Power Plant Analysis Using CFD and Process Simulation

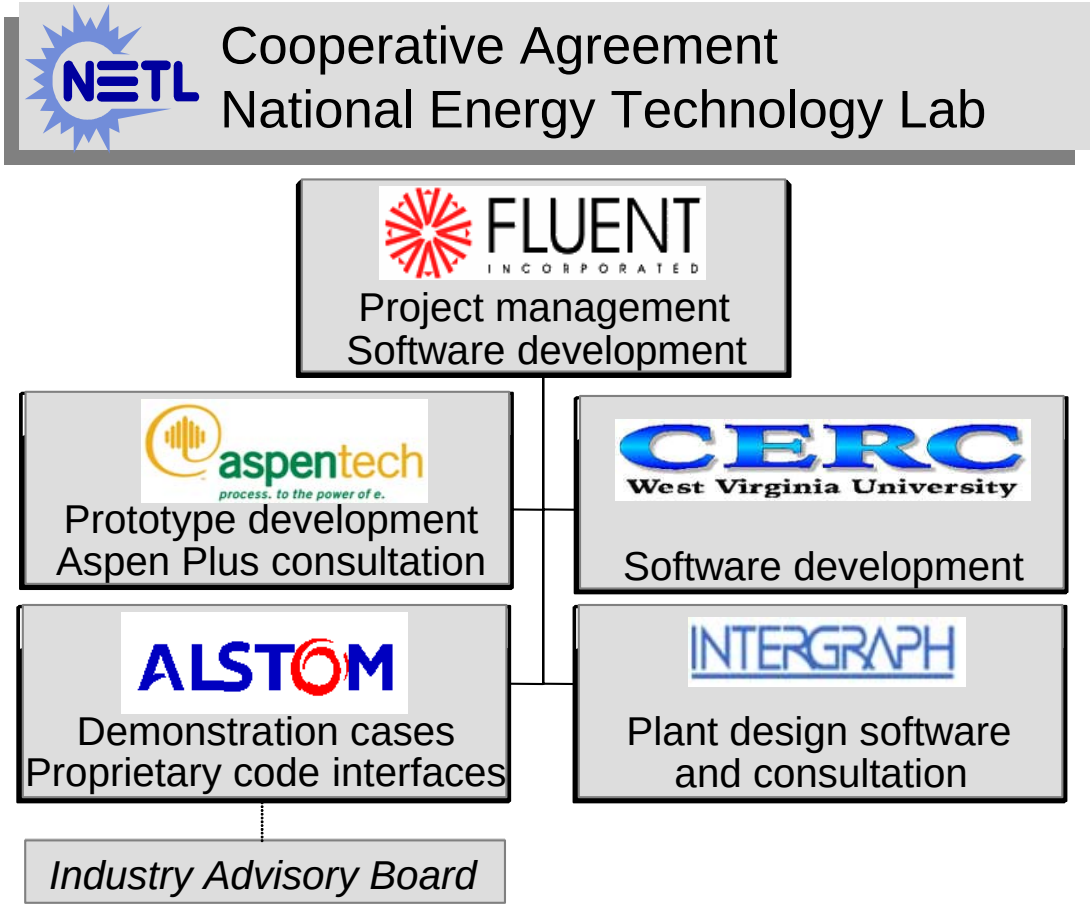
2nd Annual U.S. CAPE-OPEN Meeting

May 25-26, 2005

ALSTOM

Vision 21 Project

- NETL Cooperative Agreement (Oct 2000 through Dec 2004)
- Goal: Develop software infrastructure for enabling *Virtual Simulation* of advanced power plants



Integrated Component and Process Modeling

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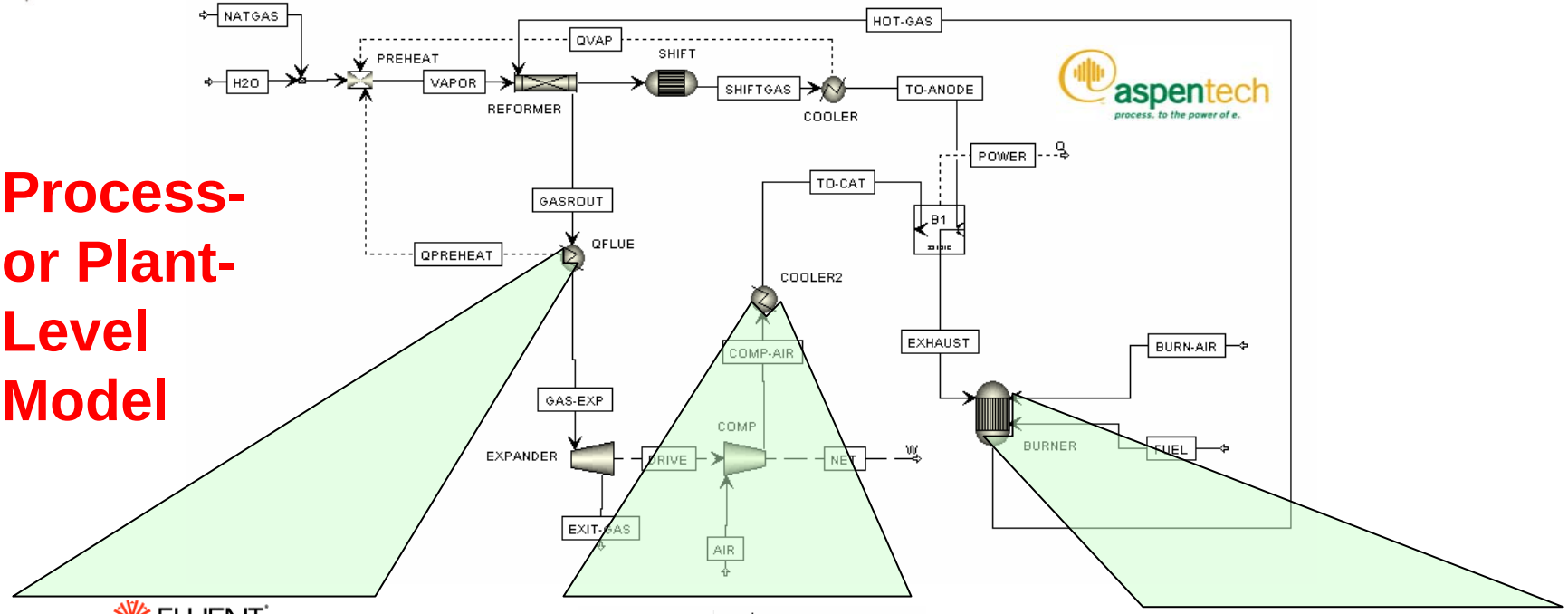
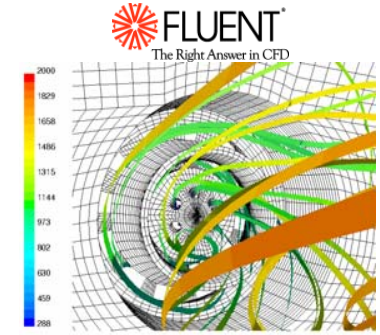
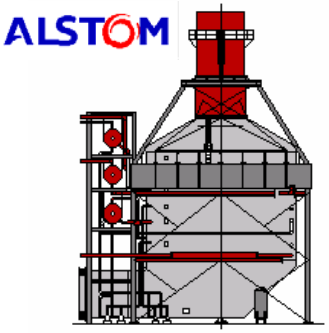
Process- or Plant-Level Model

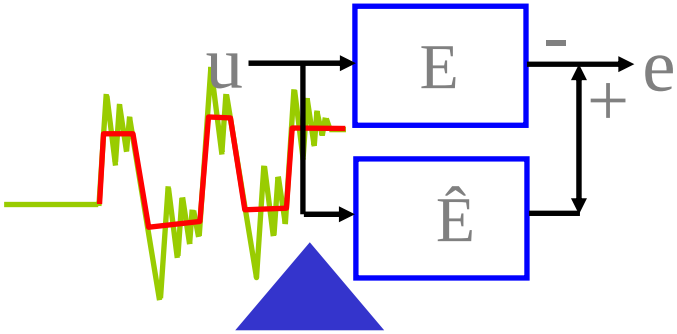




CFD Packages



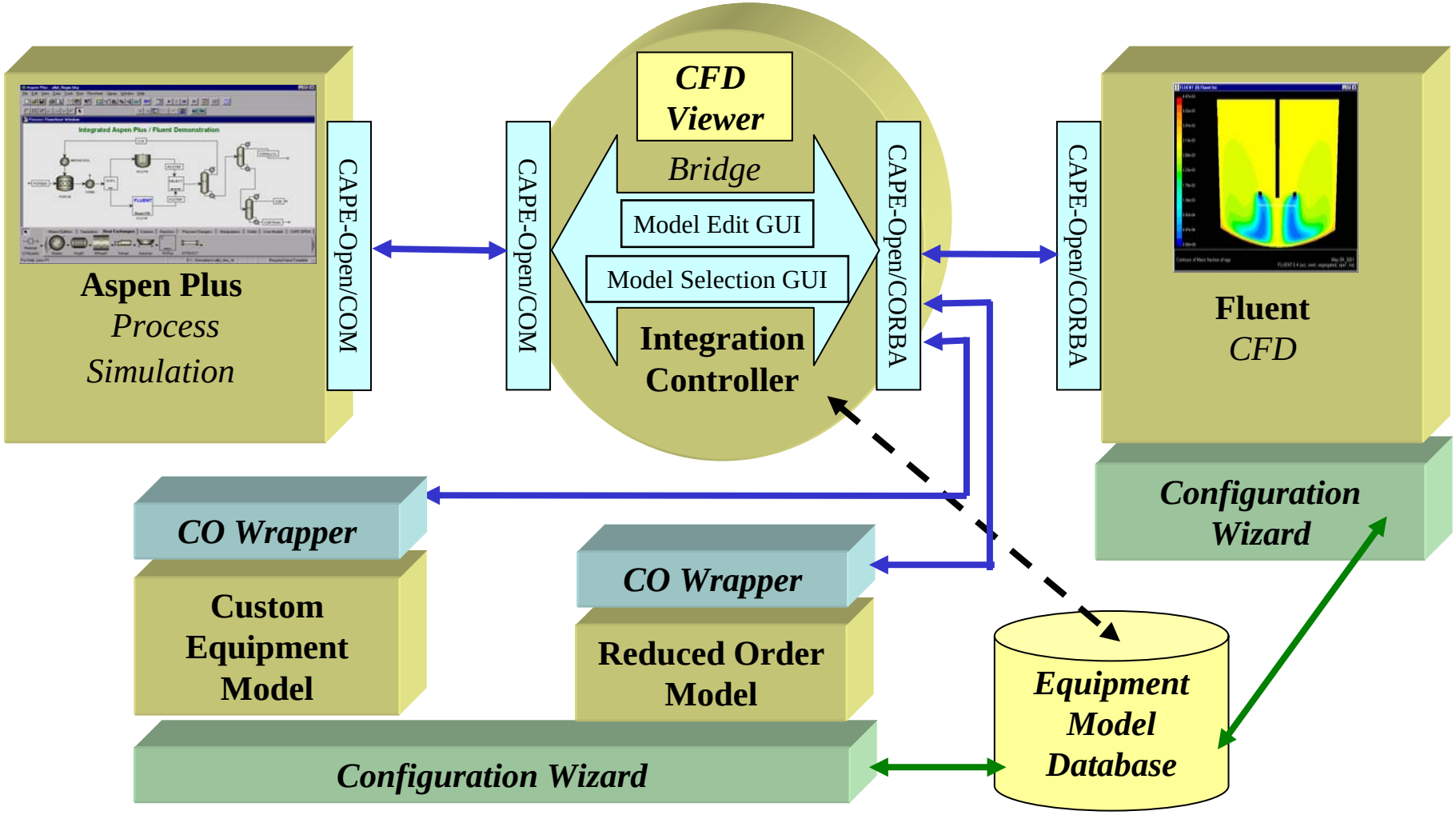
Industrial Codes



Reduced Order Models

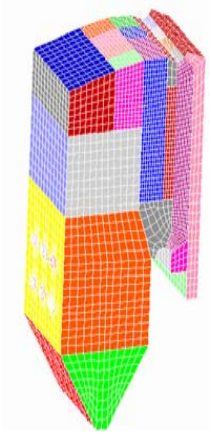
Component- or Equipment-Level Models

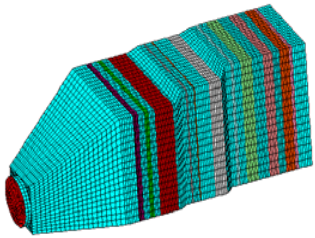
Software Architecture

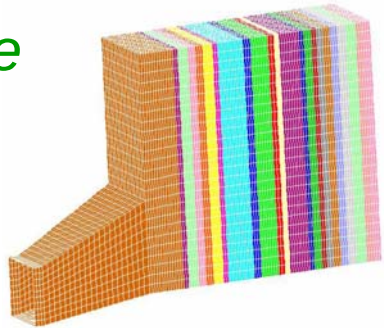


Demonstration Cases
ALSTOM Task Overview

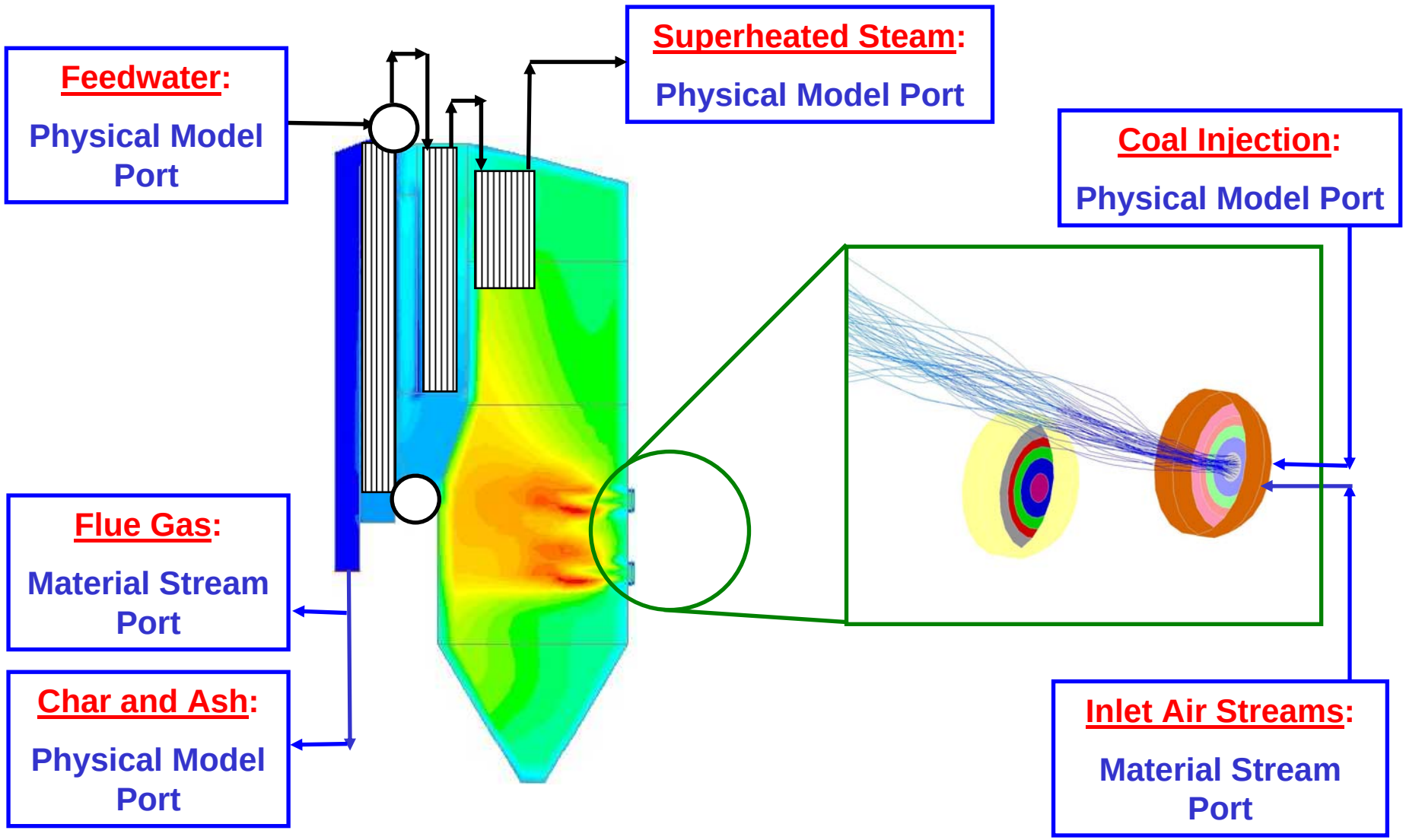
- ALSTOM task: Demonstration of Integration Controller interfaces/wrappers with multiple application cases
- Demo Case 1: *Conventional Steam Cycle*
  - Replaced furnace/boiler module
  - ALSTOM design code and FLUENT CFD simulation
  - Cases run on local PC over load range
- Demo Case 2: *Natural Gas Combined Cycle*
  - Replaced heat recovery steam generator (HRSG)
  - ALSTOM design code and FLUENT CFD simulation
  - Cases run on local PC and LAN over load range
- Demo Case 3: *Integrated Gasification Combined Cycle*
  - Replaced HRSG module with FLUENT CFD case
  - Case run over LAN



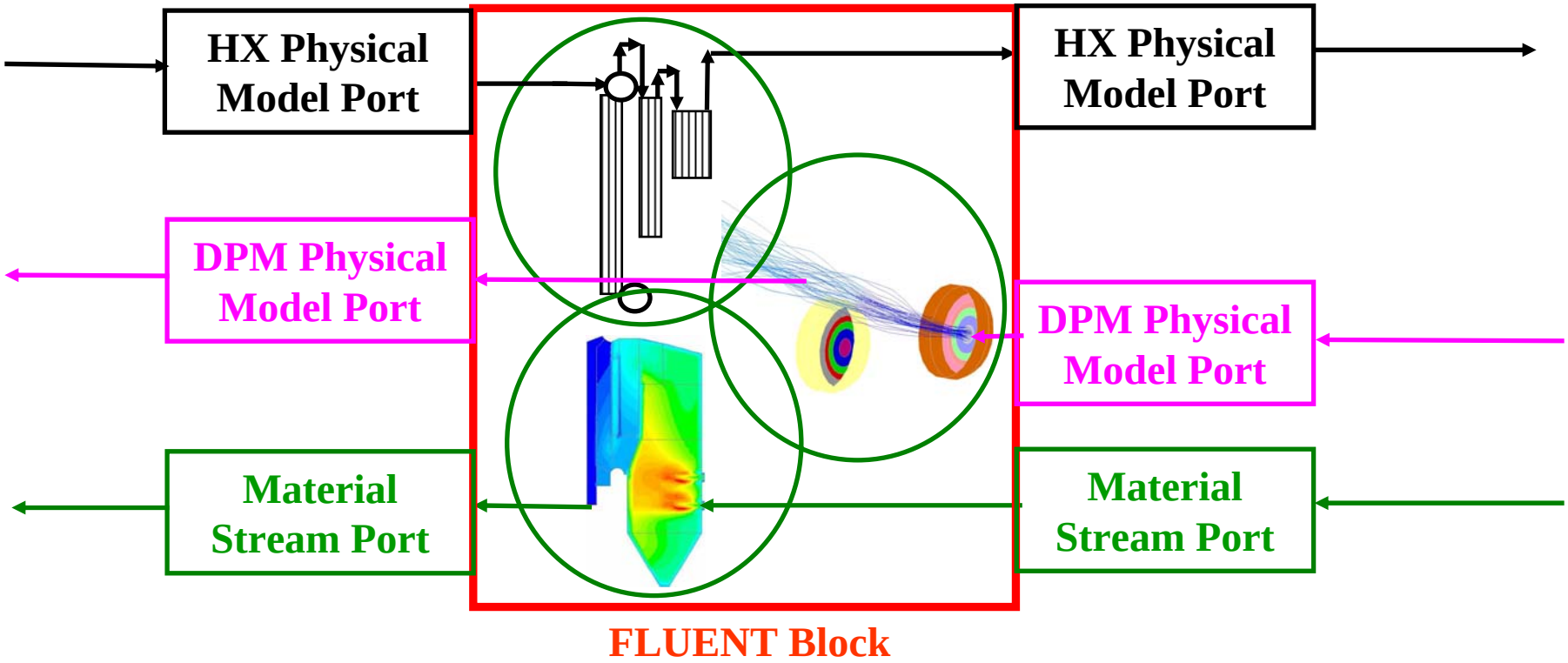




Physical Model and Material Stream Port Connectivities

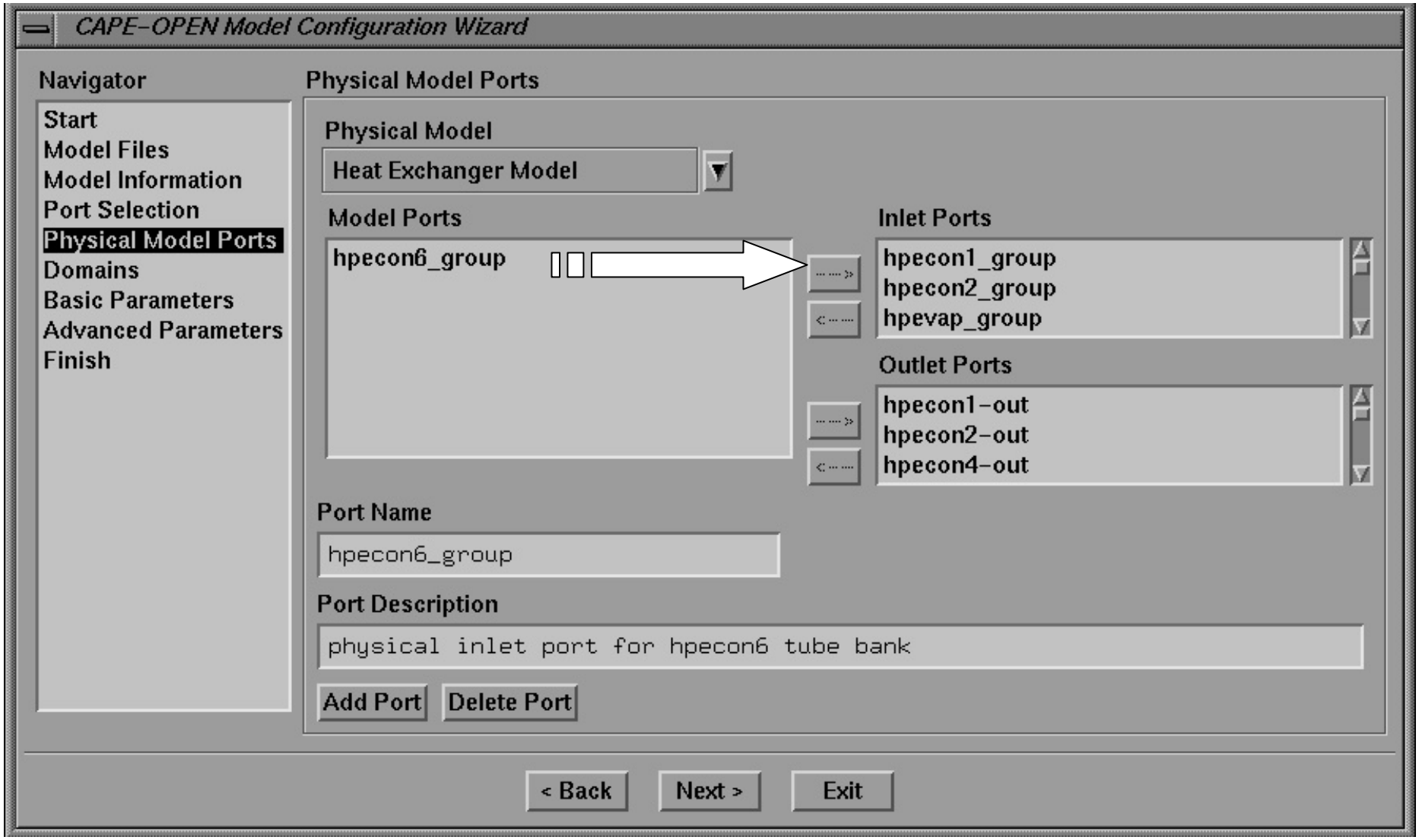


Physical Model and Material Stream Port Connectivities



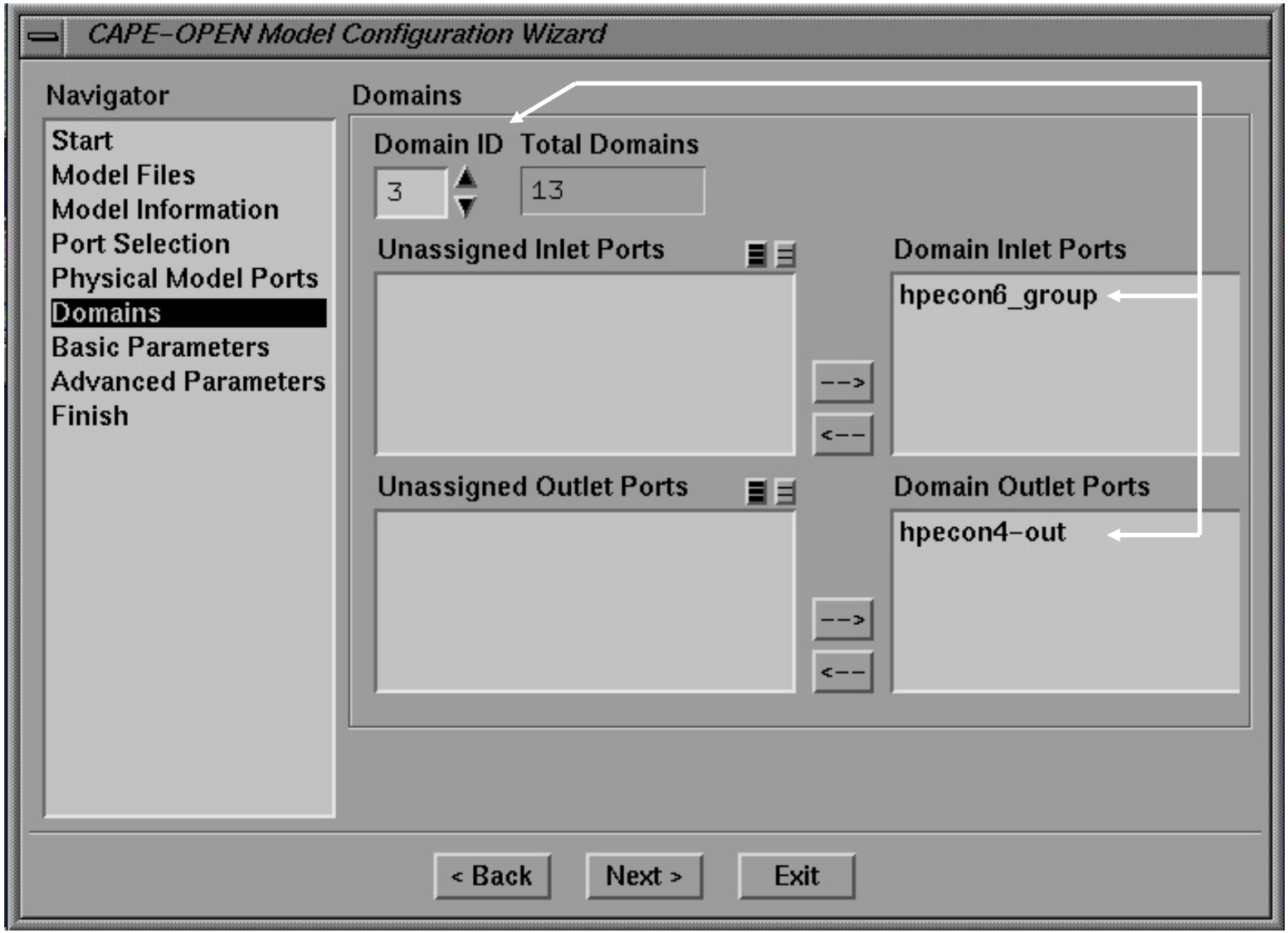
- "Physical model" ports for generic, tube bank HX, and DPM models have been added to the Integration Controller
- Aspen Plus process streams can be connected directly to the HX and DPM submodels in an instantiated FLUENT block

Configuration Wizard
HX Physical Model Ports



Configuration Wizard

HX Physical Model Port Domain IDs



Configuration Wizard
Defining CO Parameters

ALSTOM

CAPE-OPEN Model Configuration Wizard

Navigator
- Start
- Model Files
- Model Information
- Port Selection
- Domains
- Basic Parameters
- Advanced Parameters
- Finish

Advanced Parameters

Defined Parameters
- bb-inlet-pressure
- bb-inlet-quality
- bb-inlet-temperature
- bb-mass-rate
- bb-pressure-drop
- hx-evaporative-heat-transfer
- hx-superheat-heat-transfer
- hx-superheat-outlet-temperature
- hx-total-heat-transfer
- ltsh-inlet-pressure

Name: hx-superheat-outlet-temperature

Type: real

Access: read-write

Default Value: 762.59

Dimensionality: K

Lower Bound: 700

Upper Bound: 800

Description: superheat outlet temperature

Command: hx-superheat-outlet-temperature

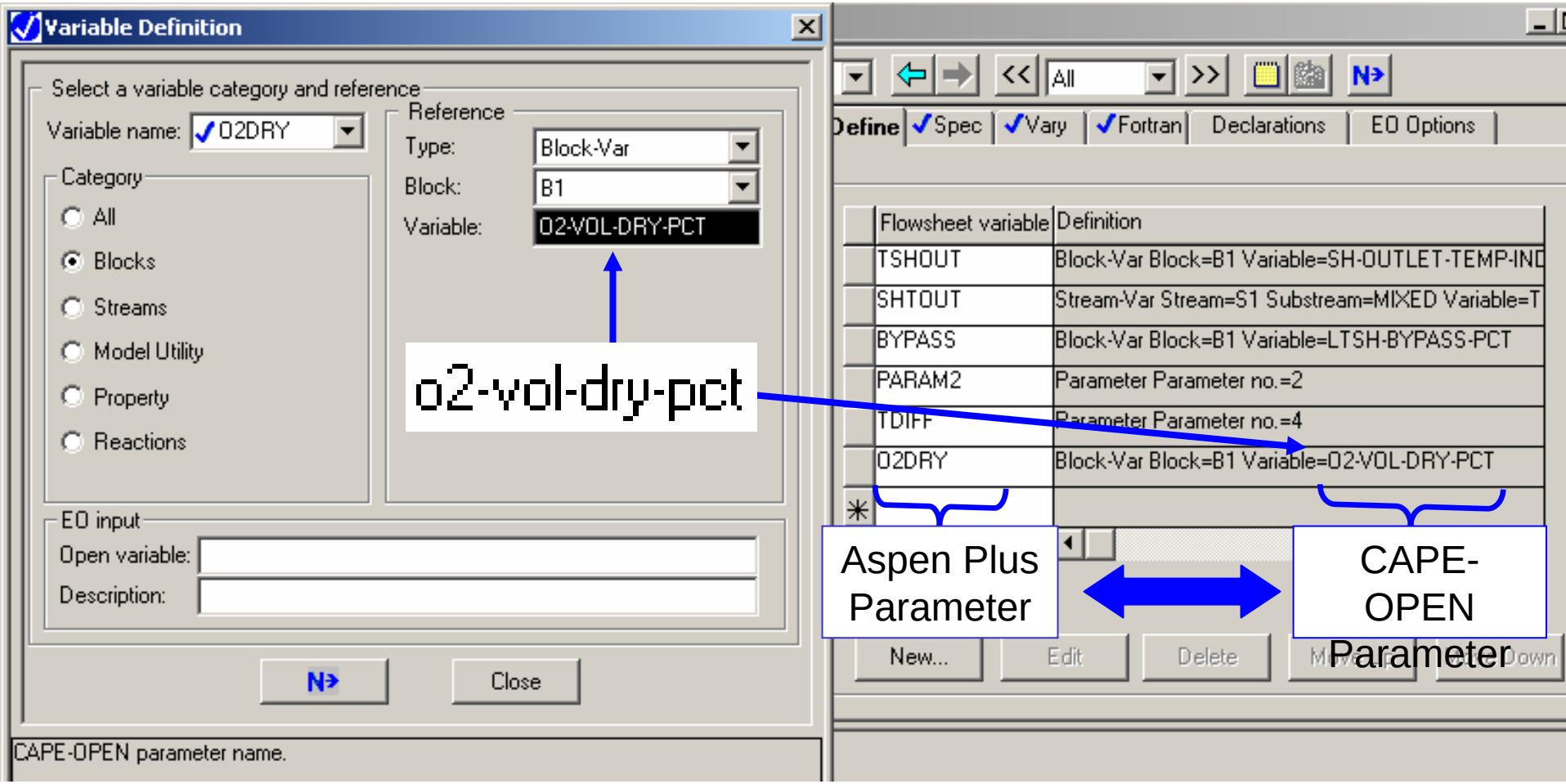
(•) rp-var ( ) TUI ( ) Scheme Function

Delete Command

Create | Delete | New

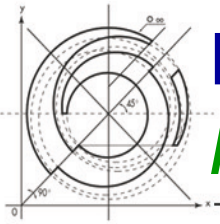
< Back | Next > | Exit

Linking of CO Parameters to the Aspen Plus Variables

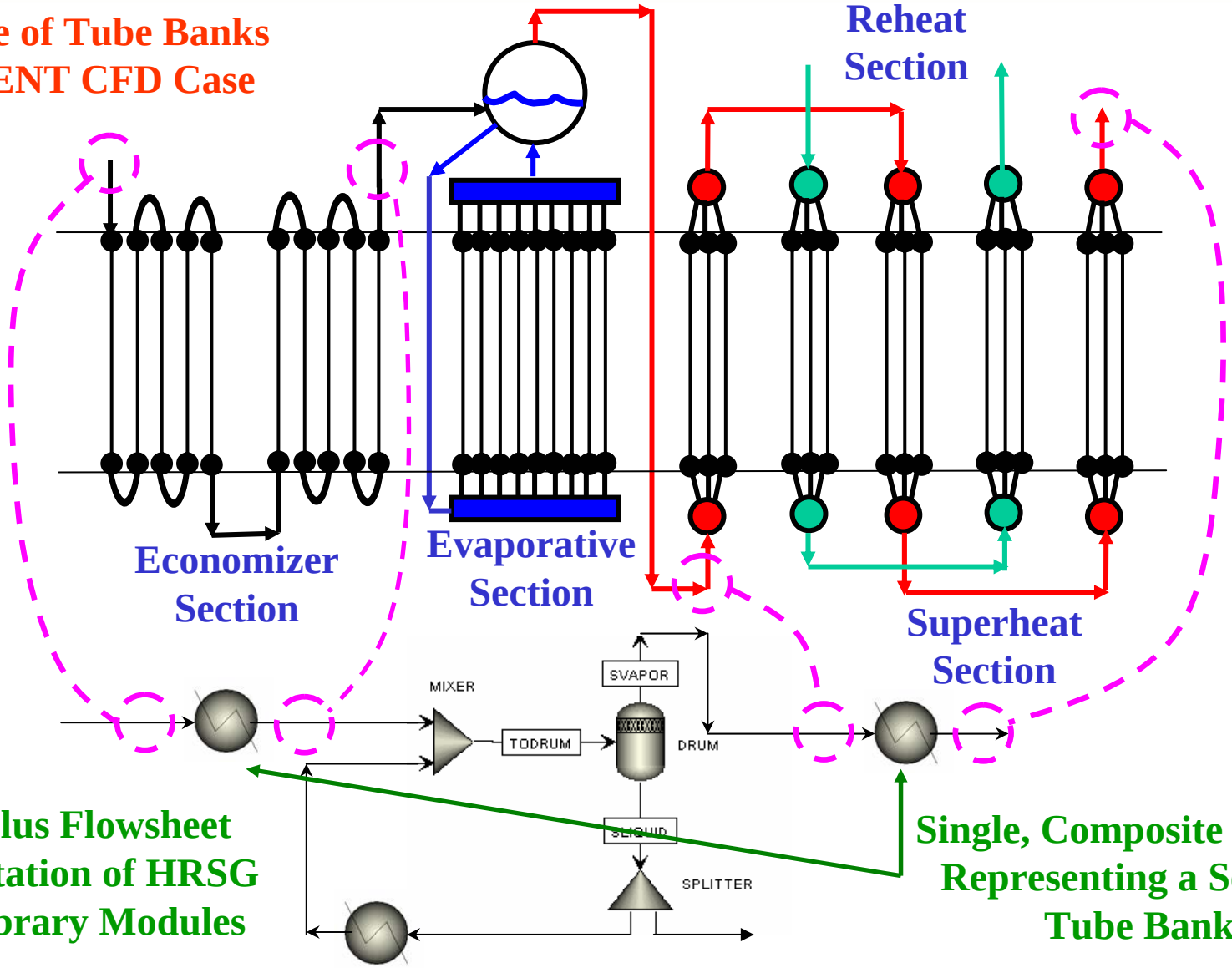


HX Solution Methodology

First Step



Sequence of Tube Banks in FLUENT CFD Case

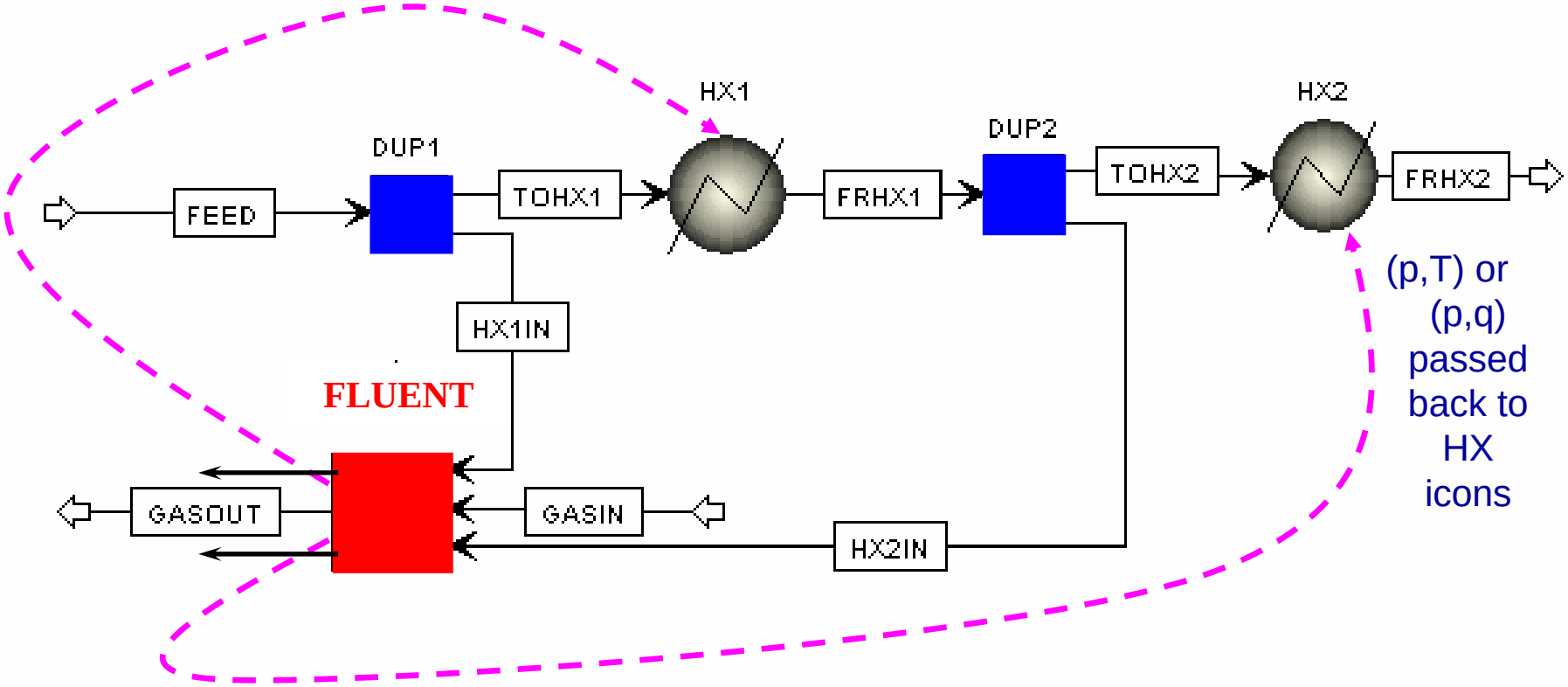


Aspen Plus Flowsheet Representation of HRSG Using Library Modules

Single, Composite HX Icon Representing a Series of Tube Banks

HX Solution Methodology
Second Step

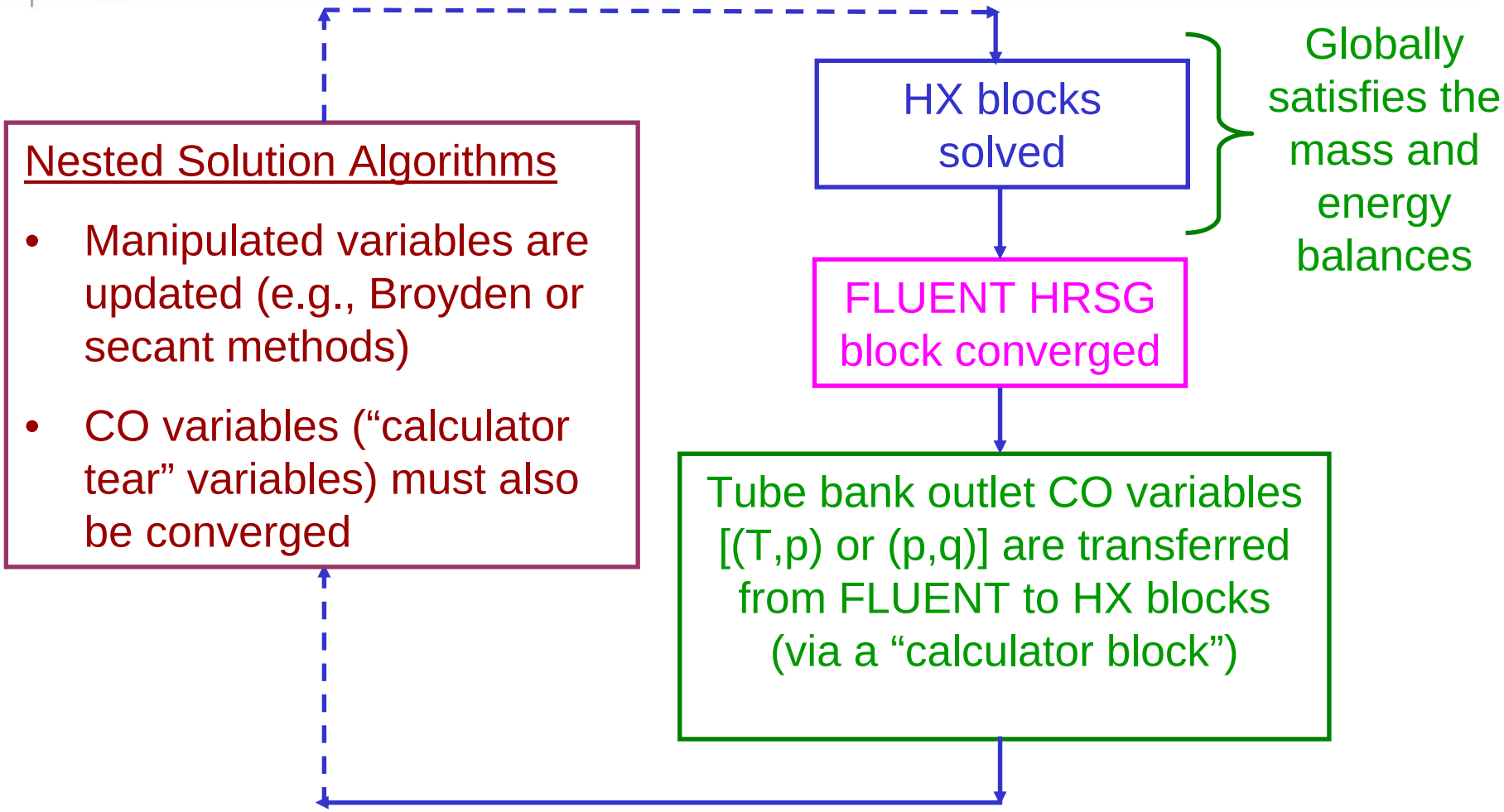
- Streams duplicated and connected to physical model ports



- FLUENT HX outlet values passed to Aspen as CO variables
- Outlet steam/water conditions of Aspen's HX icon overwritten with corresponding FLUENT tube bank info

HX Solution Methodology

Solution Sequence



- Redundancy of FLUENT and HX blocks is advantageous for those CFD blocks that are simultaneously connected to many parts of the cycle.

Demonstration Case 2
Natural Gas Combined Cycle

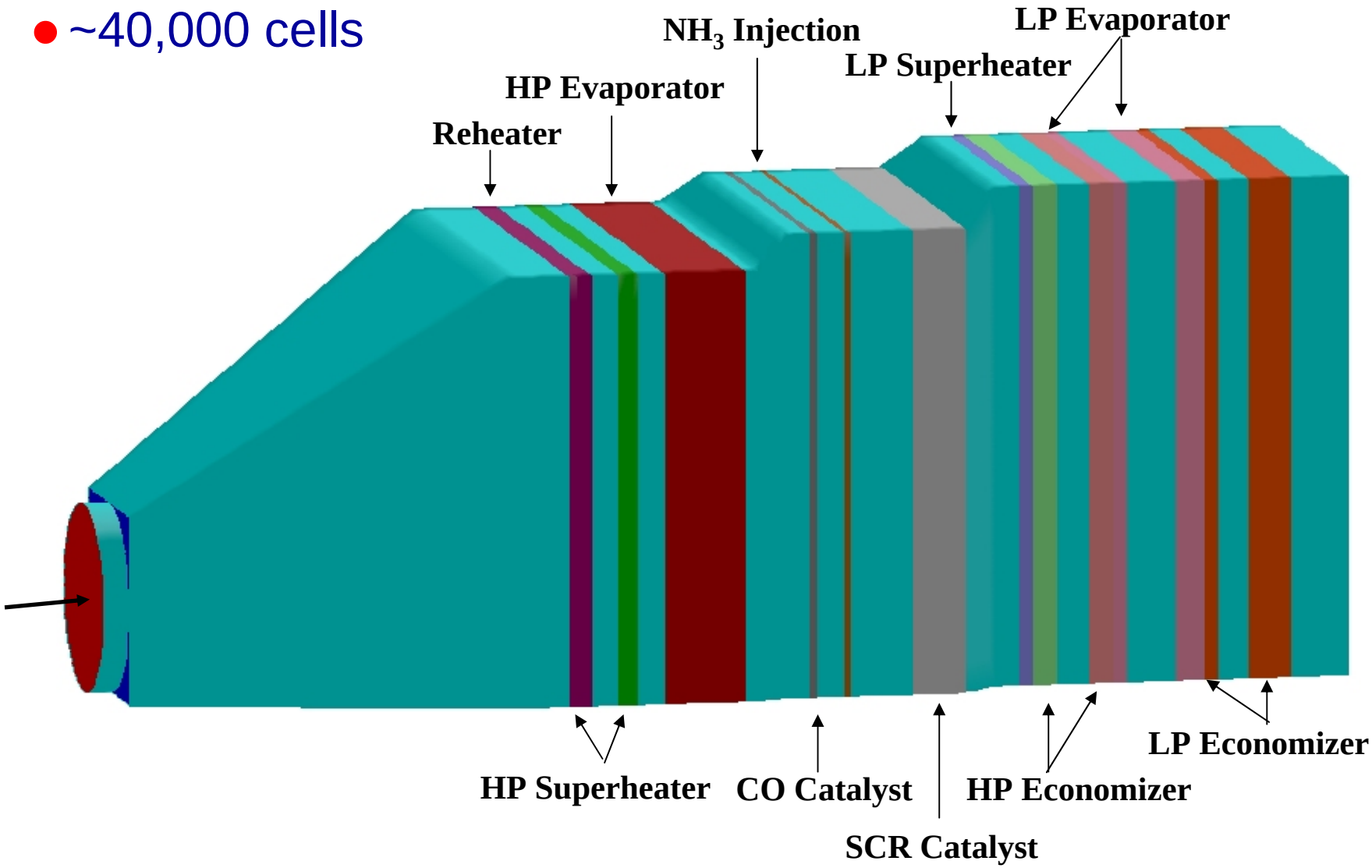
- Combined cycle power plant
  - 270 MWe
  - natural gas-fired
  - gas turbine
  - steam turbine
  - heat recovery steam generator (HRSG)

- HRSG
  - high pressure (HP)
  - low pressure (LP)
  - reheat (RH)

270 MWe Combined Cycle Power Plant

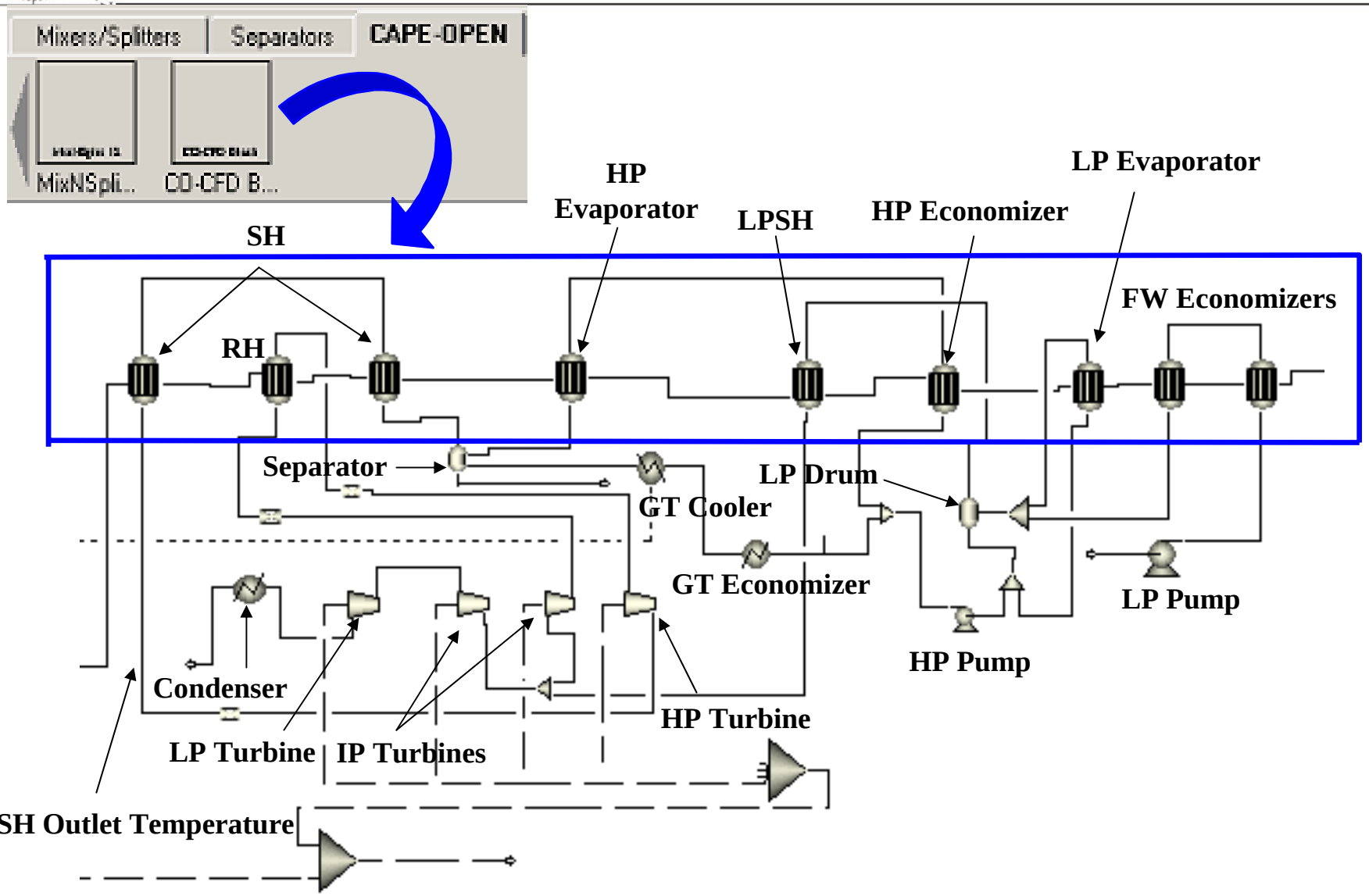
Case 2: CFD-Aspen Coupling
HRSG Geometry

- ~40,000 cells



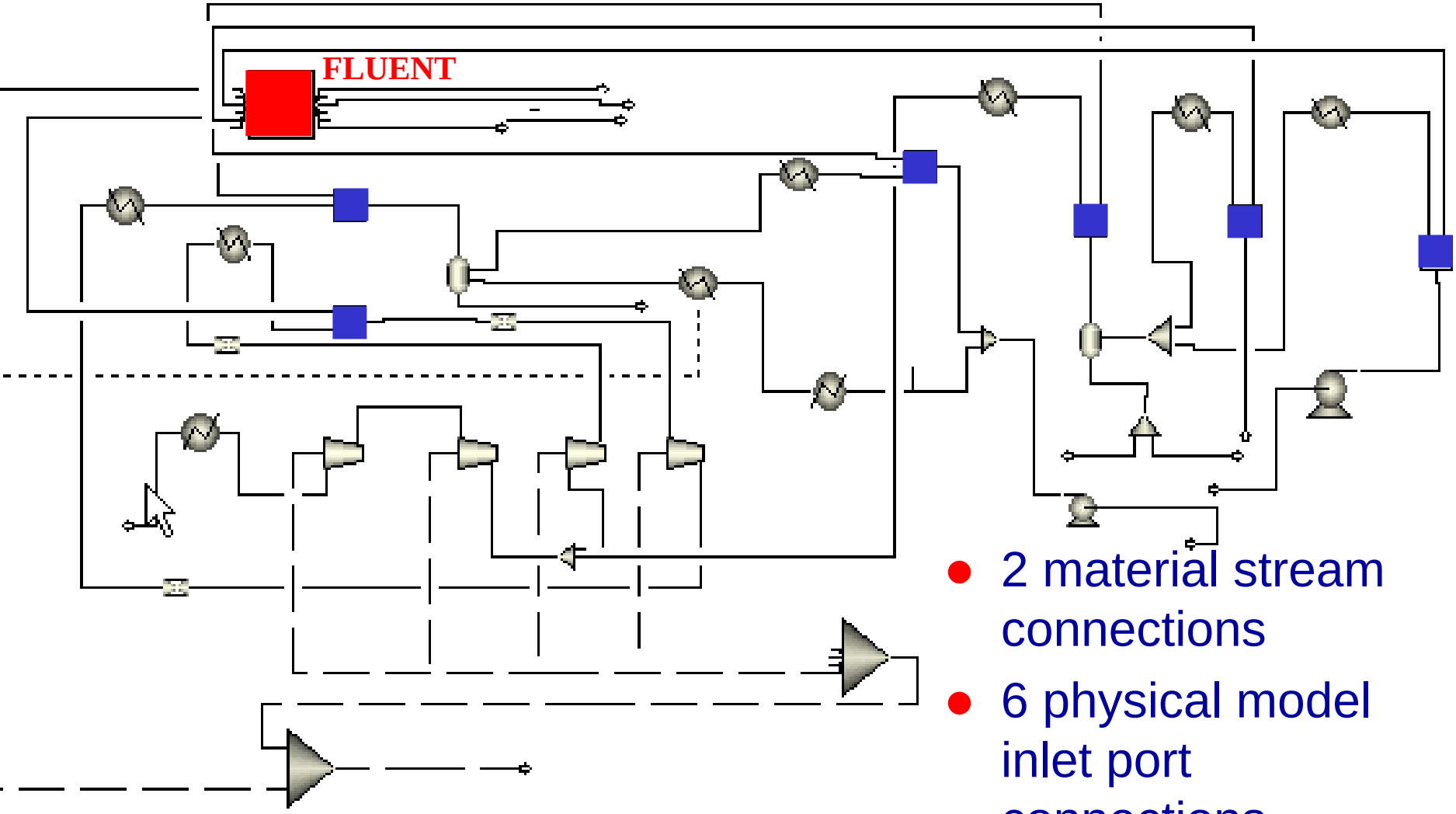
Case 2: CFD-Aspen Coupling

Cycle Construction



Case 2: CFD-Aspen Coupling

Instantiation and Block Arrangement

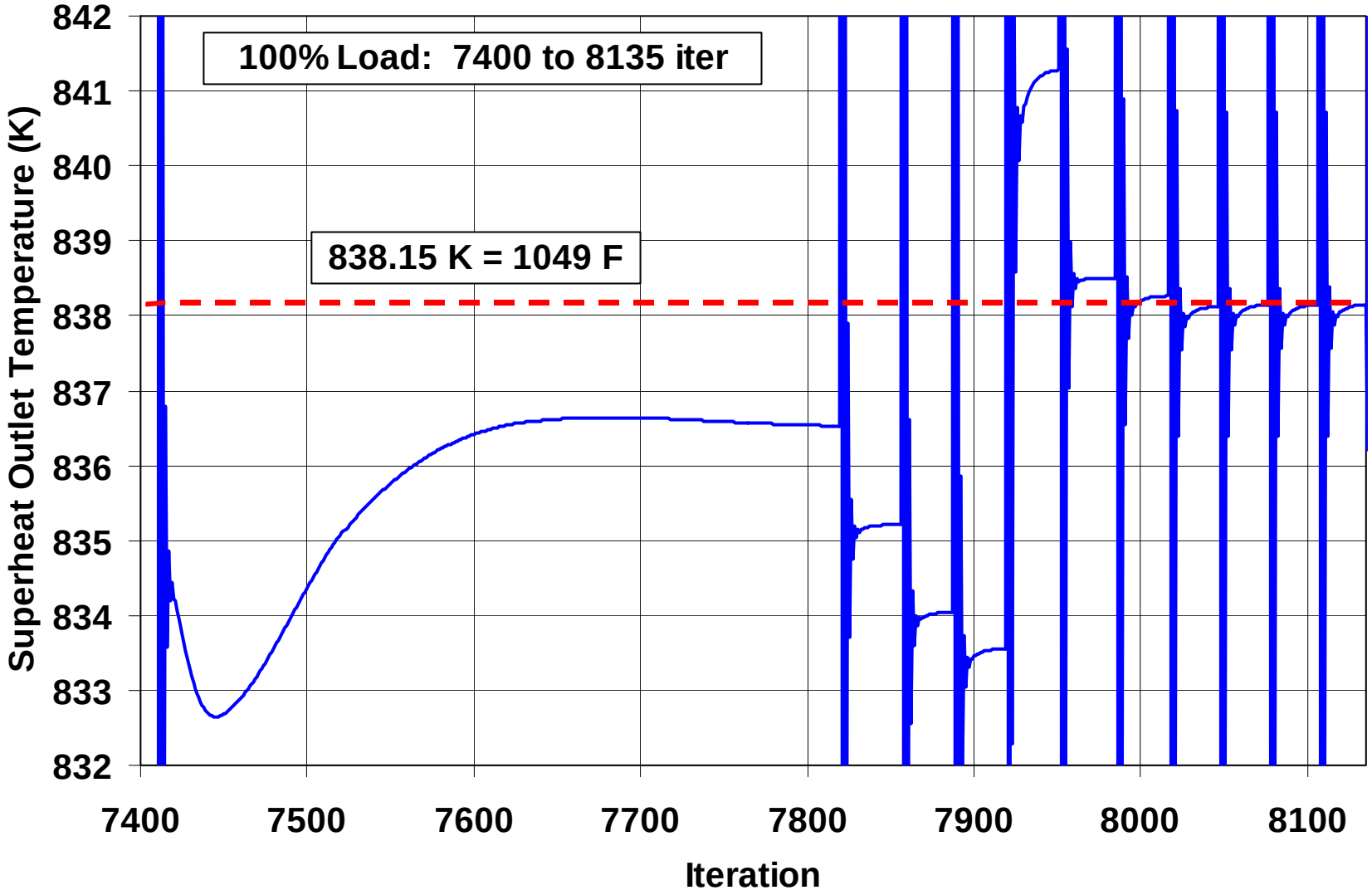


- 2 material stream connections
- 6 physical model inlet port connections

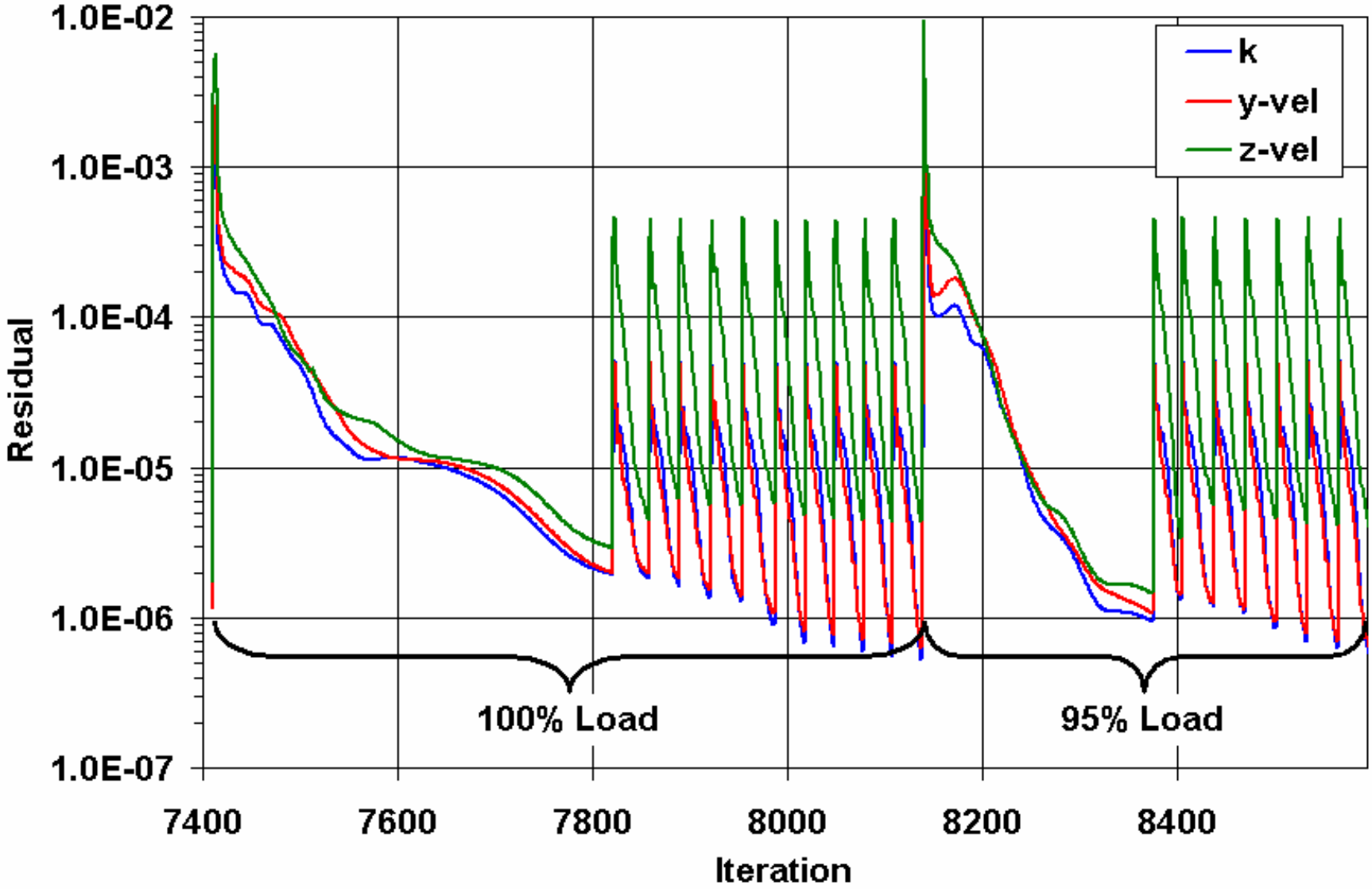
Case 2: CFD-Aspen Coupling
Solution Approach

- 9 tube banks in HRSG collapsed to 6 HX blocks on flowsheet
- Based on control strategy for “once-through” HRSGs:
  - design spec based on Broyden method
  - HP flow rate manipulated to achieve desired SH outlet temperature
- Feedwater flow rate adjusted through “balance block” to achieve circulation mass balance around LP drum
- Tube bank outlet CO variables
  - 6 x 4 = 24 variables (T, p, mass flow rate, q)
  - 12 calculator tear variables [2 per HX block in form of (T,p) or (p,q)]

Case 2: CFD-Aspen Coupling
Convergence History

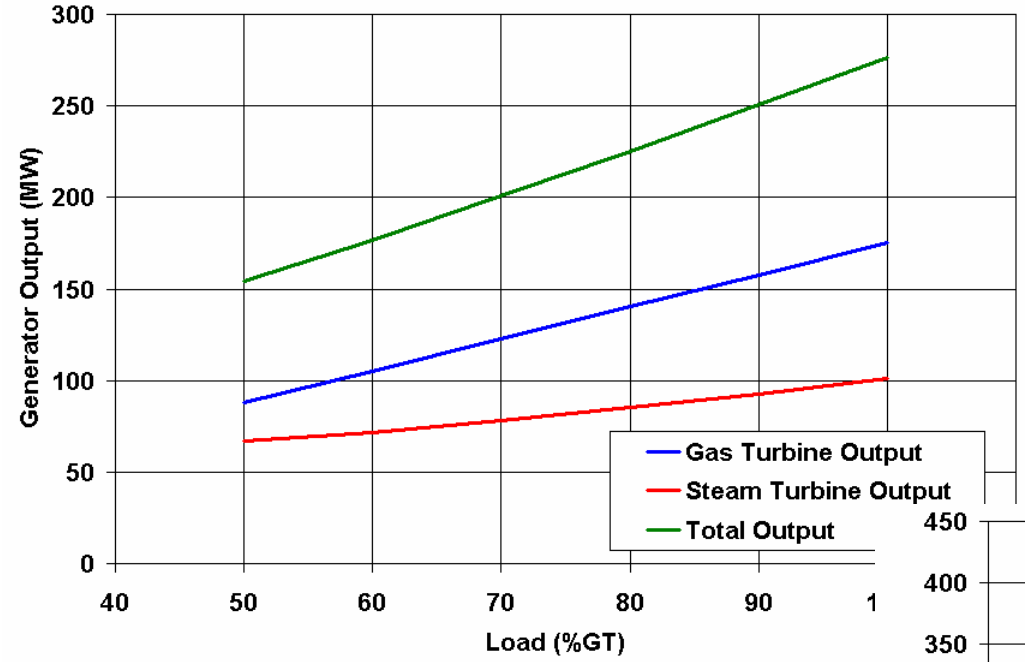


Case 2: CFD-Aspen Coupling
Residual Traces

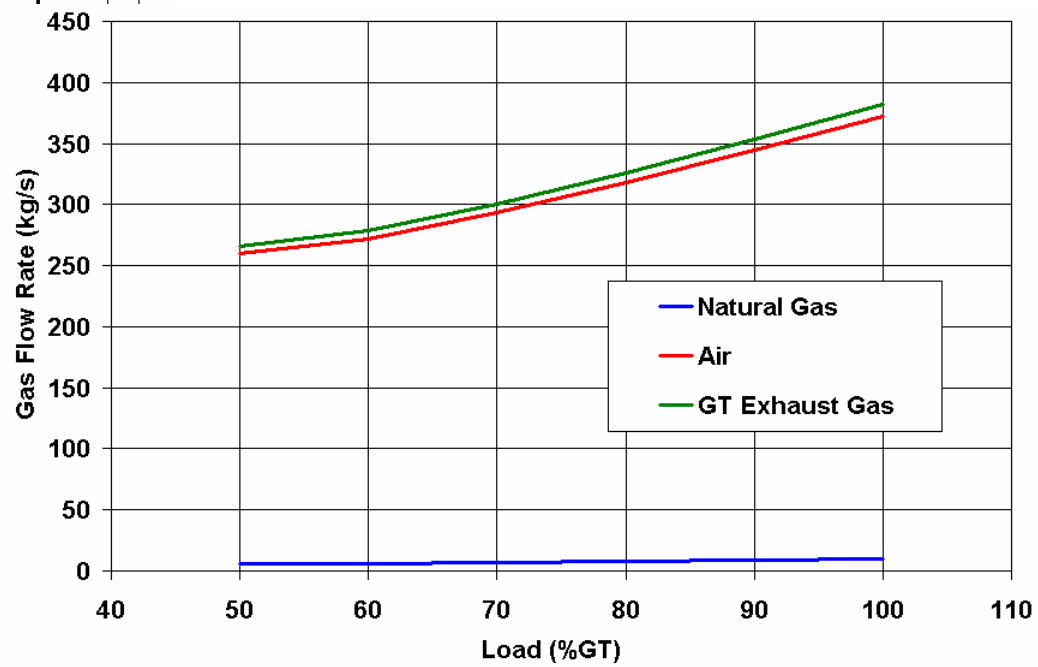


Case 2: CFD-Aspen Coupling

Final Results - MW and Flow Rates



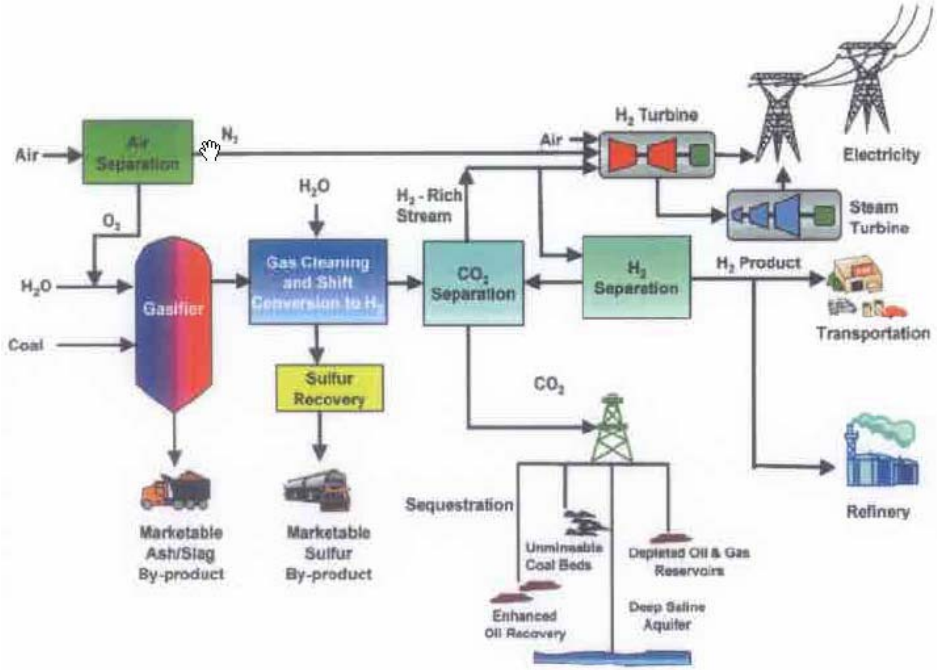
- Aspen Plus on PC
- FLUENT running on LINUX over ALSTOM local area network (LAN)



- 11 load points over range from 100% to 50% load (%GT)

Demonstration Case 3
FutureGen Cycle

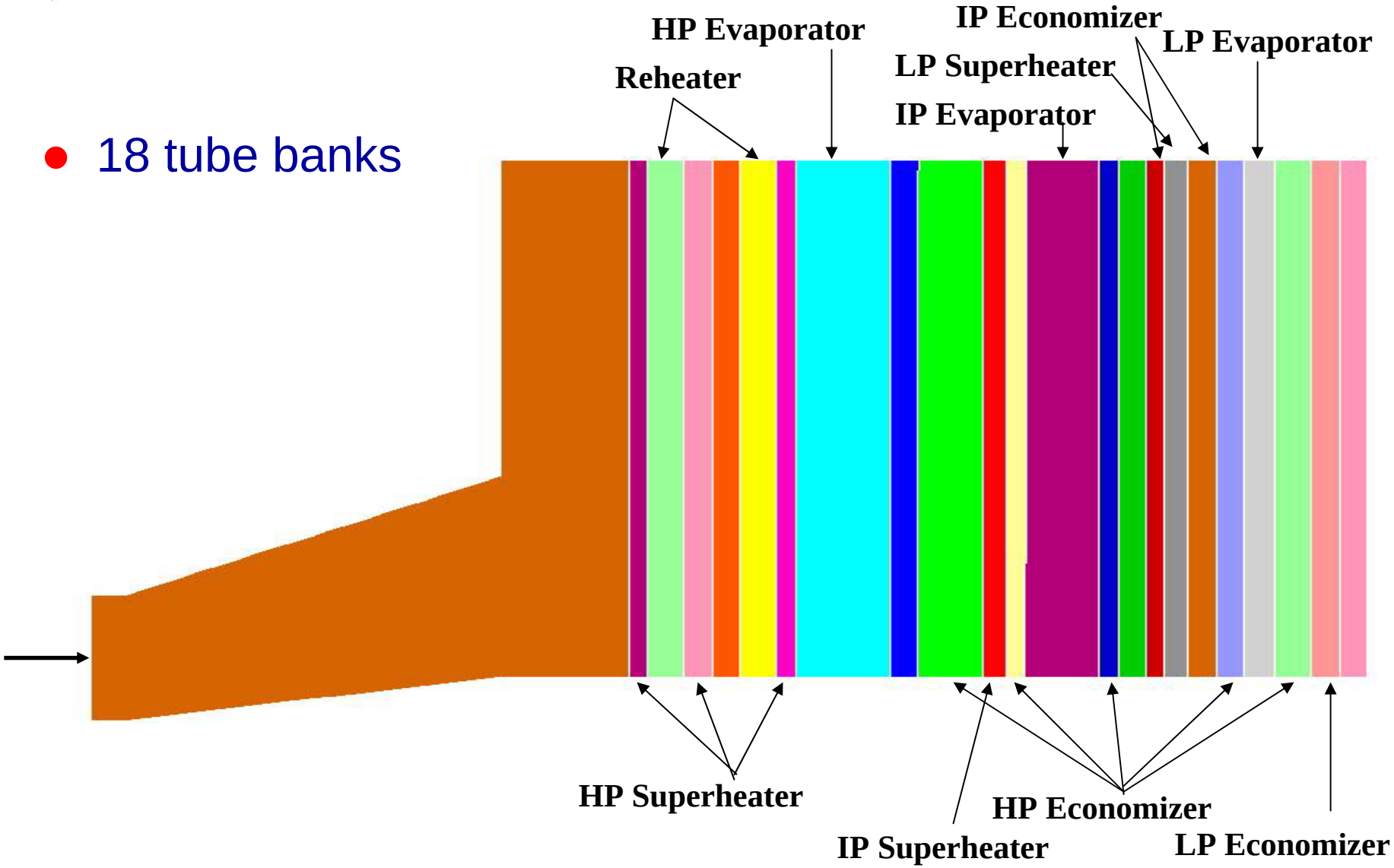
- FutureGen Cycle
  - 250 MWe IGCC
  - gasifier
  - CO_2 capture
  - gas turbine burning H_2-enriched syngas
  - pressure-swing absorption (PSA)
  - air separation unit (ASU)
  - 3-pressure heat recovery steam generator (HRSG)
  - acid-gas cleanup



Case 3: CFD-Aspen Coupling

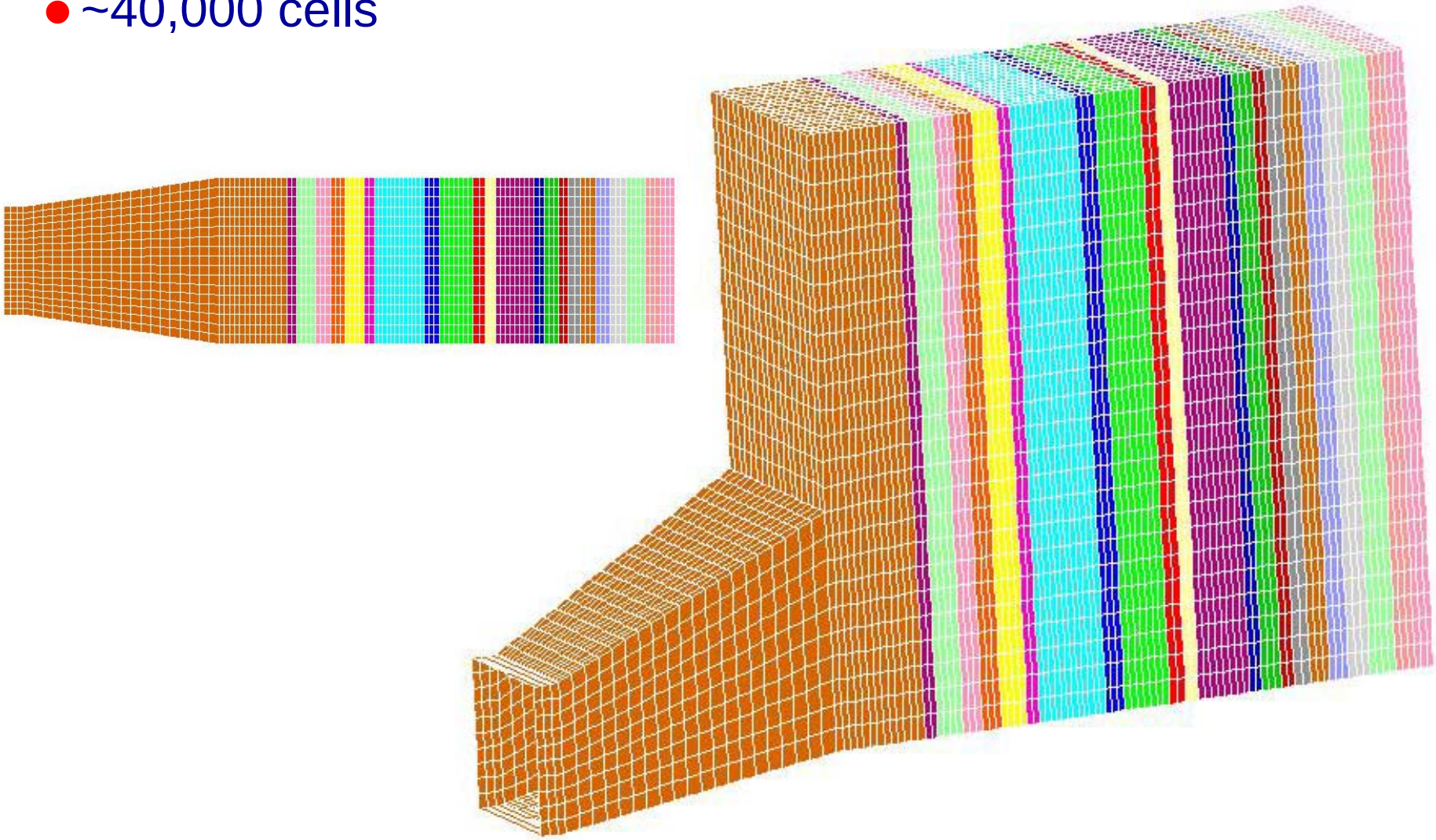
HRSG Geometry (Elongated View)

- 18 tube banks



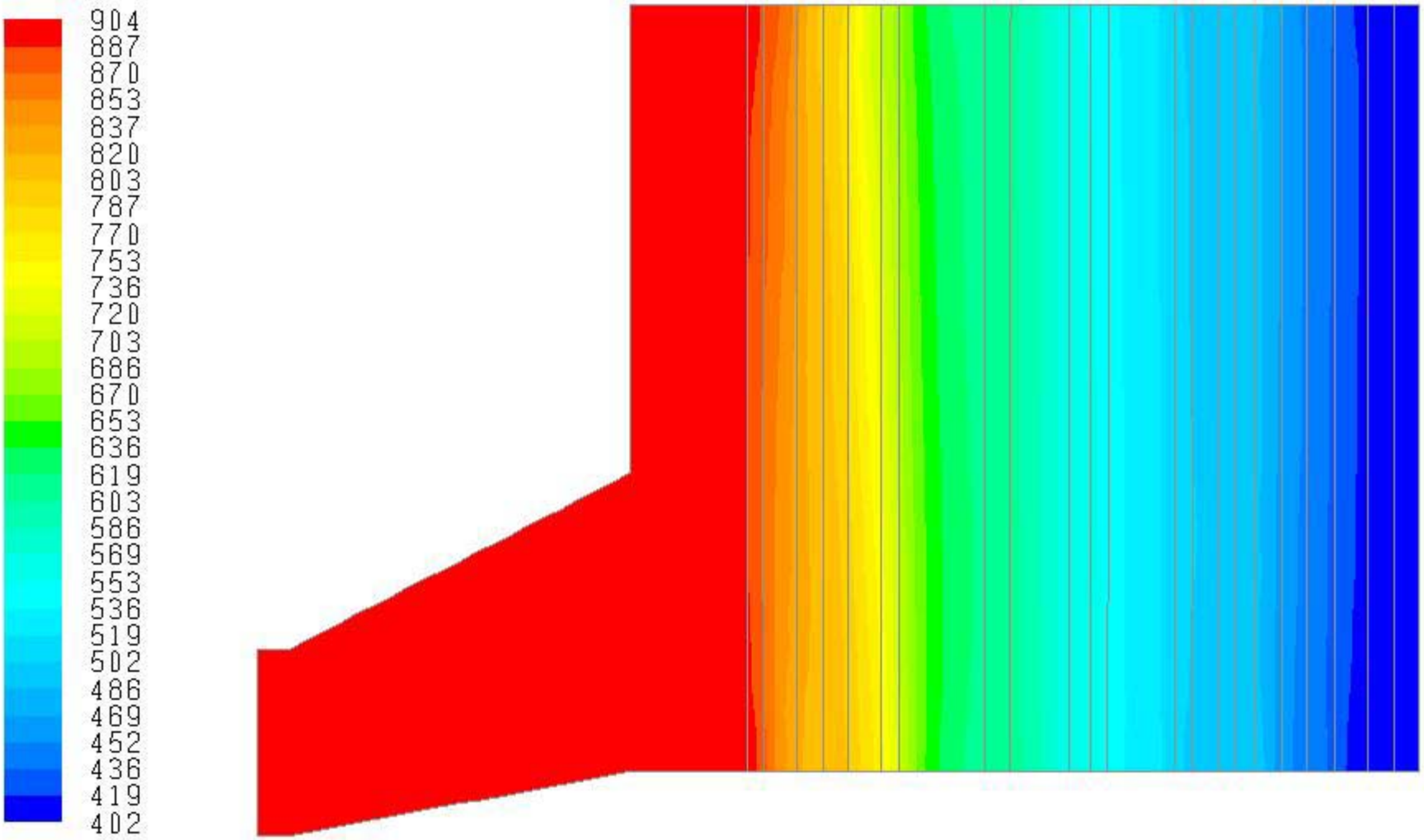
Case 3: CFD-Aspen Coupling
HRSG Geometry and Grid

- ~40,000 cells

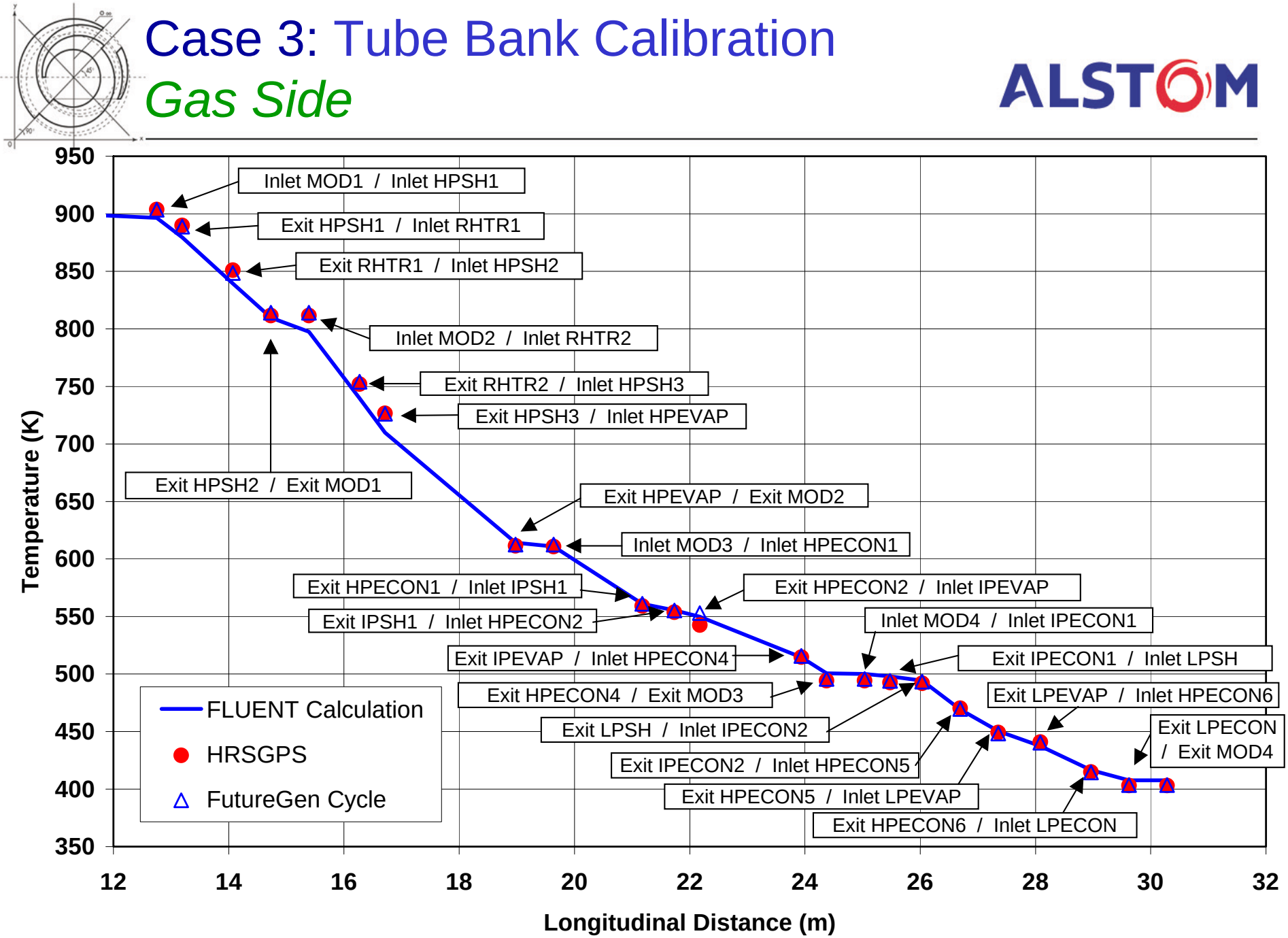


Case 3: CFD-Aspen Coupling
Temperature Contours (Midplane)

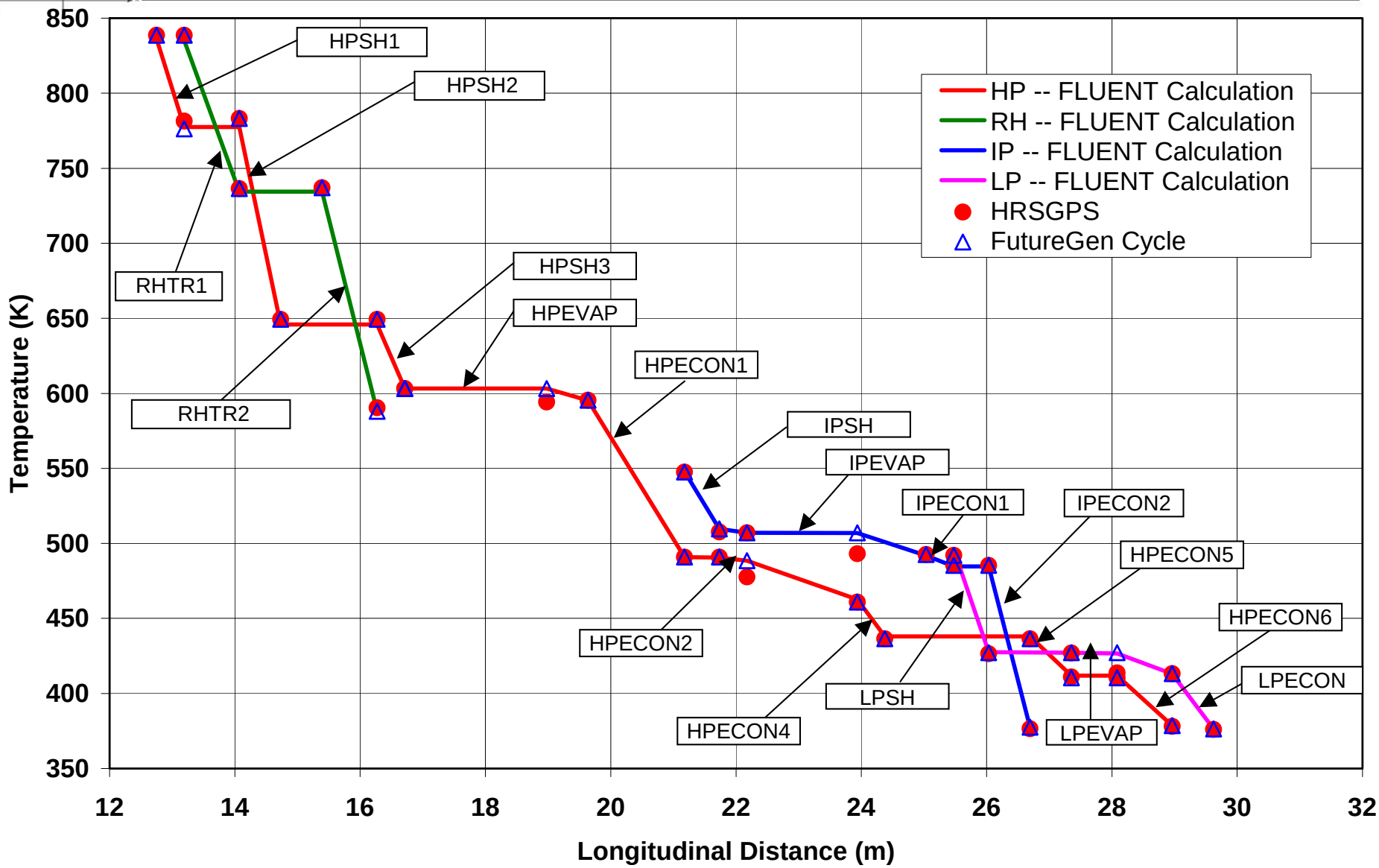
Temperature (K)



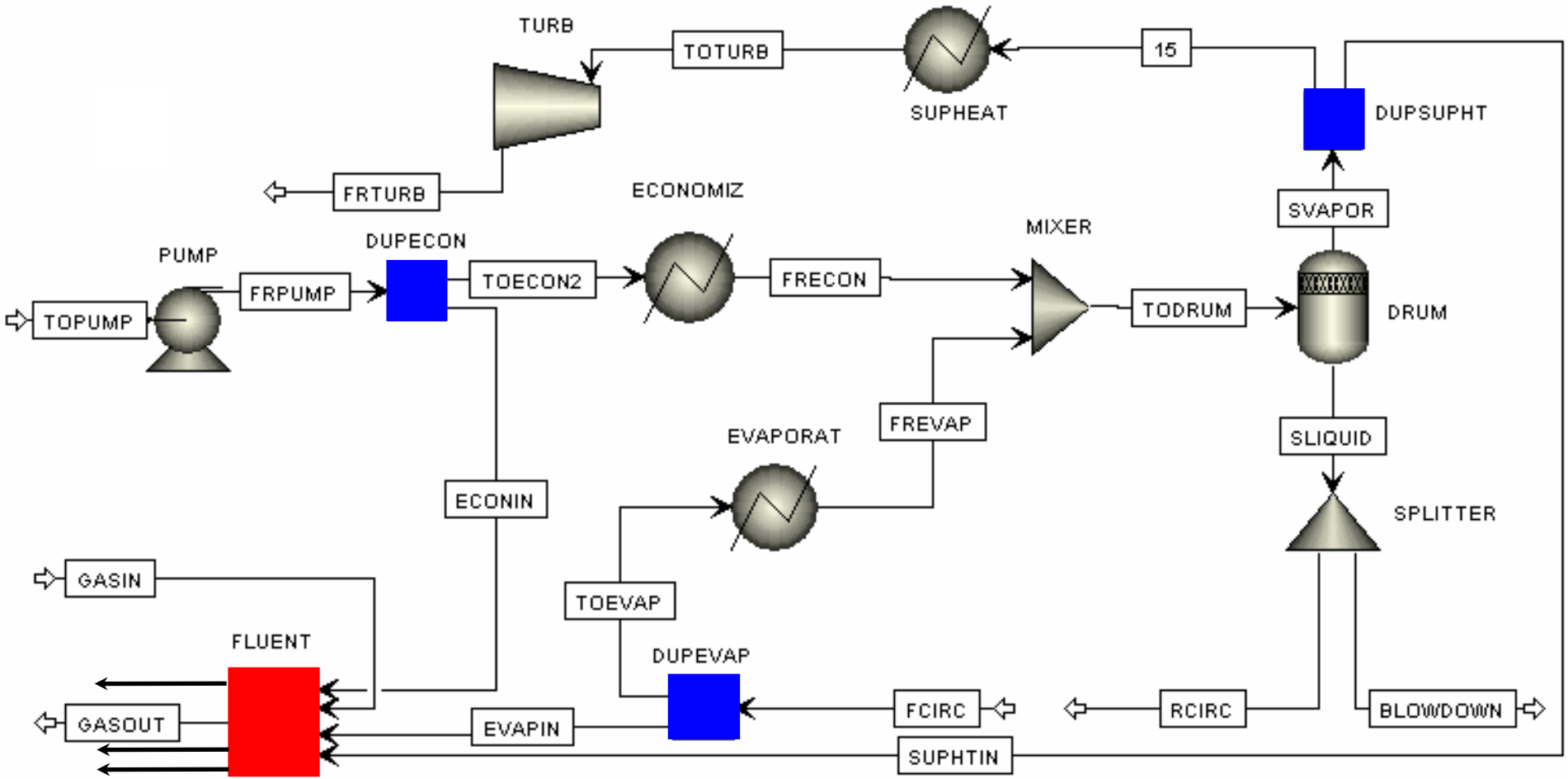
Case 3: Tube Bank Calibration
Gas Side



Case 3: Tube Bank Calibration
Coolant Side



Case 3: CFD-Aspen Coupling
Solution Concept

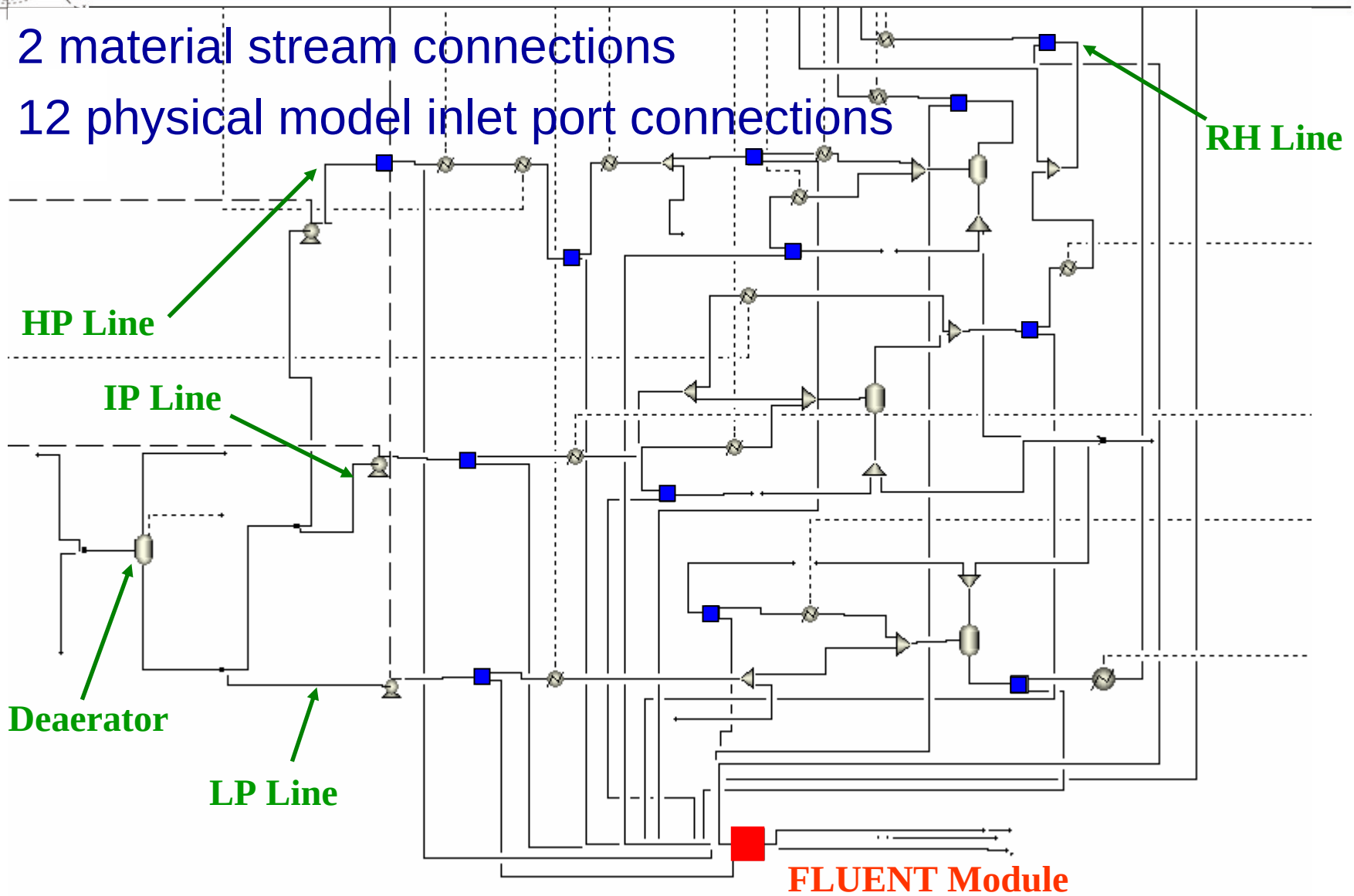


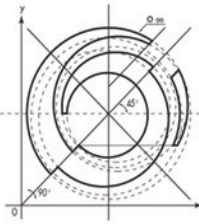
- Design spec: manipulate the economizer flow rate until the circulation flow rate through the evaporator is balanced

Case 3: CFD-Aspen Coupling

Instantiation and Block Arrangement

- 2 material stream connections
- 12 physical model inlet port connections



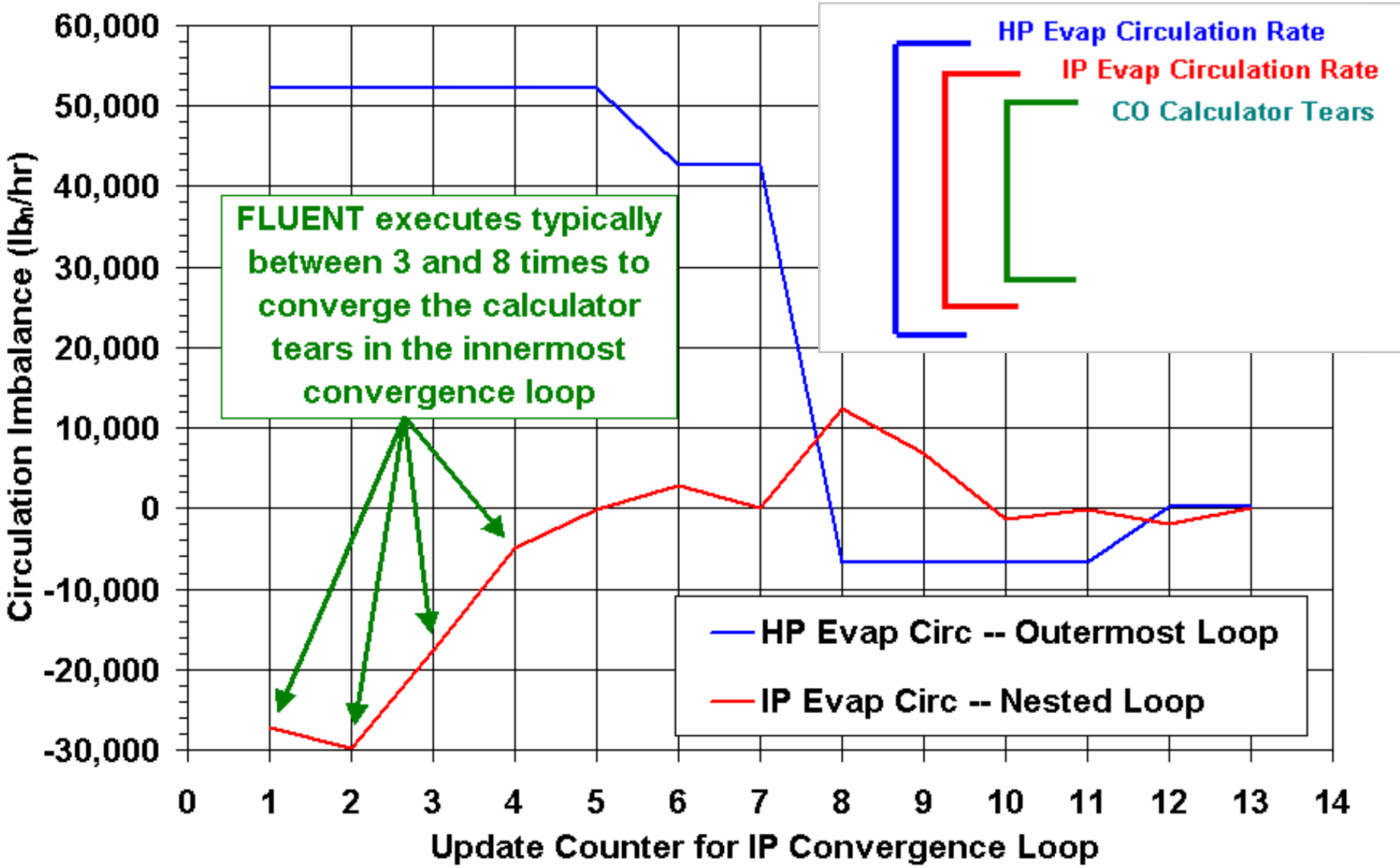


Case 3: CFD-Aspen Coupling
Solution Approach

ALSTOM

- 18 tube banks in HRSG collapsed to 12 HX blocks on flowsheet
- Based on control strategy for HRSGs with drums:
  - recycle stream from drum to evaporator is torn
  - economizer flow rate manipulated until circulation rate through evaporator is balanced
  - design specs based on secant method
- Tube bank outlet CO variables
  - 12 x 4 = 48 variables (T, p, mass flow rate, q)
  - 24 calculator tear variables [2 per HX block in form of (T,p) or (p,q)]
  - FLUENT executed typically between 3 and 8 times to converge calculator tear variables in innermost loop

Case 3: CFD-Aspen Coupling
Sample Convergence History



Future Work
Phase II Program Recently Awarded

- Potential Future Work Scope
  - Reduced order models to speed cycle calculations
  - Coupling with advanced visualization and 3D virtual plant walk-through software
  - Parallel execution of flowsheet sections
  - Geometric scaling and optimization of instantiated FLUENT module
  - Extensions to EO solution methodology and dynamic simulations
  - Additional advanced cycle applications

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