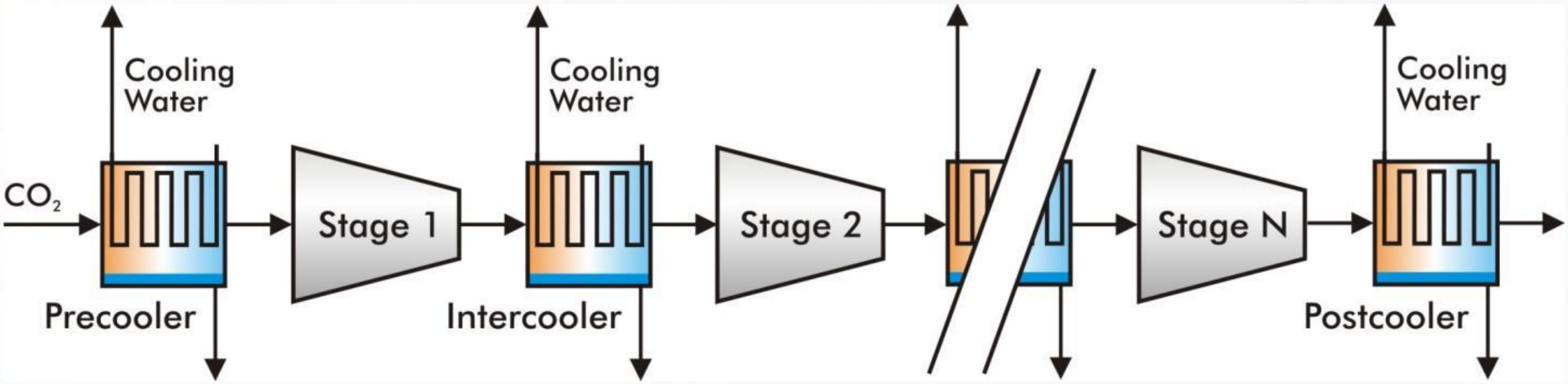
- Solex downward flow moving bed
  - Completed lab tests and modeling using Solex custom software
  - Preliminary design has promising technical and economic potential
- Technip fluidized bed
  - Initial assessment indicates design is not a practical approach

Sources and Sinks for Waste Heat

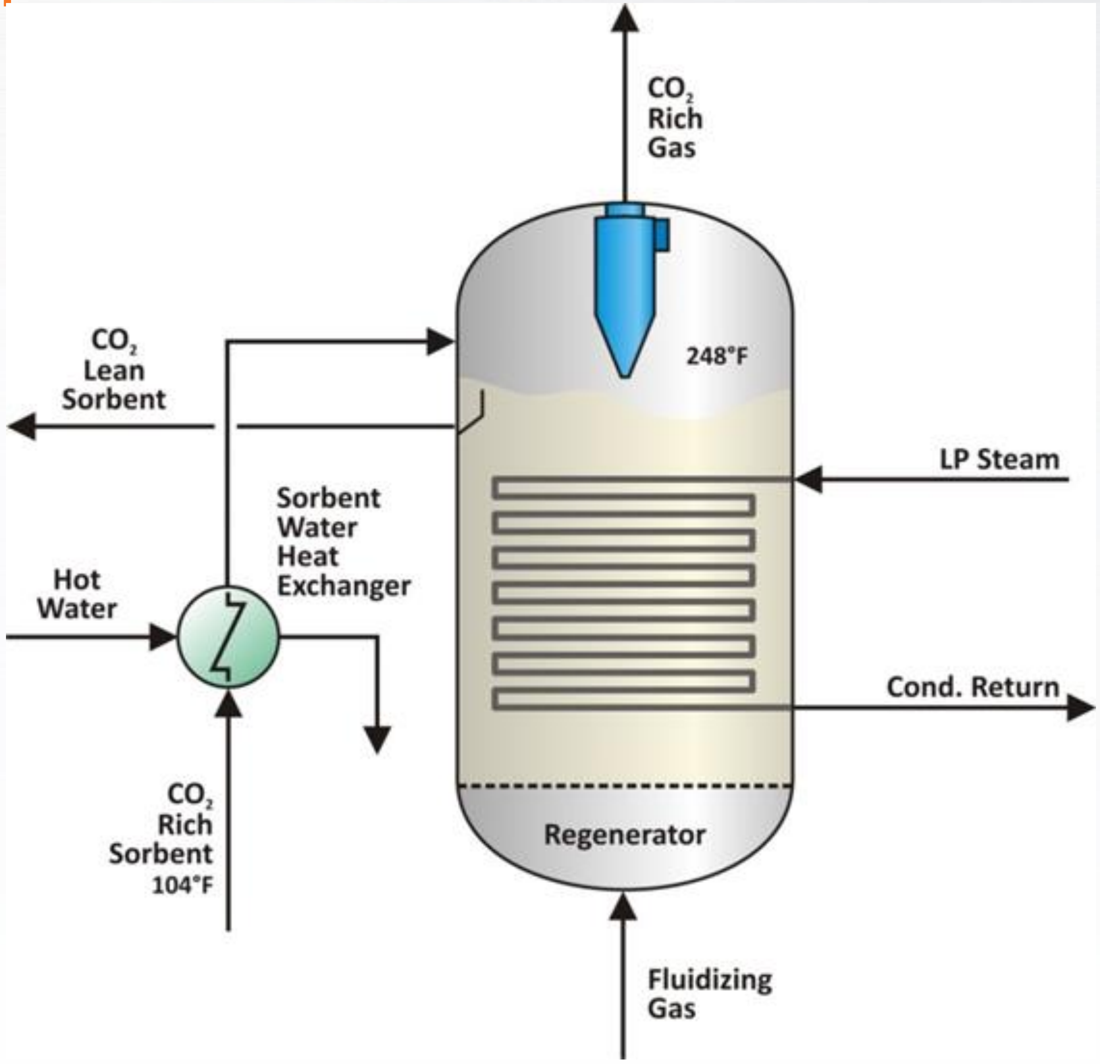


Lehigh Model

CO_2 Precooler & Compressor Intercoolers



Sorbent Regenerator with Heat from Steam Turbine Extraction, CO_2 Cooler and CO_2 Compressor



Predicted Impacts of Waste Heat Integration and Cross Heat Exchanger on Net Unit Heat Rate with Illinois #6 Coal

Case	ΔHR [%]
BASE	0
(1)	-0.96
(2)	-6.86
(1,2)	-7.36
(1,2,4)	-15.02

(1) Flue Gas Cooler Heat Integration

(2) CO_2 Cooler & CO_2 Compressor Intercooler Heat Integration

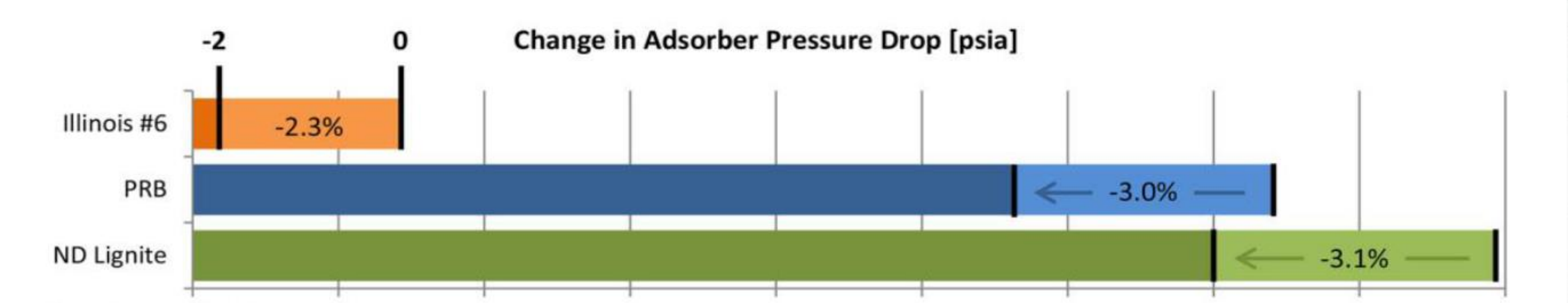
(3) Optimal Adsorber and Regenerator Operating Temperatures

(4) Addition of Cross Heat Exchanger (Effectiveness of 1.0)

Lehigh Model Results

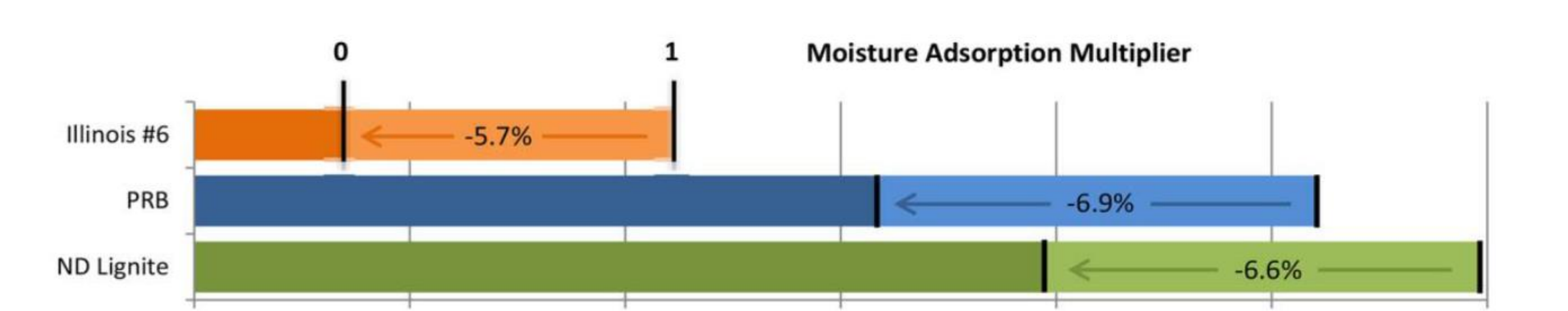
Other Key Improvements

- Flue Gas Blower
  - *Accounts for between 25 to 28 percent of the parasitic power*



Relative Heat Rate

- Sorbent moisture adsorption characteristics

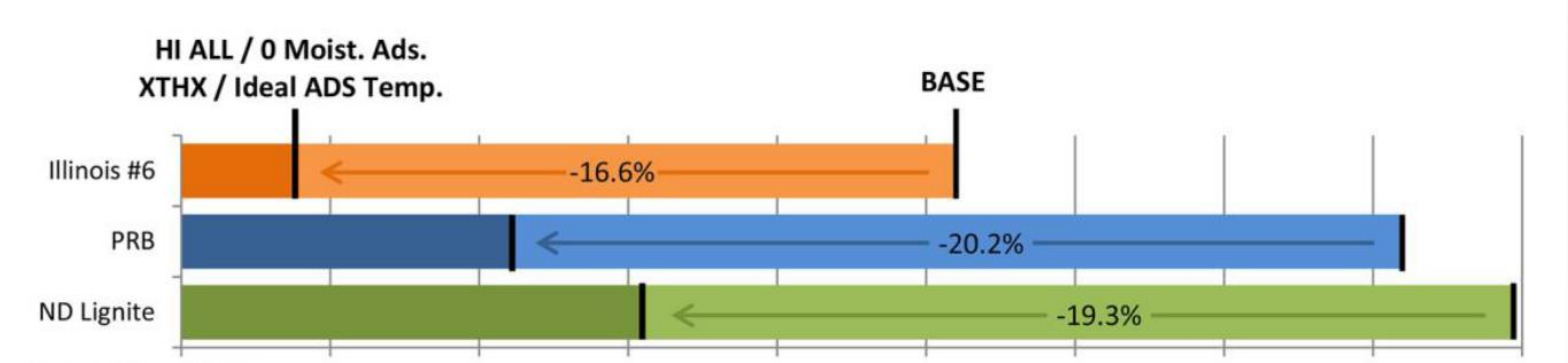


Relative Heat Rate

Lehigh Model Results

Combining Benefits

- Combining waste heat integration, eliminating sorbent moisture adsorption, incorporating a cross heat exchanger and optimizing adsorption temperature can have significant impacts on heat rate for plants using an ADAsorb™ capture system



Relative Heat Rate

Lehigh Model Results

Additional Potential Improvements

- Develop sorbents with lower moisture uptake and lower temperature swing (Regen T- Adsorb T)
- ADAsorb™ Capture System re-design to reduce fan power requirements (pressure drop)

Summary

- Sensible heat recovery has the potential to substantially decrease net unit heat rate and reduce parasitic load based upon modeling results
- Modeling results have provided significant guidance on improving heat rate
- Initial design results of fluidized bed heat exchangers indicated that operating complexity and parasitic load outweighs benefits
- Further techno-economic analysis is required to determine whether the process benefits outweigh the cost of integrating a moving bed heat exchanger

ADA

Advancing Cleaner Energy

Questions?

Sharon Sjostrom
sharons@adaes.com

Jayson Denny
Jayson.Denney@adaes.com