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Carbon Capture Simulation Initiative

Toward rigorous heat integration tools for coal-fired power plants with CO_2 capture and compression

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11th Annual Conference on Carbon Capture, Utilization & Sequestration
April 30 - May 3, 2012, Pittsburgh

U.S. DEPARTMENT OF ENERGY

Outline

- Introduction
  - Carbon capture: Key challenges and opportunities
  - Key objectives and scope of this work
- Overview of heat integration approach
- Modeling of supercritical power plant
- 2 stage sequential optimization approach
  - Results and discussion
- Conclusions and future work

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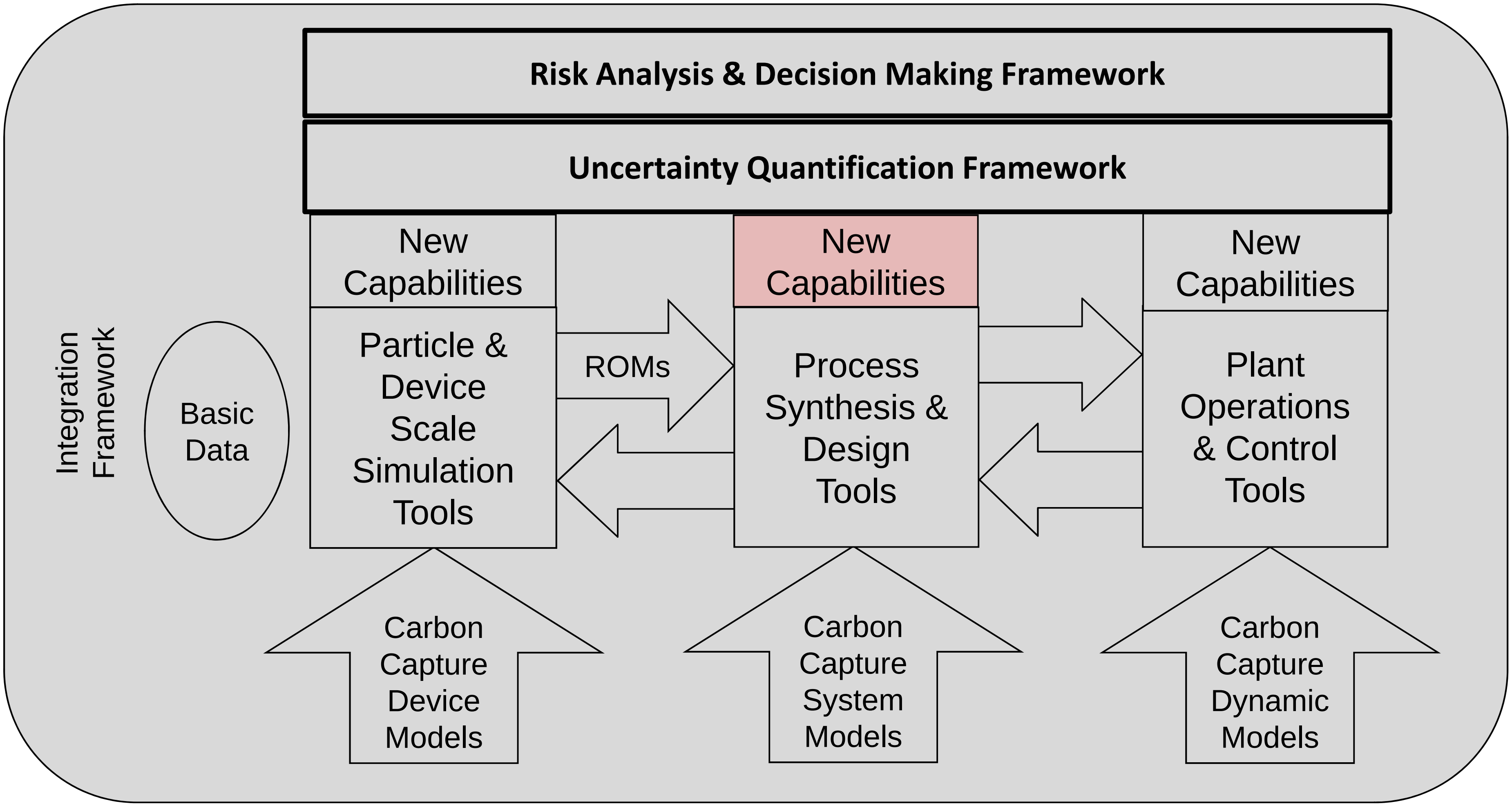

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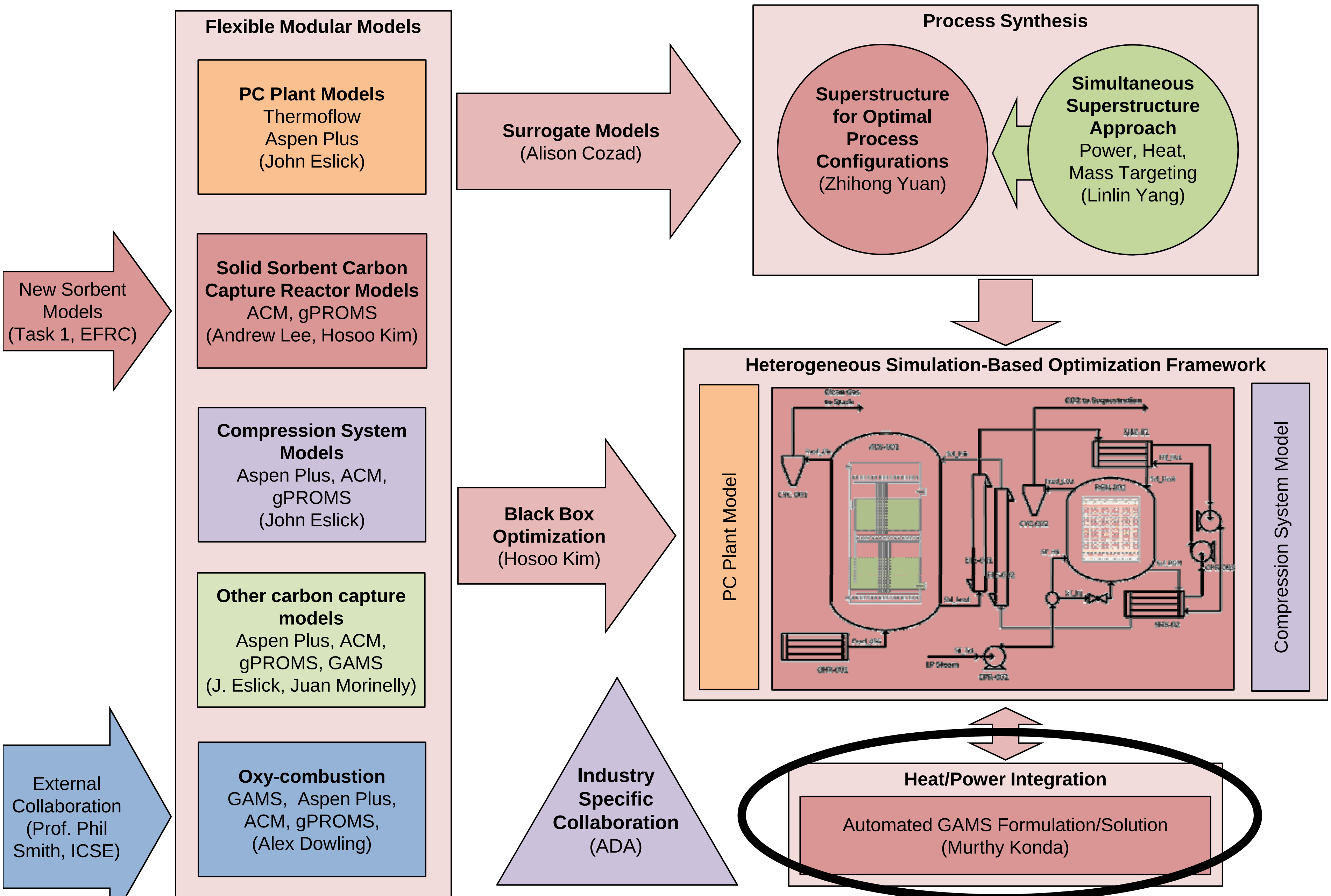

Flexible Modular Models
PC Plant Models
Thermoflow
Aspen Plus
(John Eslick)
Solid Sorbent Carbon Capture Reactor Models
ACM, gPROMS
(Andrew Lee, Hosoo Kim)
Compression System Models
Aspen Plus, ACM, gPROMS
(John Eslick)
Other carbon capture models
Aspen Plus, ACM, gPROMS, GAMS
(J. Eslick, Juan Morinelly)
Oxy-combustion
GAMS, Aspen Plus, ACM, gPROMS,
(Alex Dowling)
New Sorbent Models
(Task 1, EFRC)
External Collaboration
(Prof. Phil Smith, ICSE)
Surrogate Models
(Alison Cozad)
Black Box Optimization
(Hosoo Kim)
Industry Specific Collaboration
(ADA)
Process Synthesis
Superstructure for Optimal Process Configurations
(Zhihong Yuan)
Simultaneous Superstructure Approach
Power, Heat, Mass Targeting
(Linlin Yang)
Heterogeneous Simulation-Based Optimization Framework
PC Plant Model
Compression System Model
Heat/Power Integration
Automated GAMS Formulation/Solution
(Murthy Konda)

Heat integration approach

Models from the initial demonstration of CCSI Process Synthesis and Design Toolset

Steam cycle (Simulation Model)

CO_2 Capture System (Simulation Model)

CO_2 Compression System (Simulation Model)

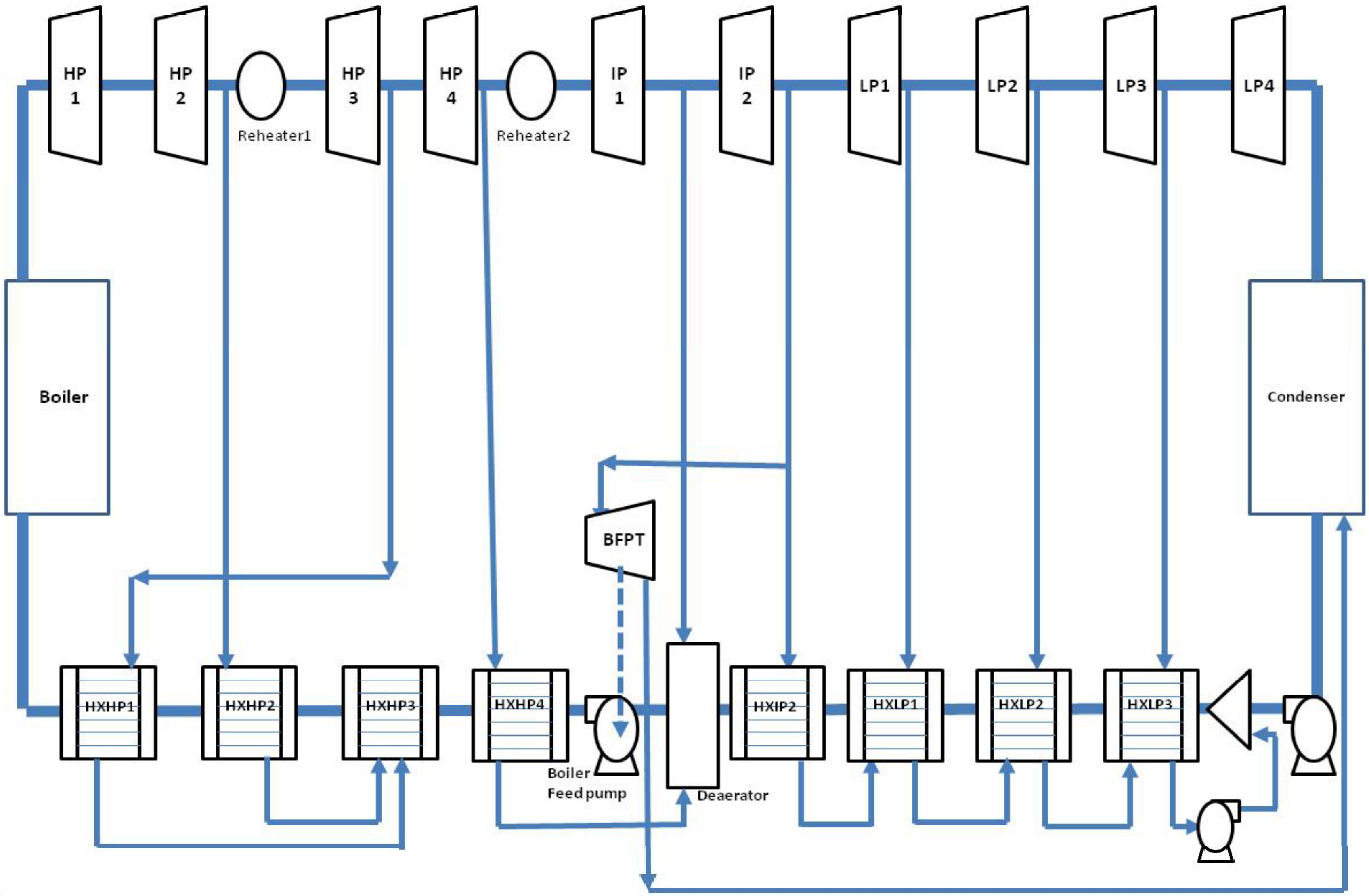
Excel interface for exporting 'stream data' (SINTER)

Steam Cycle Optimization Model (Mathematical model)

Heat Exchanger Network (HEN) Optimization Model (Mathematical model)

Integrated Analysis
→Minimize energy penalty on power plant
→Minimize Cost Of Electricity (COE)

Supercritical power plant steam cycle



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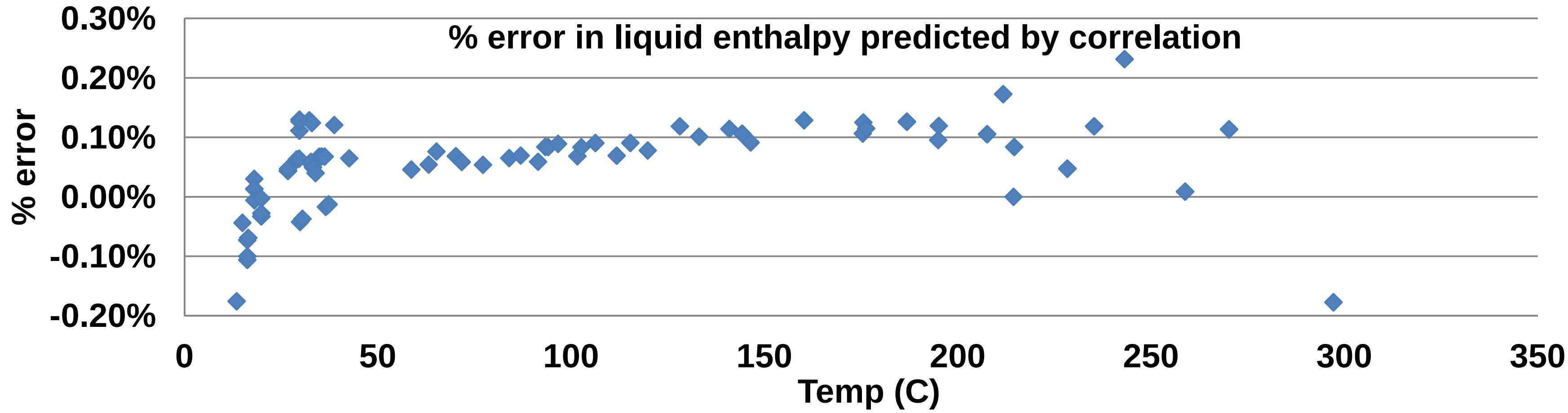
Modeling of power plant steam cycle

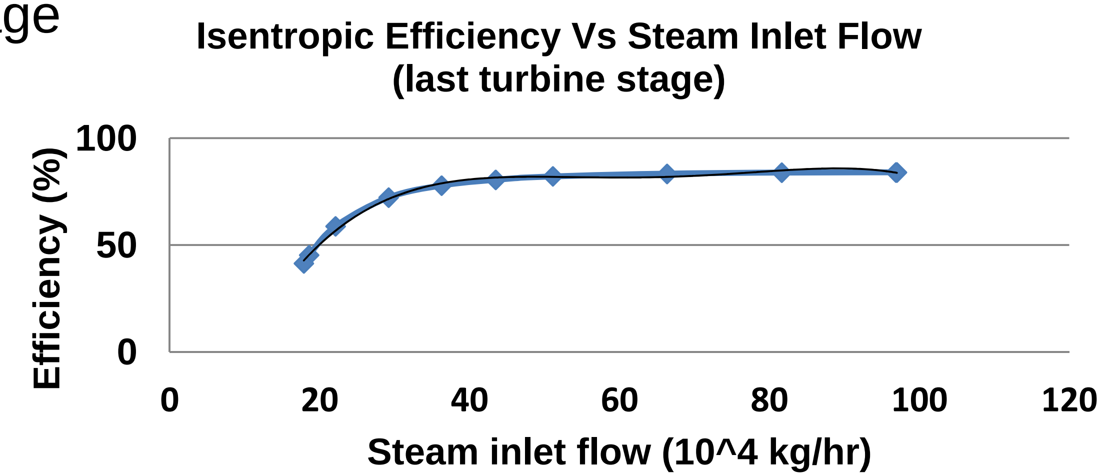
- Basis: Simulation developed in Thermoflex
- Optimization model is developed in GAMS
- GAMS model: algebraic representation of steam cycle
  - Mass and energy balances
  - Correlations for steam/water enthalpy prediction
  - Corrections for turbine efficiency

Modeling of power plant: some aspects

- Accurate enthalpy correlations as a function of temperature and pressure



- Exhaust losses are taken into account and developed efficiency correlations for the last LP turbine stage



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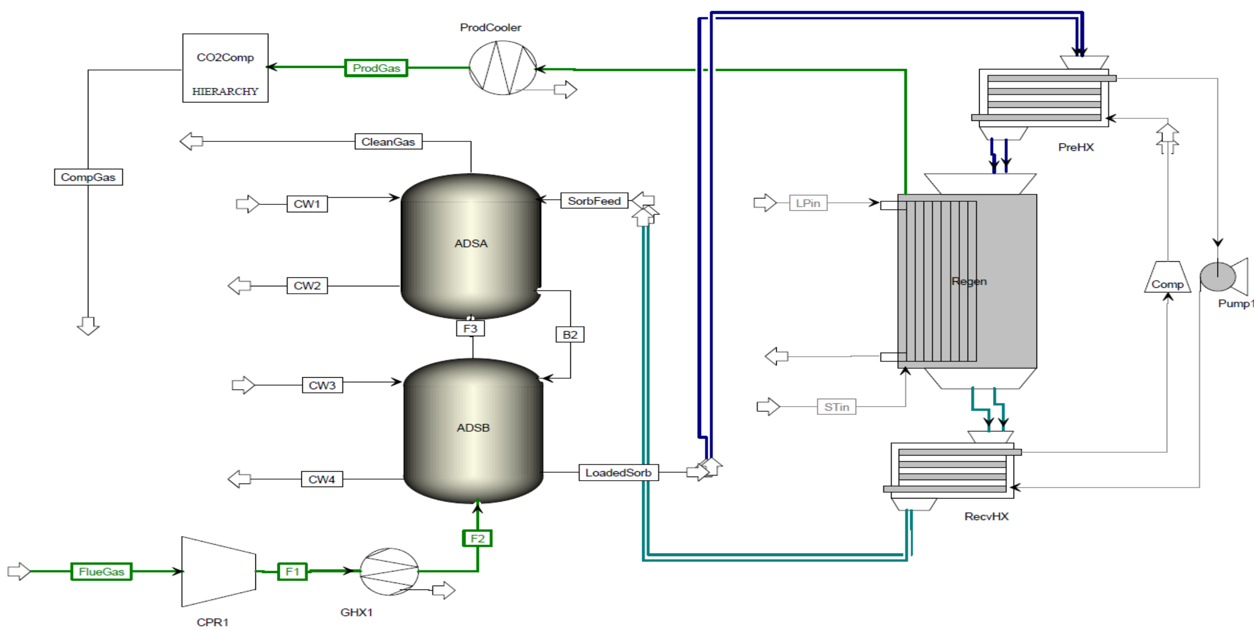
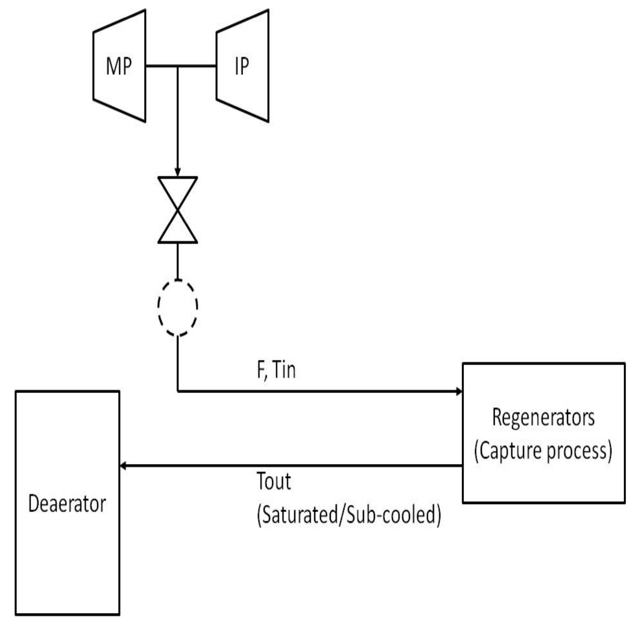
Steam extraction for sorbent regeneration

- Solid sorbent carbon capture process is from Chang et al., 2011
  - 2 bubbling fluidized bed adsorbers and 1 moving bed regenerator
  - Steam required: 138 GJ/hr/train (10 parallel regenerator trains)
- Steam extraction from IP/LP crossover (@100 psi)
  - Condensed steam is returned to the deaerator in the BFH section

CO_2 Capture Process



IP/LP Steam extraction



Chang et al. (2011). Synthesis of optimal adsorptive carbon capture processes. AIChE annual meeting, Minneapolis, MN

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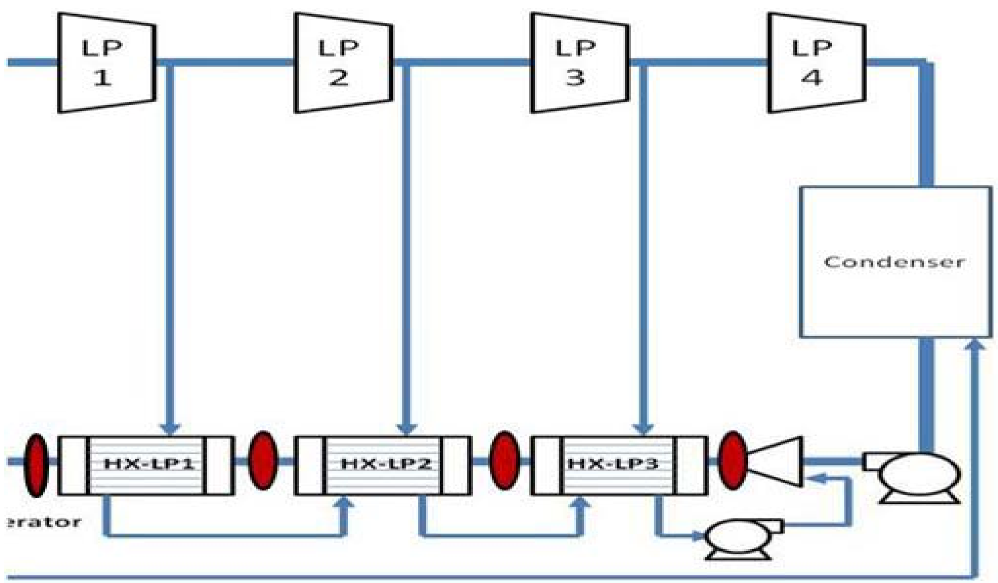
2 stage sequential optimization methodology

1. Optimize steam cycle for required steam extraction rate
   i. Determine feasible temperature profile in BFH section subjected to the amounts/quality of available 'heat sources' from capture & compression systems
   ii. Min. parasitic loss assuming available heat can be used.

2. Determine optimal matches (location of HX's) to integrate heat from capture & compression back into steam cycle to achieve 1.

Stage 1: Steam cycle and HEN model integration

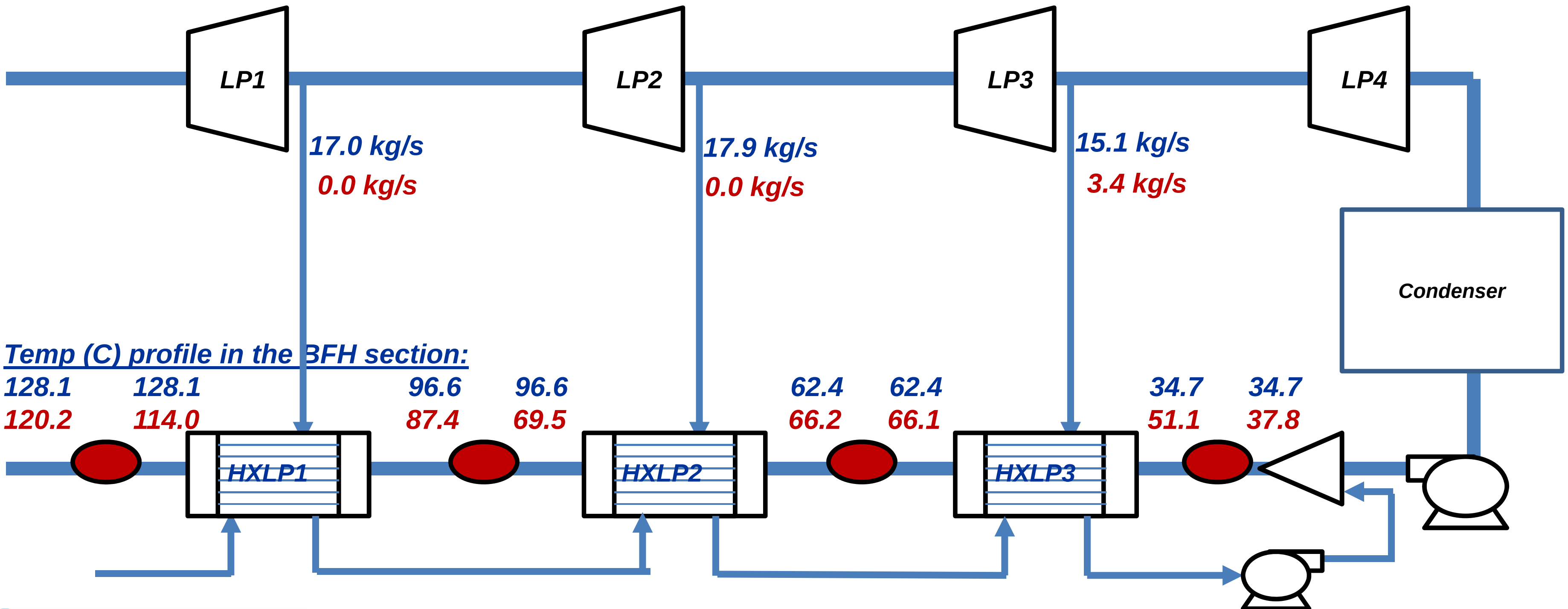
- All the 'heat sources' in the CO_2 capture and compression processes generally provide 'low-grade heat' (i.e., < 250^{0}C).
  - This heat can be fed into the steam cycle through the BFH section and cannot directly be used in the boiler to produce HP steam
  - In practice, part of this heat may also be used to produce LP steam to drive, for instance, auxiliary equipment
- Heaters (red circles) are assumed in the LP BFH section and these heaters can use 'hot energy' from CO_2 capture & compression processes



Stage 1: Results

- Heaters (red circles) have utilized heat sources from capture and compression process (and hence temperature rose across heaters)
- Steam extraction at turbine stages is lowered to improve efficiency.

- **Legend:**
- Basecase (before heat integration) conditions are shown in black
- Case 2 (after heat integration) conditions are shown in red



Stage 1: Results (continued)

- Basecase (without heat integration):
  - Net efficiency: 44.3% → 33.8%
  - Gross power: 709 MWe → 553 MWe

- Case 2: i.e., with heat integration (by using heat sources available in CO_2 capture and compression processes)
  - Net efficiency: 33.8% → 36.4%
  - Gross power: 553 MWe → 591 MWe

Stage 2: Model for optimal HEN design

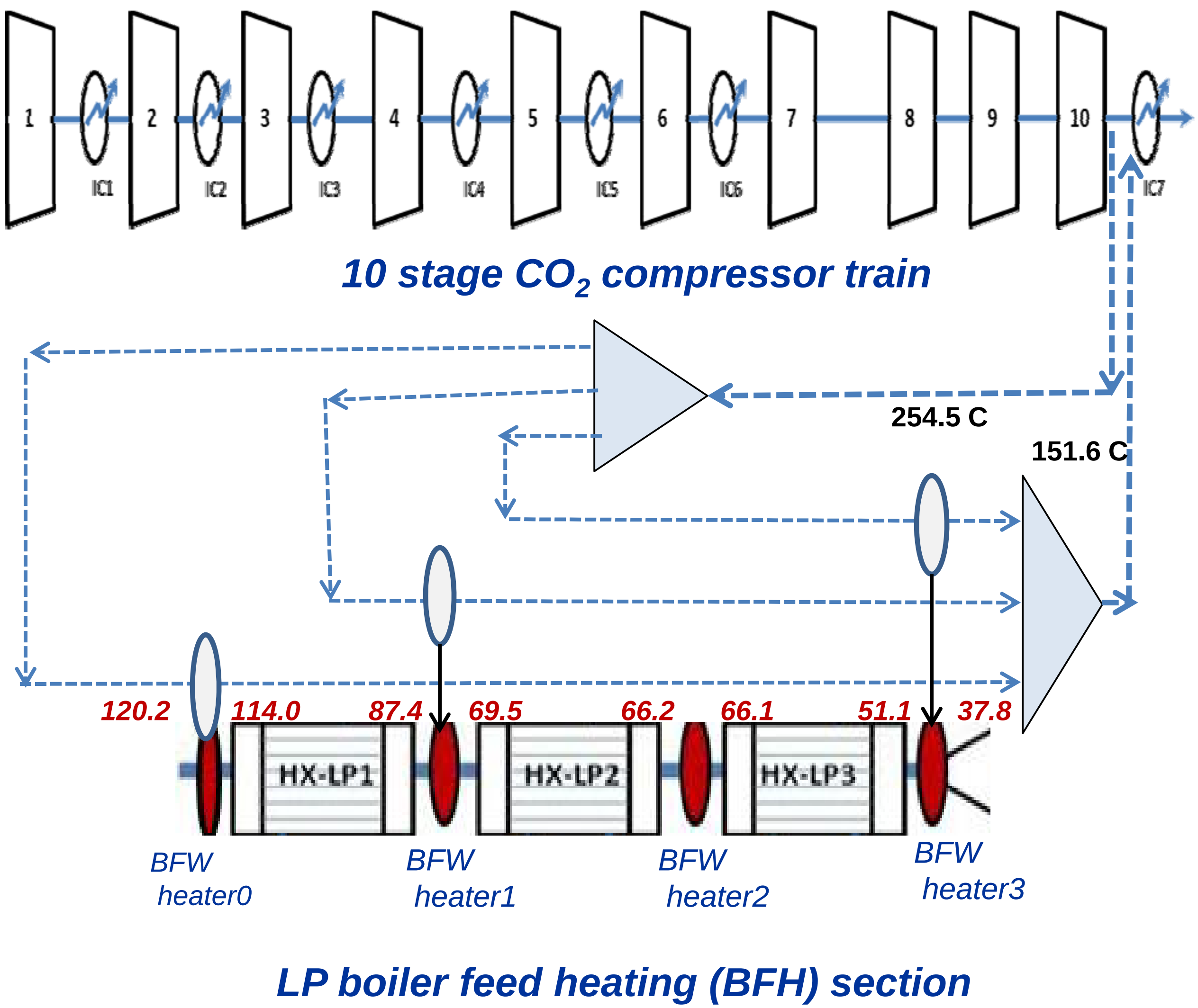
- Given:
  - Process and utility stream data
    - T_{in}, T_{out}, heat capacity & heat transfer coefficients
  - Cost data
- Objective is to:
  - Minimize total cost of the network
- While optimizing (i.e., decision variables):
  - Hot and cold stream matches (binary variables)
  - Load, approach temp and area of each heat exchanger (continuous variables)
- Formulation (Yee and Grossmann, 1990)
  - Multi-stage network with isothermal mixing

Yee and Grossmann (1990). Simultaneous optimization models for heat integration – 2. Heat exchanger network synthesis.

Stage 2: Stream data for hot and cold sources

HOT STREAM DATA				COLD STREAM DATA			
Stream Name	TIN (C)	TOUT (C)	MCp (MJ/hr-C)	Stream Name	TIN (C)	TOUT (C)	MCP (MJ/hr-C)
FlueGas_Cooler	81.	43.	13646.	BFW heater3	38.	51.	2,200
ProdCO_2_Cooler	71.	40.	22933.	BFW heater2	66.	66.	2,201
IC_01	86.	43.	612.	BFW heater1	69.	87.	2,209
IC_02	88.	43.	643.	BFW heater0	114.	120.	2234
IC_03	86.	43.	563.				
IC_04	88.	43.	513.				
IC_05	87.	43.	490.				
IC_06	89.	43.	488.				
IC_07	254.	60.	802.				

Stage 2 Results: HEN configuration



<u>Legend</u>: *Dashed lines represent HEN connections and circles on the dashed lines represent locations of heat exchange with BFH section*

<u>Note:</u> *HEN configuration is preliminary and further improvements/investigation are necessary*

Intercooler 7 (from compression system) is sufficient to satisfy heating loads on the new BFW heaters (red circles). Heat available in flue gas cooler and product CO_2 cooler (from capture process) are not needed.

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Conclusions and future work

- Rigorous optimization model for a supercritical power plant is developed
  - Optimization of BFH temperature profile can help reducing energy penalty due to steam extraction (for sorbent regeneration).
- Net efficiency can be improved from 33.8% to 36.4%.
- Work in progress:
  - Integrate into single stage, simultaneous algorithm

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