Using an Operator Training Simulator in the Undergraduate Chemical Engineering Curriculum

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Outline

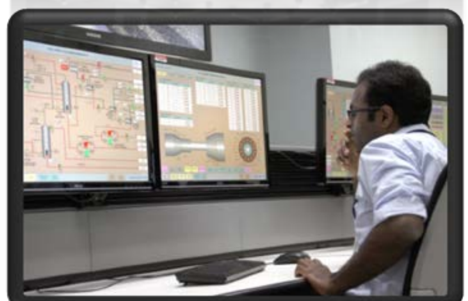
- What is an Operator Training Simulator (OTS)
- Using the OTS in undergraduate education:
  - Chemical Process Simulation course
  - Process Dynamics and Control Course
- Conclusions

Operator Training Simulators

AVESTAR Center Facilities

- **Locations**
  - NETL in Morgantown, WV
  - WVU, National Research Center for Coal & Energy
- **Facilities**
  - OTS Room: Control Room
    - Divider for 2 Simulators
  - ITS Room: Plant/Field
  - Local area network
- **Training Systems**
  - IGCC OTS
    - 8 Operator Stations
    - 2 Instructor Stations
    - 2 Engineering Stations
  - IGCC ITS
    - 2 Field Stations
    - 1 Instructor Station

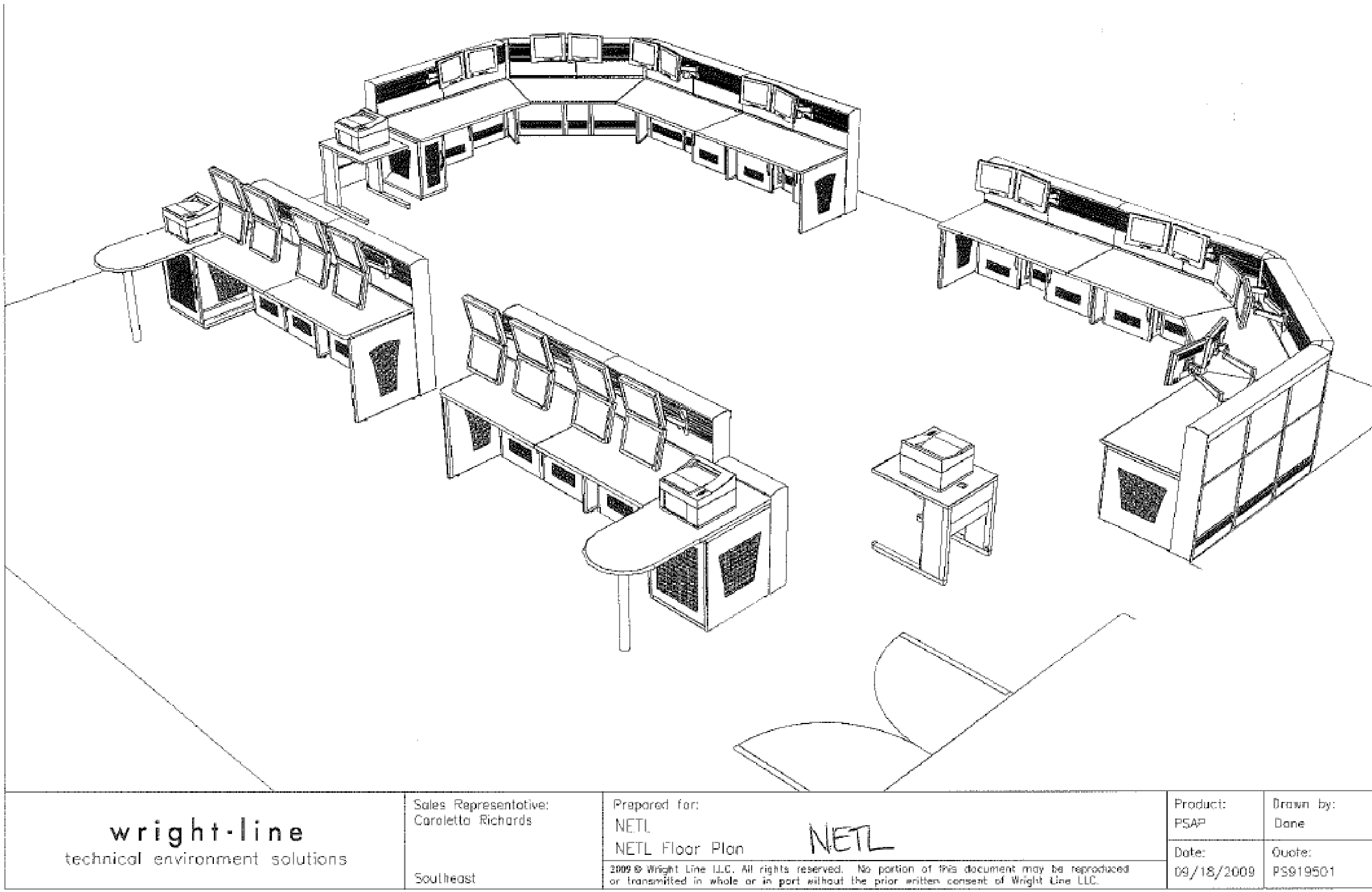
AVESTAR Center at NETL



AVESTAR Center at WVU

AVESTAR™

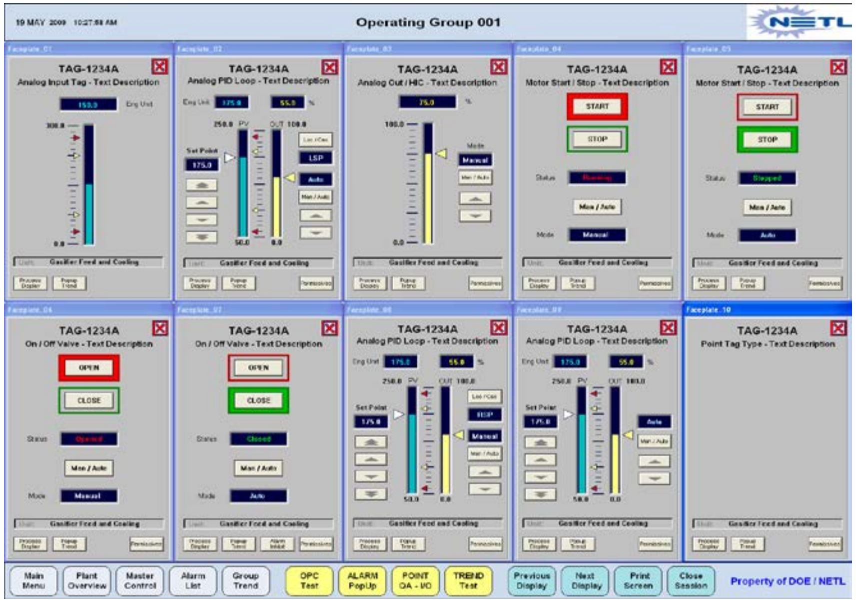
Operator Training Simulators

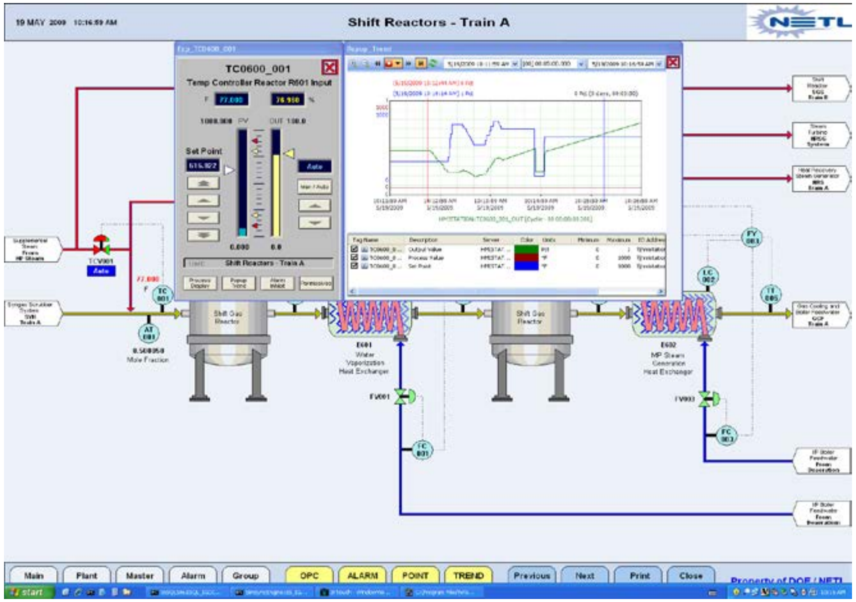


Operator Training Simulators

Operator Training Simulators

HMI Displays for Alarms and Trending





(Courtesy of Invensys Operations Management)

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Chemical Process Simulation course

Student exposure in Simulation Course

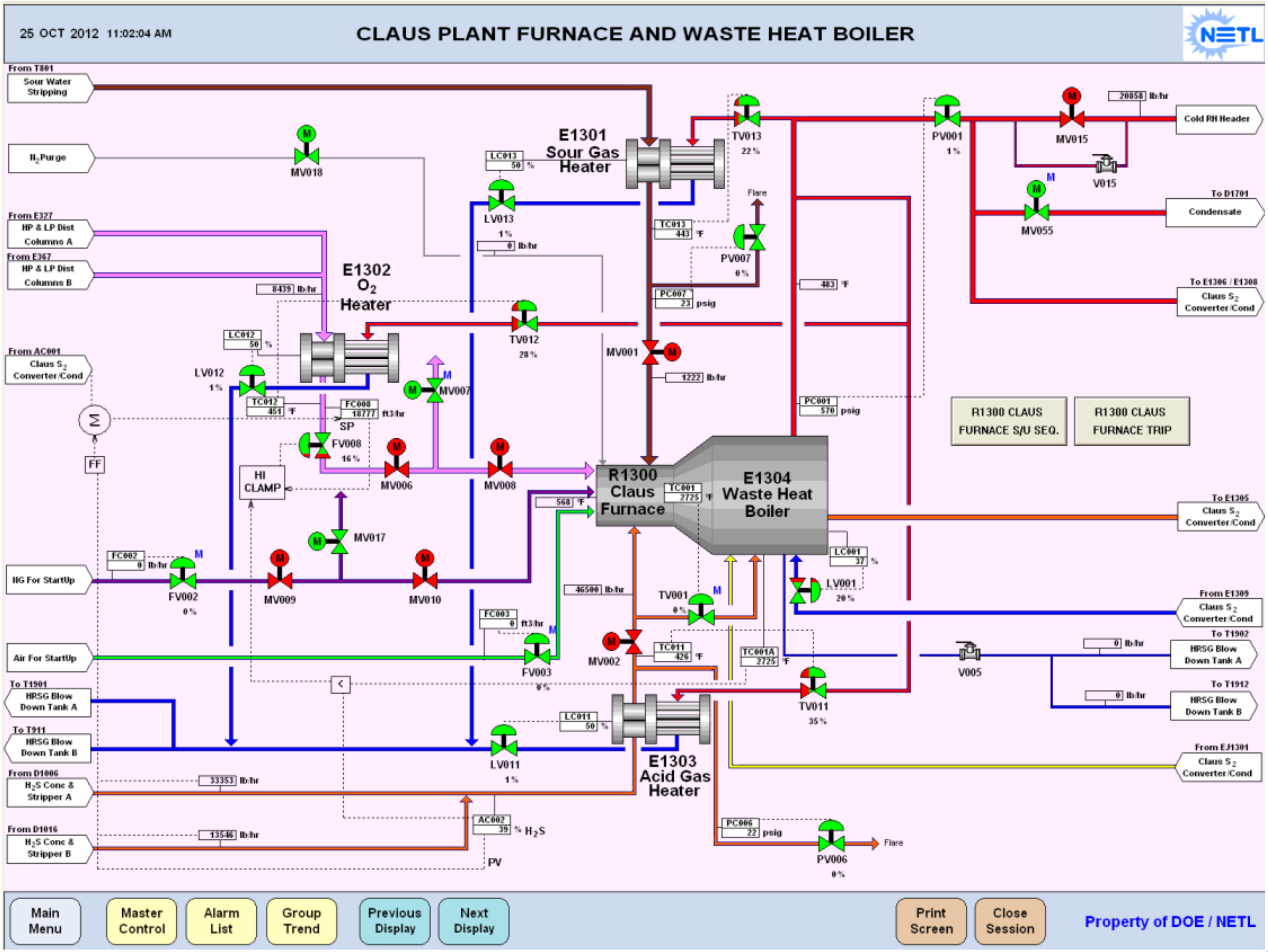
- 1st Lecture – discussed IGCC plant overview, key features of the OTS including:
  - navigation between HMI screens and plant overview screens
  - trending features
  - control panels and control operation
  - digital logic and permissives
  - alarms
  - links to dynamic model through data historian and the emulation of the plant

Chemical Process Simulation course

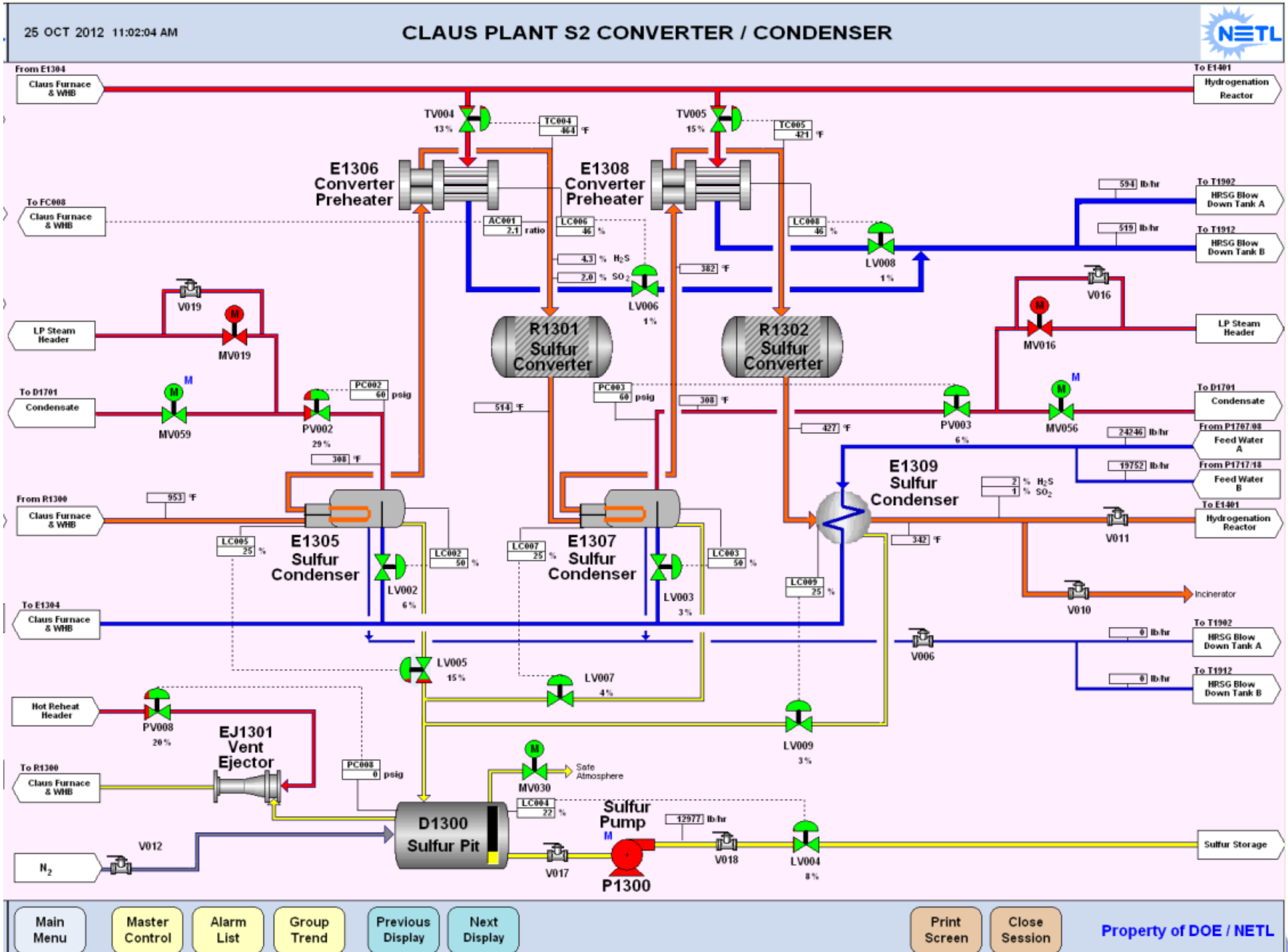
Student exposure in Simulation Course

- Simulation course ran for 6-8 weeks prior to a 1-day work session by the students starting up the Claus unit. Key features covered in the 1-day session were:
  - Exposure to start-up procedures
  - Equipment preparation
  - Digital logic (switches and permissives)
  - Timing of actions
  - Different control strategies
  - Physical interpretation (analysis) of process changes

Chemical Process Simulation course



Chemical Process Simulation course



Chemical Process Simulation course

Not all valves in P&ID are on HMI – remote function (RF) valves located in plant and are manually operated

Student exposure to OTS in Simulation Course

Example 1 - Start up procedures

Area 1300				
272.	VERIFY that BFW from Area 1700 is flowing to E1309 by OPENING RF1700_033 (E1309 will be water filled).	1300-SRU-001 1700-BWT-003 1700-BWT-004	Remote Function	A1700_Feedwater_A Check with A1700 for water availability
273.	VERIFY E1304 drain valve RF005 is closed.	1300-SRU-001	Remote Function	A1302_Furnace_WHB
274.	Place LC001 in MANUAL with an output of 10%.	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
275.	When E1304 level is approximately 30%, place LC001 in AUTOwith a setpoint of 35%.	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
276.	VERIFY E1305 drain valve RF006 is closed.	1300-SRU-002	Remote Function	A1303_First_Sulf_Cond
277.	Place LC002 in MANUAL with an output of 10%.	1300-SRU-002	Claus Plant S2 Converter/Condenser	
278.	When E1305 level is approximately 50%, place LC002 in AUTOwith a setpoint of 50%.	1300-SRU-002	Claus Plant S2 Converter/Condenser	
279.	VERIFY E1307 drain valve RF008 is closed.	1300-SRU-002	Remote Function	A1304_Second_Sulf_Cond
280.	Place LC003 in MANUAL with an output of 75%.	1300-SRU-002	Claus Plant S2 Converter/Condenser	
281.	When E1307 level is approximately 50%, place LC003 in AUTOwith a setpoint of 50%.	1300-SRU-002	Claus Plant S2 Converter/Condenser	

Chemical Process Simulation course

Student exposure to OTS in Simulation Course

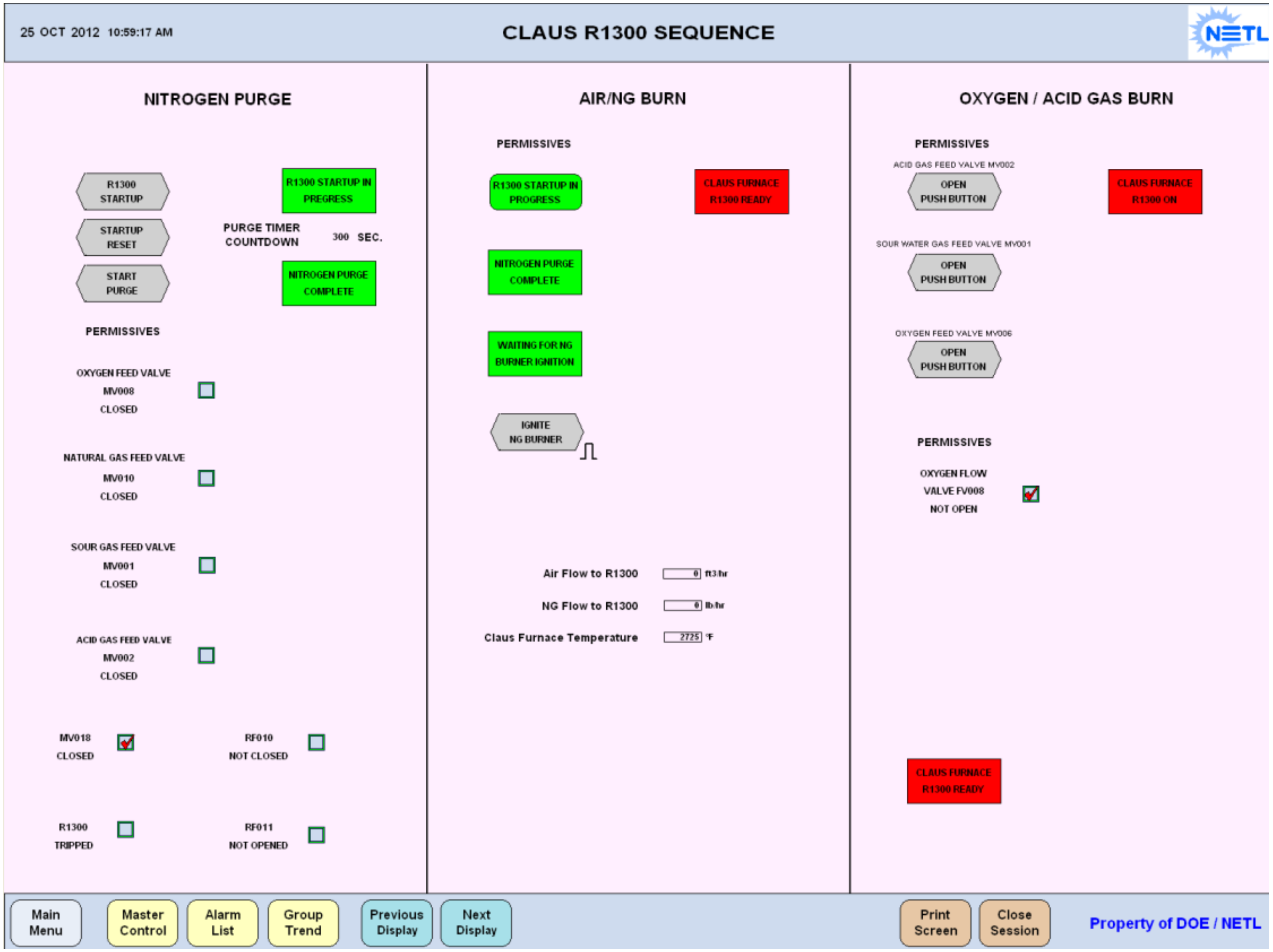
Example 2 – Digital logic and permissives

24.3.3	**SRU S/U PREPARATION SEQUENCE** - All steps mentioned in this sequence pertain to Area 1300			
293.	OPEN RF010 valve to the Incinerator and block the flow to the TGTU by closing the RF011 located at the outlet of the third sulfur condenser E1309.	1300-SRU-002	Remote Function	A1305_Third_Sulf_Cond FS This ensures gas flow is set to go to the incinerator and not to the hydrogenation unit.
294.	Make sure all the motor valves are in AUTO mode on both Claus Furnace 2 WHB.		Claus Furnace and Waste Heat Boiler Claus Plant S2 Converter/Condenser	MV001, MV002, MV006, MV007, MV008, MV009, MV010, MV015, MV016, MV017, MV018, MV019 & MV030
295.	Make sure all the Permissive are met to start the R1300. PRESS the R1300 STARTUP RESET Button.	1300-SRU-001	Claus Plant S2 Converter/Condenser	
296.	Initiate the Claus Furnace Purge and Heat up by pressing the R1300 STARTUP Button.		Claus R1300 Sequence	N2 Purge Valve MV018 should open to purge with N2 for 5 minutes.
297.	Once the MV018 purge valve opens, PRESS the TRIPOVERRIDE button to reset the R1300 trip signal.	1300-SRU-001	Claus Trip Points	
298.	VERIFY that MV017 Closes and that the WAITING FOR NG BURNER IGNITION indication turns red.		Claus R1300 Sequence	
299.	Once the Purge is complete, PRESS the NG BURNER ON button to introduce the natural gas and air into the Claus Furnace.		Claus R1300 Sequence	

Chemical Process Simulation course

Student exposure to OTS in Simulation Course

Example 2 - Digital Logic and permissives



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Objectives

- Demonstrate the real life application of the controls theory
- Show the students where their current course work fits into the real process plant
- Demonstrate the crucial role that the control system plays
- Demonstrate interactions between different equipment/systems/variables
- Provide the students with a big picture view as well as finer details as much as tractable and applicable in about 4 hours of time

The Course at a Glance

- The course focuses on dynamics and control of chemical processes. This is a senior year course for Chemical Engineering undergraduates. Currently there are 42 students in this class.
- For the undergraduates, this is the only course so far concentrating on both process dynamics and control.
- Mainly linear single input single output (SISO) systems are studied.
- Only software used in the class (of course not considering the OTS demonstrations) is Matlab/Simulink.
- This is the second year when the dynamic simulator is being used in teaching this course.

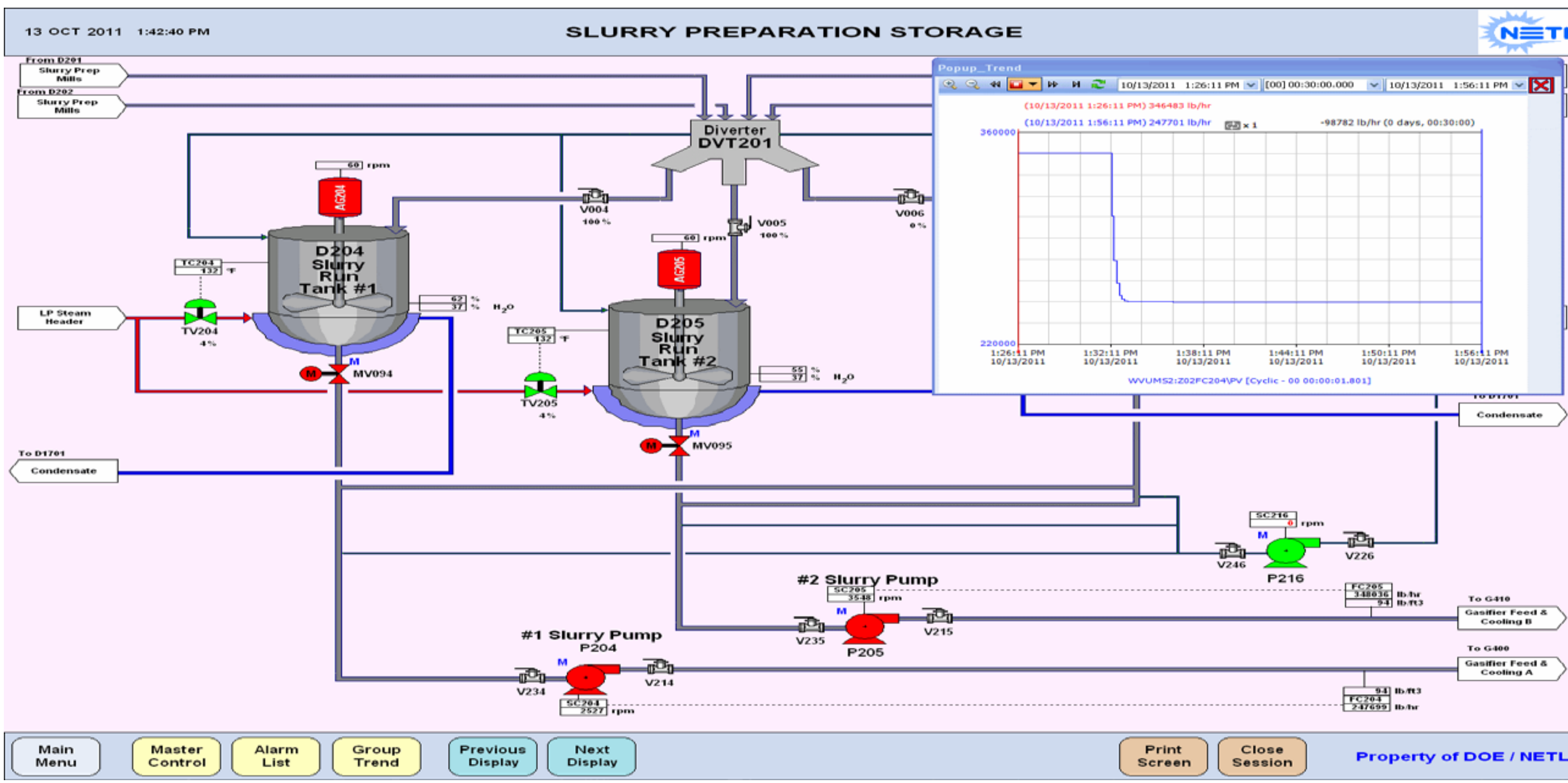
Demonstration Outlines

- The course can be broadly divided into two sections:
  - **Process dynamics**
  - **Process control**
- A number of demonstration such as development of first principles dynamic model, implementation of ideal forcing functions, Typical responses of lower and higher order processes, use and advantages/disadvantages of various control strategies such as ratio control, split-range control, cascade control, feedback-augmented feedforward control, process model identification, controller tuning, limiting gain for closed-loop stability, etc. are demonstrated
- Process Dynamics example shown here:
  - Time-delay systems
- Process Control example shown here:
  - Open-loop unstable systems

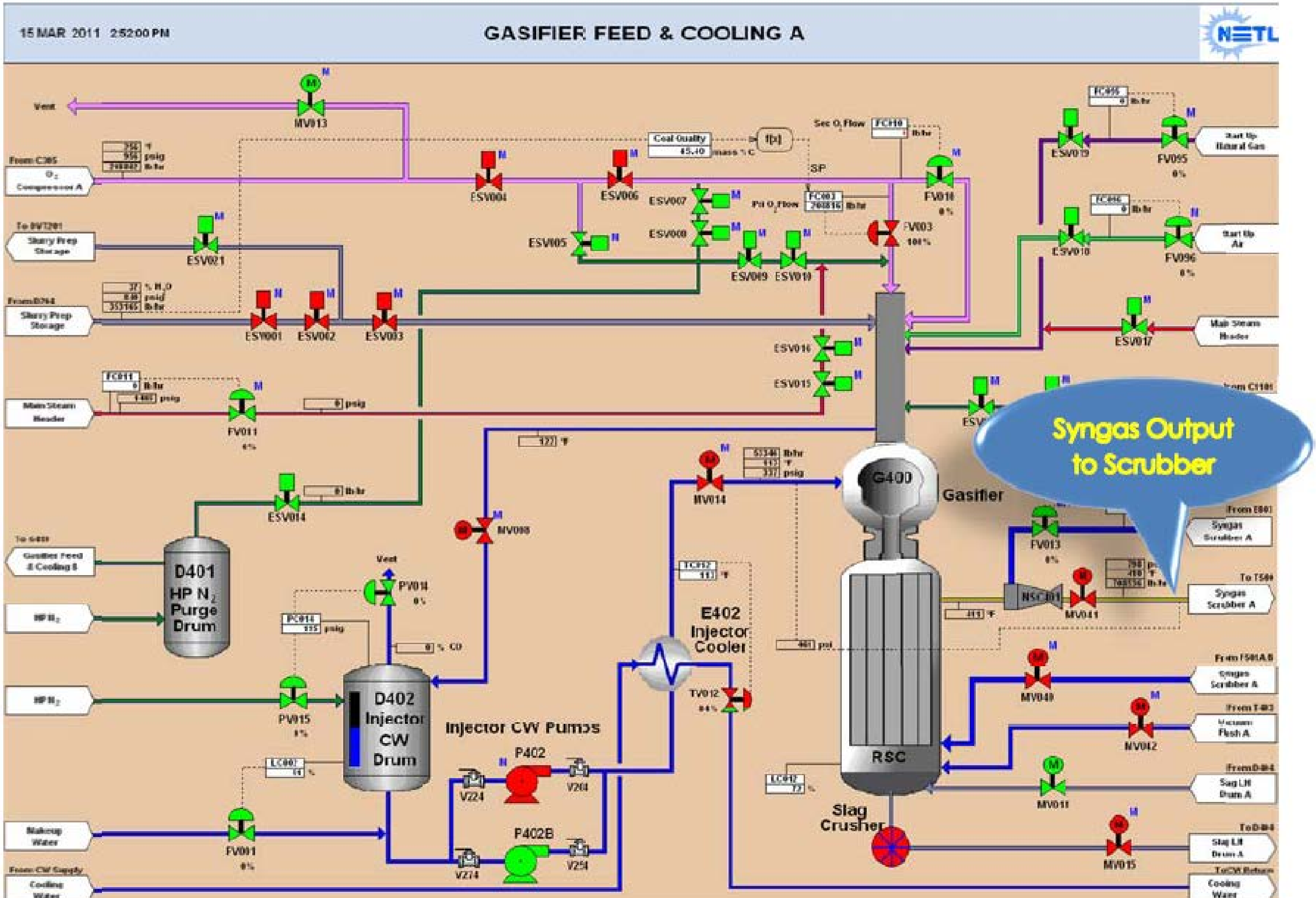
Process Dynamics Example

Time-Delay Systems

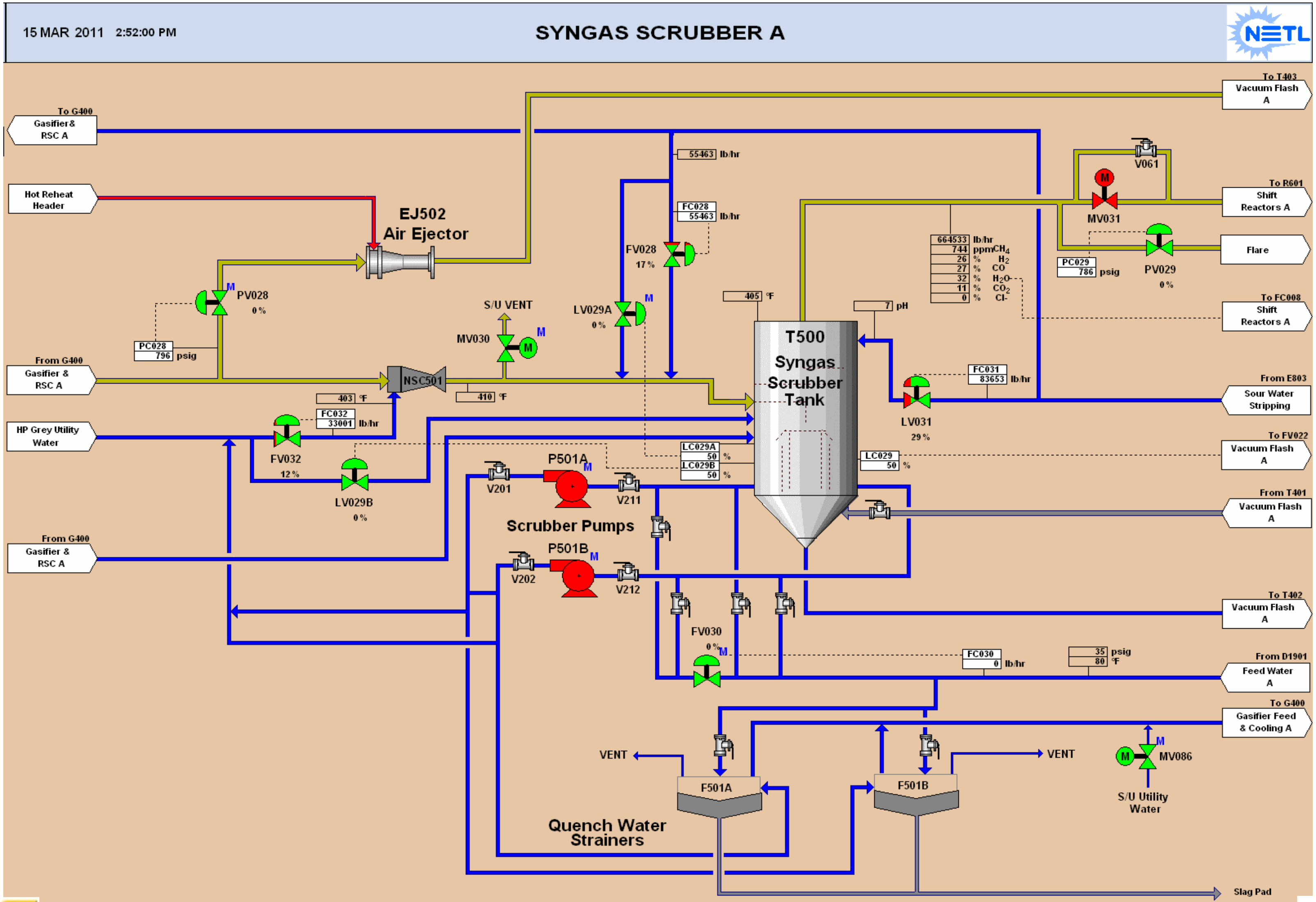
- Show how time-delay occurs in an actual plant
- Use the step response data for identifying process model
- Coal feed to the plant is step decreased
- Transient response in the CO_2 composition at the inlet of the H_2S absorber is recorded



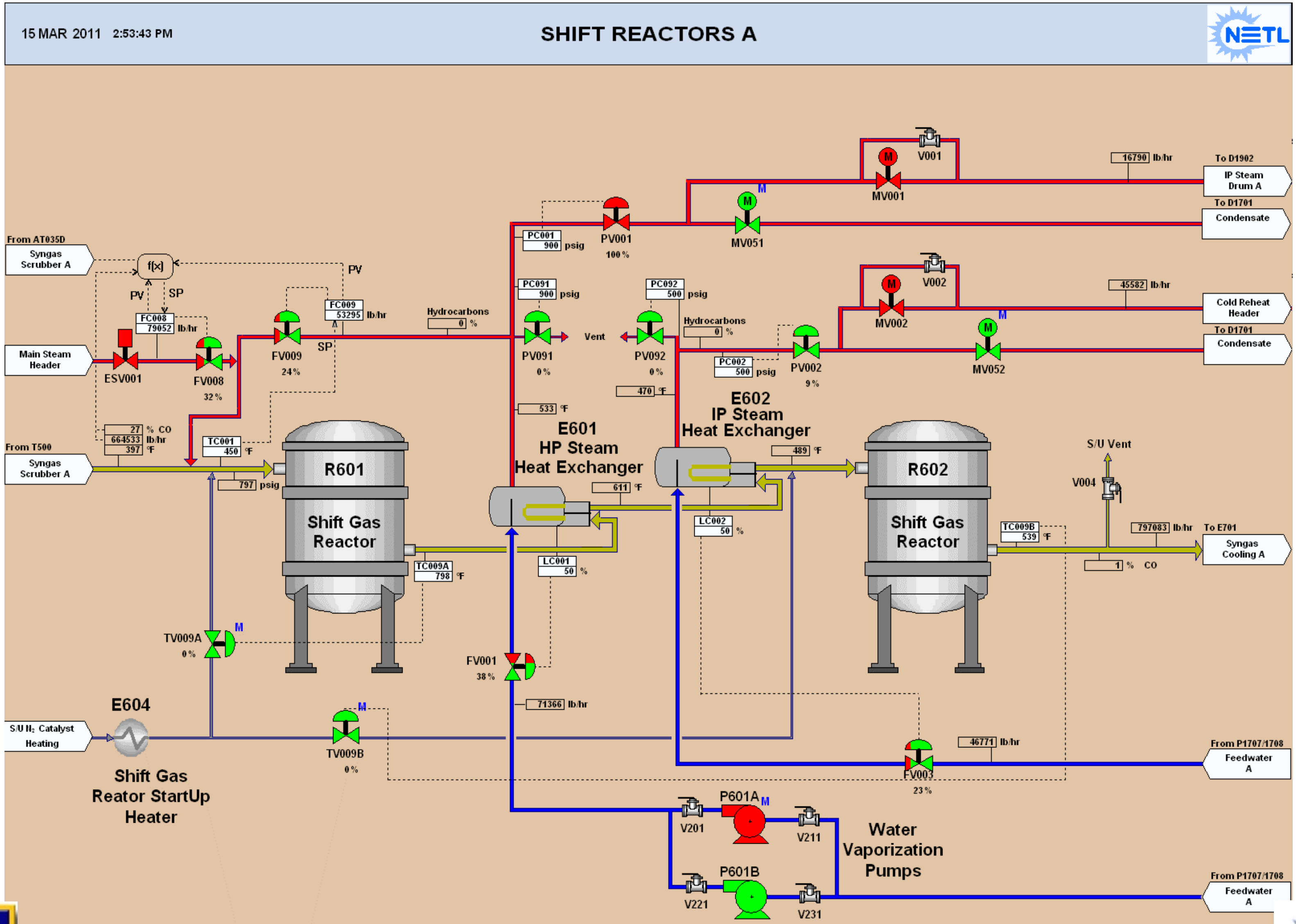
Coal-feed/syngas flow path



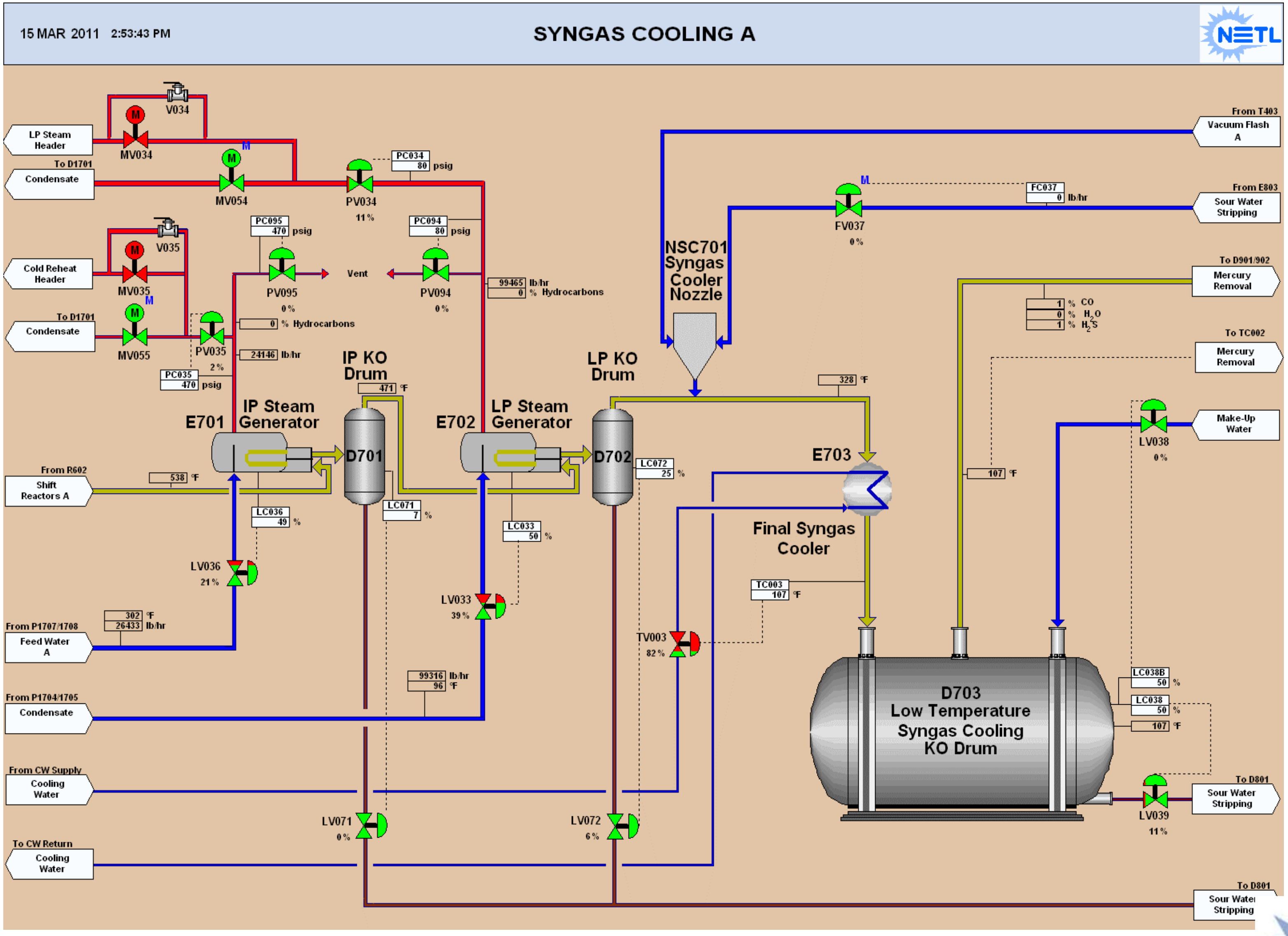
Syngas flow path



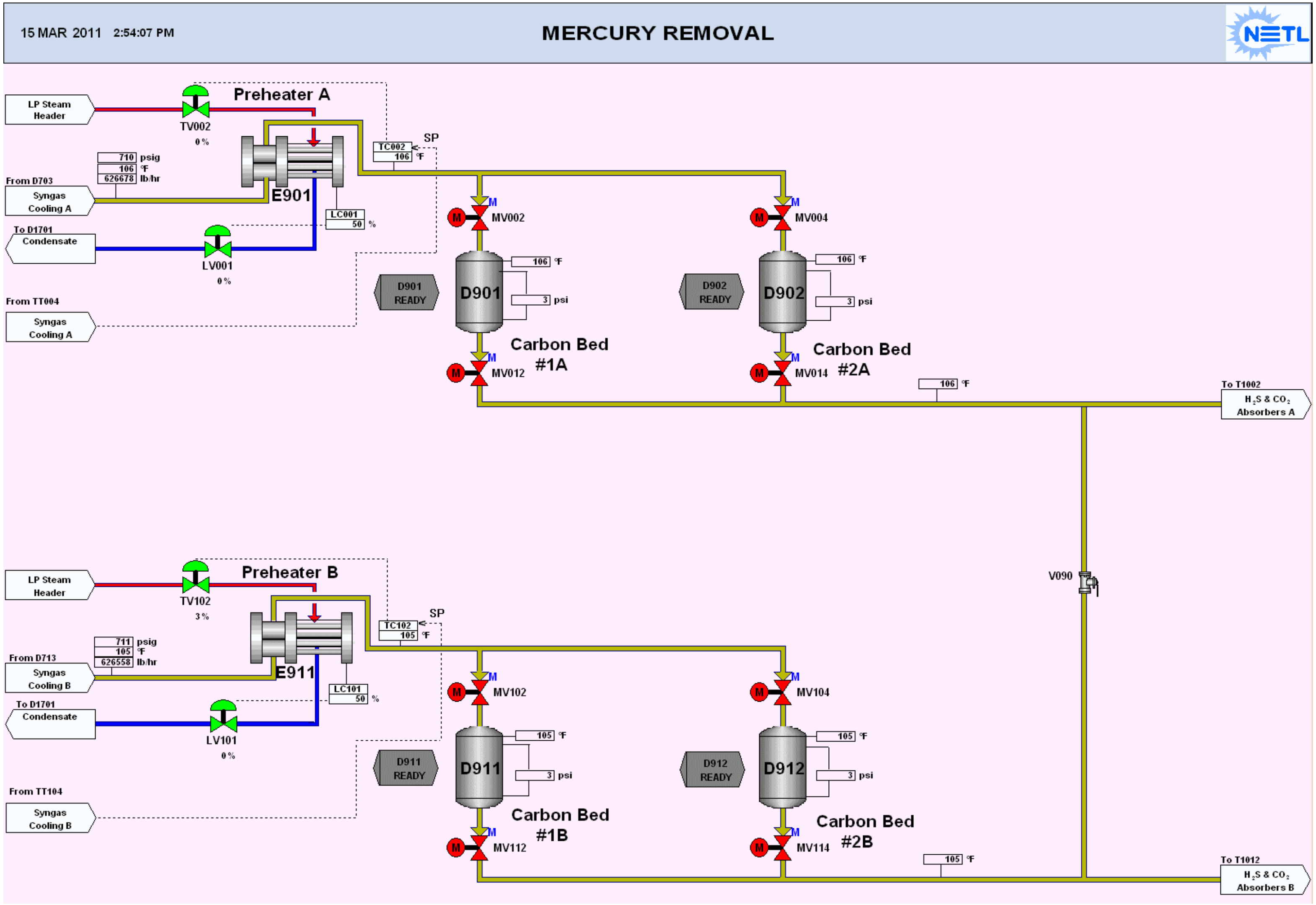
Syngas flow path



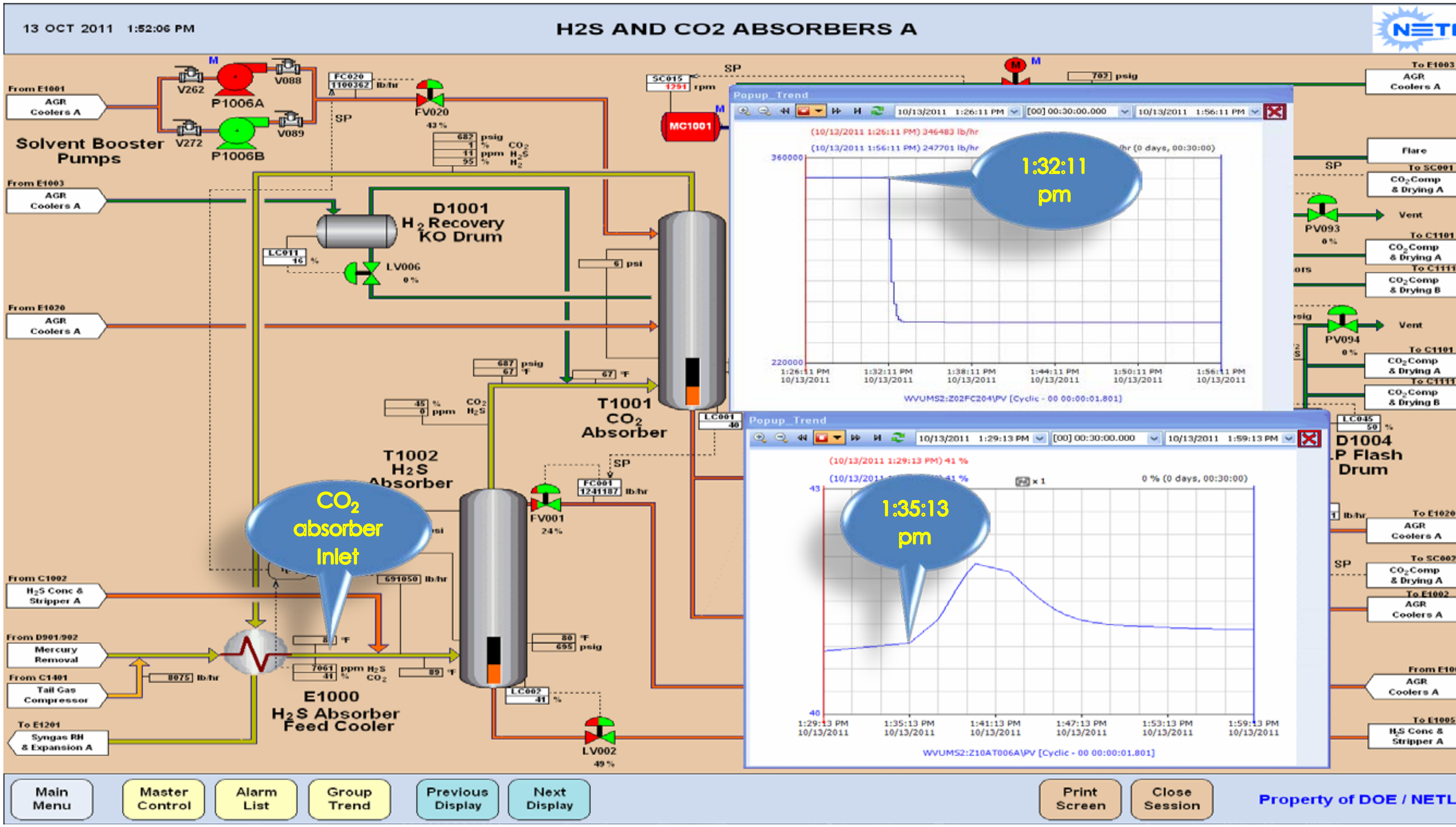
Syngas flow path



Syngas flow path



CO_2 concentration at the CO_2 absorber inlet

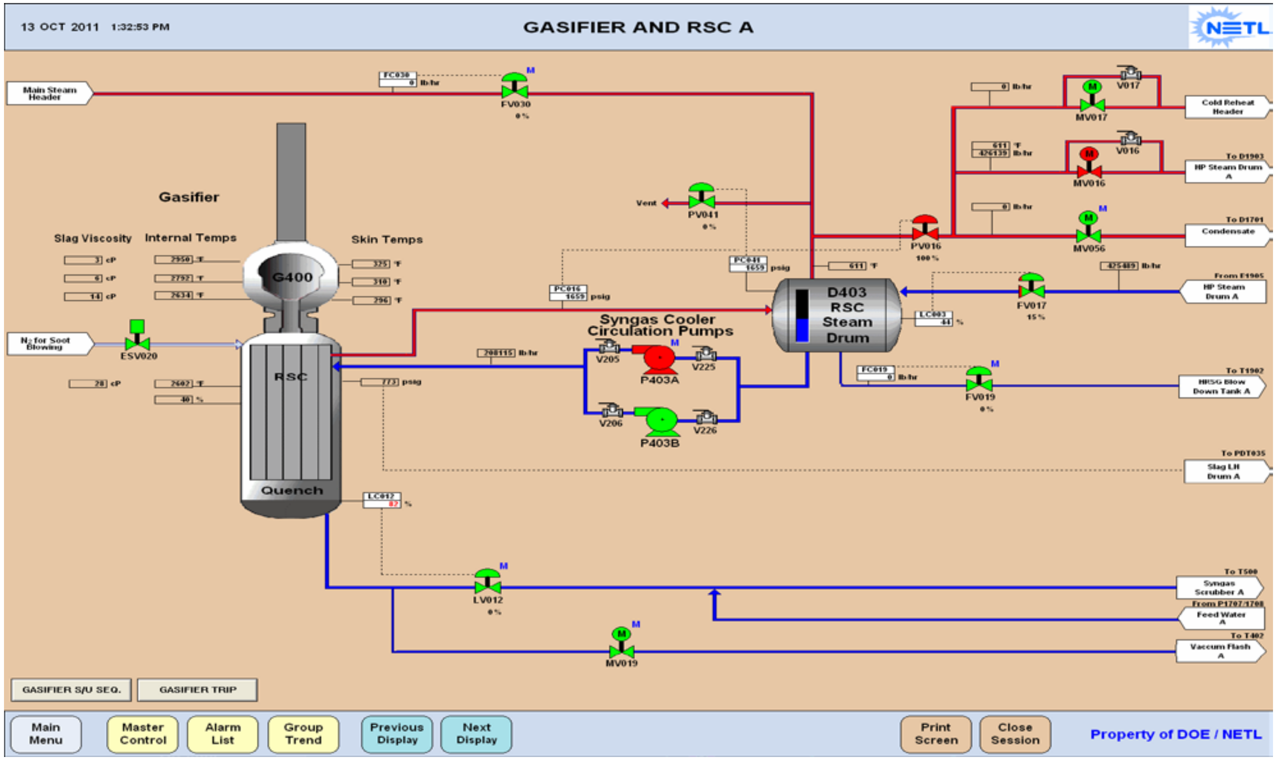


Process Control Example

Open-Loop Unstable Systems

- **Case 1**: Closed-loop system
- **Case 2**: Open-loop system, emergency controller takes over
- **Case 3**: Open-loop system, No emergency controller, plant shuts down

Demonstration example: Radiant syngas cooler (RSC) steam generator

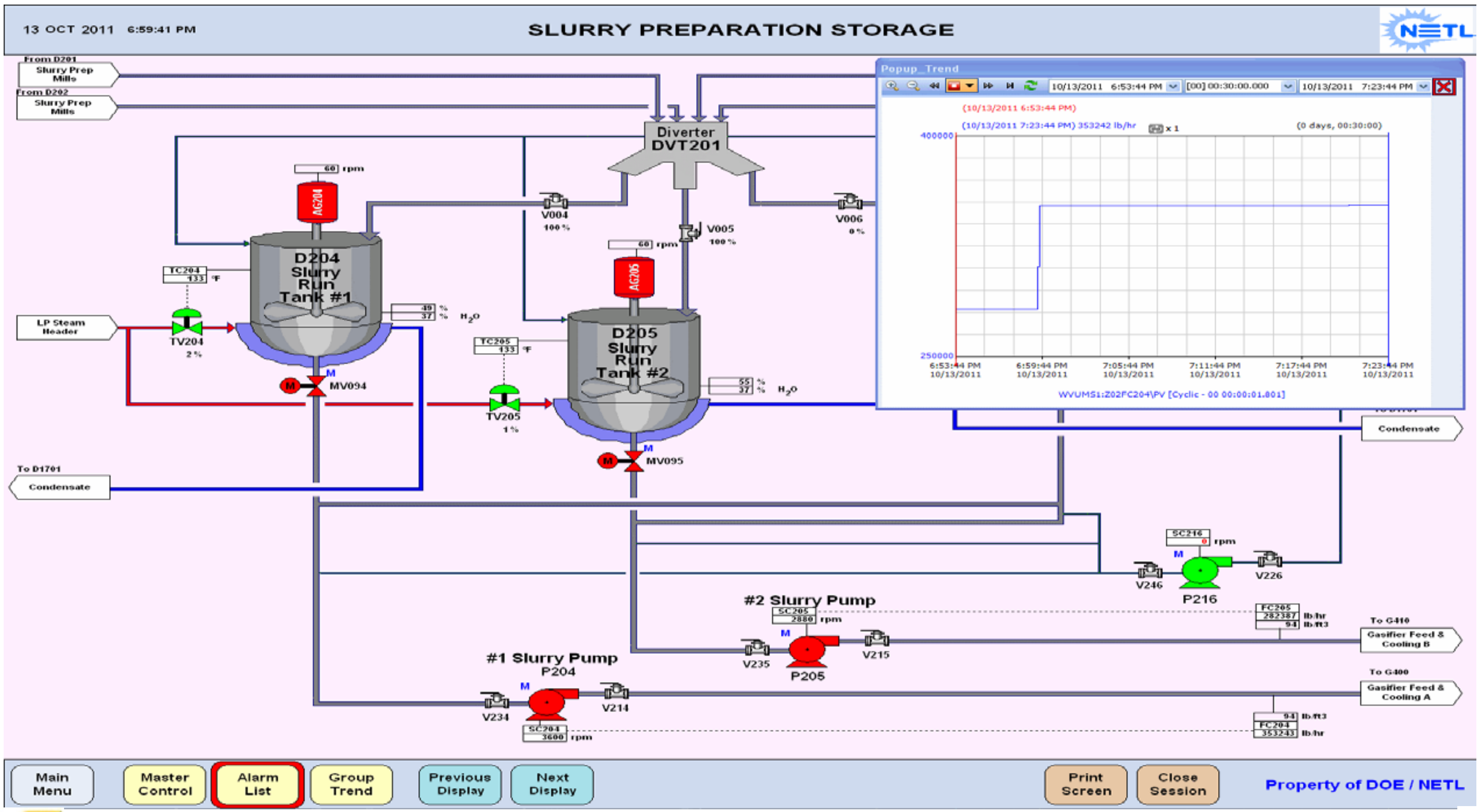


- **Case 1**: Closed loop system

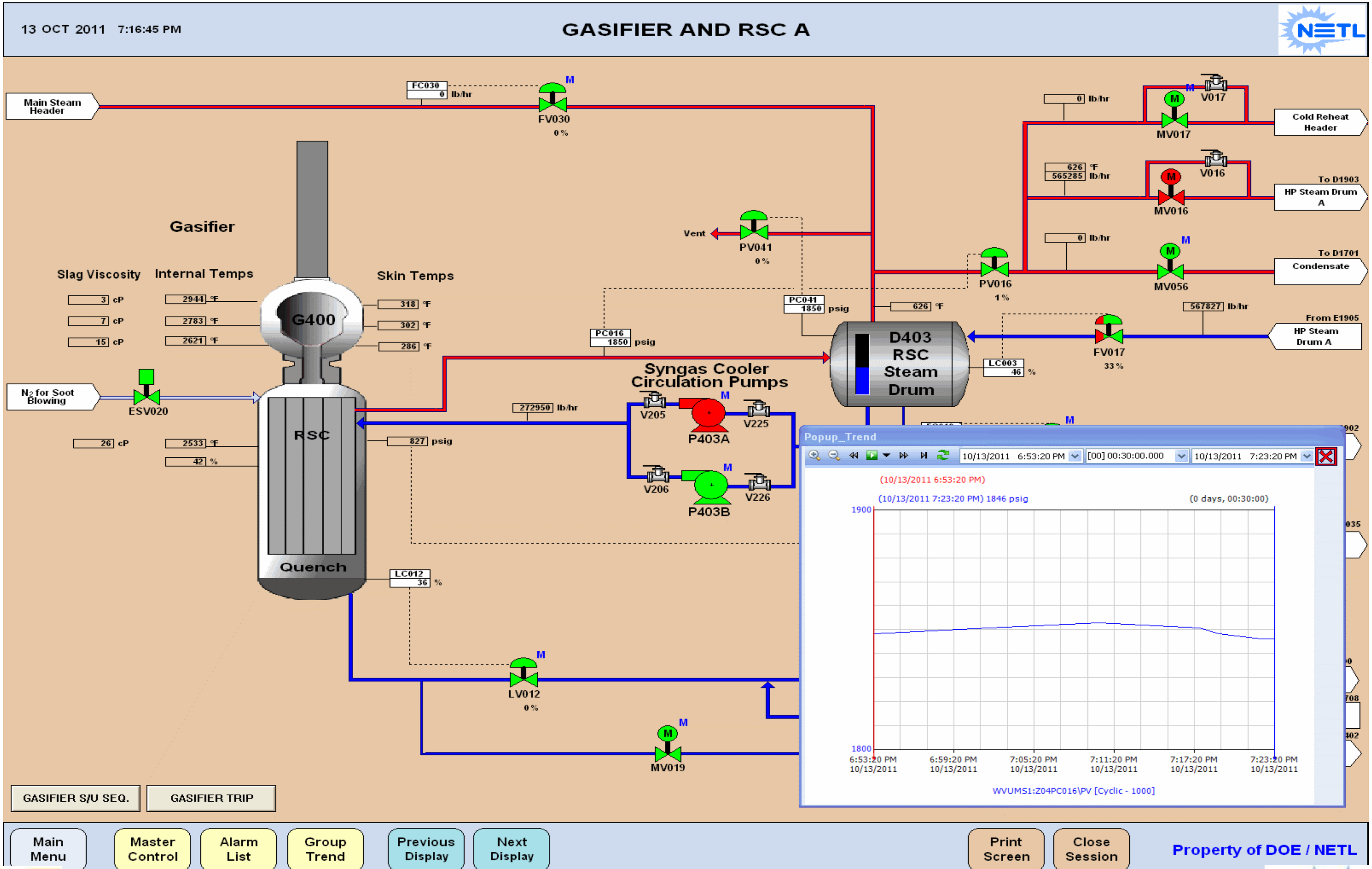
  : Coal feed-flow is step increased

  : Demonstrate control loop performance for disturbance rejection

  : Demonstrate how different systems interact in an actual plant



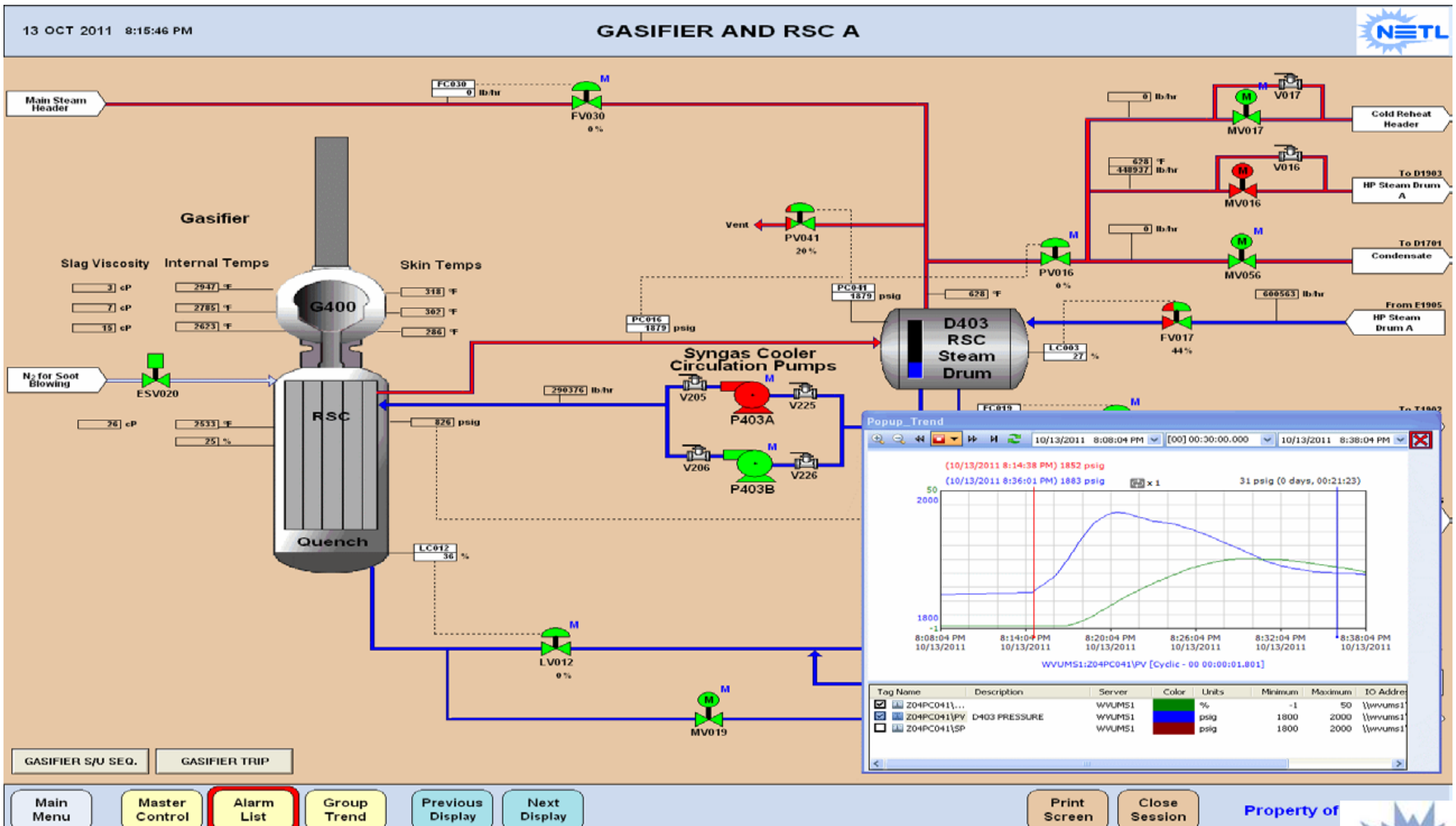
Transient Response of the RSC Steam Drum Pressure



- **Case 2**: Open-loop system, emergency controller takes over

  : The plant still operates normally with a loss of efficiency

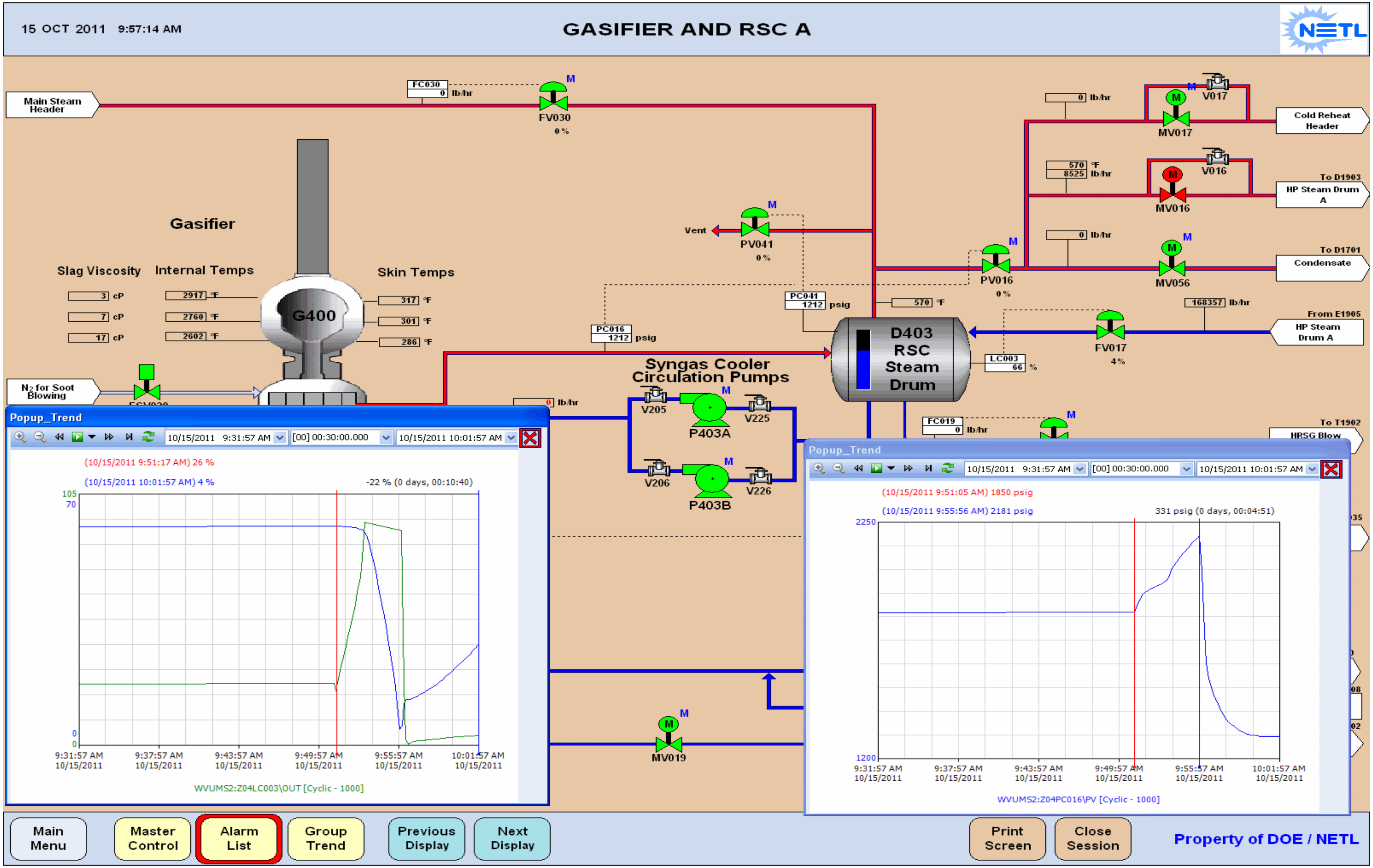
  : Demonstrate the necessity of a “good design” for which the dynamic consideration is crucial



- **Case 3**: Open-loop system, No emergency controller, plant shuts down

  : Drum level decreases to a very low level triggering a plant shutdown

  :Demonstrate other "lines of defense"- emergency shutdown system



Conclusions

- A state-of-the-art dynamic simulator is being used for teaching process dynamics and control to the undergraduates
- A few examples are cited. Many other possibilities are being explored. Suggestions are welcome.

Acknowledgement

- National Energy Technology Laboratory (NETL)

Thank You

IGCC with CO_2 Capture Dynamic Simulator

Reference Plant (2 Trains)

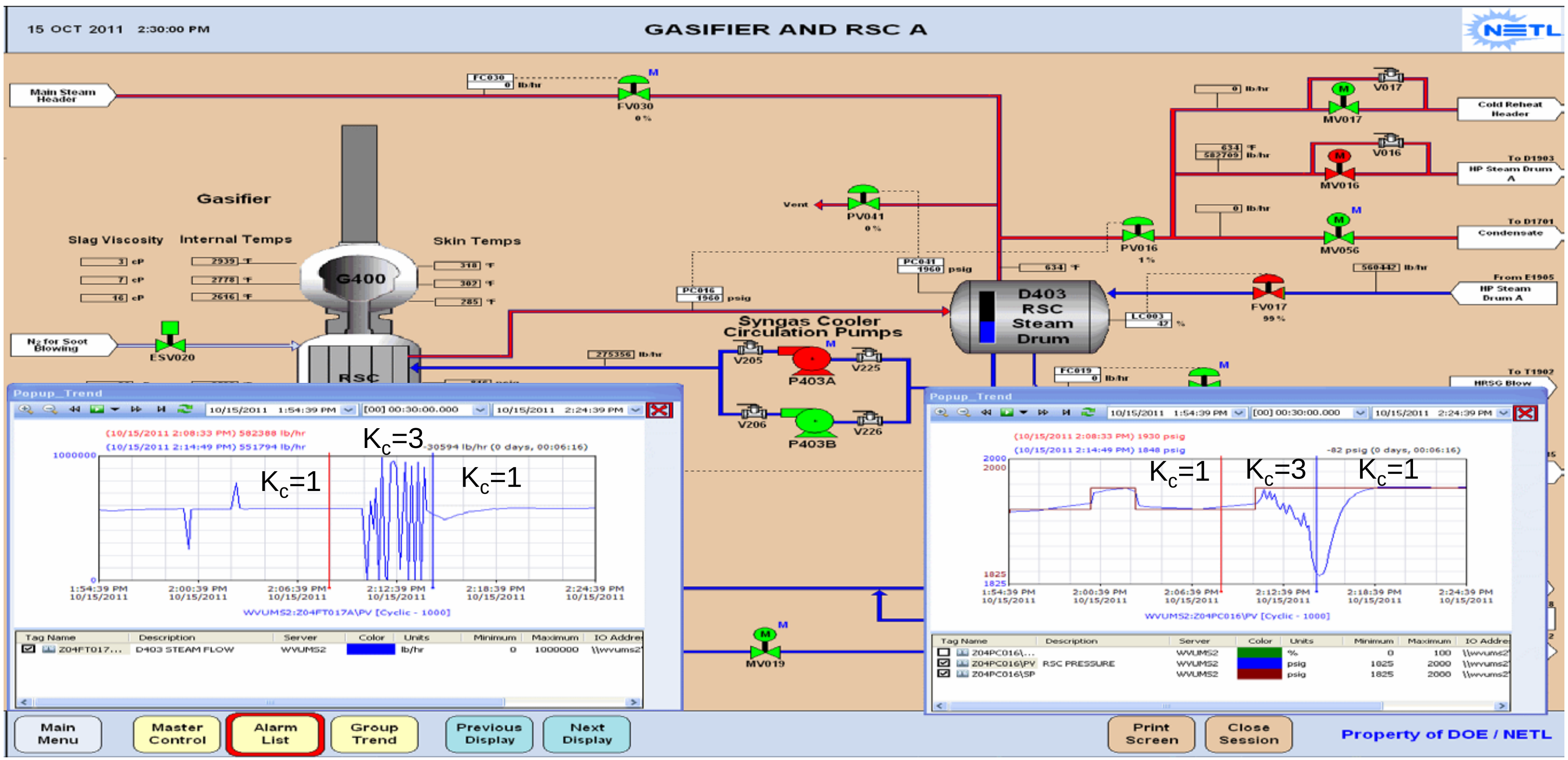
Plant Section	Description
Gasification	Entrained-flow Gasifier
Air Separation	Elevated-P Cryogenic ASU (95% vol O_2)
H_2S Separation	Physical Solvent AGR 1^{st} Stage
Sulfur Recovery	Claus Plant
CO_2 Separation	Physical Solvent AGR 2^{nd} Stage
CO_2 Compression	Four stage (2200 psia)
Gas Turbines	Adv. F Class (232 MW output each)
Steam Cycle	Subcritical (1,800 psig/1,000ºF/1,000ºF)
Power Output	746 MW gross (556 MW net)

References

- *IGCC Case #2, Cost and Performance Baseline for Fossil Energy Power Plants Study, Volume 1: Bituminous Coal and Natural Gas to Electricity*, National Energy Technology Laboratory, www.netl.doe.gov, DOE/NETL-2010/1397, November 2010.

Closed-loop stability: Proportional Gain for Stability Limits

- Students carry out closed-loop stability analysis (by Routh stability analysis, direct substitution, etc.) to determine the limiting proportional gain for stability of the closed-loop system.
- Demonstration of the theory with the RSC pressure control by slowly modifying the proportional gain.



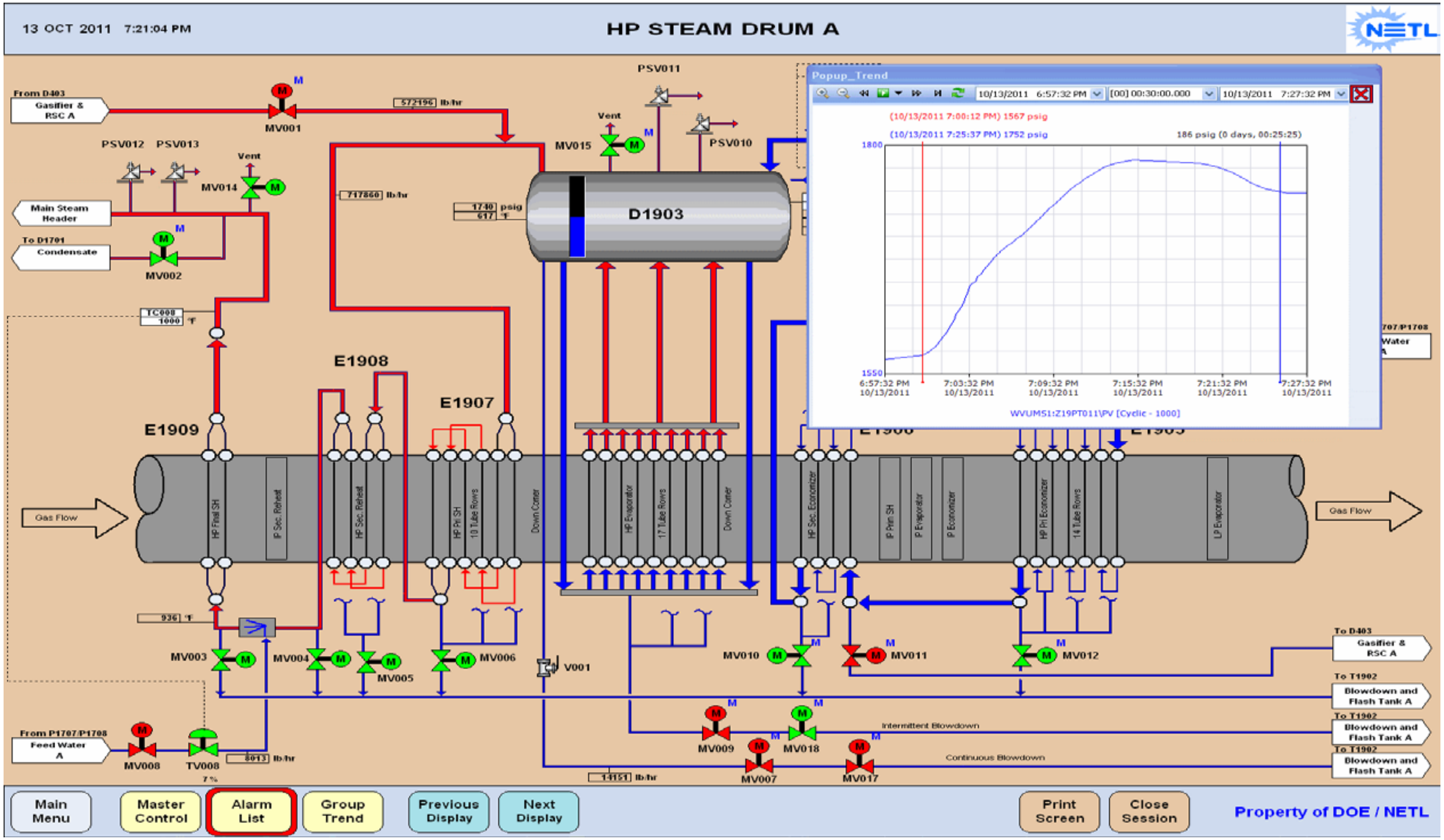
Practical Control Test

A few sample questions:

1. Choose any arbitrary flowsheet and any arbitrary controller. What are the input and output of the controller that you have selected? What are the input and output of the process that you have selected?
2. Draw a block diagram of the closed loop system.
3. Is this system open-loop stable? Why or why not? [Note: you can answer this question theoretically or by carrying out an experiment]
4. What are the disturbance variables(s) for this system?
5. Check the controller performance for servo control. How did you check it? What will you do to improve its performance for servo control further?
6. Check the controller performance for regulatory control. How did you check it? What will you do to improve its performance for regulatory control further?
7. Please note any loop interaction that you have observed while testing the regulatory control.

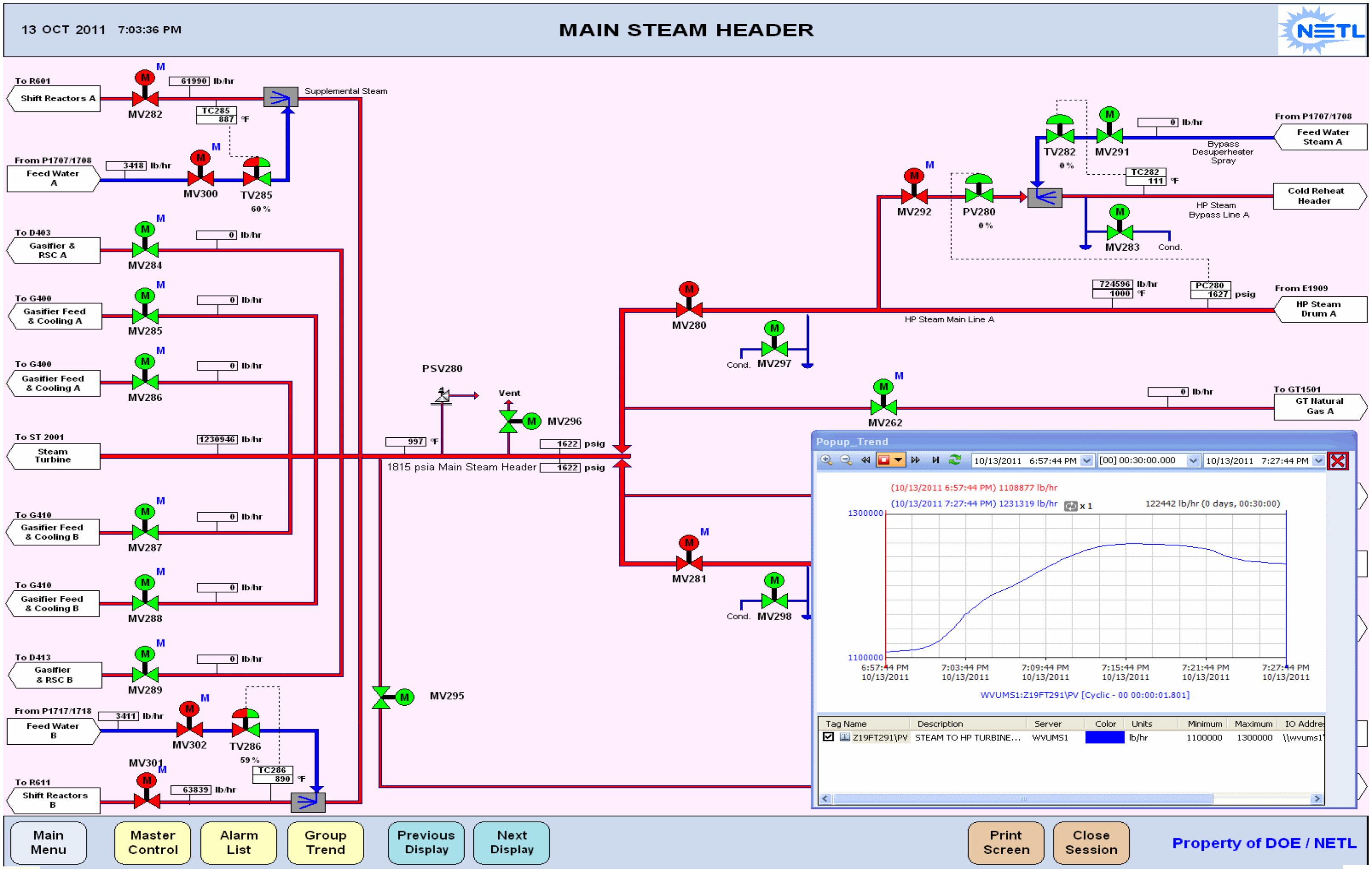
Interaction of the RSC steam drum with other systems

Main HP Steam Generation System



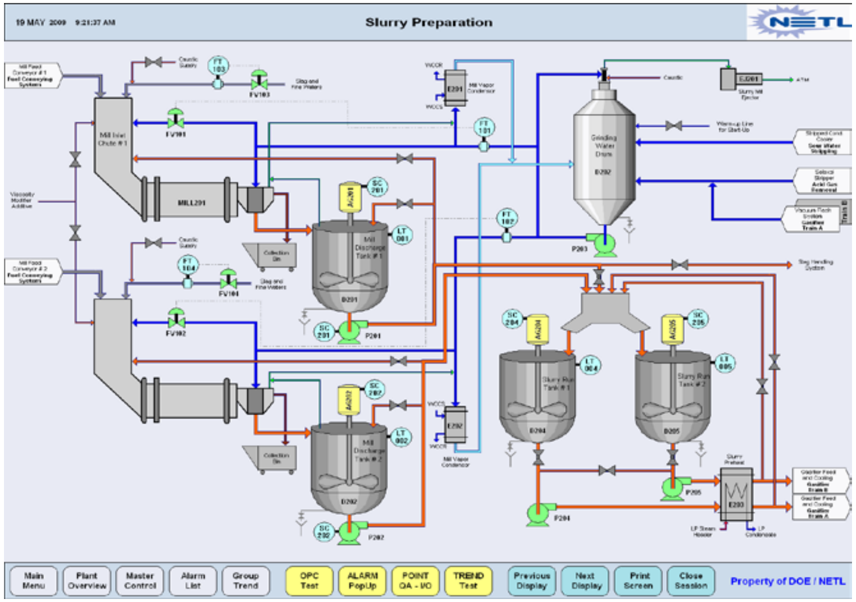
Interaction of the RSC steam drum with other systems

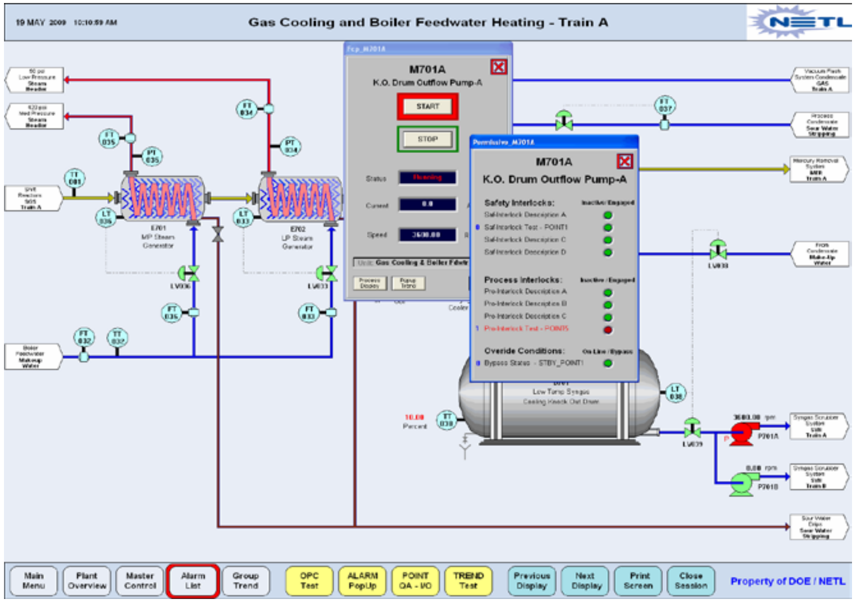
HP Steam Header



Operator Training Simulators

HMI Displays for Plant Areas





(Courtesy of Invensys Operations Management)

Operator Training Simulators

Chemical Process Simulation course

Student exposure to OTS in Simulation Course

Example 3 – Physical Interpretation of Actions

300.	Place WHB Steam drum overpressure controller PC001 in AUTO with a SP of 570 psig	1300-SRU-001	Claus Furnace and Waste Heat Boiler	Condenser Vacuum and Condensate must be available in Combined Cycle side of simulation.
301.	Once the Waste Heat Boiler Pressure reaches 570 psig, OPEN the MV015 bleed valve RF015 to balance the pressures. After 30 seconds, the MV015 valve should open to send the IP steam to the IP Steam Header	1300-SRU-001	Claus Furnace and Waste Heat Boiler	A1302_Furnace_WHB FS