Helium Operators Familiarization Program

Unit 321/322 – Inlet compression and Purification

Competency Assurance and Training

Doha, January 2013 I CARRIERE Céline, PICHOT Delphine, SCHULLER Audrey I Air Liquide

Course Agenda

1. Introduction
2. Design conditions
3. Process Description
4. Process Variables and Control
5. Hazards and Precautions

Course Agenda

1.Introduction

2.Design conditions

3.Process Description

4.Process Variables and Control

5.Hazards and Precautions

1. Introduction – Purpose of units 321 and 322

- Receive the Crude Helium from RasGas and QatarGas extraction units
- Increase Crude Helium pressure by compression
- Produce pure Helium in 3 steps:
  - Upgrade Crude Helium purity up to ~ 90% by removing some Nitrogen
  - Remove H_2 from the Upgraded Crude Helium
  - Remove all remaining impurities (N_2, Methane, Argon, CO_2, CO and O_2) by adsorption
- Send the purified stream to unit 323 and 324 for Helium Compression and Liquefaction

Course Agenda

1.Introduction

2.Design conditions

3.Process Description

4.Process Variables and Control

5.Hazards and Precautions

2. Design Conditions – Specification

- The Helium plant is designed to recover 98% of the inlet feed gas' Helium

HELIUM SPECIFICATION		
Characteristic	**Units**	**Value**
Pressure	psig	3
	bar abs	1.22
Helium content	% mol	≥ 99.999
Water (vapor)	Ppmv	≤ 1.5
Dew point	°C	≤ -73
Total hydrocarbon as methane	ppmv	≤ 0.5
Hydrogen content	ppmv	≤ 1
Oxygen content	ppmv	≤ 1
Nitrogen + Argon content	ppmv	≤ 5
Neon content	ppmv	≤ 2
Carbon Dioxide + Carbon Monoxide content	ppmv	≤ 0.5

2. Design Conditions – On site conditions

Climatic conditions:

	Summer	Average	Minimum	Design (for ASU)
Atmospheric dry bulb air temperature (°C)	49°C	26.7°C	4°C	44°C
Atmospheric air relative humidity (%)	80% (*)	59% (*)	35% (*)	60%
Atmospheric air pressure (bar a)	1.020		0.995	1.013

(*) Daily max humidity: 95%

Cooling Water conditions:

	Max	Normal	Min	Design
Supply temperature (°C)	38		18	42
Supply pressure (bara)	10.63	10.63	10.63	10.63

Instrument Air :

	From Air Compr.	From ASU	From RasGas
Supply temperature (°C)	20	30	Ambient
Supply pressure (bara)	8	6.5	8

Design Conditions – Feed Gas caracteristics

- Feed Gas:

Parameter	QatarGas Design Basis	RasGas Design Basis	Combined Design Basis
Flow Rate (kgmol/hr)	299	130	429
Temperature (°C)	10-38	10-38	10-38
Feed Pressure (bara)	1.5	1.5	1.5
Composition (mol %)			
Helium, He	47.6086%	50.7665%	48.5655%
Nitrogen, N_2	49.3892%	46.3122%	48.4568%
Methane, CH_4	1.9611%	1.8802%	1.9366%
Hydrogen, H_2	1.0218%	1.0218%	1.0218%
Argon, Ar	0.0119%	0.0119%	0.0119%
Neon (*), Ne	0.0034%	0.0034%	0.0034%
Carbon Monoxide, CO	0.0040%	0.0040%	0.0040%
Total =	100.0000%	100.0000%	100.0000%

(*) Due to some uncertainty in the Neon measurement a 100% design safety margin is required for sizing the cold-end liquefier traps [i.e., 68ppm]

Course Agenda

1.Introduction

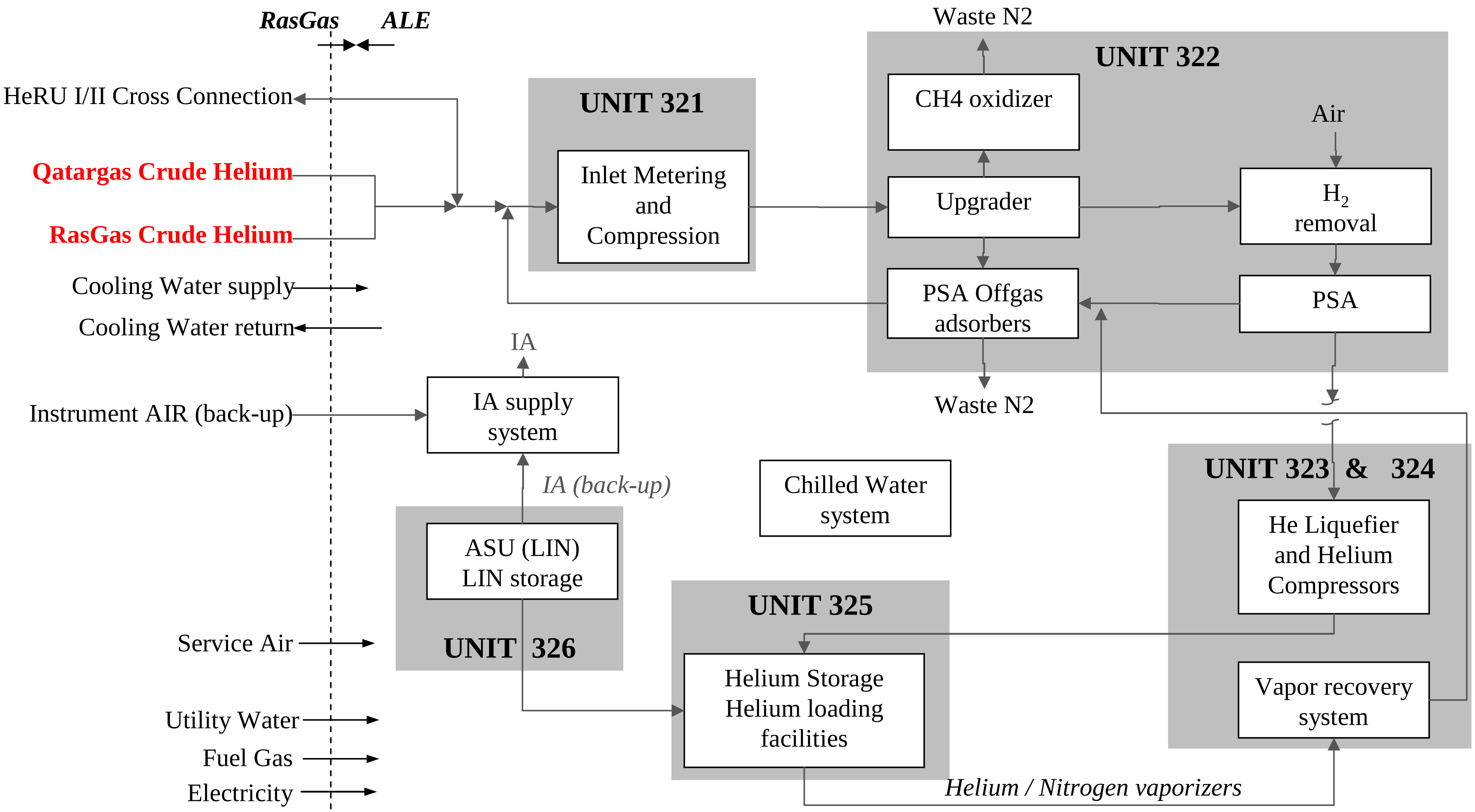
2.Design conditions

3.Process Description

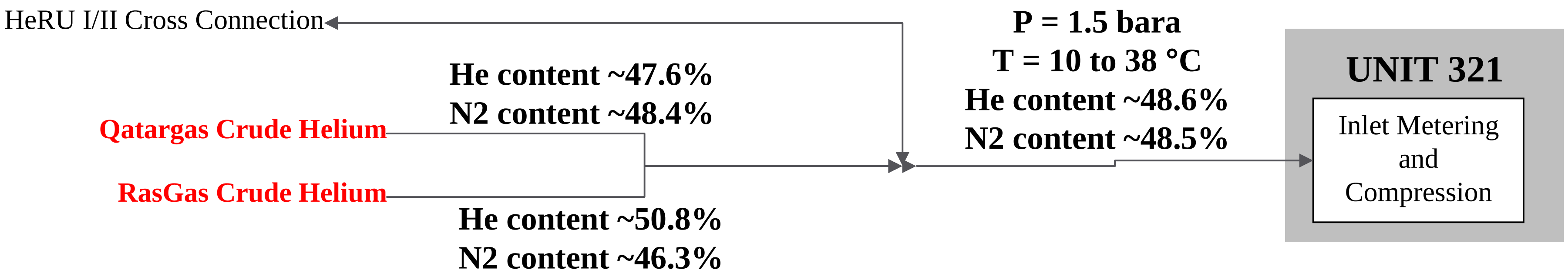
4.Process Variables and Control

5.Hazards and Precautions

3. Process Description

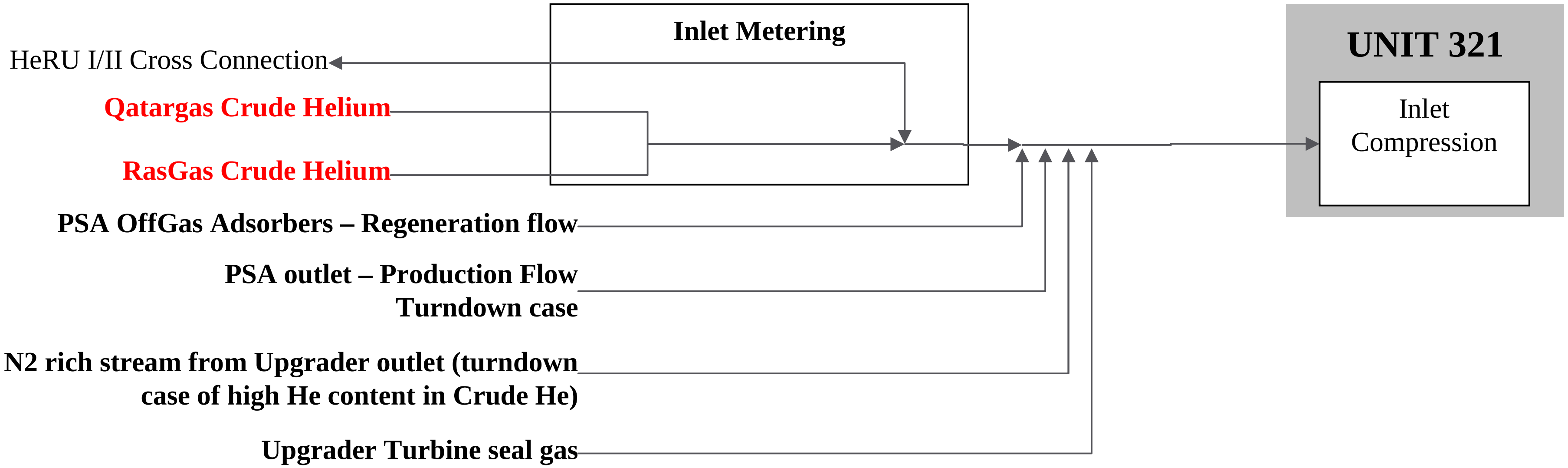


3. Process Description - Unit 321 – Inlet Metering and Inlet Compression Unit



- Crude Helium feeds from RasGas and QatarGas are dry and CO_2-free
- The 3 inlet crude helium streams and the mixed stream are metered
- The Crude Helium contains traces of Methane, Argon, Hydrogen, Neon and CO
- The interconnection line HeRU I/II allows connecting HeRU I and HeRU II plants to increase availability and Helium recovery:
  - If one plant is venting, the cross connection valve opens to unload the venting plant in the other plant ➔ Avoid venting i.e. increase Helium recovery
  - If one plant is below its turndown feed, the cross connection valve opens to load this plant with the other plant's feed ➔ Avoid turndown i.e. increase availability

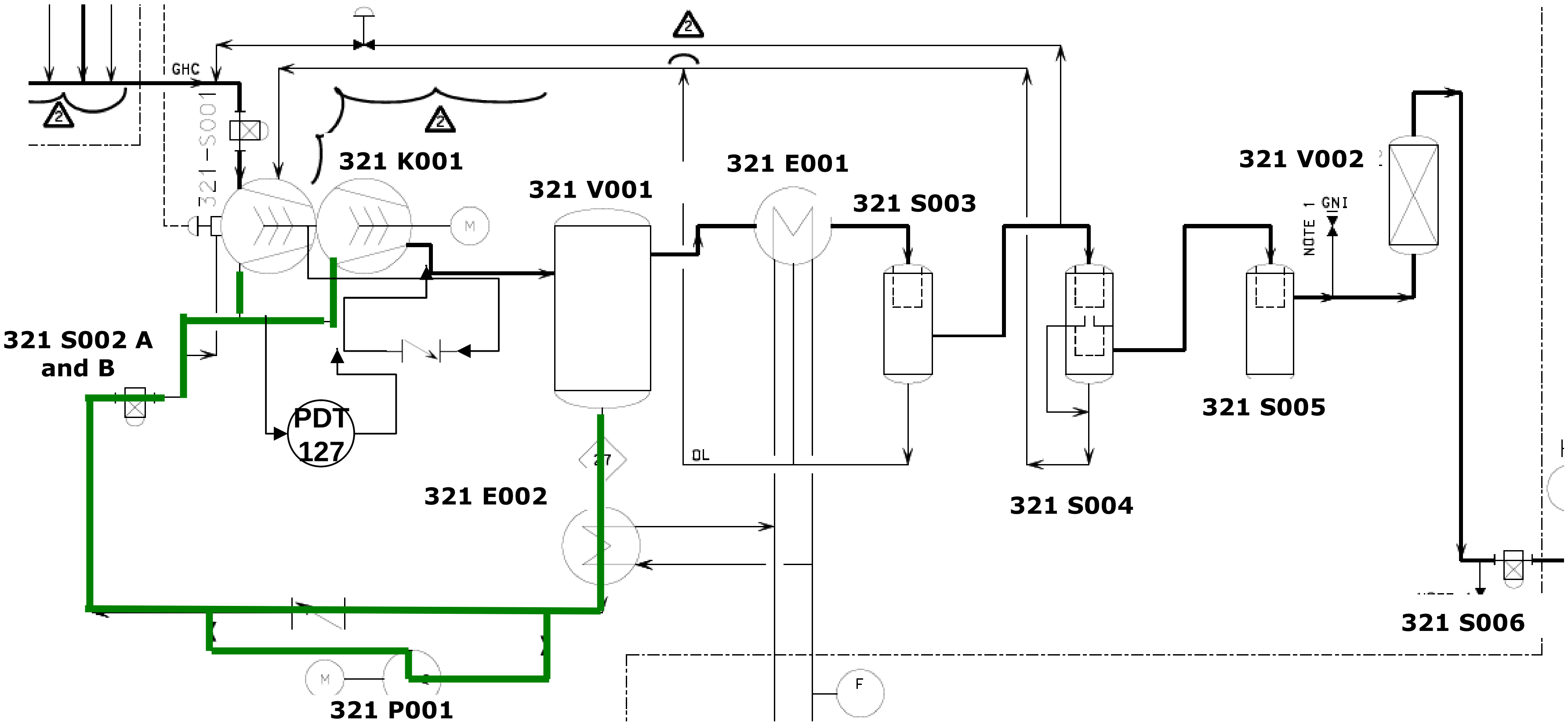
3. Process Description - Unit 321 – Inlet Metering and Inlet Compression Unit



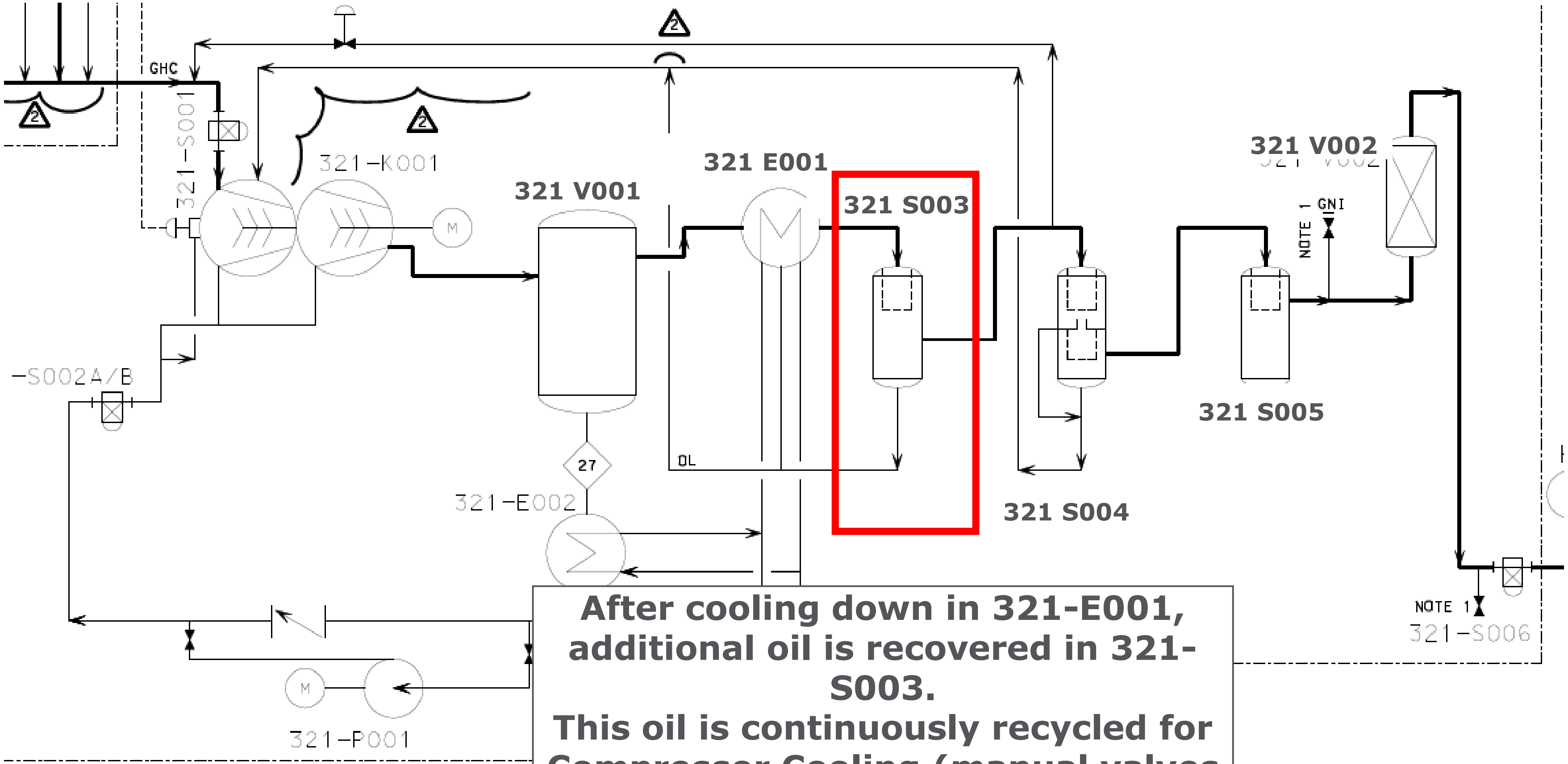
- Crude Helium is mixed with the following recycle lines:
  - GHC (Crude Helium) from PSA OffGas Adsorbers
  - RWN (Waster Nitrogen) from Upgrader Exchanger 322 E001
  - GHC (Crude Helium) from Upgrader Expander
  - GHP (Pure Helium Gas) from PSA Production outlet. PSA turndown is 50% of nominal capacity, whereas the plant turndown is 25%. To be able to operate when the feed flow is between 25 and 50%, the PSA outlet is recycled to increase the flow at PSA inlet.

3. Process Description - Unit 321 – Inlet Metering and Inlet Compression Unit

- Inlet Compressor suction stream (feed + recycle lines) is filtered in 321 S001 and compressed from 1.5 bara to 24.7 bara.
- At Compressor discharge, Compressed Helium is cooled down in 321 E001 and oil is separated from Helium by 2 Oil Separators (321-V001 and 321-S003), 2 coalescers (321-S004 and S005) and 1 charcoal adsorber (321-V002)
- The final filter (321-S006) allows removing ultimate particles
- The compressor slide valves allow the operation between 25% and 100% of the compressor's nominal capacity.
- Oil is injected during compression. Its functions are:
  - **Coolant**: oil is finely dispersed to have a large contact surface with helium. Oil absorbs the major part of the compression heat
  - **Lubricant**
  - **Seal**: oil is as a binding material for helium so that gas leaks through seals are avoided

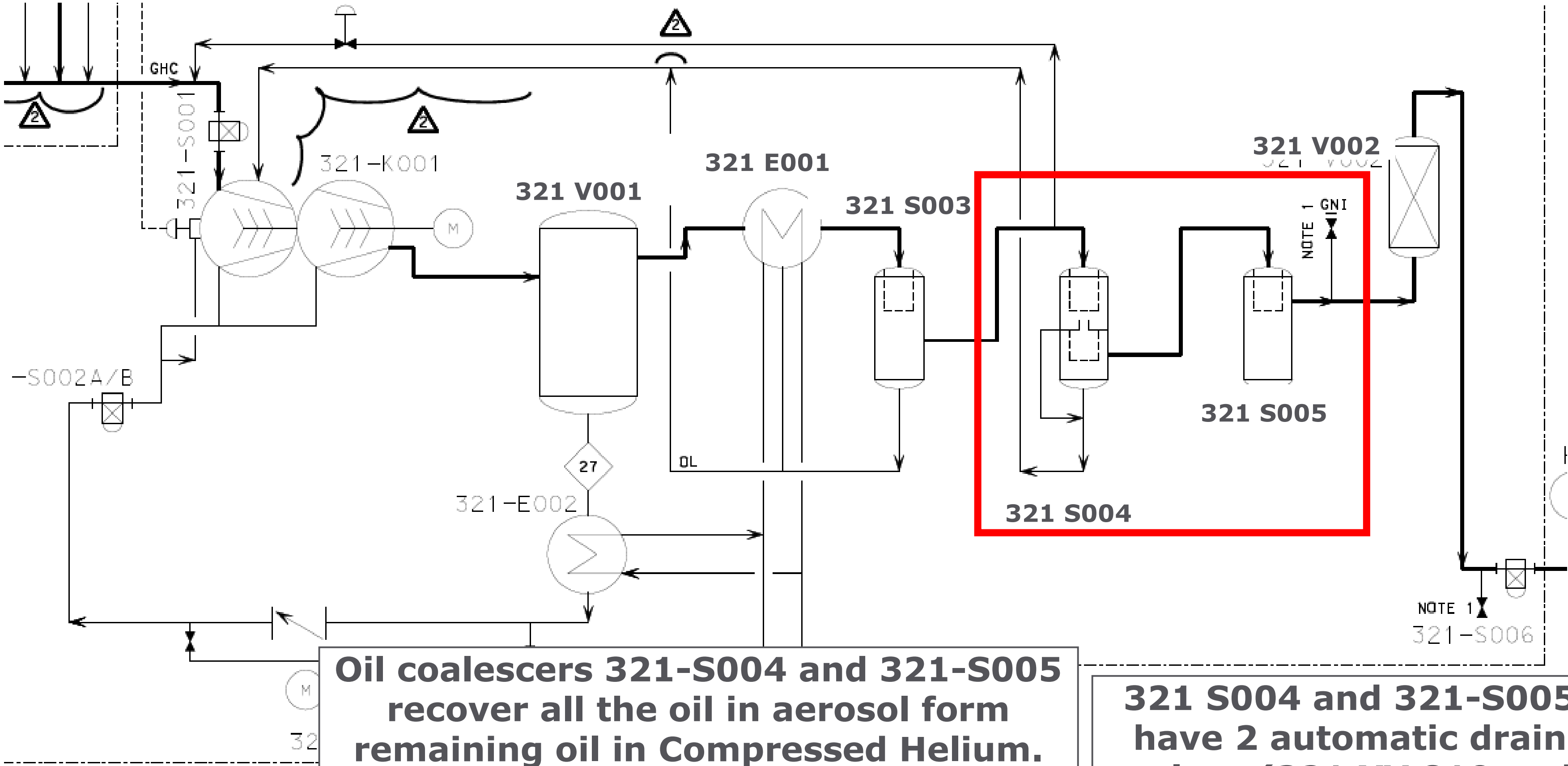


- The Oil at the outlet of the Inlet Compressor is at ~110°C.
- The Oil is recovered in 321 V001 acting as an oil buffer, cooled down to ~71°C in 321 E002, filtered by 321 S002 A or B, and sent back to the compressor.
- 321 P001 is used only during the start up and shutdown of the compressor.
- When the compressor is running and PDT 127 is high enough, 321 P001 automatically stops after 30 seconds.



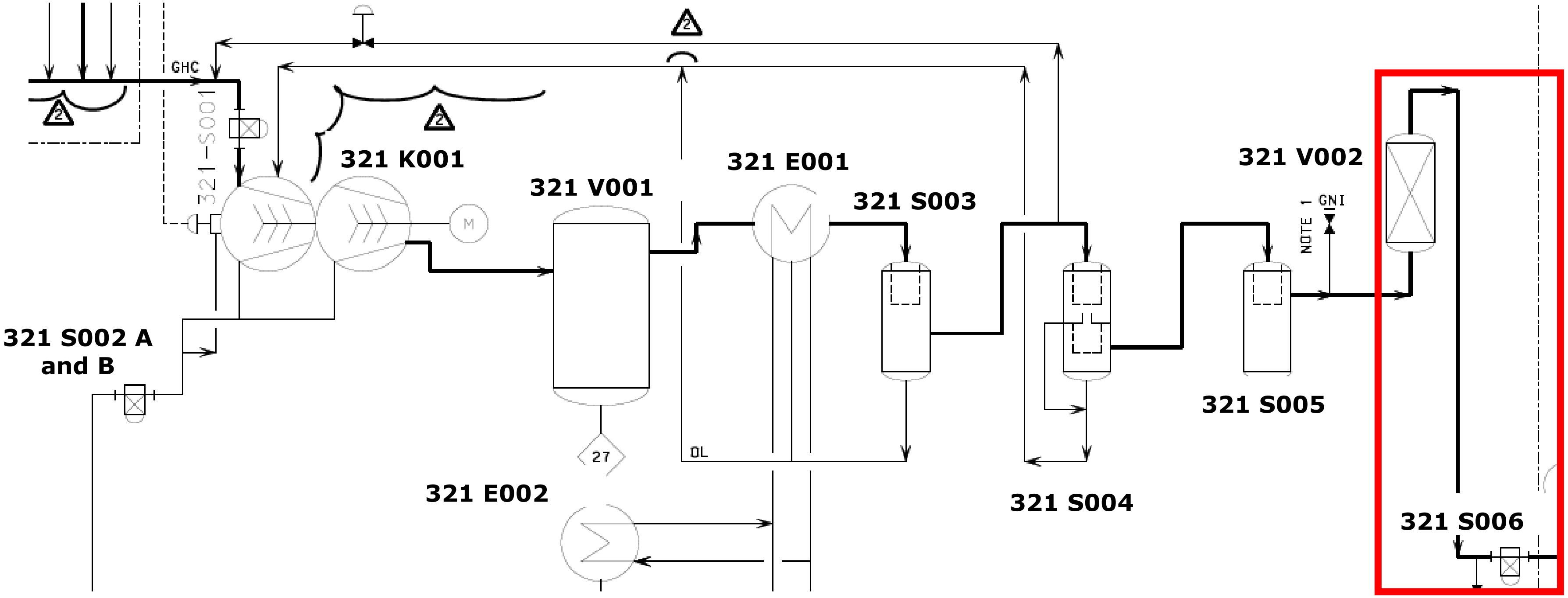
After cooling down in 321-E001, additional oil is recovered in 321-S003.
This oil is continuously recycled for Compressor Cooling (manual valves 321 MV 207 and 209 are *Normally Open*)

3. Process Description - Unit 321 – Inlet Metering and Inlet Compression Unit



Oil coalescers 321-S004 and 321-S005 recover all the oil in aerosol form remaining oil in Compressed Helium. Almost all the aerosol is recovered in 323-S004, and the last traces are recovered in the back-up coalescer. The level in 321-S005 shall remain low.

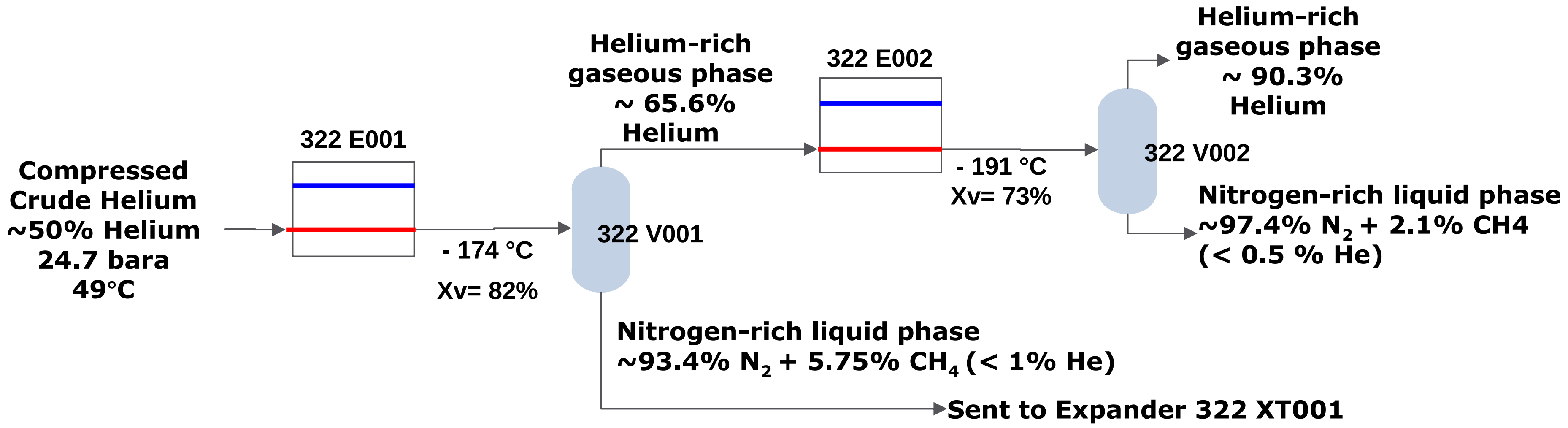
321 S004 and 321-S005 have 2 automatic drain valves (321 XV 810 and 820): drain valves open when oil level in the coalescer is too high.



- The oil in vapour form is adsorbed in the charcoal adsorber 321-V002. At 321 V002 outlet oil content is below 10 ppbv.
- Compressed Helium is ultimately filtered through the filter 321-S006 to remove any remaining particles.
- At compressor discharge, oil content in Compressed Helium will not affect the downstream Upgrader operation

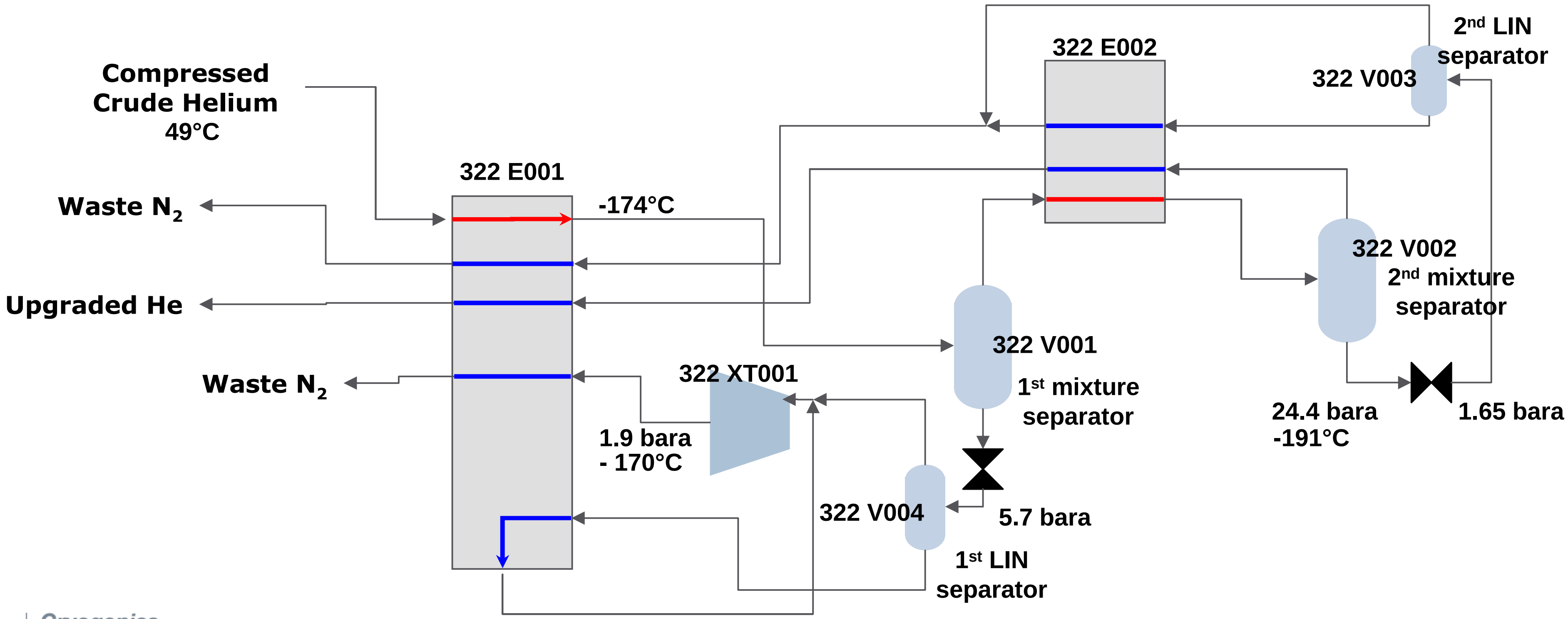
Process description – Unit 322 – Upgrader

- Through the Upgrader, a 50% Helium content inlet stream is upgraded to 90% Helium content by removing the Nitrogen using mixture separators.



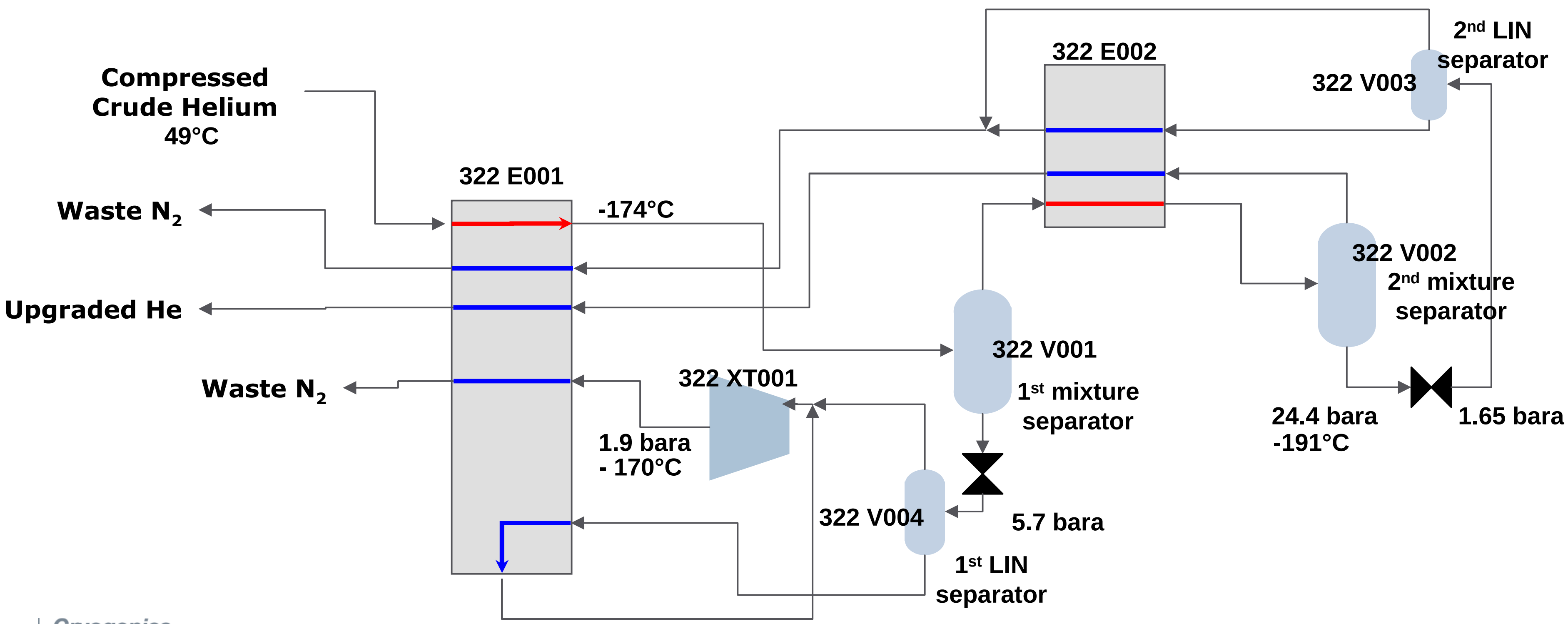
Process description – Unit 322 – Upgrader

- Cold fluids of 322 E001 are:
  - Upgraded Helium from 322 V002 Second Mixture Separator vapor outlet
  - RWN (Waste Nitrogen) from the outlet of 322 XT001 Upgrader Expander
  - RWN from 322 V003 Second LIN separator outlet
  - RWN from 322 V004, first LIN separator liquid outlet



Process description – Unit 322 – Upgrader

- Cold fluids of 322 E002 are:
  - RWN from 322 V003 Second LIN Separator liquid outlet
  - Upgraded Helium from 322 V002 Second Mixture Separator vapor outlet



Process description – Unit 322 – Upgrader

Expander and cold production in 322 E001 control:

- **322 TC 010**: in specific runs, He content in Feed is high and exchanger 322 E001 is very cold. If temperature is too cold, Waste Nitrogen is recycled to increase N_2 content and warm up 322 E001
- **322 PC 010**: Turbine by-pass 322 PV 010 controls pressure at turbine inlet. Set point is fixed at 5.8 bara.
- **322 PC 033**: Expander outlet pressure is maintained fixed at 1.8 bara by adjusting 322 PV 033 (Waste Nitrogen outlet to PSA OffGas and RTO)
- ➔ Pressure drop in expander is fixed.
- **322 FV 010**: the total flow sent to the expander and its by-pass is maintained constant by adjusting the opening of 322 V001 liquid outlet
- **322 SC 010**: the opening of 322 SV 010 at turbine inlet controls the turbine speed. The SP of 322 SC 010 is adjusted with the level in 322 V001 (correction control with 322 LC 010).

Process description – Unit 322 – Upgrader

322 E002 control:

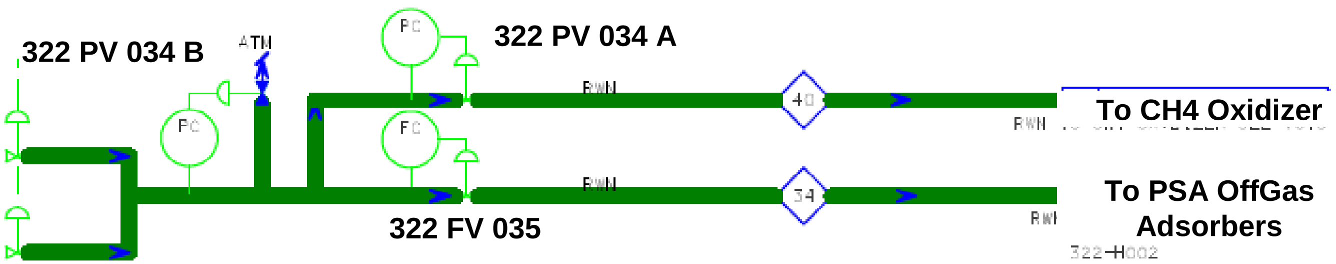
- **322 LC 025**: Liquid level in 322 V002 is maintained constant thanks to 322 LV 025 opening/closure .
- **322 PC 026:** The pressure of the Waste Nitrogen is maintained at 1.5 bara by adjusting 322 PV 026
- **PC 029** (on the Upgraded Helium): allows starting or running of the Upgrader when the downstream equipments are not in service. The helium production is venting to the atmosphere by the opening of 322 PV 029, with SP = 24 bara.

Monitoring

- Outlet temperatures are monitored via 322 TI 030, 322 TI 031 and 322 TI 032

Process description – Unit 322 – Upgrader outlet

- Waste Nitrogen at the Upgrader outlet is used to regenerate the PSA Offgas Adsorbers. In order to regenerate the adsorbers, a sequence is running. During regeneration step, a constant flow is sent to regenerated the bottle.
  - SP [322 FC 034] = 1250 Nm^3/h
- When there is no vessel in regeneration step, this flow is sent to atmosphere through valve 322 PV 034 B. This controller mode is set by purification vessel sequence.
  - SP [322 PC 034 B] = 1.35 bara
- In normal operation, the excess of Waste Nitrogen flow is sent to the methane oxidizer in order to oxidize methane contained in the mixture.
- In order to maintain a constant pressure on this line, 322 PV 034 A valve is pressure controlled.
  - SP [322 PC 034 A] = 1.3 bara



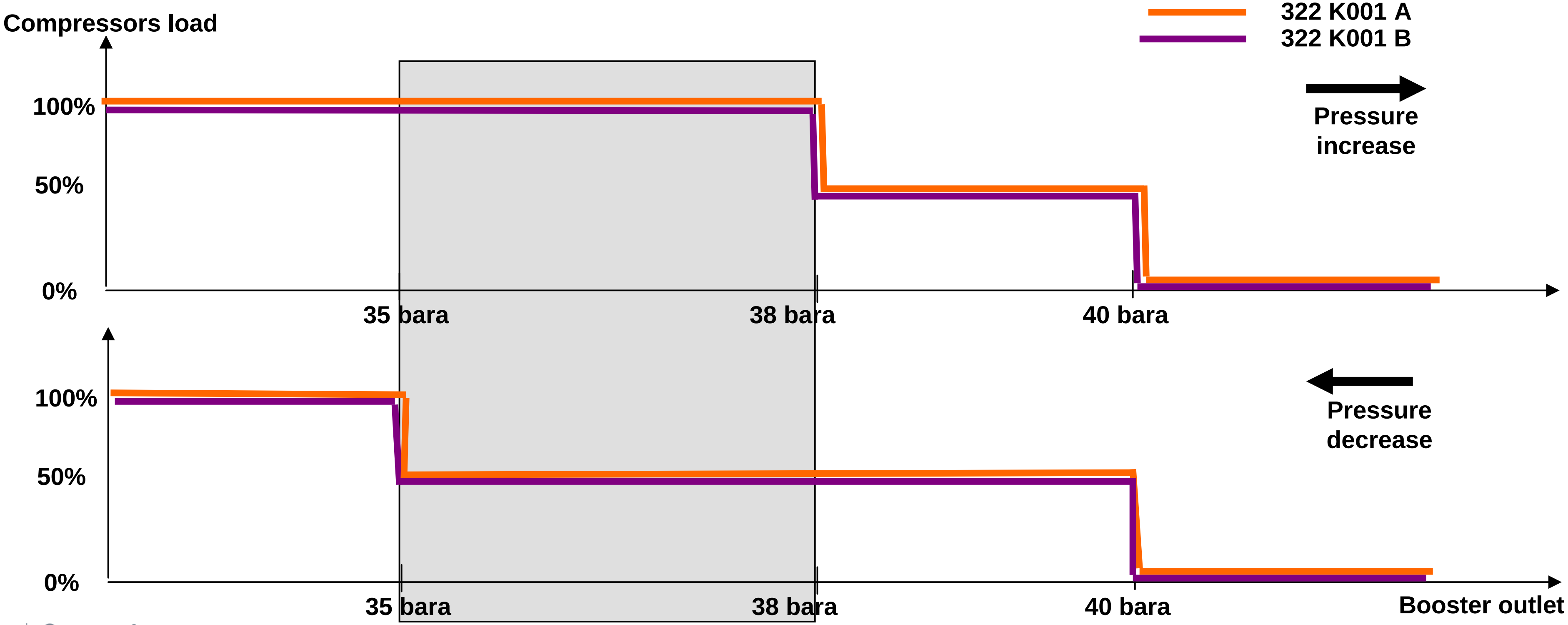
Process description – Unit 322 – Catalytic Reactor

- **Purpose**: remove H_2 from Upgraded Helium
  - Based on H_2 conversion into H_2O through the reaction

  $H_2 + ½ O_2 \rightarrow H_2O$
  - Catalyzed reaction at Pd/AlO_3 surface
  - Reaction occurs in 322 V005, filled in with Pd/AlO_3 in which high pressure Air is injected.
  - Nominal air flow: 235 Nm^3/h ➔ 21% x 235 = 49 Nm^3/h O_2;
  - Nominal GHC flow: 7541 Nm^3/h ➔ 1.26% x 7541 = 95 Nm^3/h H_2.
- **Specification**: at Catalytic Reactor outlet, H2 < 0.5 ppmv
  - **Air injection:**
  - Reactor Air Boosters 322 K001 A and B allow high pressure Air injection (P ~38 bara).
  - Each compressor can be loaded at 0%, 50% or 100%
  - Each compressor is designed to maintain 40 bara of the whole air flow
  - 322 V007 at the outlet of the boosters acts as a buffer.

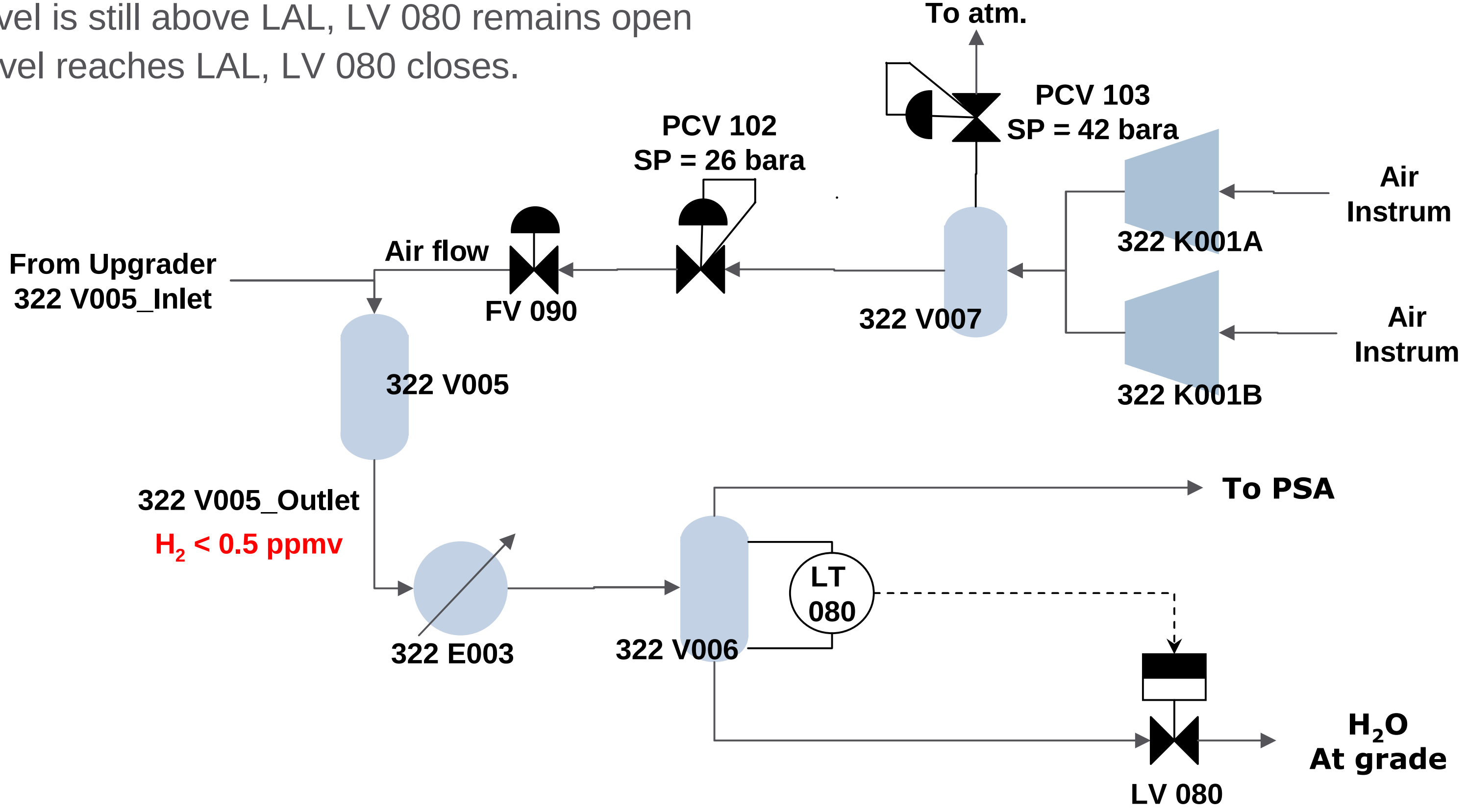
Process description – Unit 322 – Reactor Air Boosters

- The load of Reactor Air Boosters depends on outlet pressure:
  - If P > 40 bara, both compressors are unloaded
  - If P < 35 bara, both compressors are loaded at 100%
  - If 38 < P < 40 bara, both compressors are loaded at 50%
  - Between 35 and 38 bara, the load depends on pressure trend:



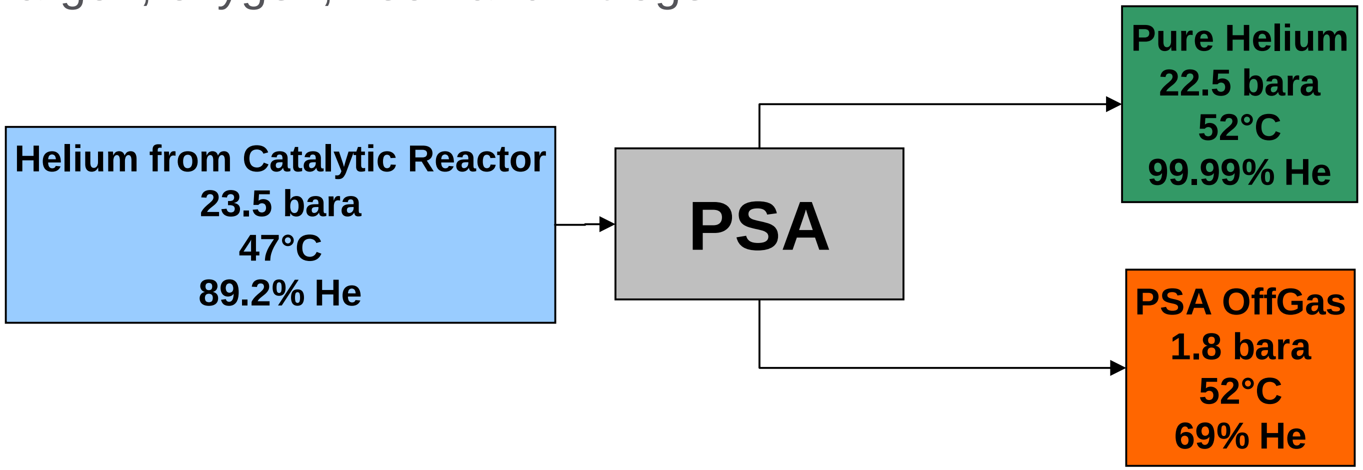
Process description – Unit 322 – Catalytic Reactor

- The outlet of the reactor stream is cooled in the cooler 322 E003 down to 47ºC with cooling water
- Some of the water formed during the reaction condenses and is removed in 322 V006.
- V006 level is automatically controlled by the control valve 322 LV 080:
  - When level > LAH, LV 080 opens
  - While level is still above LAL, LV 080 remains open
  - When level reaches LAL, LV 080 closes.



Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- The PSA allows pure Helium production:
  - Adsorbed components: Nitrogen, Methane, Oxygen, Argon, Carbon Dioxide, Hydrogen, Carbon Monoxide and Water
  - At PSA outlet, Helium Product is 99.99% purity, and contains traces of argon, oxygen, neon and nitrogen

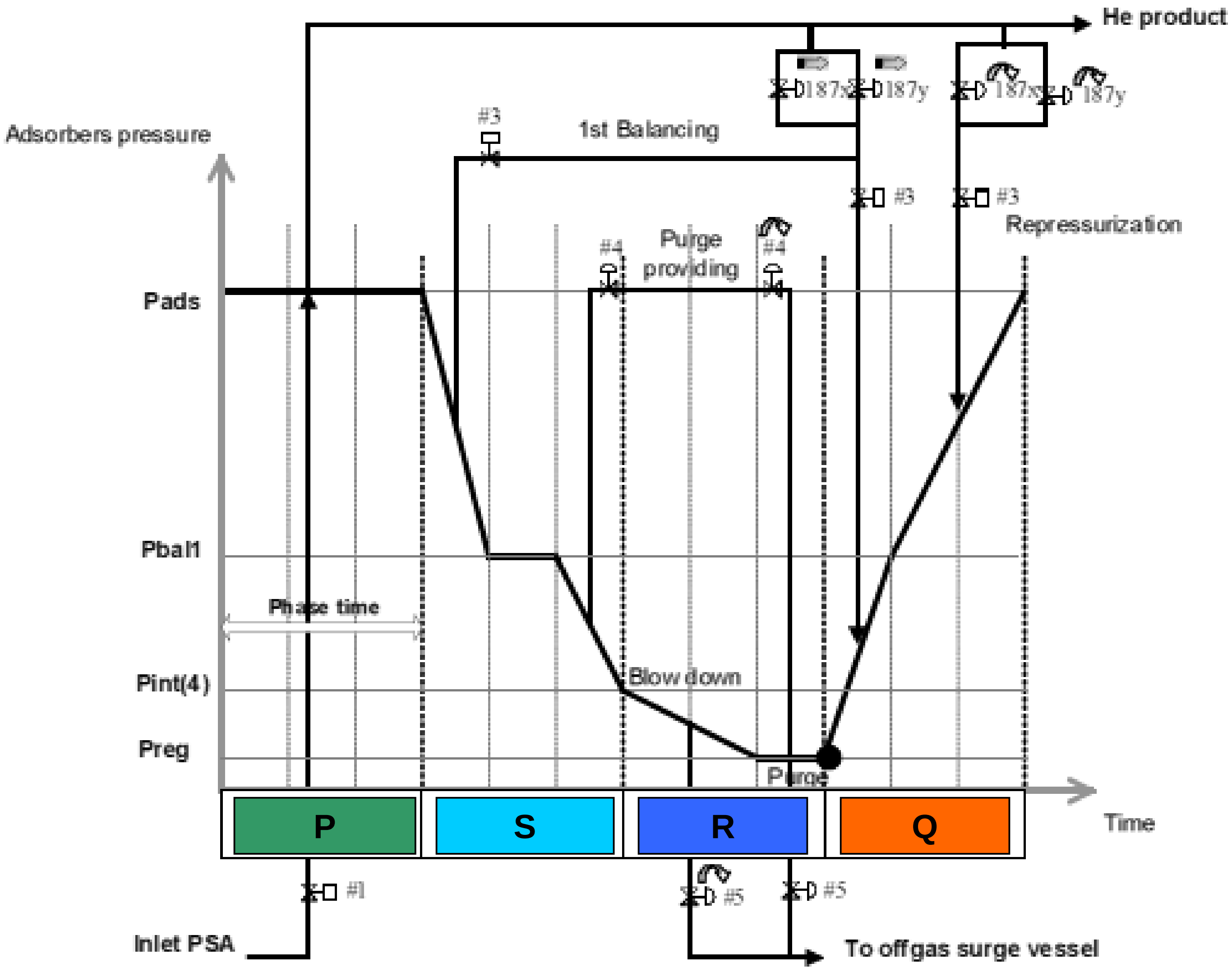


- Helium is weakly adsorbed:
  - Recovery rate = 73%
  - To improve the overall Helium Recovery rate, the PSA OffGas is treated in PSA OffGas Adsorbers and loops back to Inlet Compressor's suction.

Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Helium at expected purity is produced by cycling 4 phases in Normal Run:
  - Each phase is divided into 3 temporal units (t)
  - 1 cycle = 4 phases and 1 phase corresponds to 1 vessel
  1. **Phase 1 = Adsorption**: while circulating in a bottle, impurities are adsorbed and pure helium is produced.
  2. **Phase 2 = depressurization – Divided into 3 steps:**
     1. Pressure equalization with the vessel in phase 4
     2. Waiting
     3. Further depressurization, providing purge to vessel in phase 3
  3. **Phase 3 = depressurization – Divided into 2 steps:**
     1. Vessel depressurization by pressure equalization with 322 V010 (vessel at PSA LP outlet) – This step lasts 2 temporal units
     2. Elution: at LP, the purge provided by vessel in phase 2 is evacuated
  4. **Phase 4 = Repressurization – Divided into 2 steps:**
     1. Pressure equalization with the vessel in phase 2
     2. Repressurization with PSA HP outlet

Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*



4-1-1 Cycle Pressure Diagram

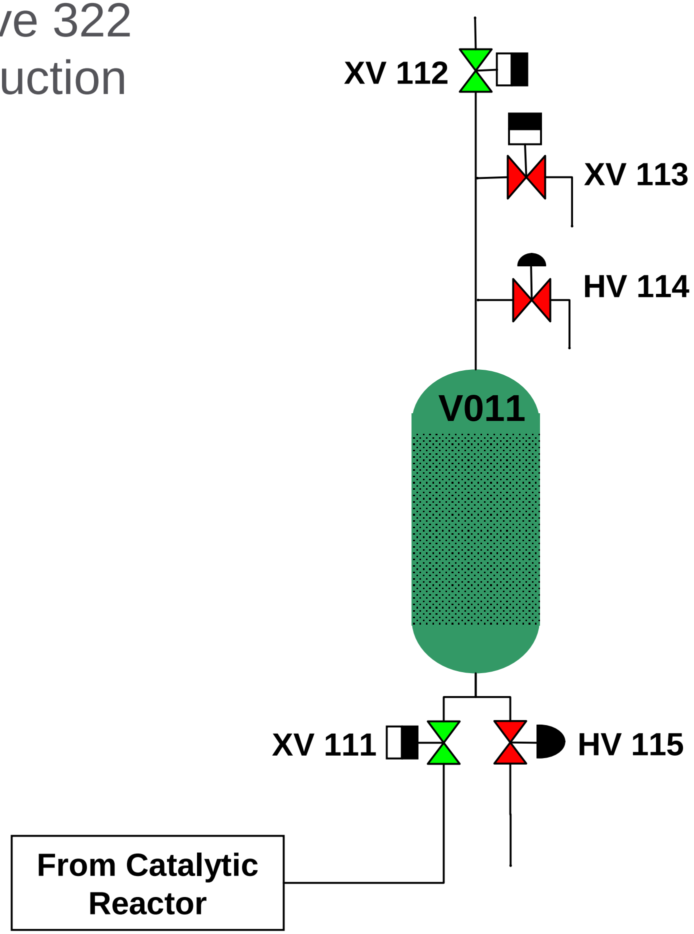
P = Vessel in first production step

S = Vessel in first depressurization step

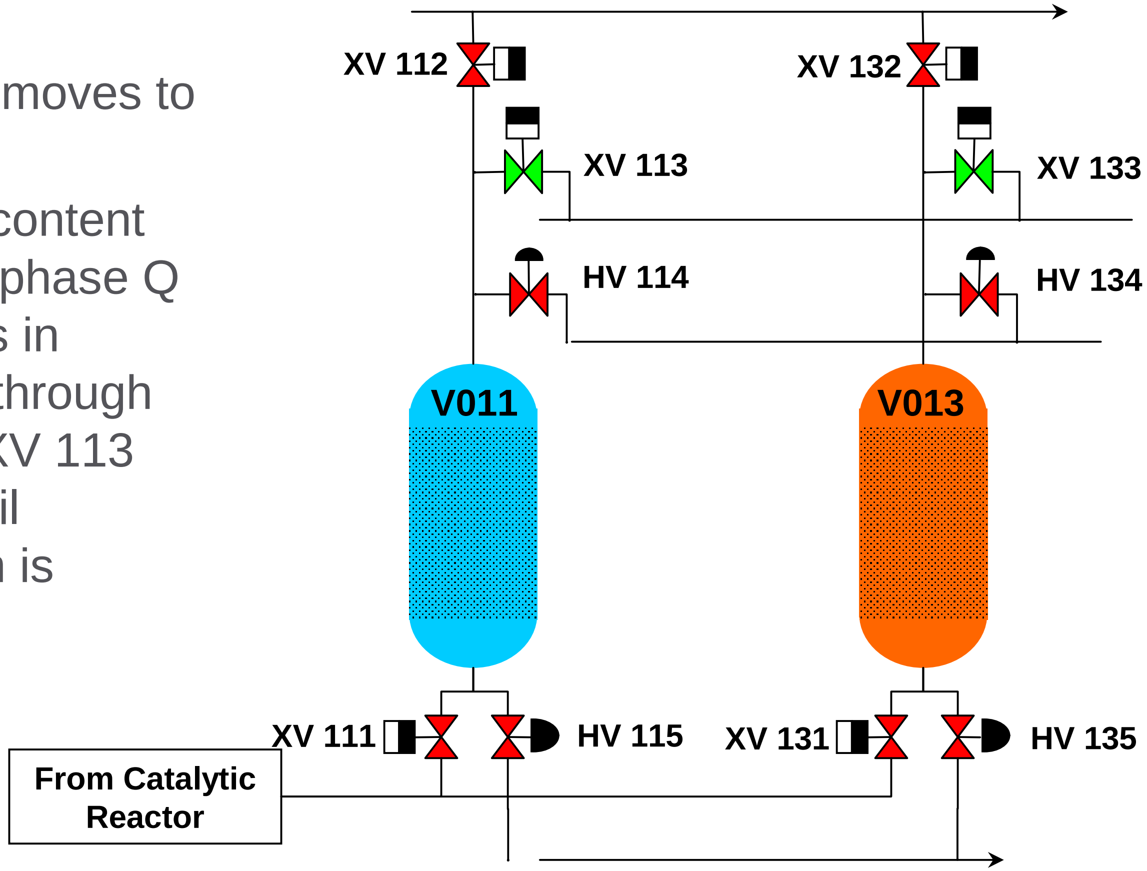
R = Vessel in second depressurization step and regeneration

Q = Vessel in first regeneration step

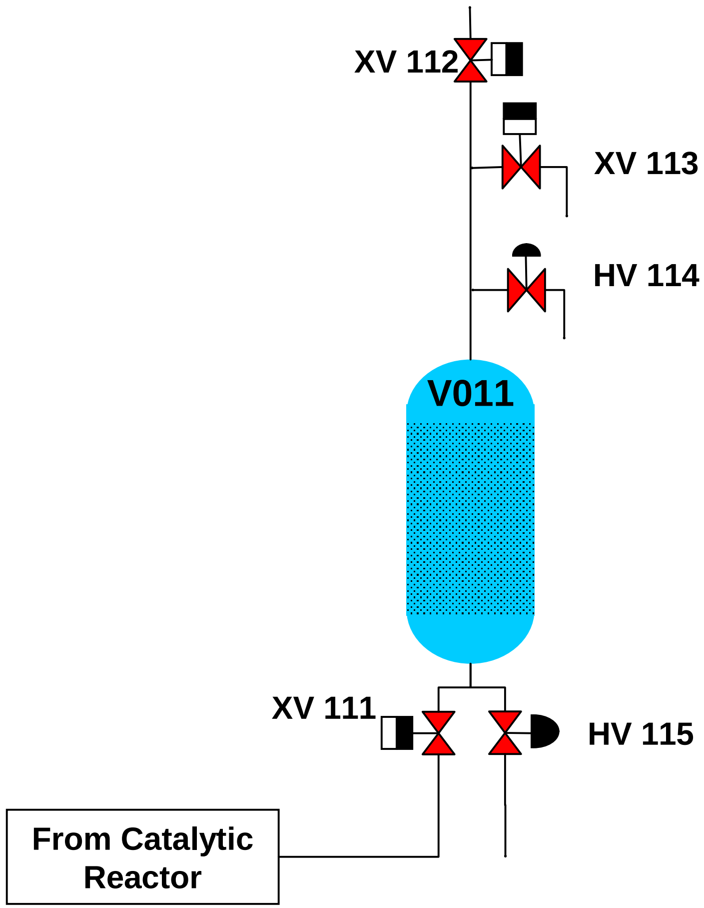
- **PHASE P**
- **ADSORPTION**
  - Upgraded Helium enters through feed valve 322 XV 111 and exits the vessel to reach production header through 322 XV 112.
  - Vessel 322 V011 is around 23.5 bar abs.



- **PHASE S – STEP 1**
- **Balancing Down**
  - Valves 322 XV 111 and 322 XV 112 close
  - Adsorber 322 V011 moves to phase S
  - 322 V011 pours its content into the adsorber in phase Q (322 V013), which is in Balancing Up step, through the top valves 322 XV 113 and 322 XV 133 until pressure equilibrium is reached.

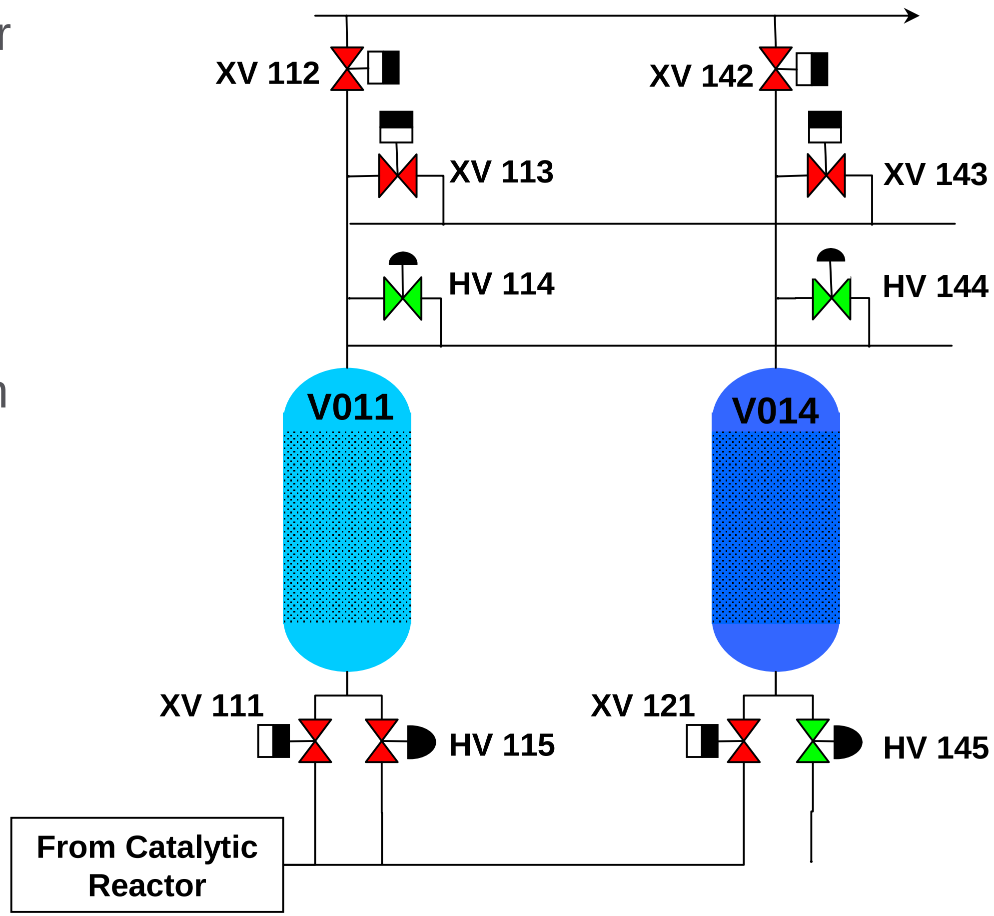


- **PHASE S – STEP 2**
- **Waiting**
  - During the waiting step, valve 322 XV 113 closes.
  - The pressure of the vessel 322 V011 remains constant all along the step (all valves of the vessel are closed).



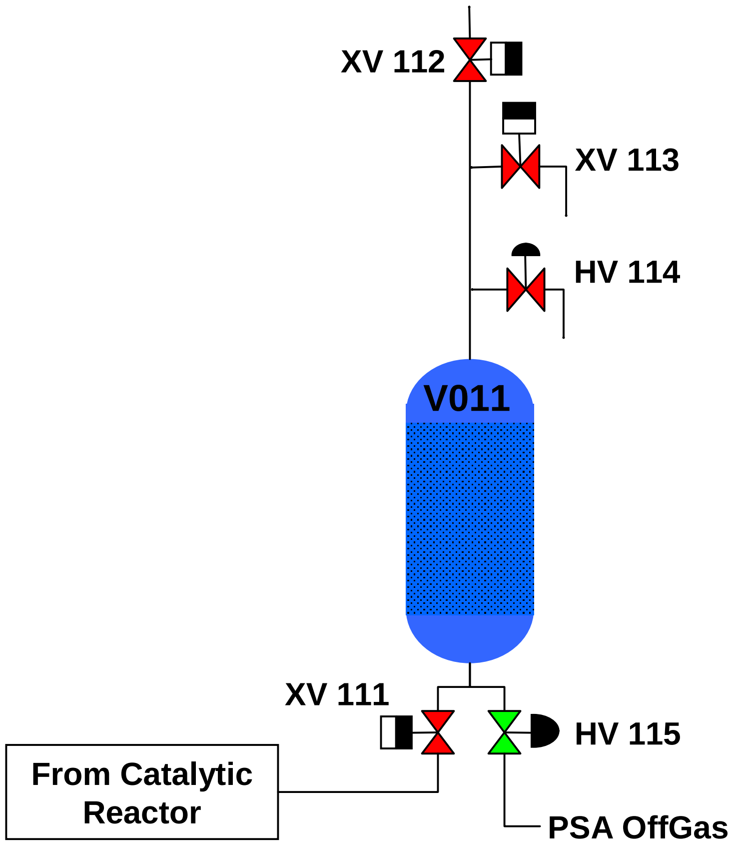
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- **PHASE S – STEP 3**
- **Purge Providing**
  - Pressure in 322 V011 is further decreased by sending gas to clean the vessel in purge step (phase R) 322 V014.
  - Purge gas is sent through control valve 322 HV 114 which is fully open and through control valve 322 HV 144 which controls the pressure ramp.
  - Part of the purge gas and the impurities desorbed in 322 V014 are sent to the offgas through control valve 322 HV 145 which is fully open.

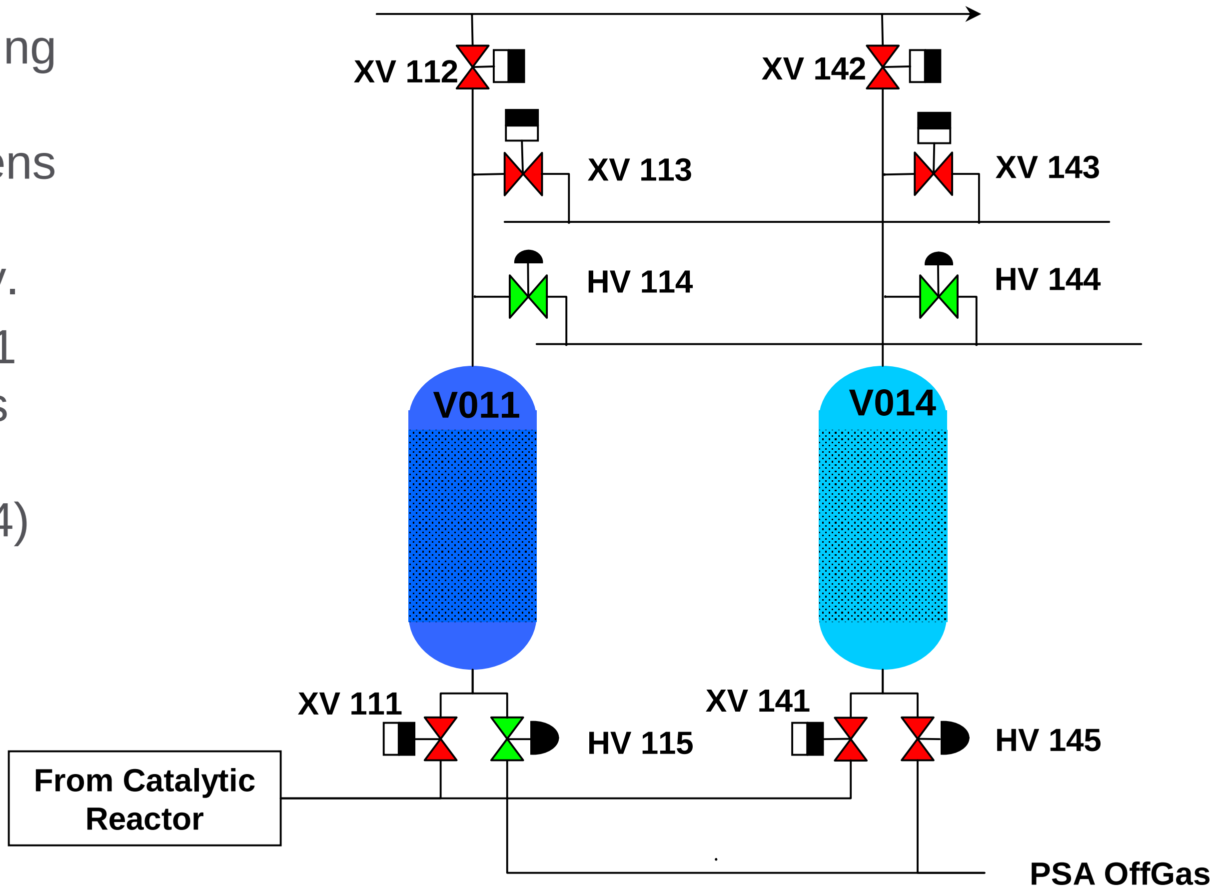


Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- **PHASE R – STEP 1**
- **BLOWING**
  - Pressure in 322 V011 is further decreased by having the adsorber blow into the offgas drum. Valve 322 HV 114 is closed
  - Valve 322 HV 115 controls the pressure ramp.

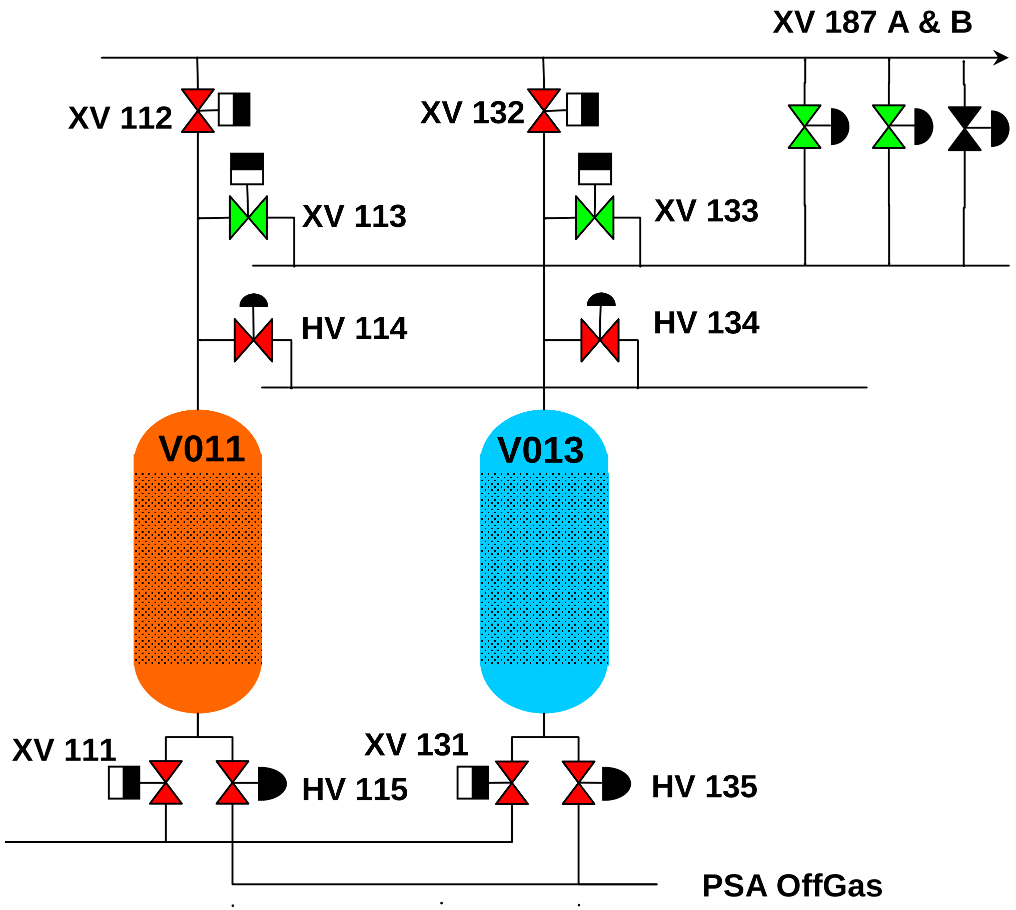


- **PHASE R – STEP 2**
- **ELUTION**
  - Valve 322 HV 115 which was controlling the Blow Down pressure ramp opens fully and valve 322 HV 144 opens fully.
  - Adsorber 322 V011 receives purge gas from adsorber in phase S (322 V014) through the control valve 322 HV 144 which controls the pressure ramp



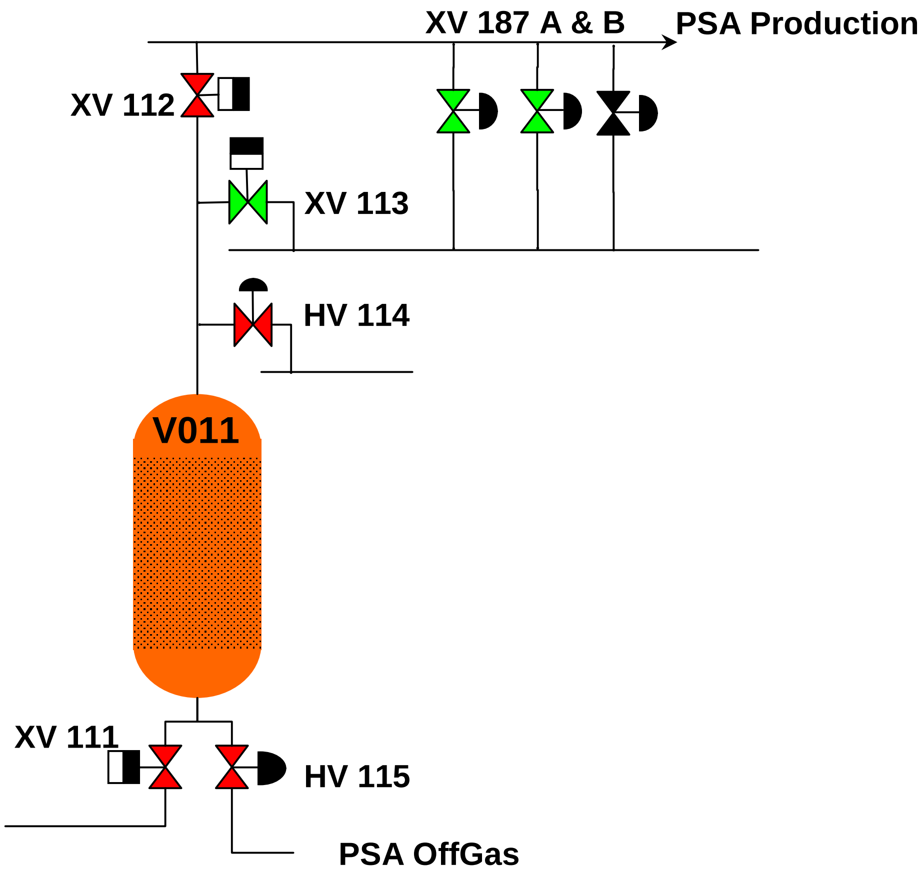
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Valves 322 HV 144, 322 HV 114 and 322 HV-115 close at the end of the elution step.
- **PHASE Q – STEP 1**
- **Balancing Up**
  - Valve 322 HV 113 opens.
  - Adsorber 322 V011 receives gas from adsorber 322 V013, which is in phase S through valve 322XV-133 until pressure equilibrium is reached
  - At the same time, adsorber 322 V011 receives gas from the production header through control valves 322 HV 187 A and B



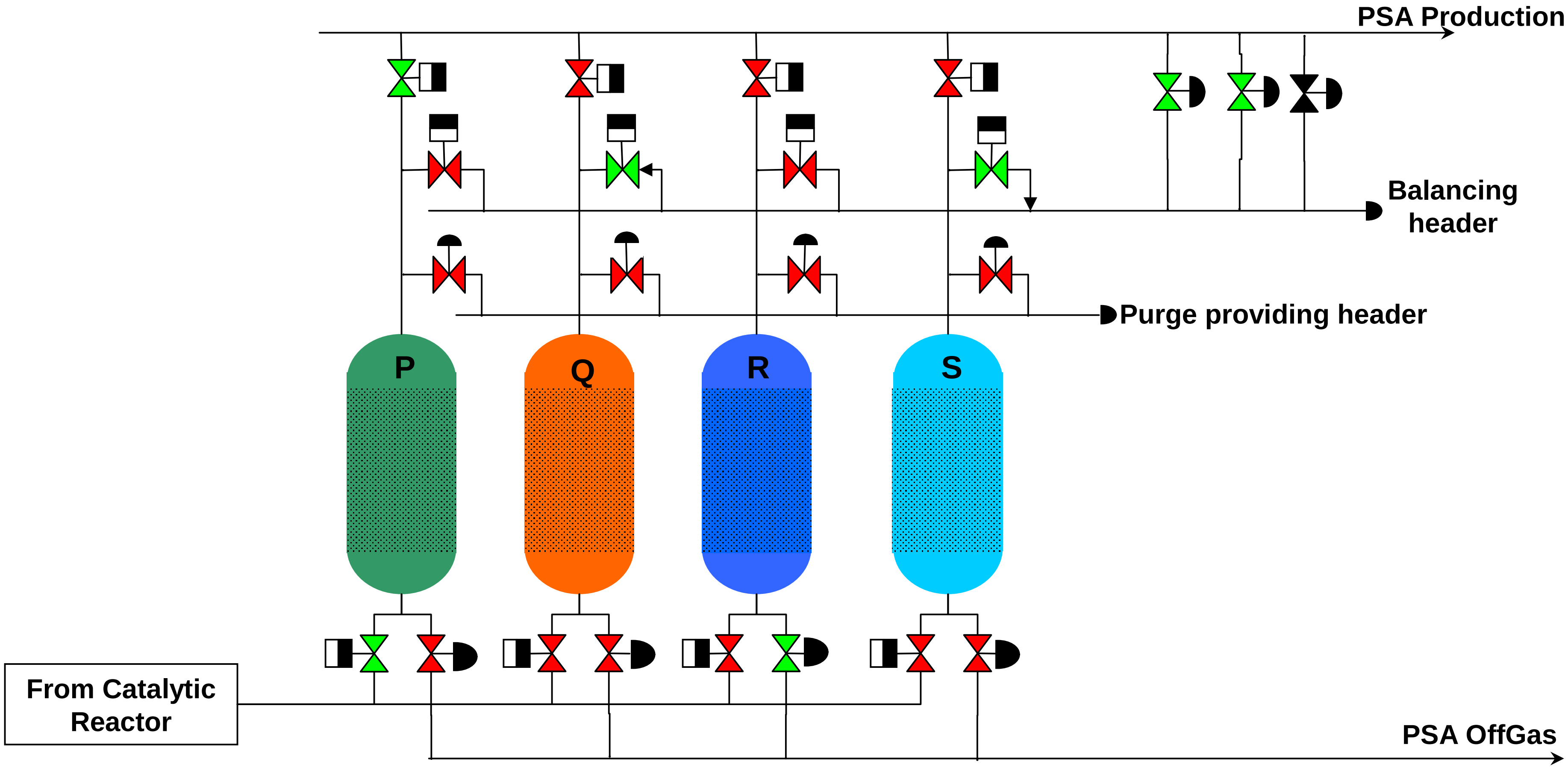
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- **PHASE Q – STEP 2**
- **Repressurization**
  - Before adsorber 322 V011 is ready to be operated in adsorption again, its pressure must be increased to 23.5 bara.
  - Gas from the production header is used for this purpose.



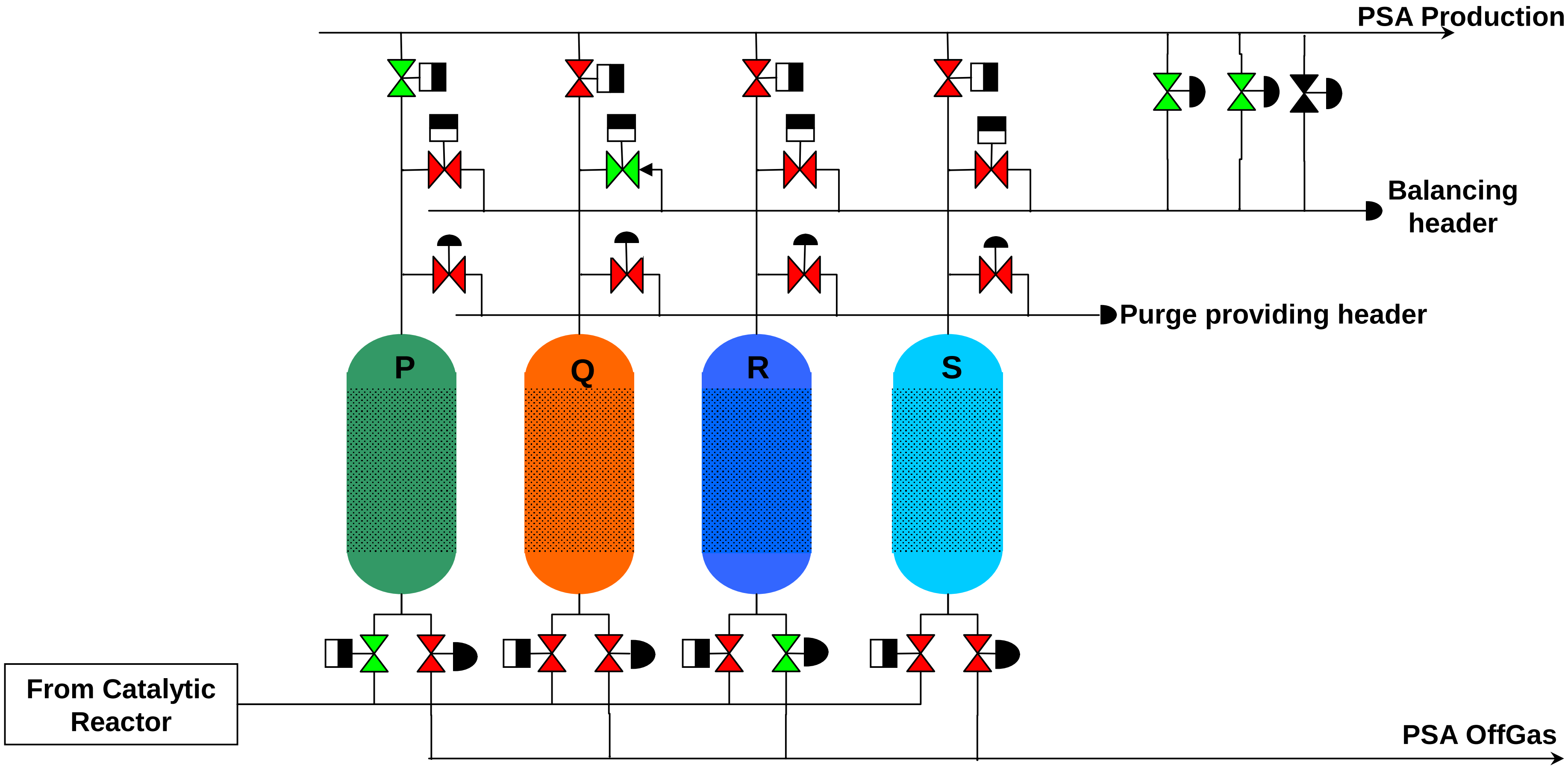
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - First temporal unit: pressure balance between Q and S



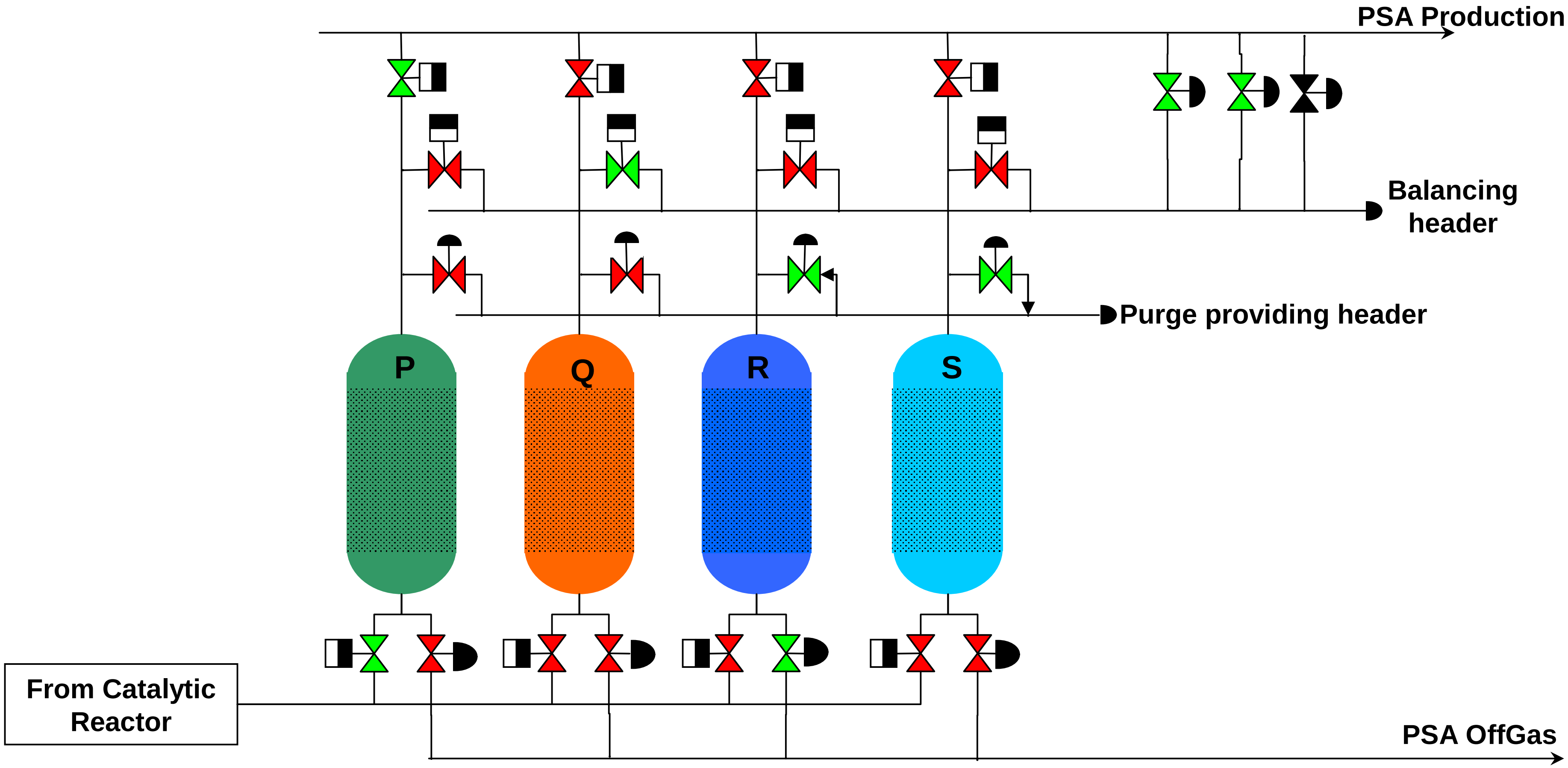
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - Second temporal unit: S is waiting, Q is in repressurization



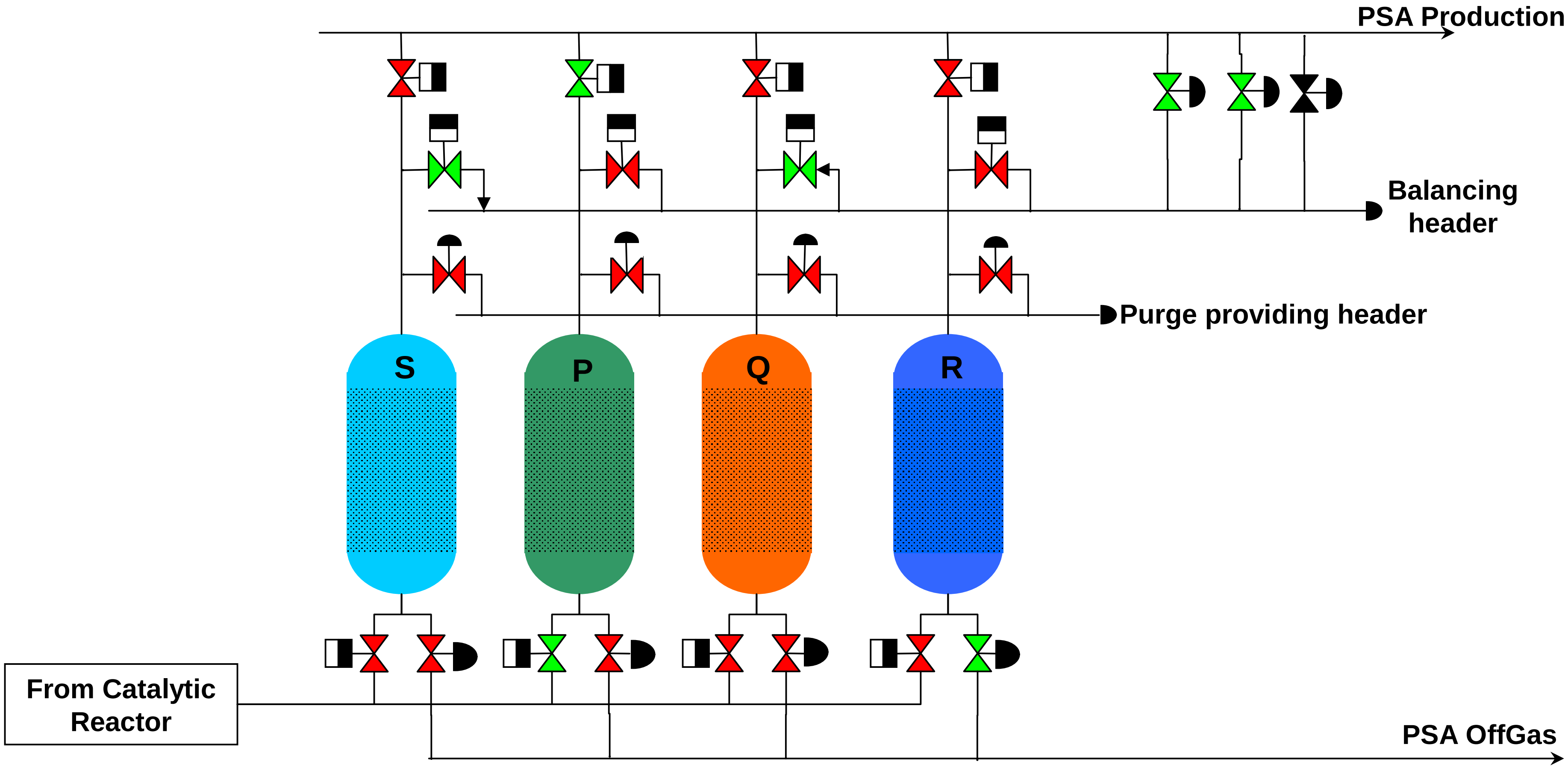
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - Third temporal unit: S provides purge to R



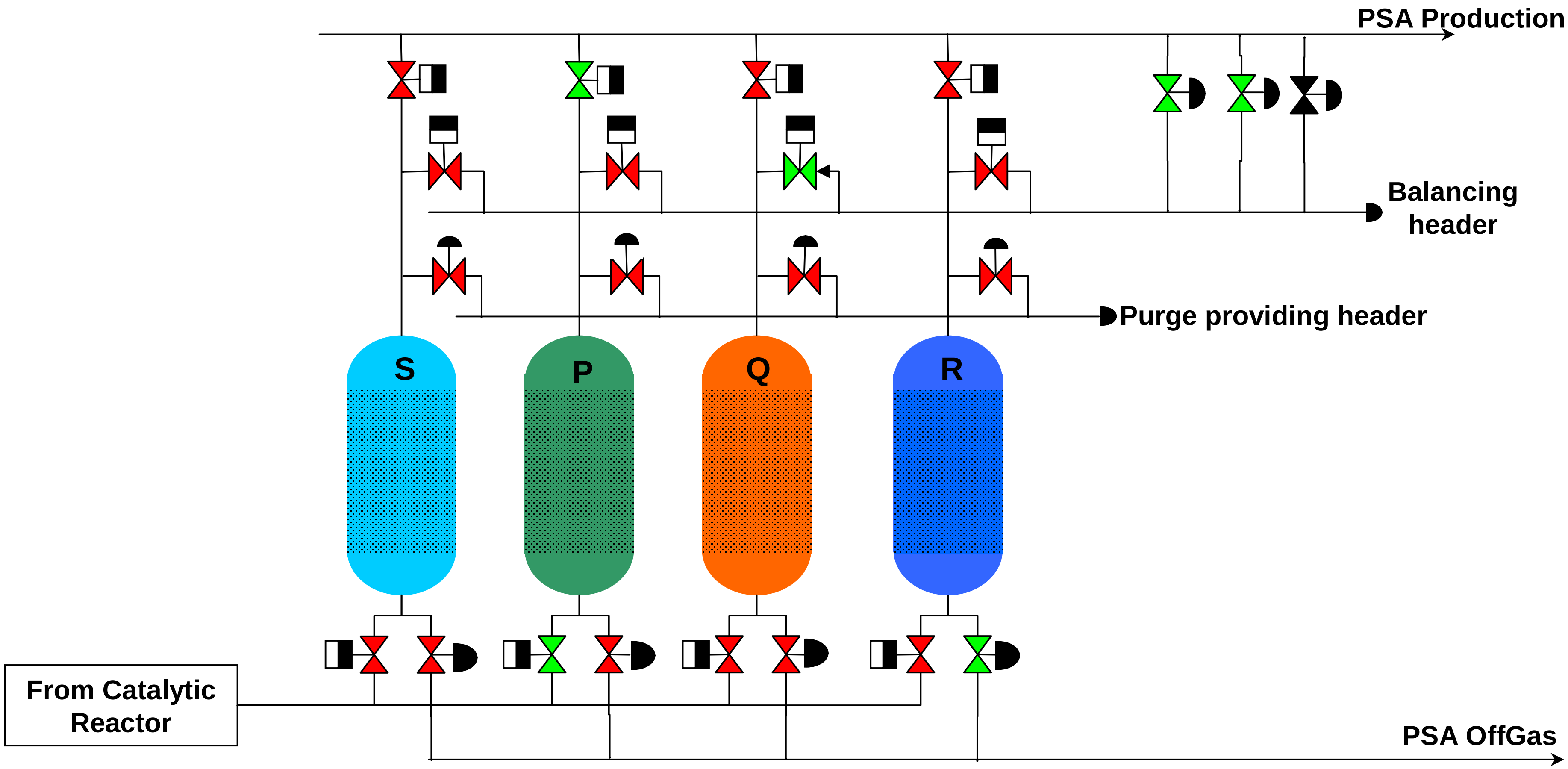
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 2
  - First temporal unit: S and Q are in pressure balance



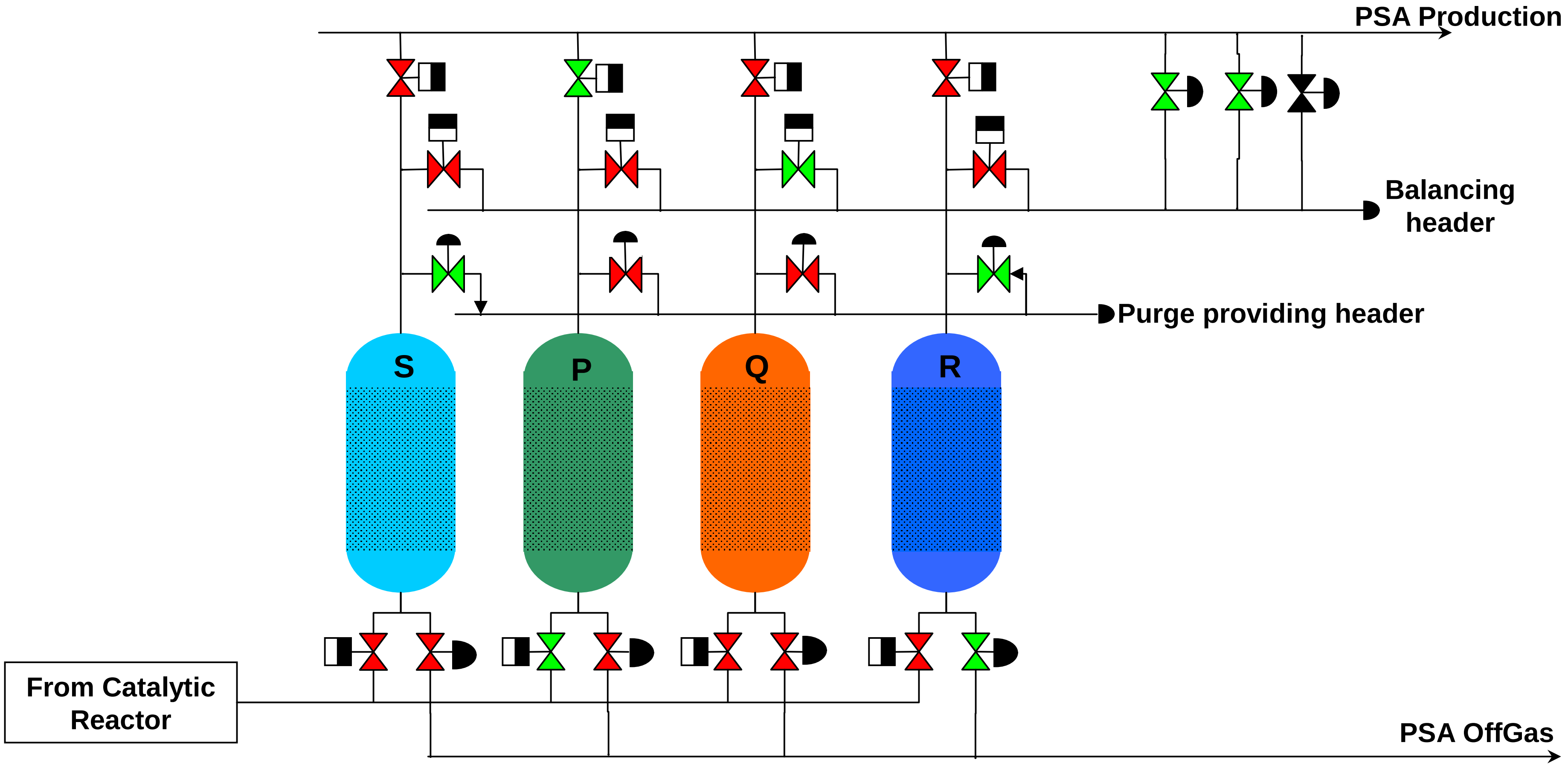
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 2
  - Second temporal unit: S is waiting, Q is in repressurization



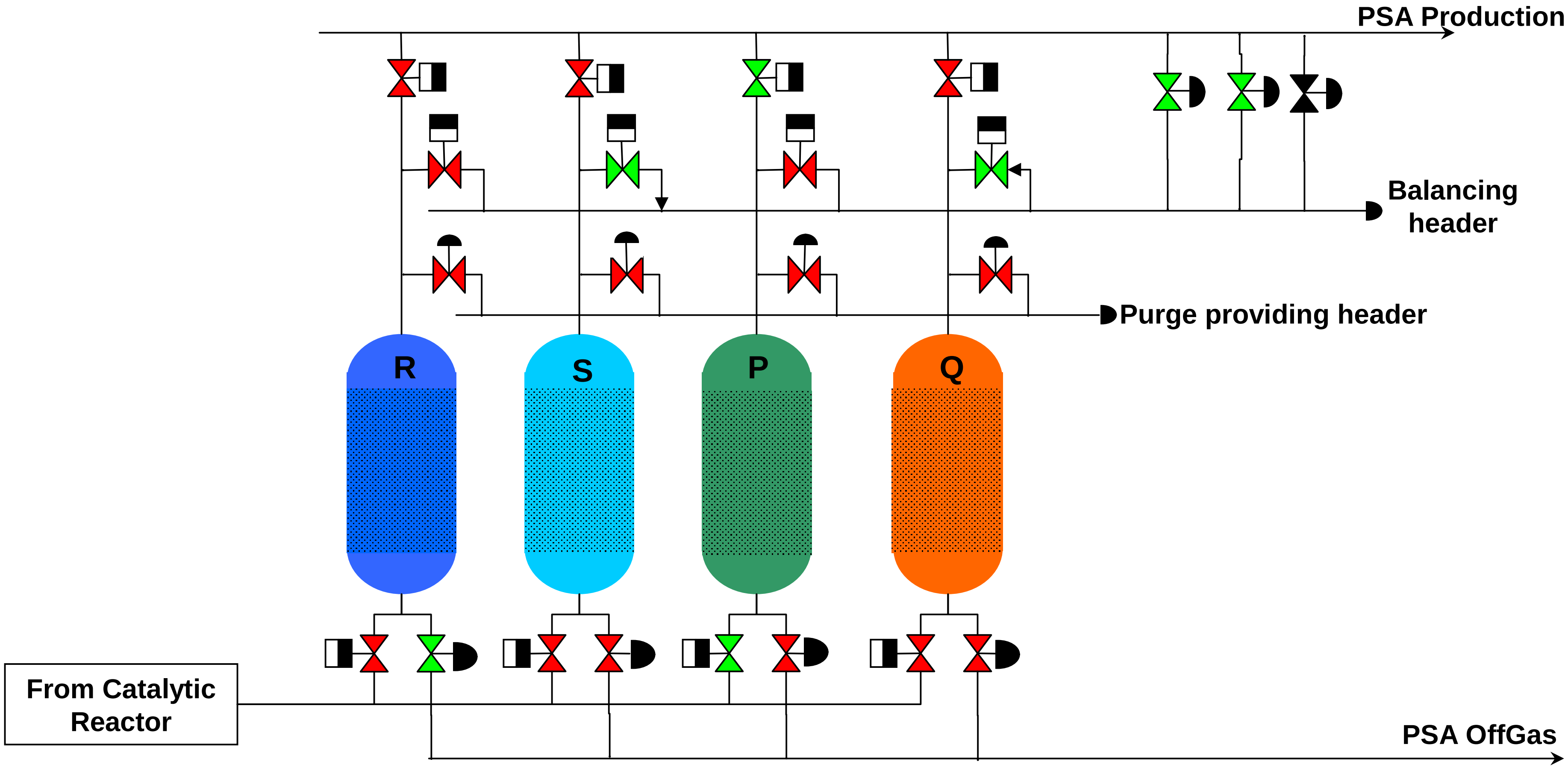
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 2
  - Third temporal unit: S provides purge to R



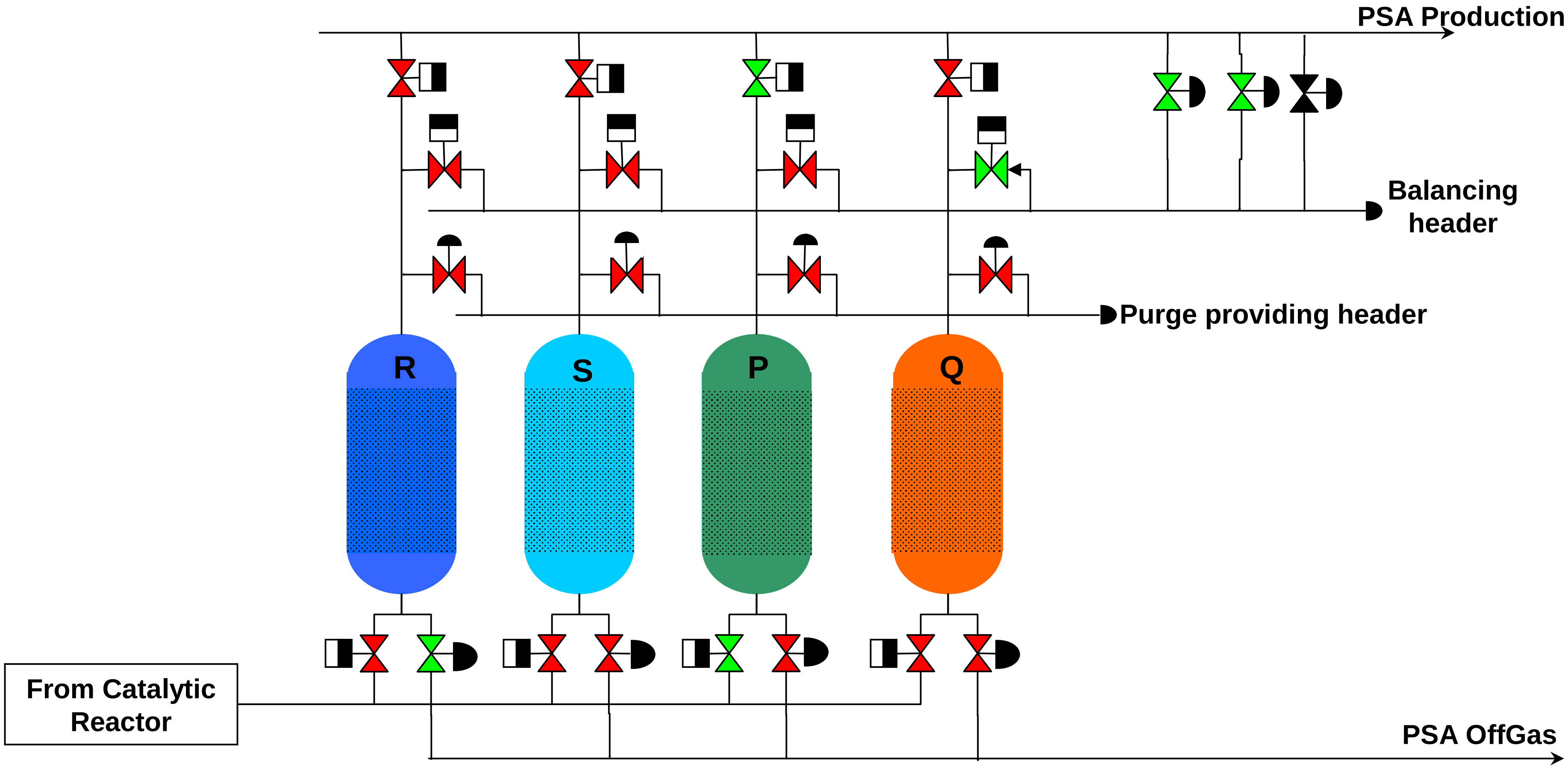
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - First temporal unit: S and Q are in pressure balance



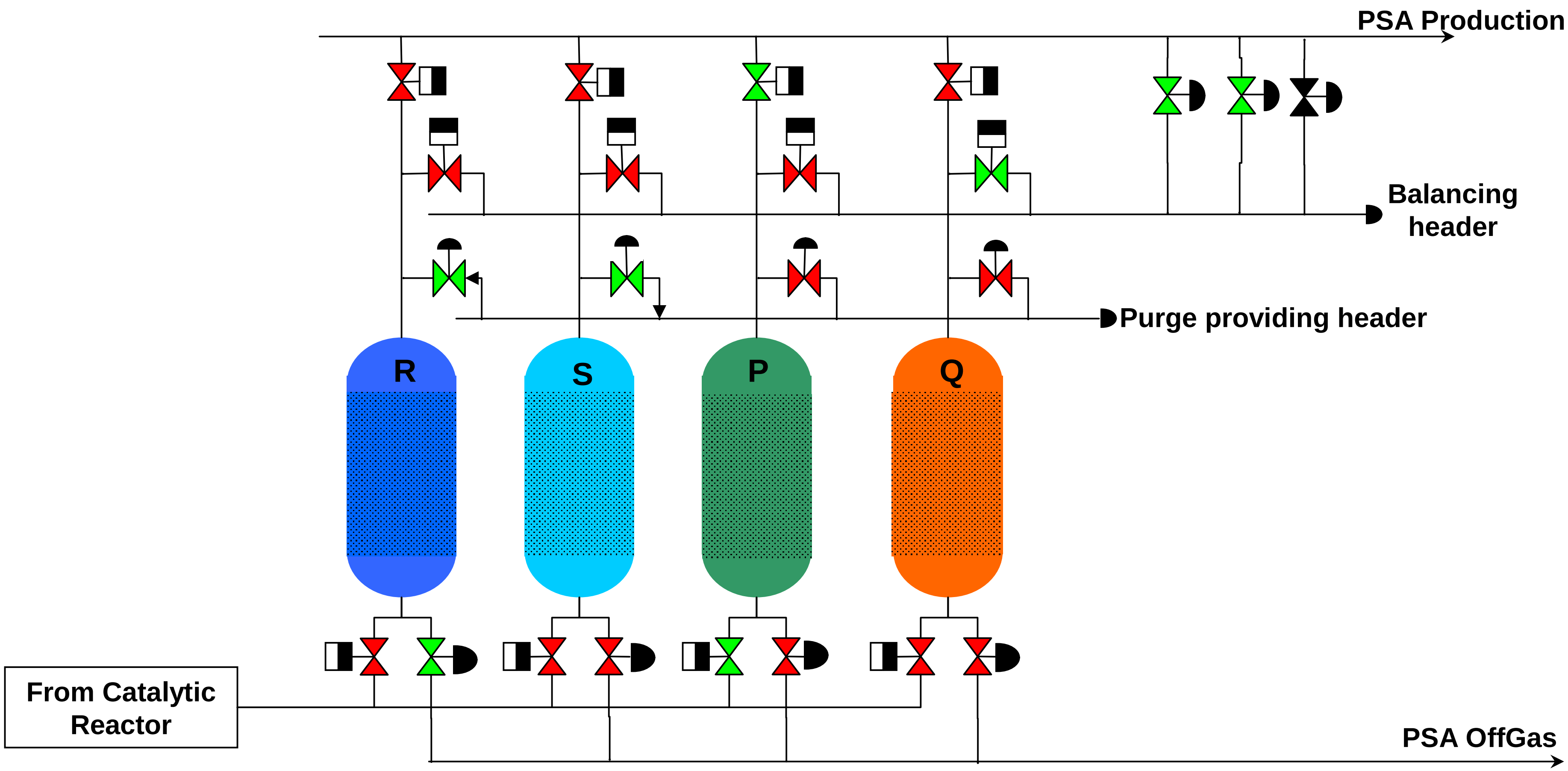
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - Second temporal unit: S is waiting, Q is in repressurization



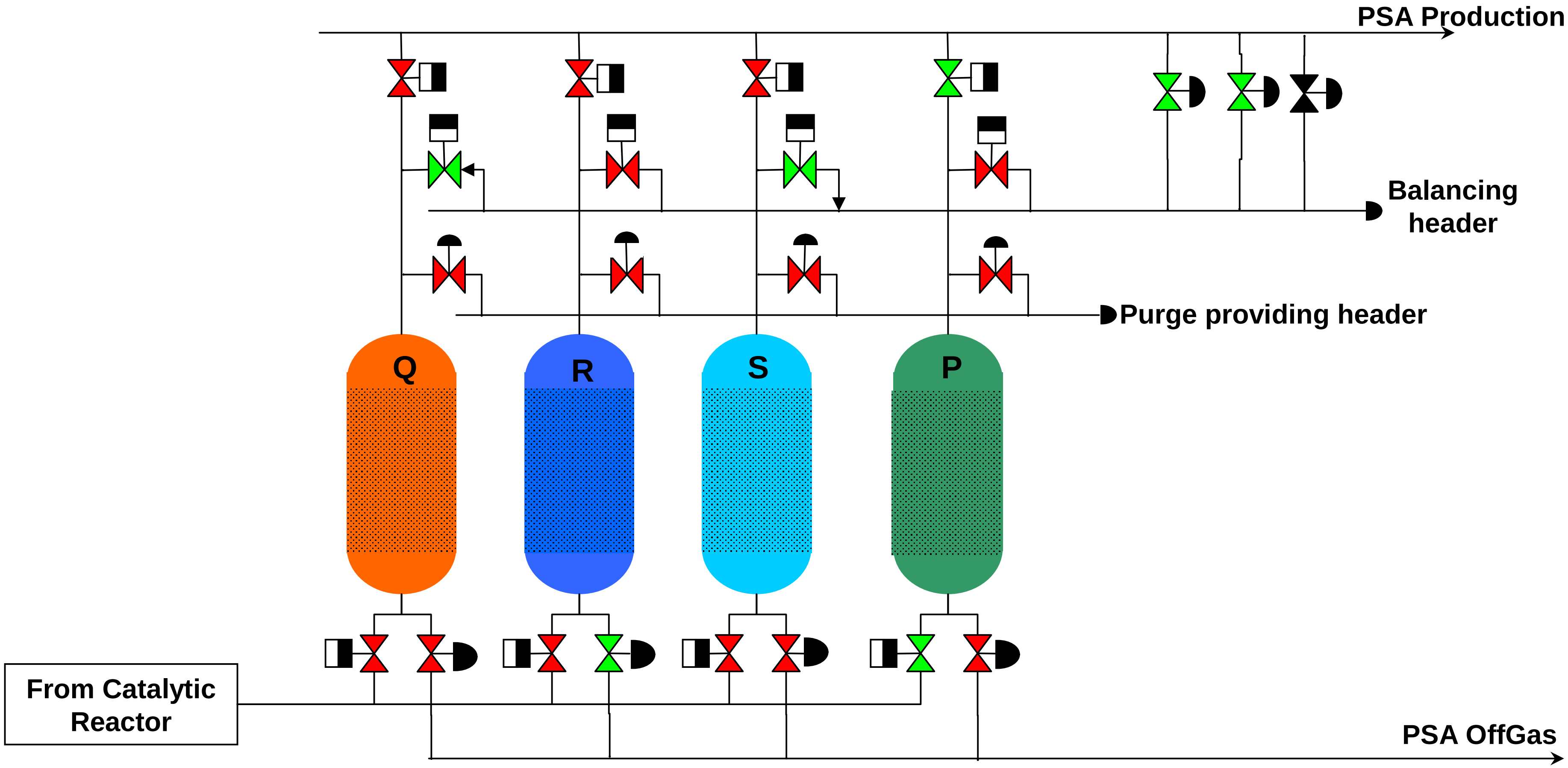
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - Third temporal unit: S provides purge to R



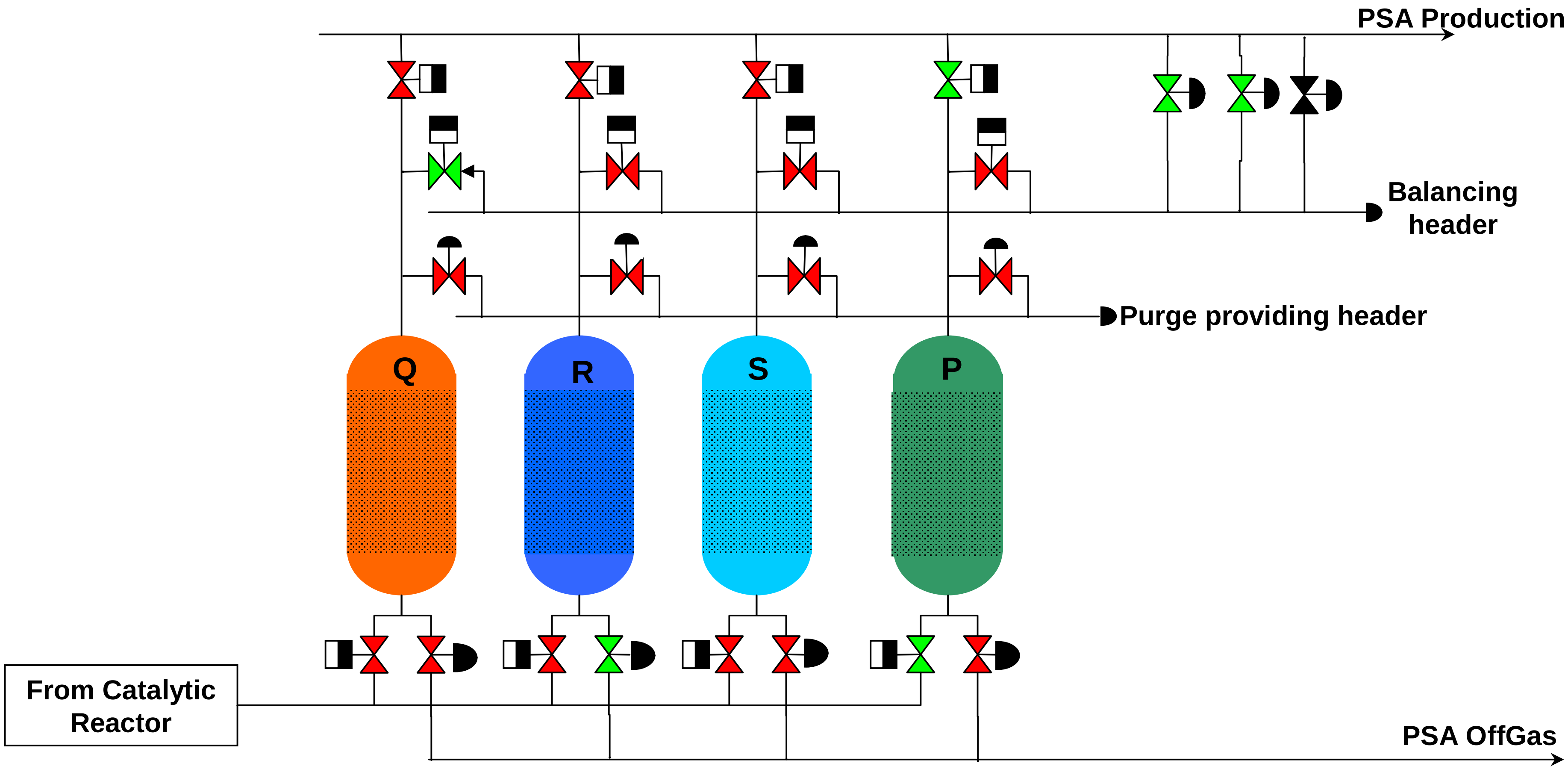
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 4
  - First temporal unit: S and Q are in pressure balance



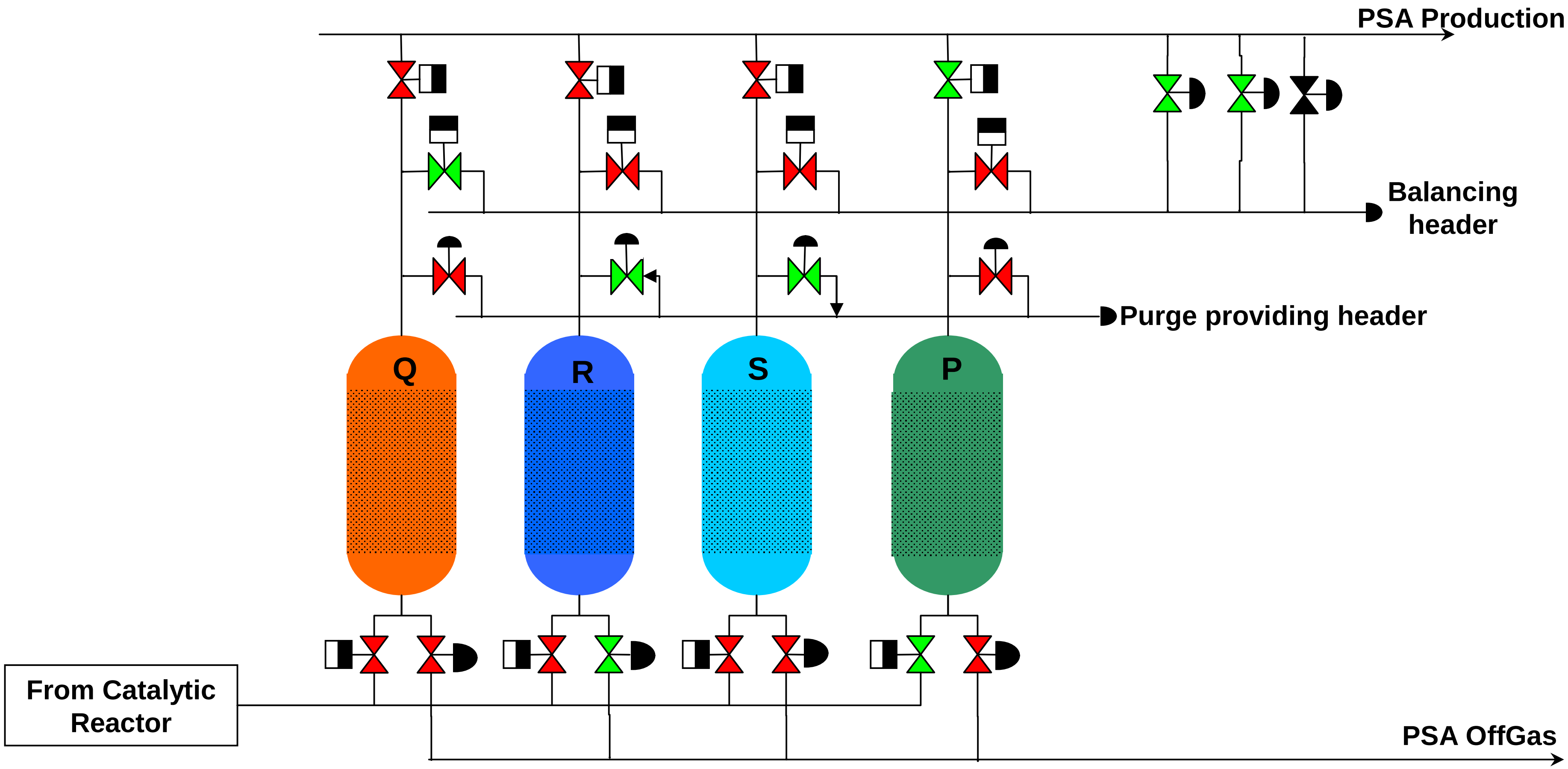
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 4
  - Second temporal unit: S is waiting, Q is in repressurization



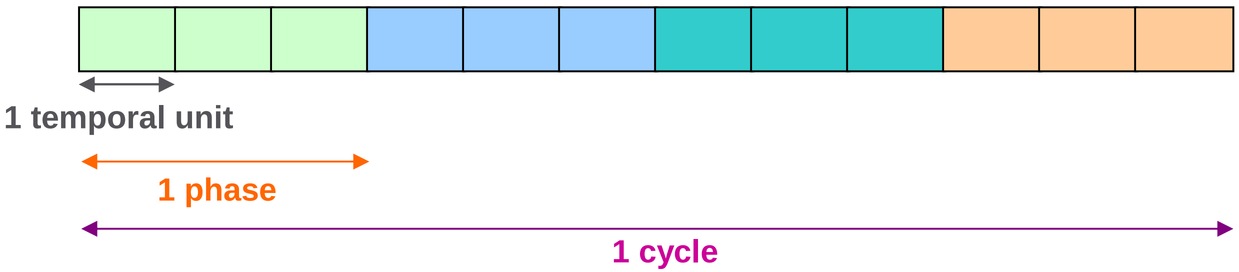
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 4
  - Third temporal unit: S provides purge to R



Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- At any time:
  - 1 vessel is under adsorption (phase 1)
  - 2 vessels are under depressurization or regeneration (phase 2 and 3)
  - 1 vessel is under repressurization (phase 4)
- One cycle = 4 phases
  - One cycle time = 4 x [phase duration] = 4 x [3 x temporal unit]
  - Depends upon the gas flow to be treated



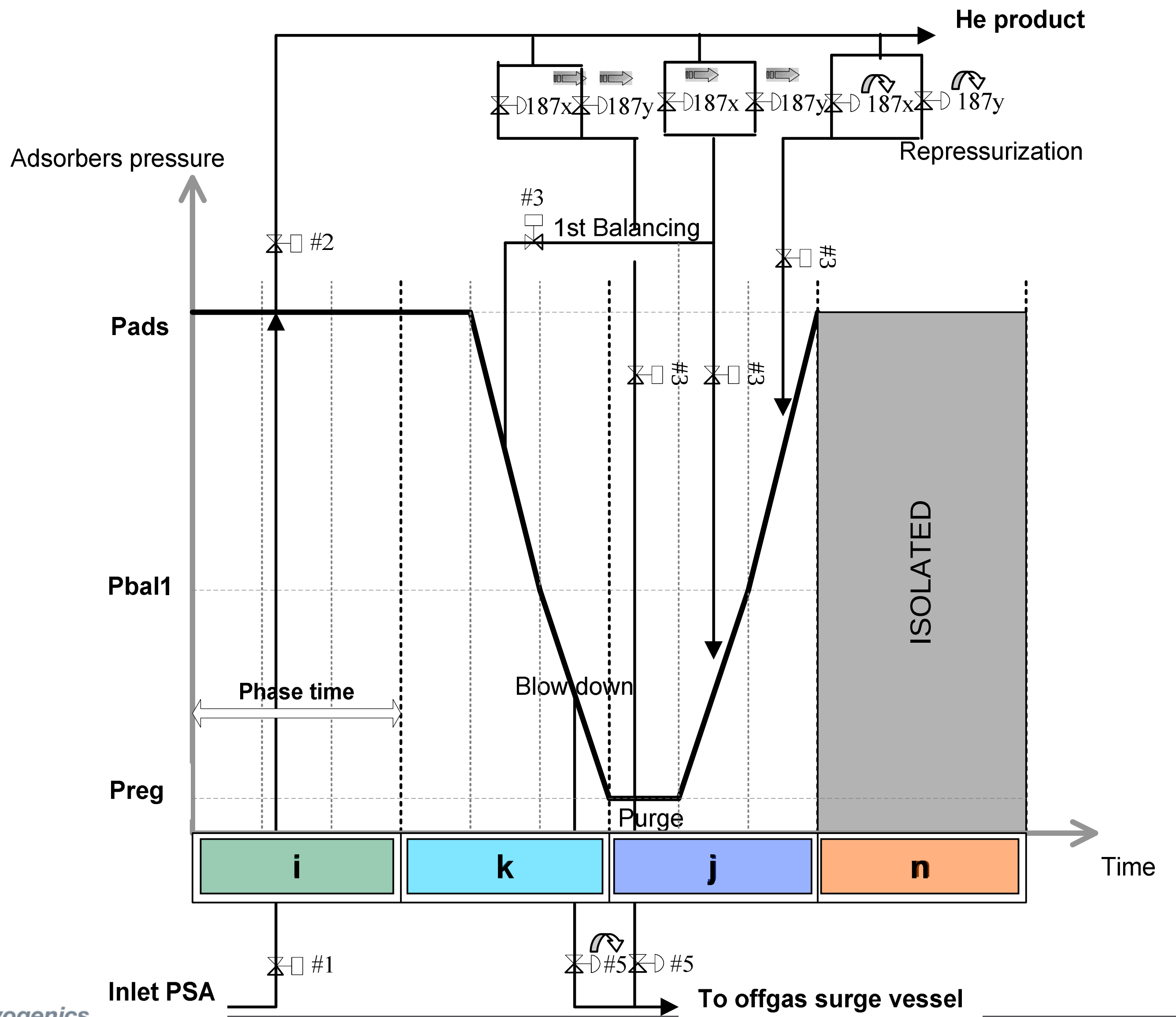
Purified Helium is mixed with the HP helium compressor 323 K002 A and B outlets and sent to Liquefier Exchanger 324 E001

Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- During exceptional valve maintenance, the PSA can run at reduced capacity with only 3 adsorbers in operation in order to allow on-line maintenance of the PSA valve skid.

- Switching the PSA from 4 to 3 adsorbers will be done on-line keeping stable and continuous He supply.

Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*



i = Vessel in production

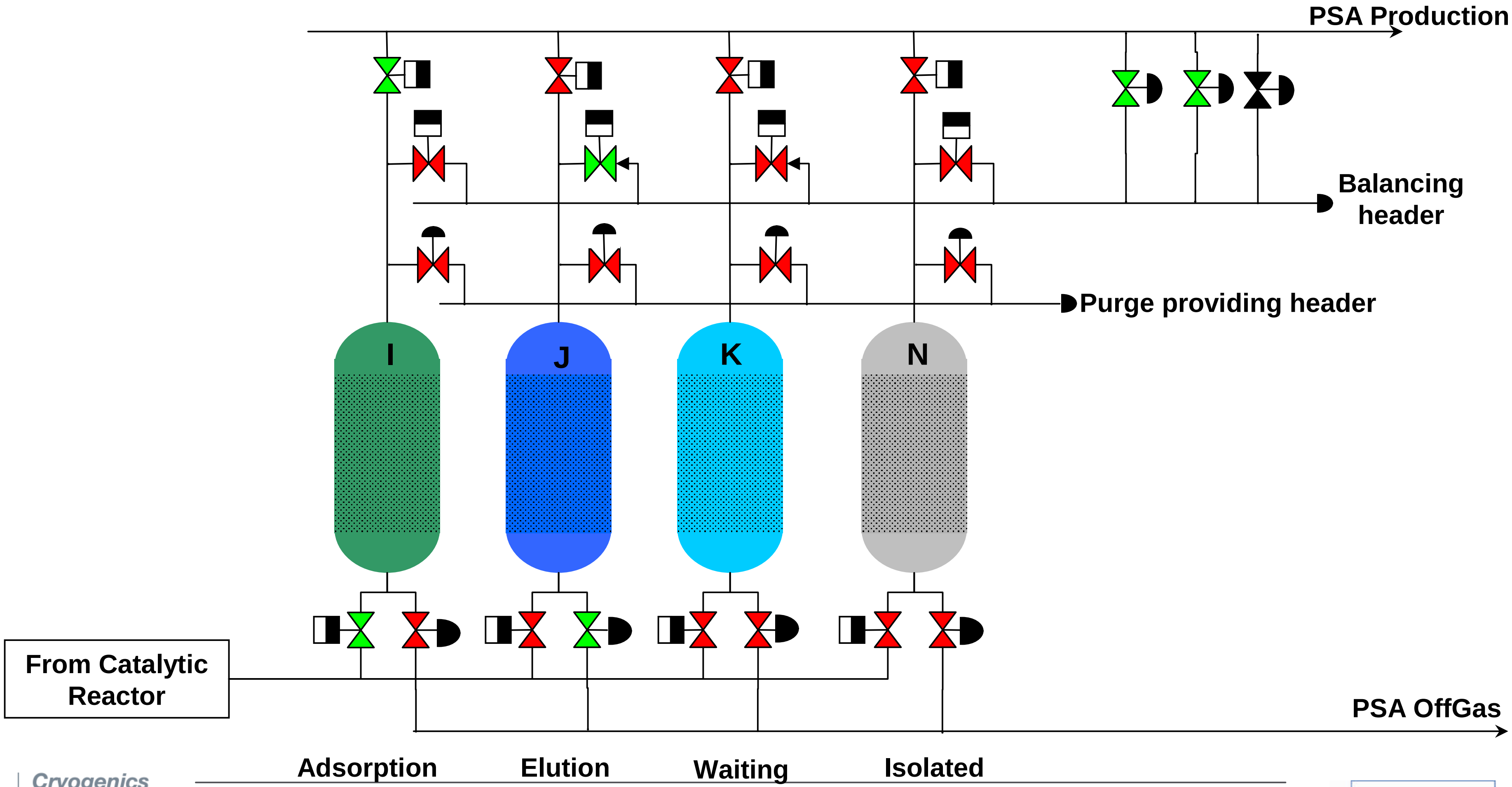
k = Vessel in depressurization

j = Vessel in regeneration/ repressurization

n = Isolated vessel

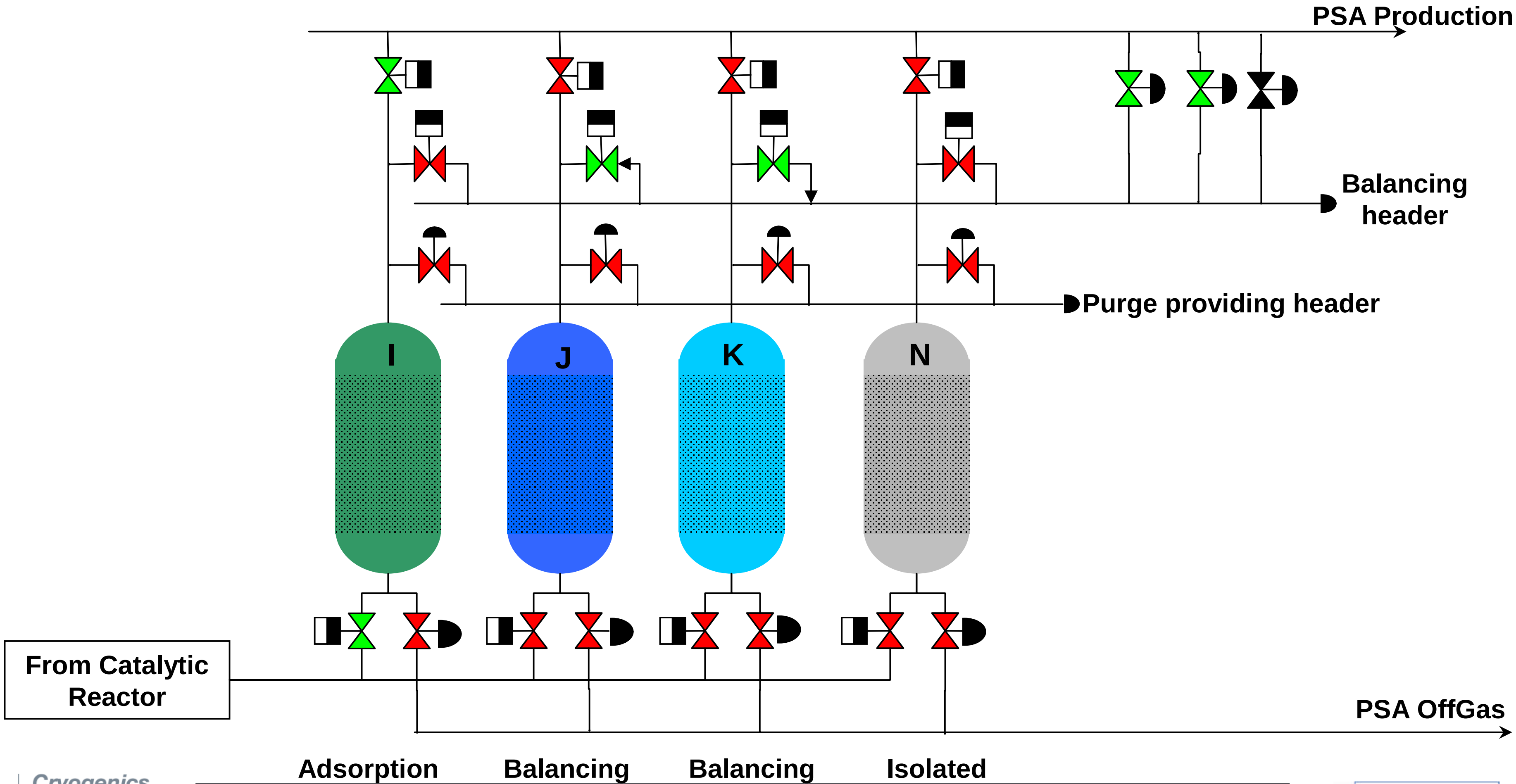
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - First temporal unit: K is waiting, J is purged with production



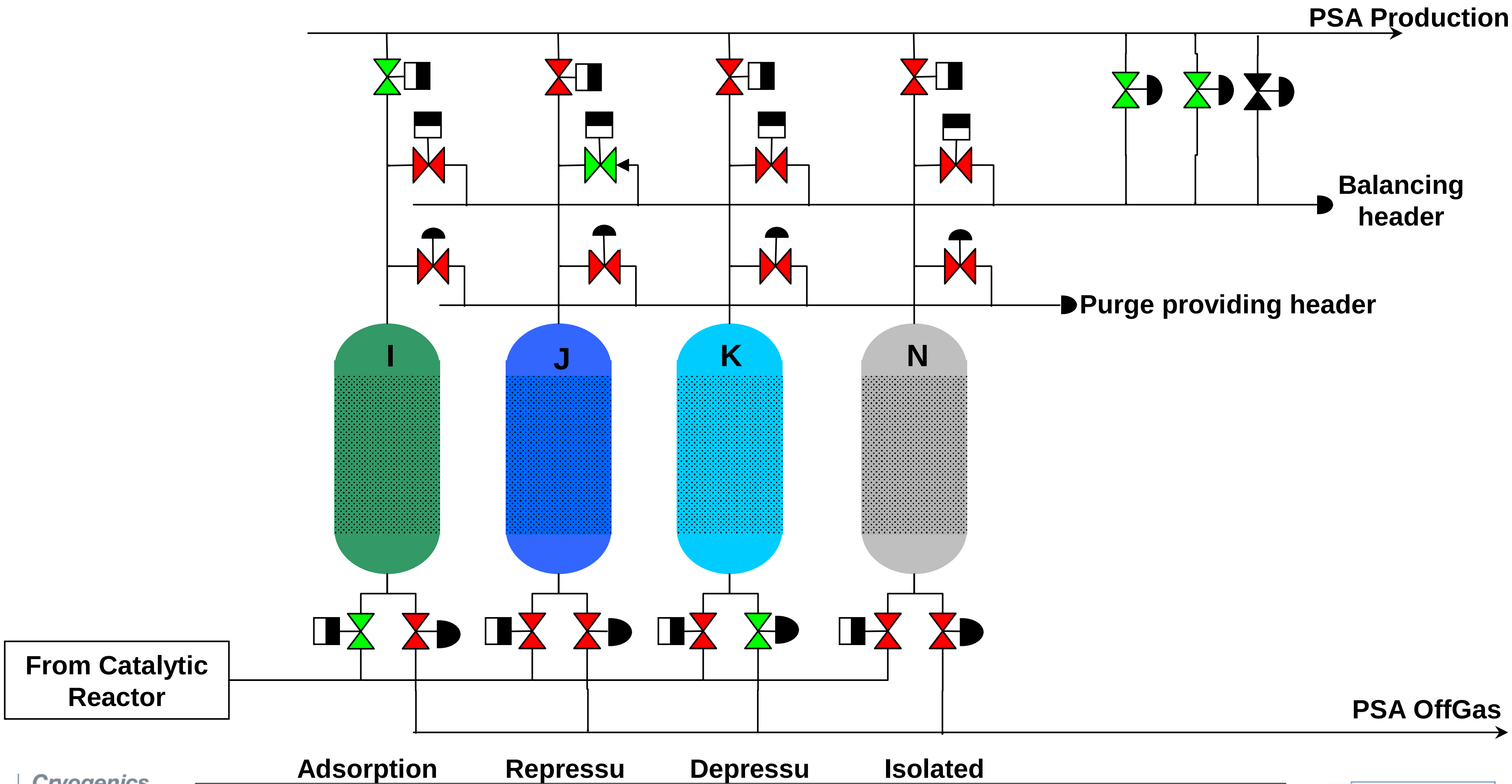
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - Second temporal unit: pressure balance between J and K



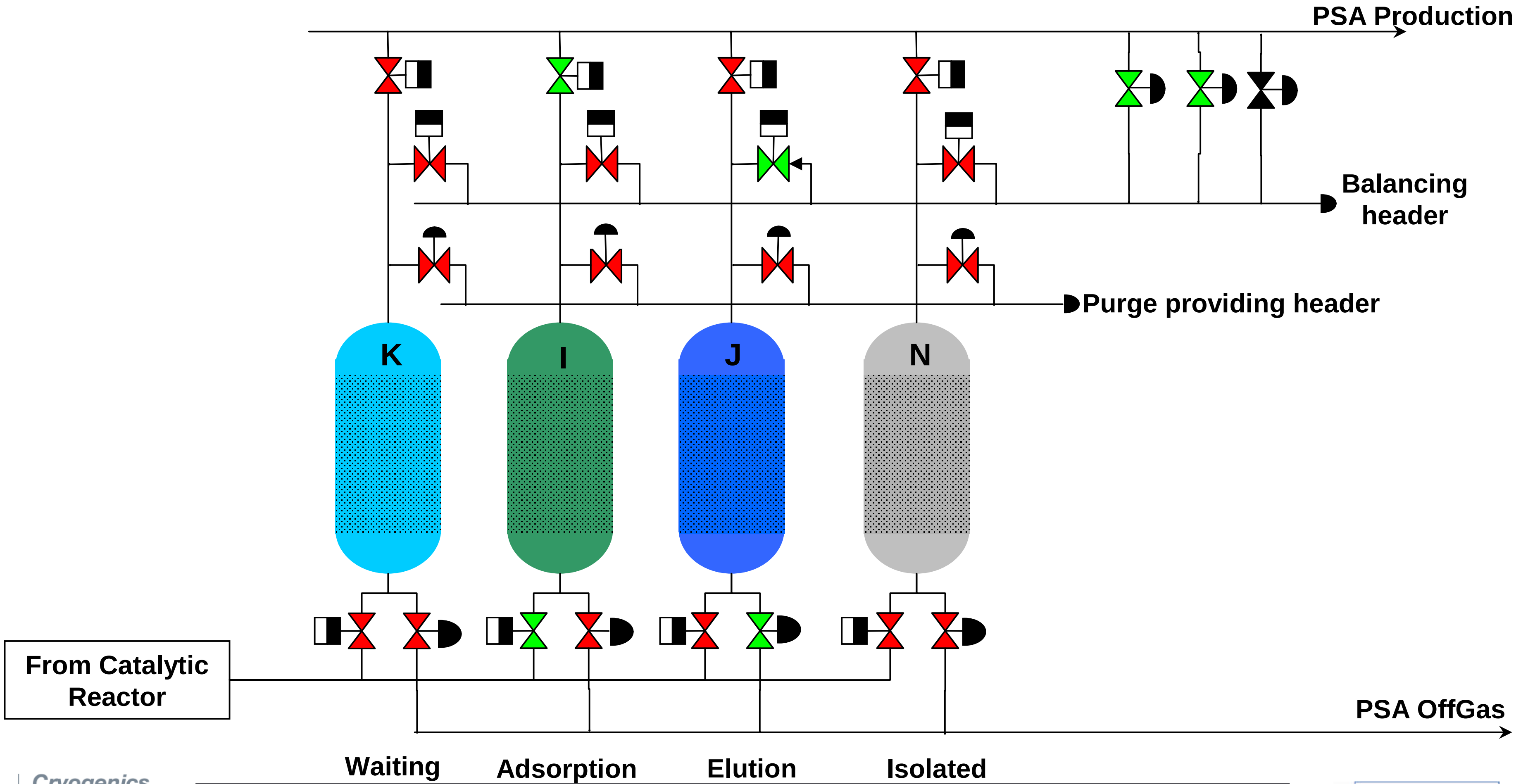
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 1
  - Third temporal unit: J is in repressurization, K is in blow down



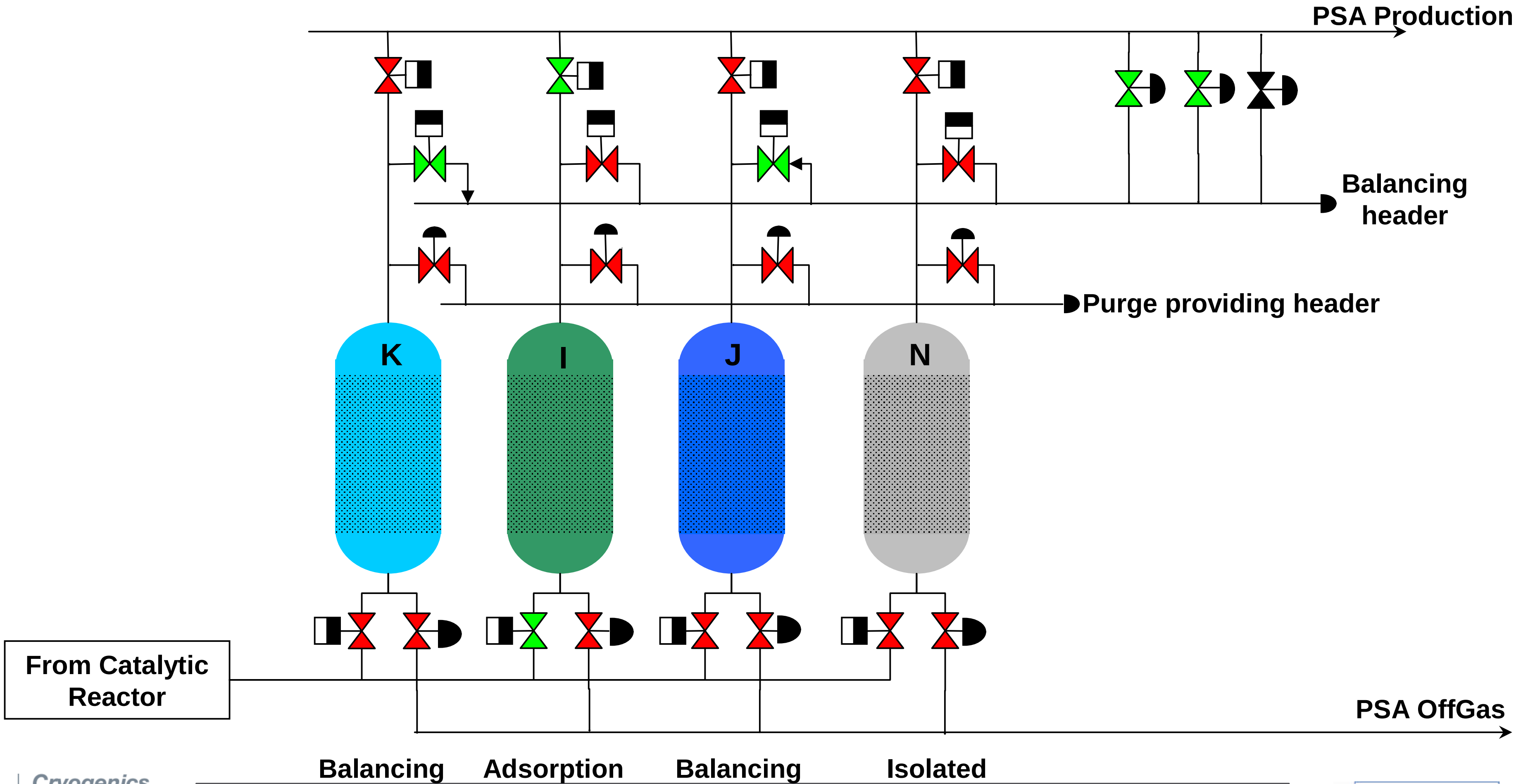
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 2
  - First temporal unit: K is waiting, J is purge with production

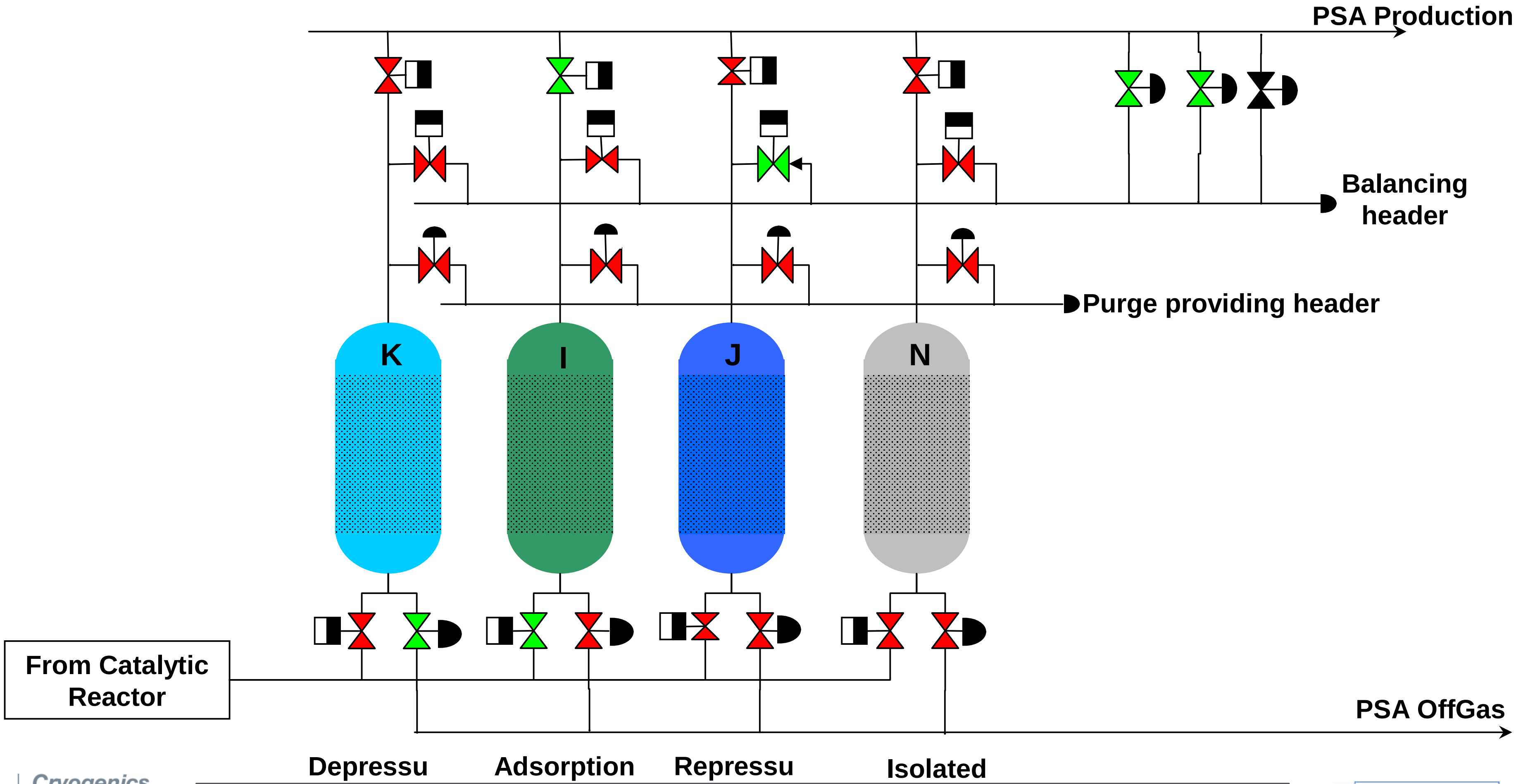


Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 2
  - Second temporal unit: pressure balance between J and K

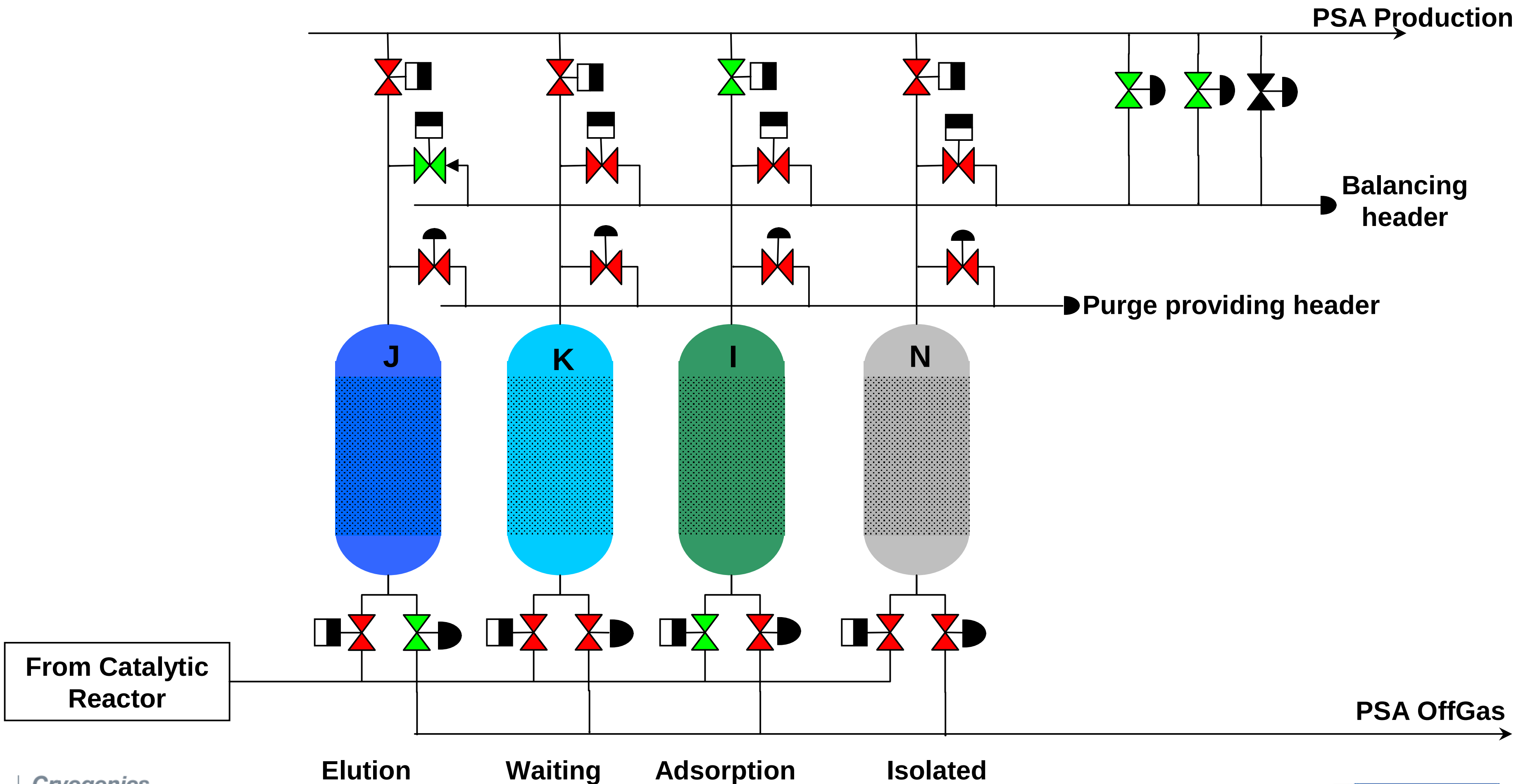


- Phase 2
  - Third temporal unit : J is in repressurization, K is in blow down



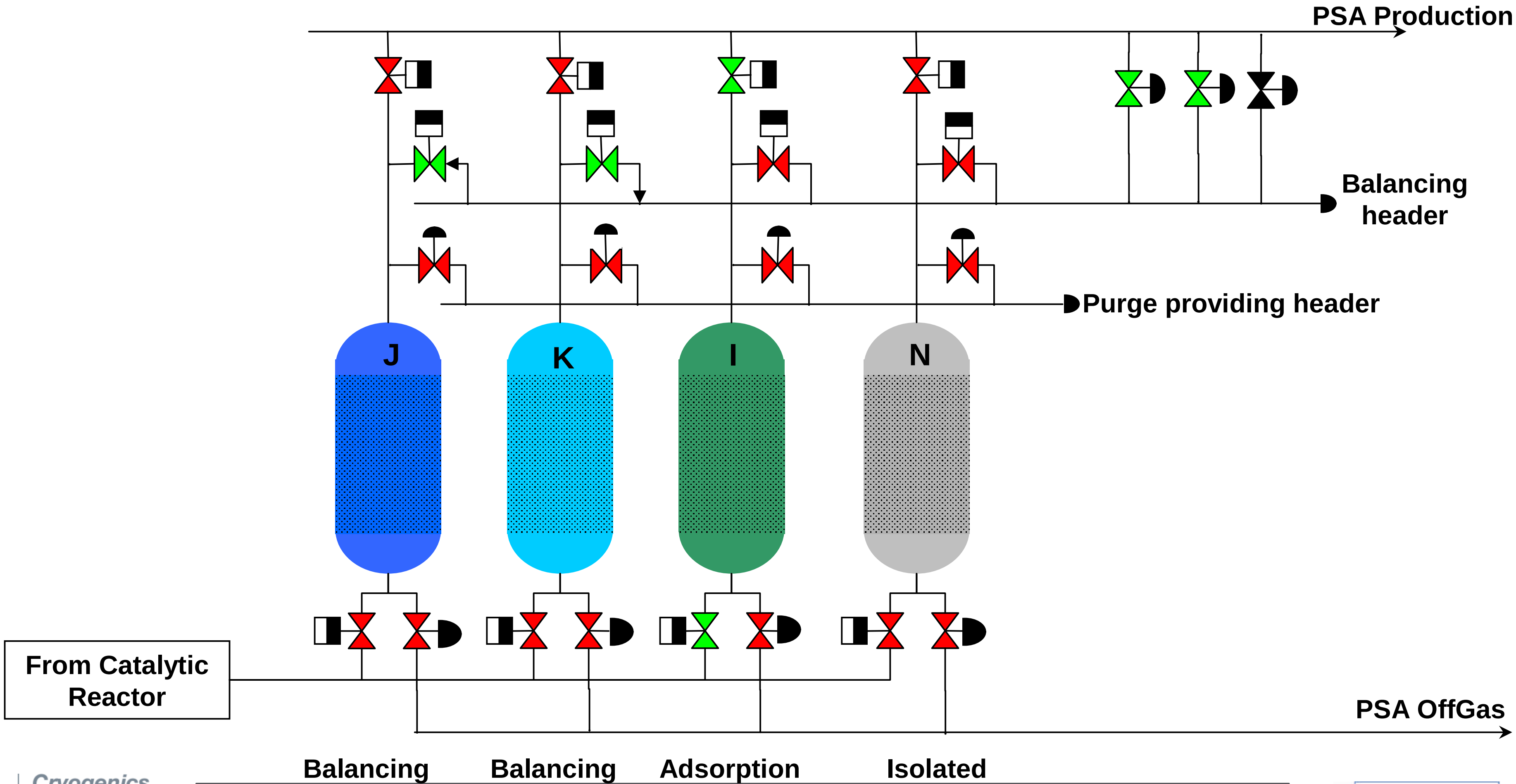
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - First temporal unit: K is waiting, J is purged with production



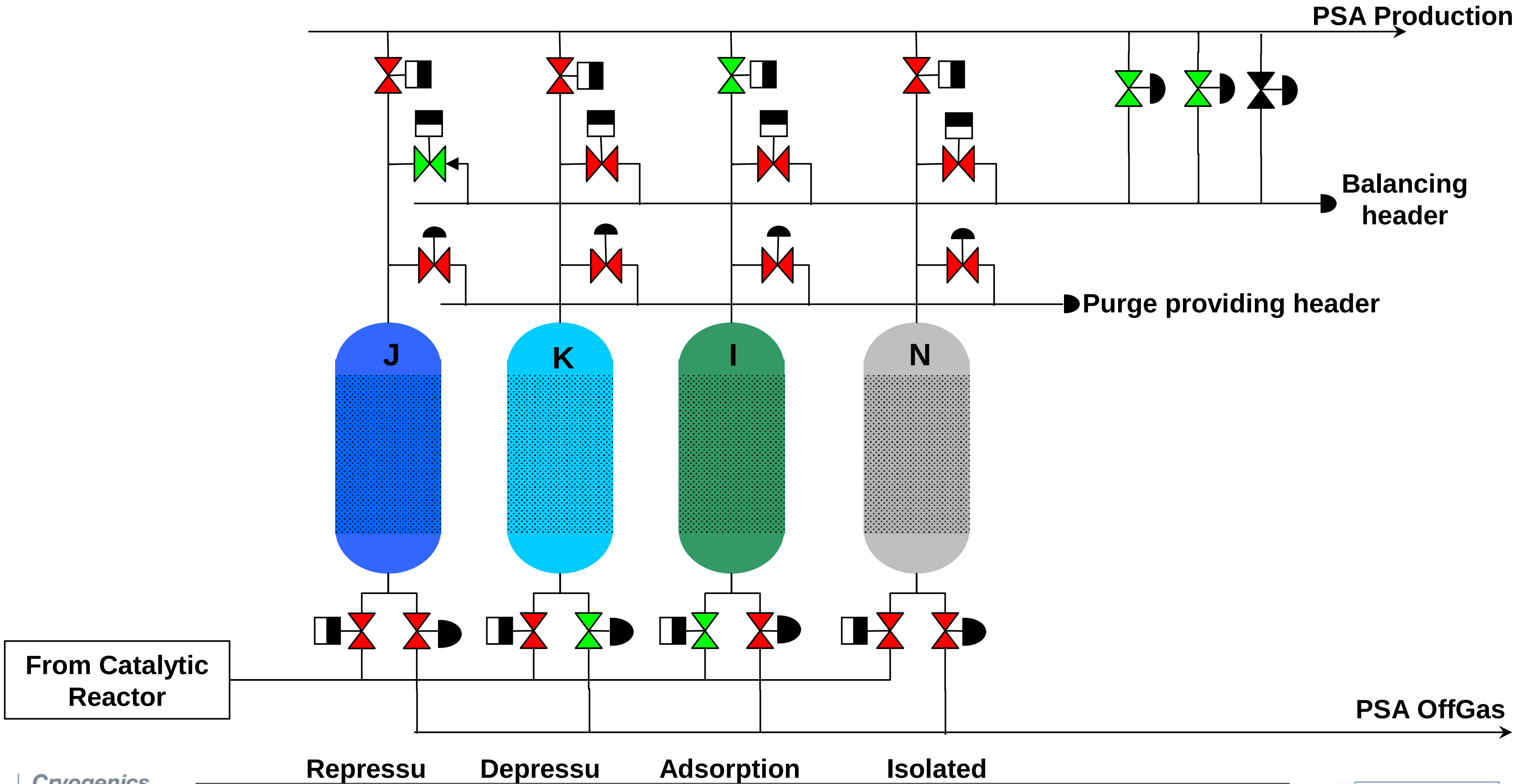
Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - Second temporal unit: pressure balance between J and K



Process description – Unit 322 – PSA (*Pressure Swing Adsorption)*

- Phase 3
  - Third temporal unit : J is in repressurization, K is in blow down



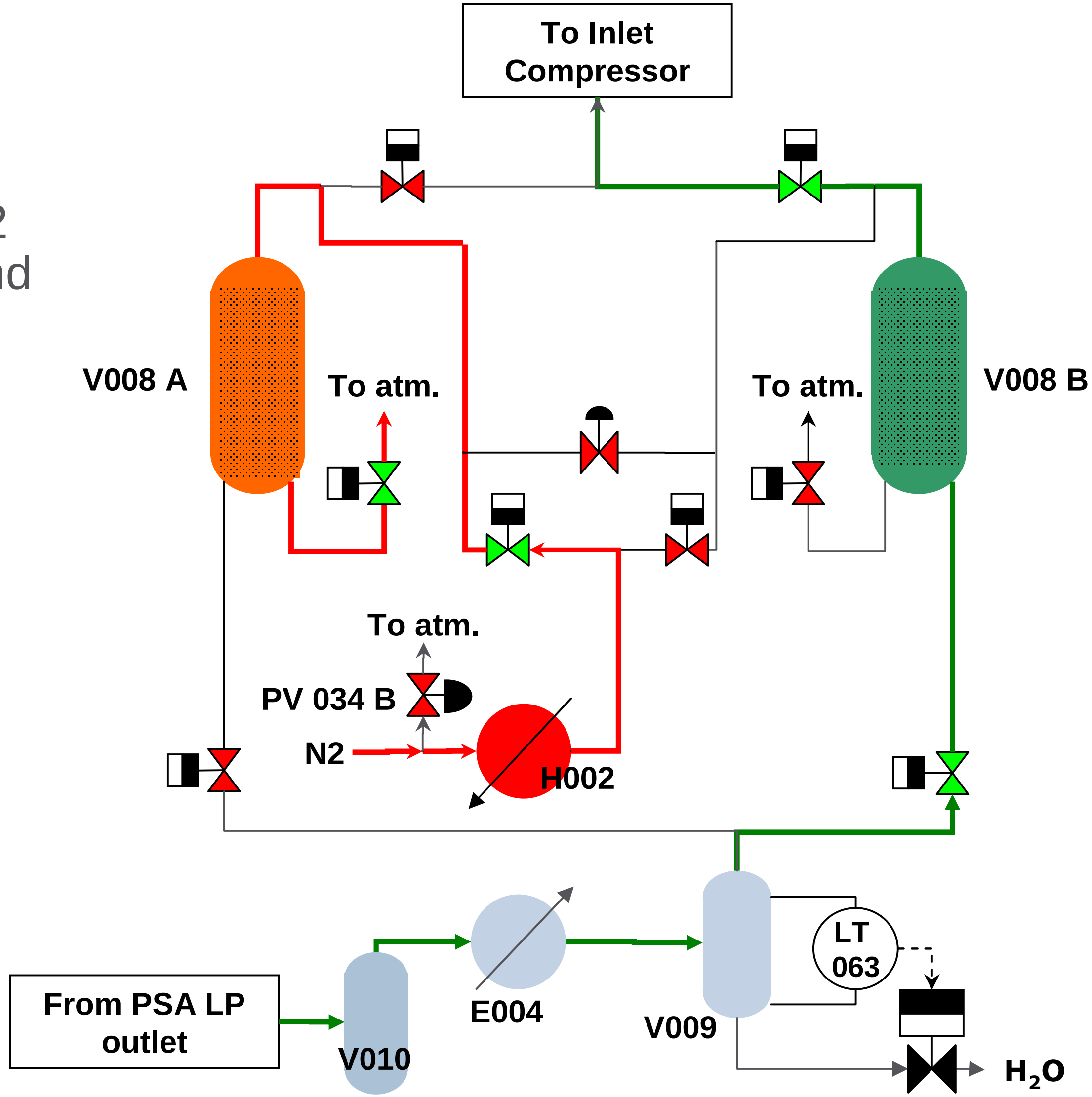
Process description – Unit 322 – PSA OffGas Adsorbers

- The LP outlet from PSA carrying over impurities is treated in the PSA OffGas Adsorbers 322 V008 A and B.
- The PSA OffGas still contains 69% Helium, thus PSA OffGas is recovered at Inlet Compressor suction, after drying in PSA OffGas Adsorbers.
- PSA OffGas Adsorbers allows removing H_2O and CO_2 from PSA OffGas.
- To ensure a continuous process, 2 adsorbers are used:
  - One is lined up: during PSA OffGas circulation in the adsorber, H2O, CO and CO_2 are adsorbed.
  - The other adsorber is in regeneration mode: a regeneration gas circulates at high temperature in the adsorber, carrying over the adsorbed impurities to atmosphere.
- Regeneration is performed with N_2 at high temperature
- Each phase (adsorption/regeneration) lasts 6 hours
- Dryer operation is fully automated with a sequence of 16 steps based on physical parameters and timers.

Process description – Unit 322 – PSA OffGas Adsorbers

ADSORPTION

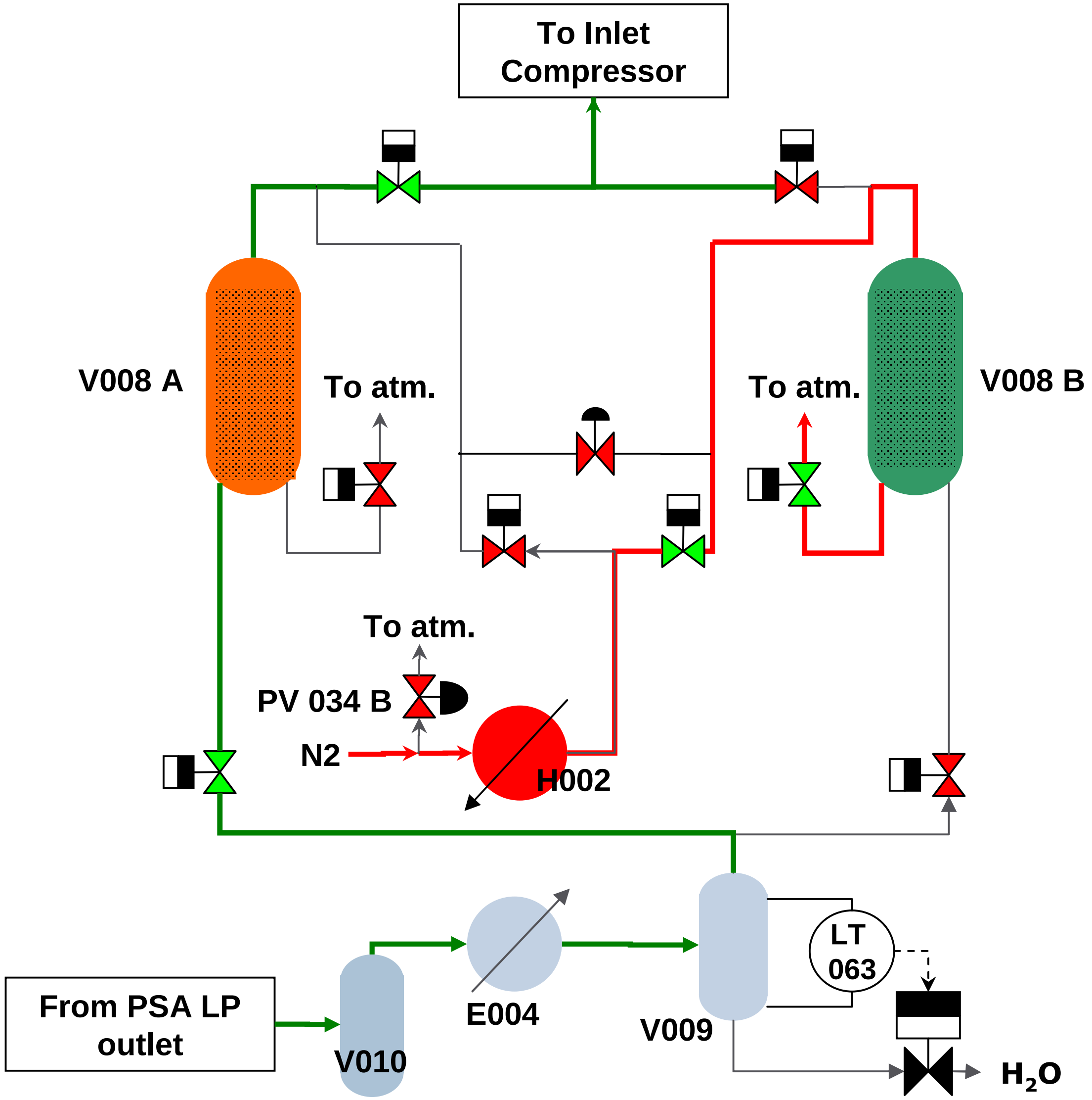
- Crude Helium from PSA OffGas Surge Vessel 322 V010 is cooled down in 322 E004 to condense water and reduce the load of the PSA Off Gas Adsorbers.
- After circulating in the adsorber, the stream is recycled at Inlet Compressor's suction.
- After 6 hours, the vessel needs to be regenerated.



Process description – Unit 322 – PSA OffGas Adsorbers

REGENERATION

- The regeneration gas is heated Waste Nitrogen coming from the Upgrader unit.
- N_2 is heated up in H002
- While circulating, hot N_2 carries over the adsorbed impurities during the adsorption step.
- Hot N_2 is then vented to the atmosphere.

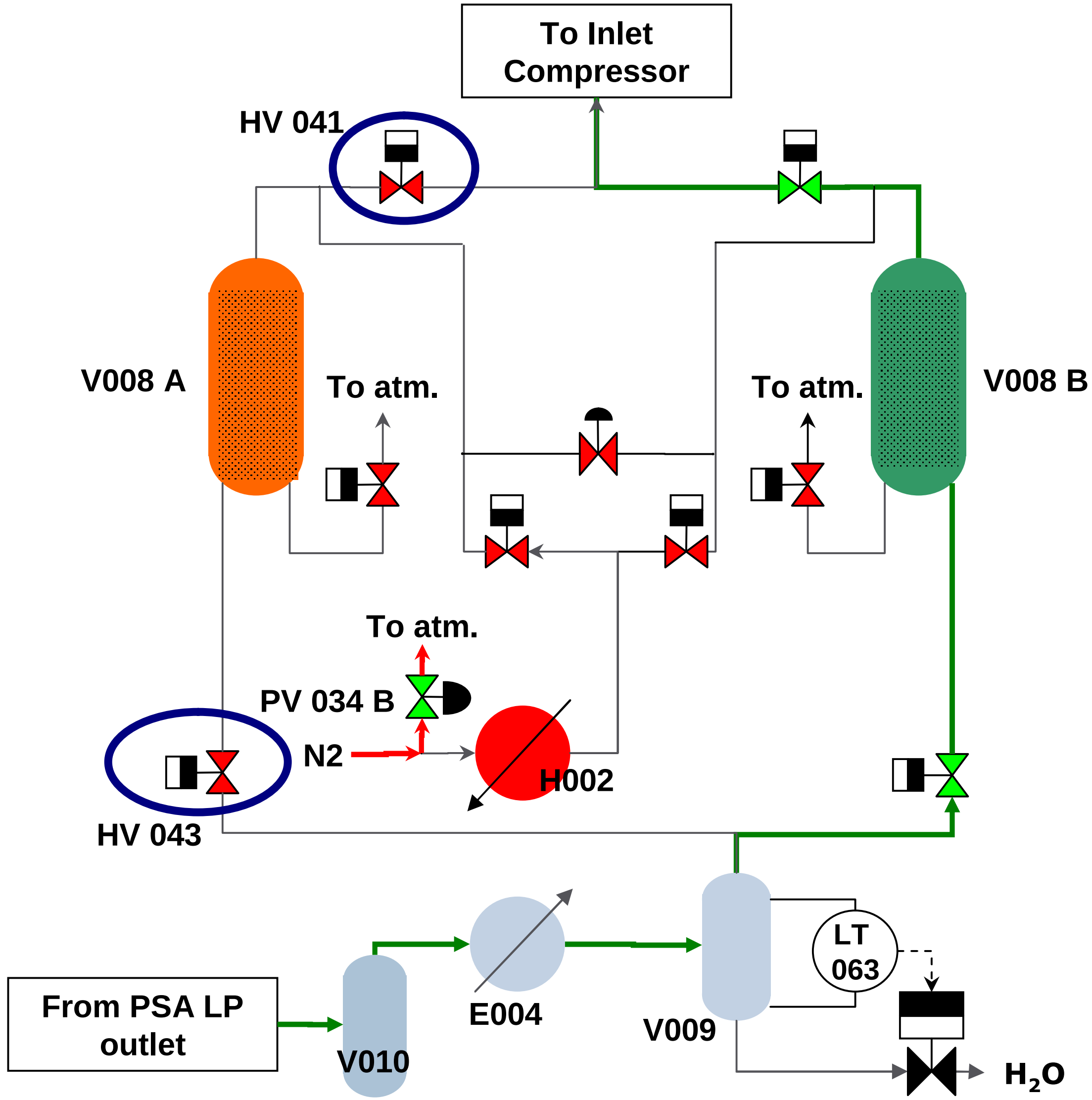


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 1:

High Pressure isolation

- 322 HV 041 and 322 HV 043 close
- The regeneration flow coming from the Upgrader is sent to atmosphere through 322 PV 034 B.

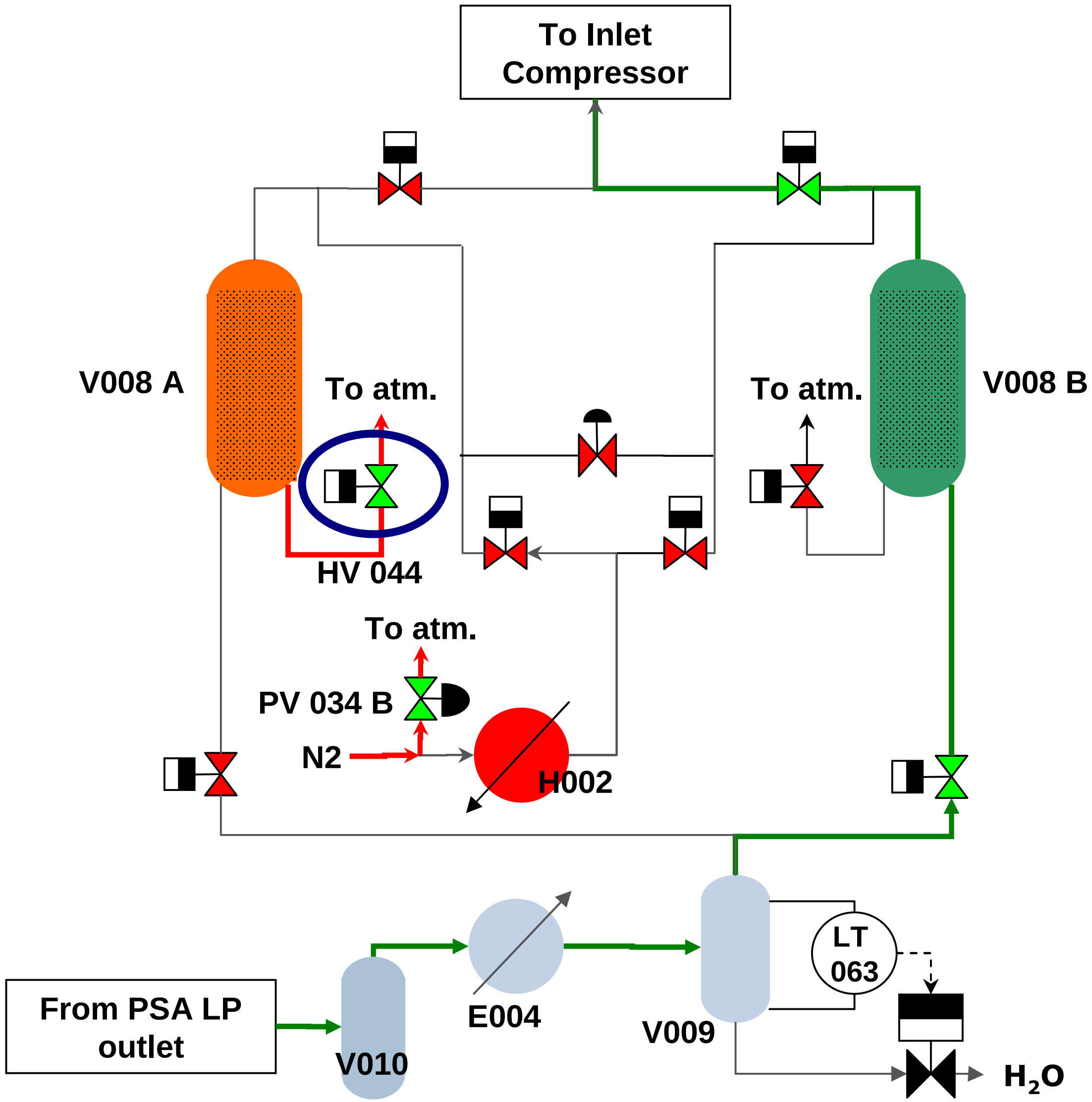


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 2 :

Depressurization

- 322 HV 044 opens

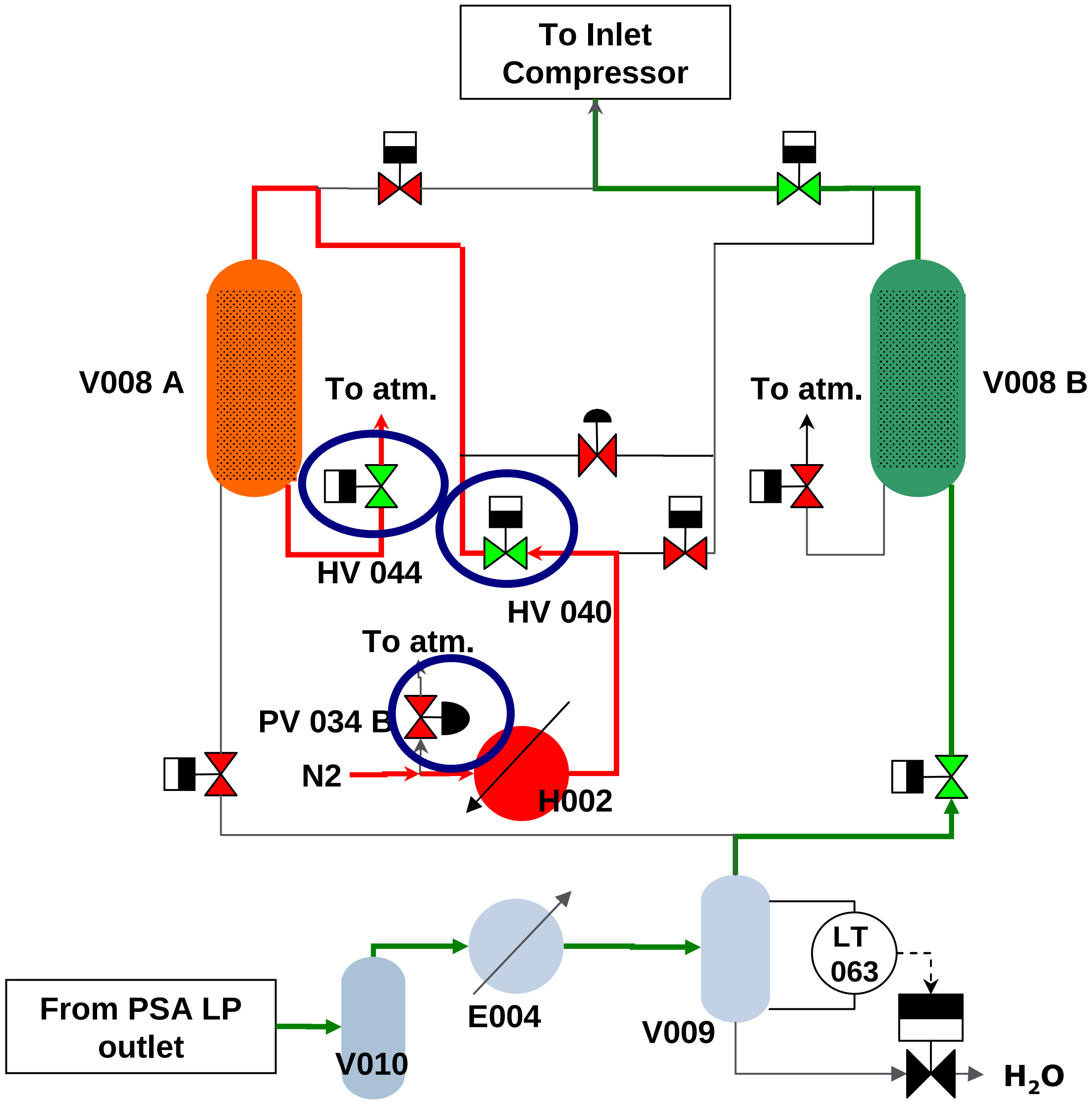


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 3:

Blowing

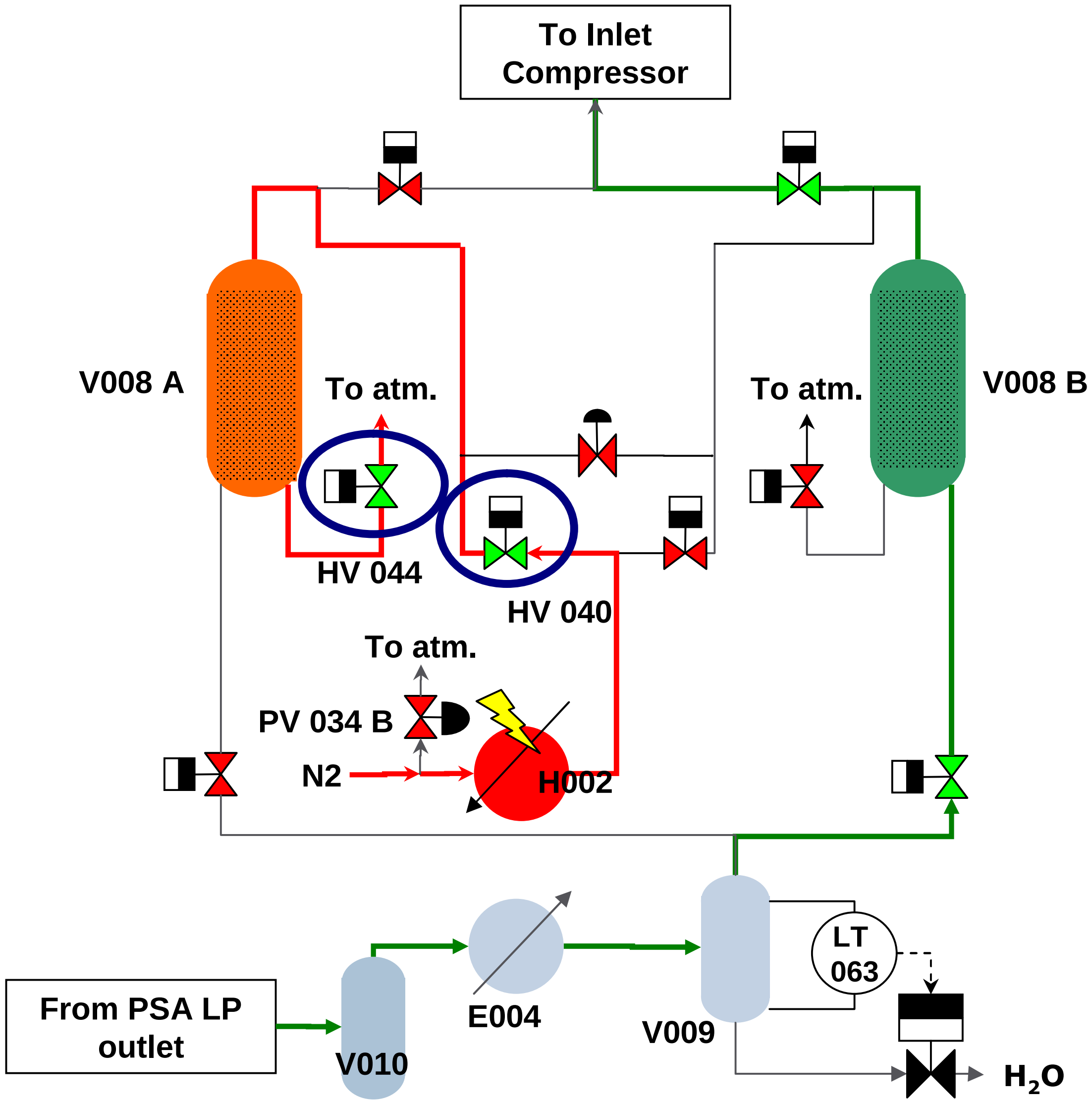
- 322 HV 040 opens
- 322 HV 044 remains open
- Vent valve PV 034 B closes and regeneration flow circulates in 322 V008A.



Regeneration step 4:

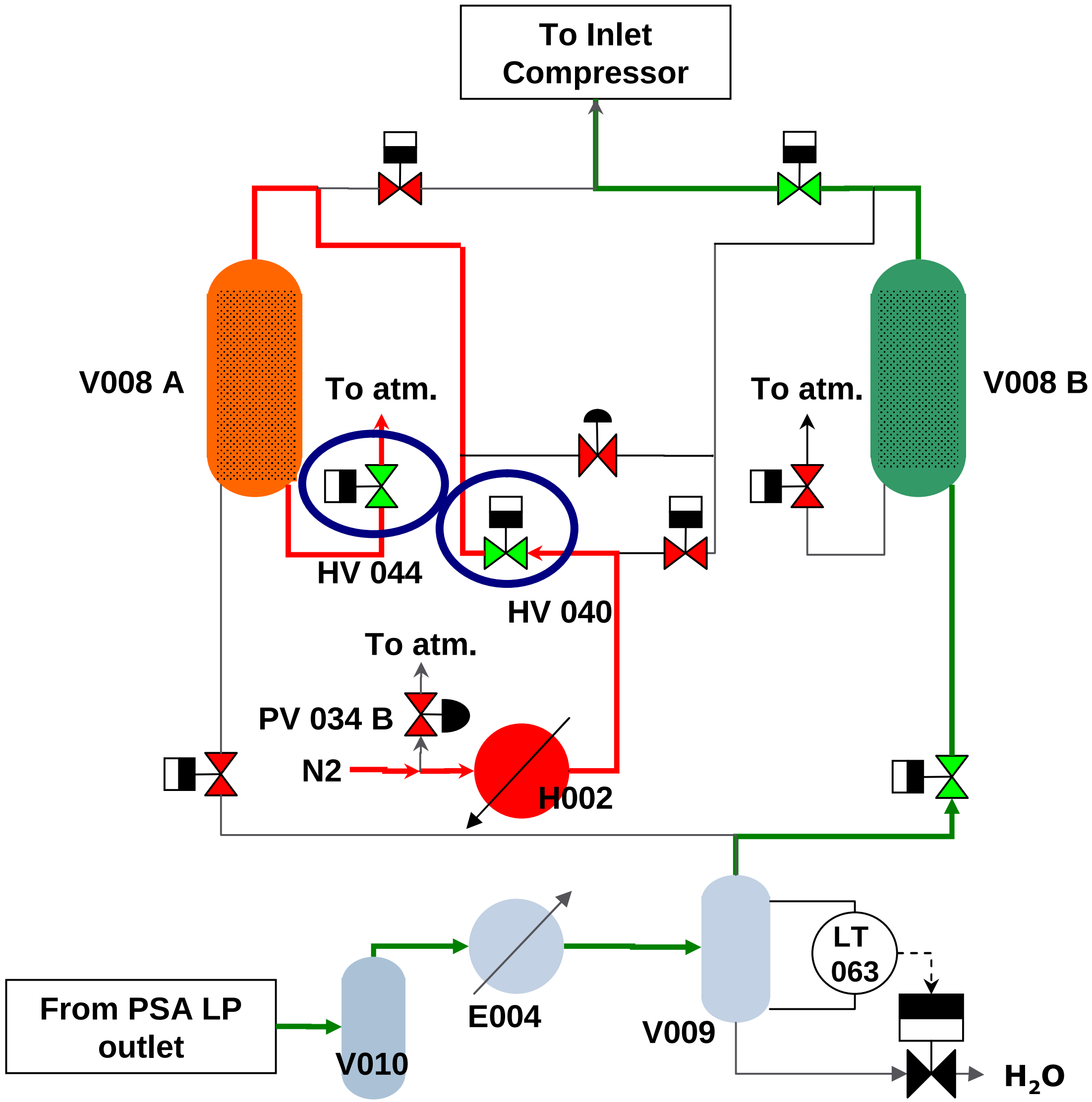
Heating

- H002 starts
- HV 040 and HV 044 remain open



Regeneration step 5:
Cooling

- H002 stops
- HV 040 and HV 044 remain open

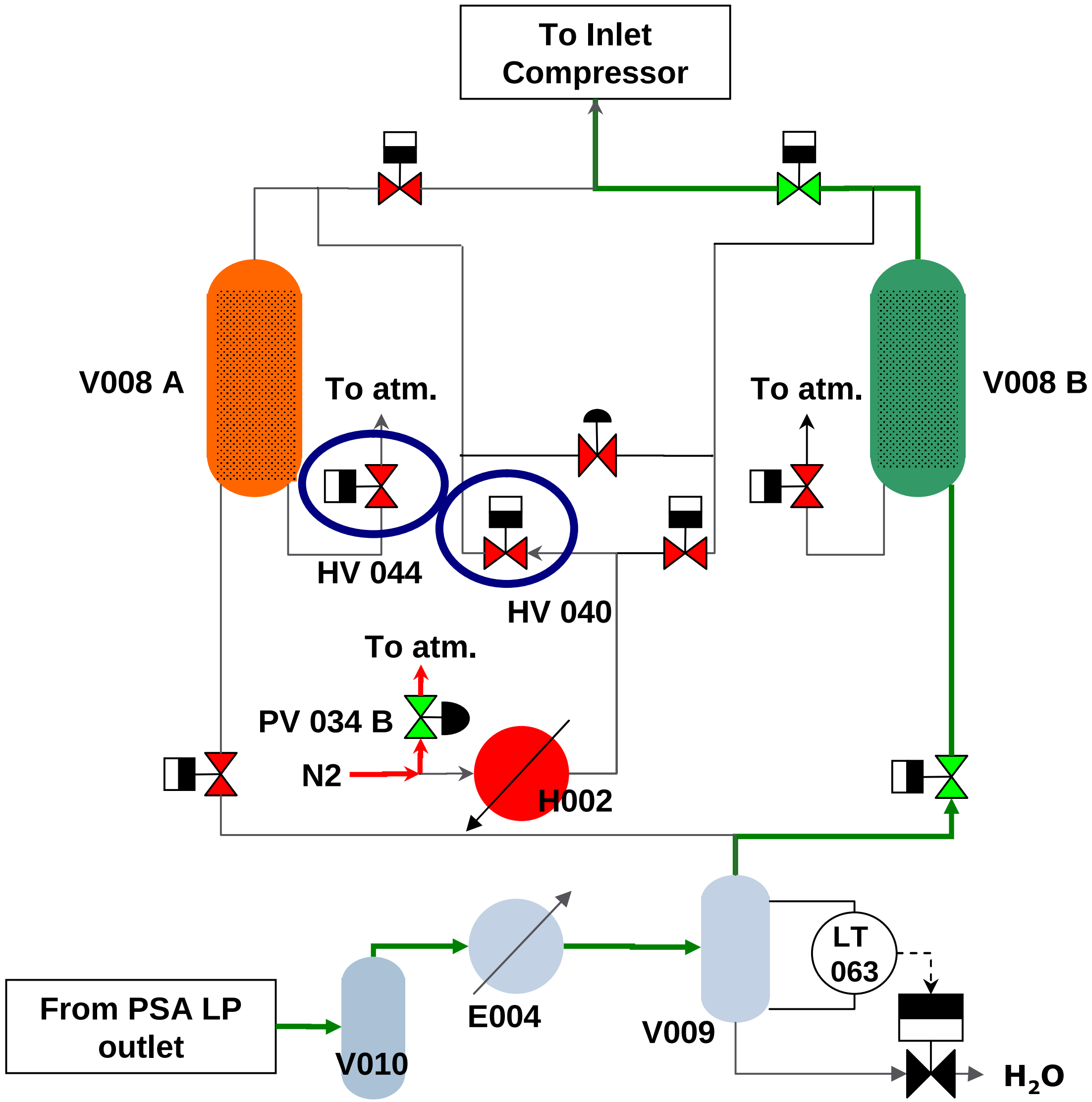


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 6:

Low Pressure Isolation

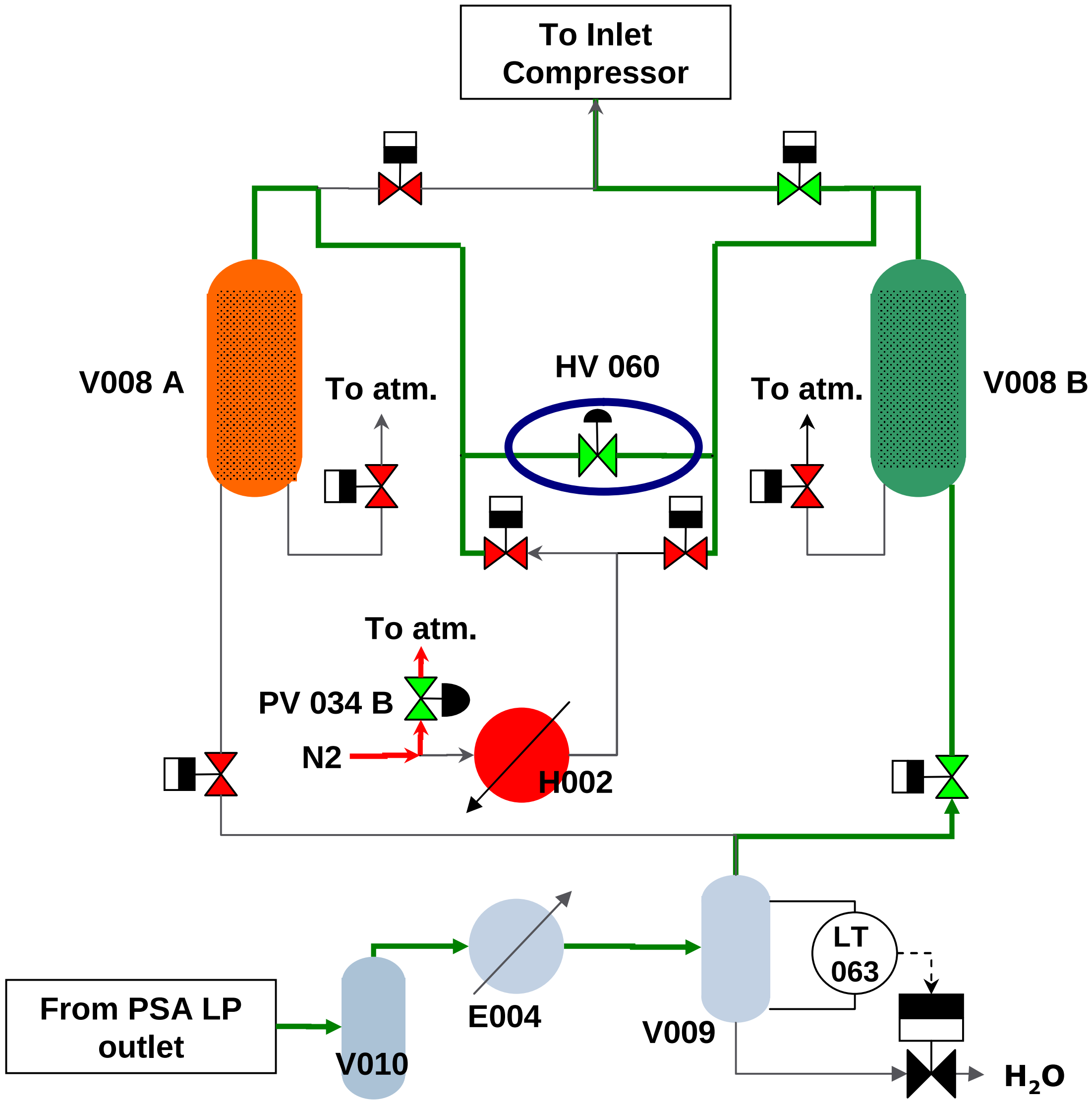
- HV 040 and HV 044 close
- PV 034 B opens to send the regeneration flow coming from the Upgrader to atmosphere.



Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 7:
Pressurization

- HV 060 slowly ramps up to 100%.
- Crude Helium gas flows from 322 V008 B to 322 V008 A
- PV 034 B remains open.

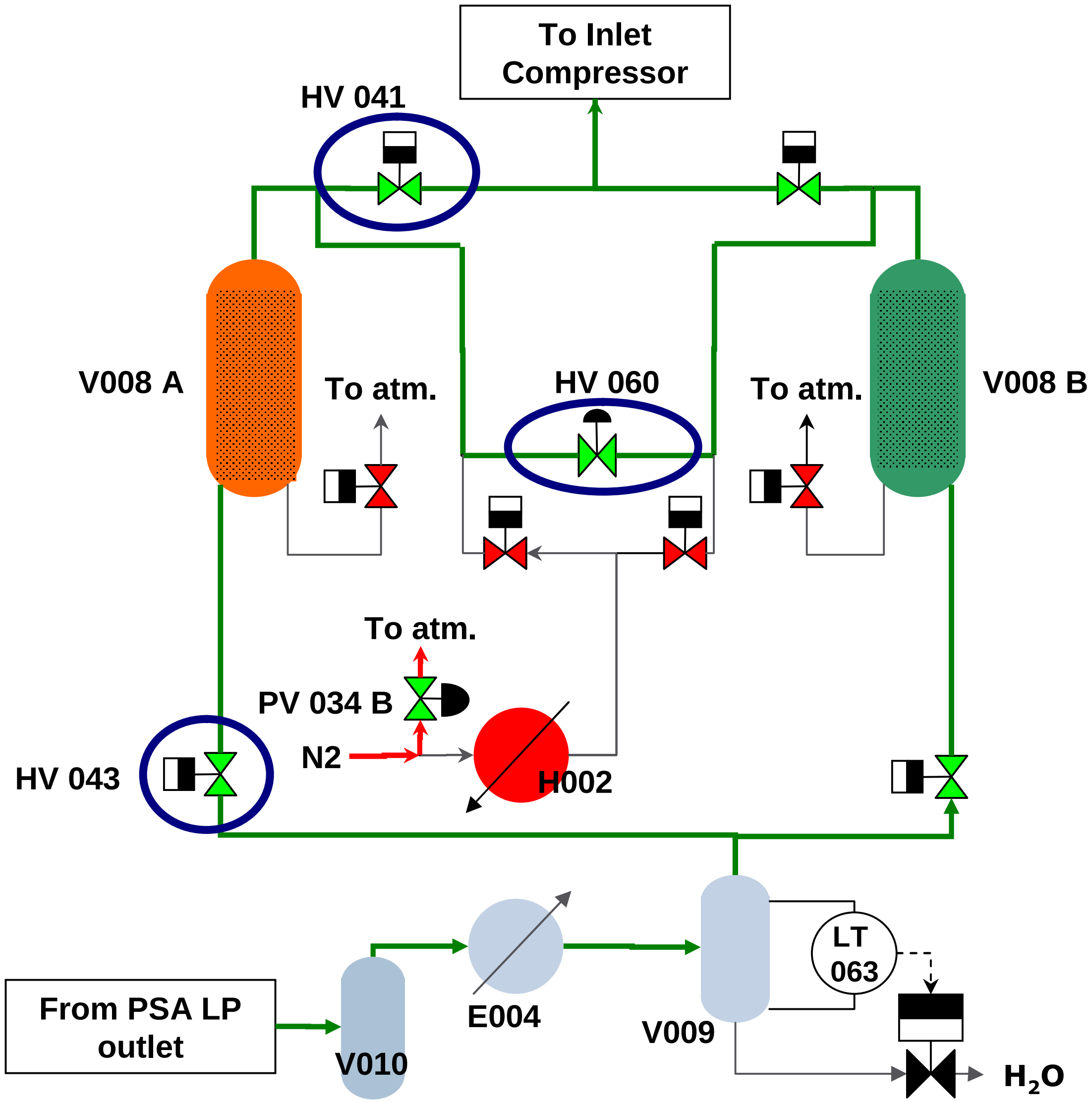


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 8:

Parallel

- HV 060 remains open
- HV 041 and HV 043 open
- PV 034 B remains open.

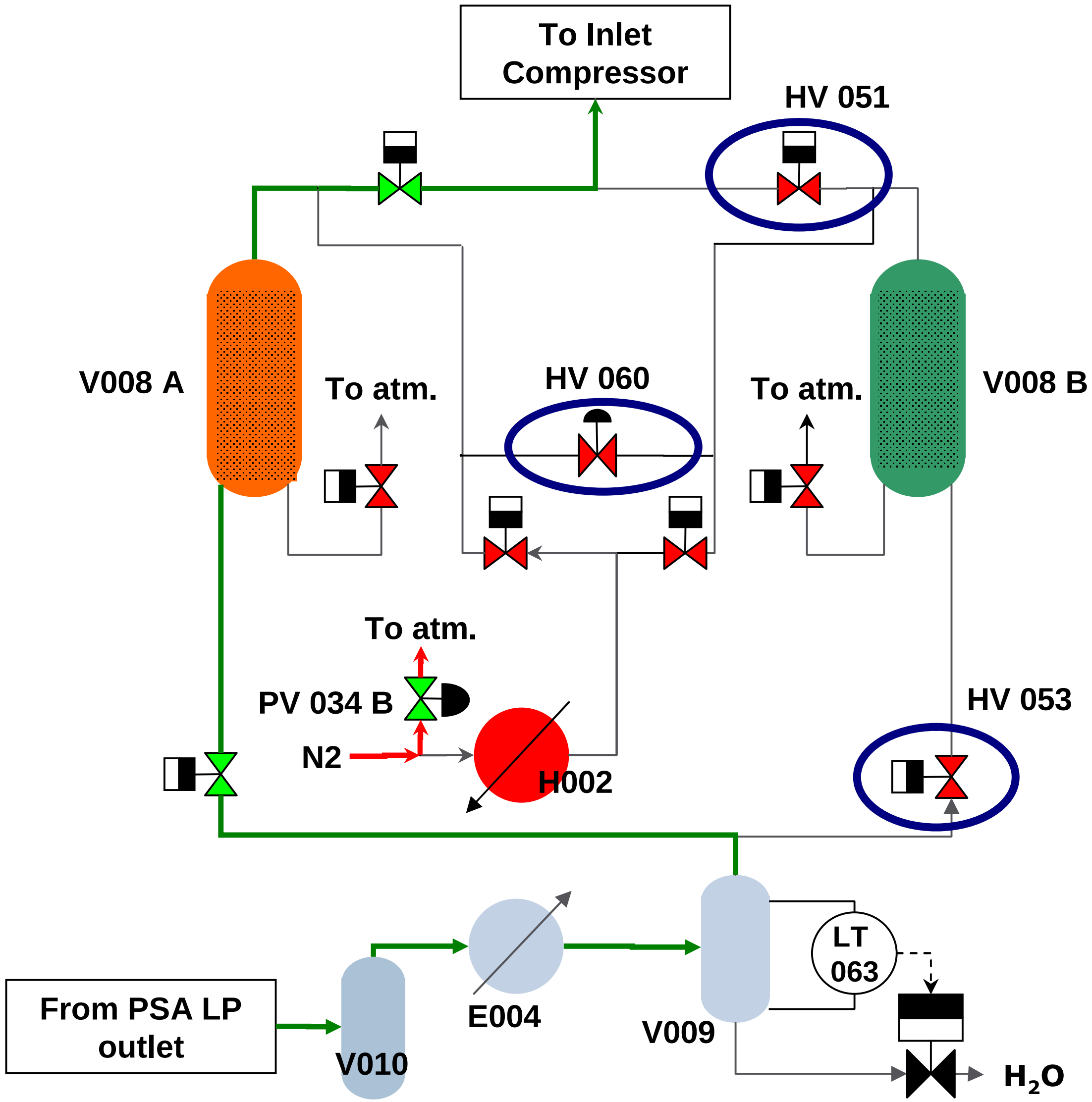


Process description – Unit 322 – PSA OffGas Adsorbers

Regeneration step 9:

End of regeneration

- V008 A is now regenerated and switches to adsorption
- V008 B moves to the first regeneration step: isolation HP.
- HV 060 closes
- HV 051 and HV 053 close
- PV 034 B remains open.



Process description – Unit 322 – PSA OffGas Adsorbers

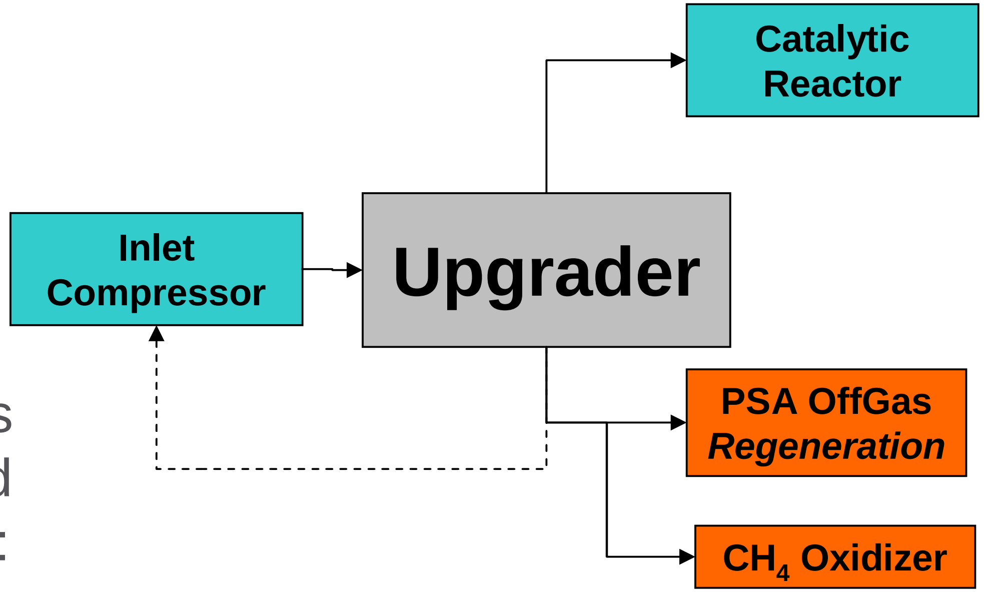
- Regeneration flow is controlled by 322 FC 035
- When there is no regeneration flow sent to the dryers, a pressure controller takes over: 322 PC 034 B
- Heating and Cooling steps are automatically controlled by timers and temperature controllers

Process description – Unit 322 – CH4 Oxidizer

- Waste Nitrogen from the Upgrader unit still contains:
  - N_2: 95.2%
  - CH_4: 3.68%
  - He: 0.51%
- The excess of Waste Nitrogen is sent to the CH_4 Oxidizer to avoid venting methane to atmosphere:
  - The amount of methane is reduced by oxidation:

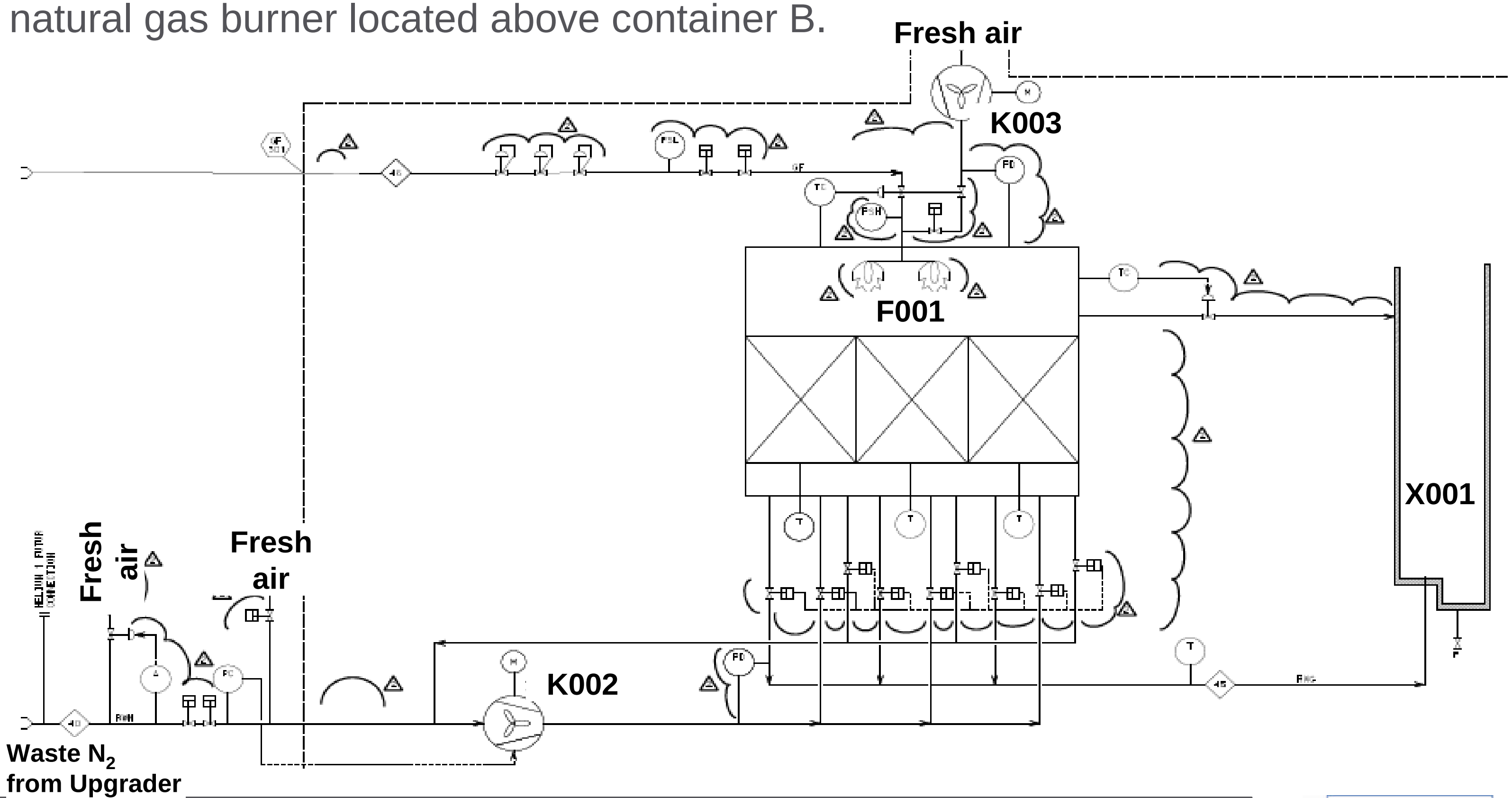
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

  - Exothermal and high temperature reaction
- The CH_4 Oxidizer is entirely controlled by a PLC



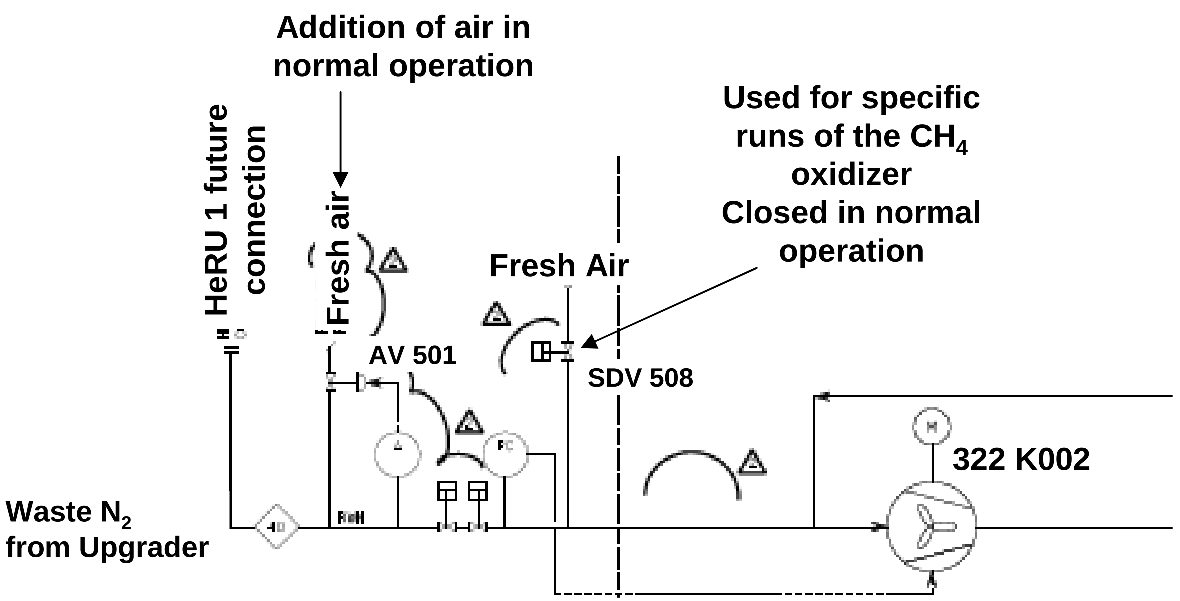
Process description – Unit 322 – CH4 Oxidizer

- The CH_4 oxidizer is composed of :
  - 3 containers (A, B and C) filled with ceramic heat exchanger material
  - A combustion chamber and a burner on top of the containers
  - 2 blowers controlling the inlet gas into the containers
  - A natural gas burner located above container B.



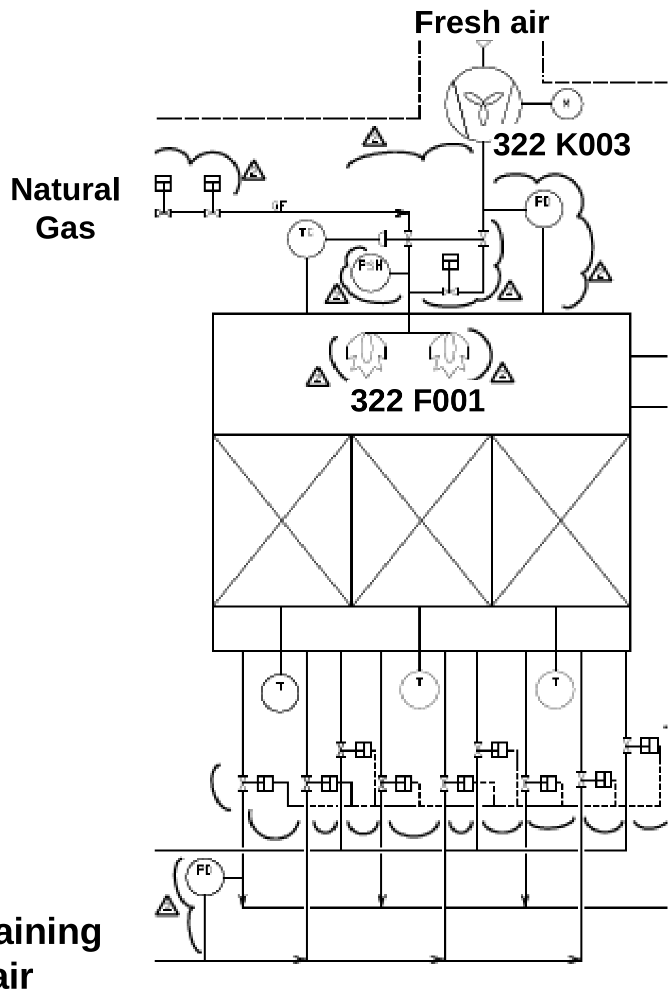
Process description – Unit 322 – CH4 Oxidizer

- Waste Nitrogen coming from Upgrader is mixed with fresh air in order to:
  - Dilute methane before oxidation
  - Create a higher differential pressure through the RTO and therefore, ensure a proper circulation
- The mixture is routed to the CH_4 oxidizer through the fan 322 K002
- The flow is maintained constant by regulating the fan speed with a variable frequency drive.



Process description – Unit 322 – CH4 Oxidizer

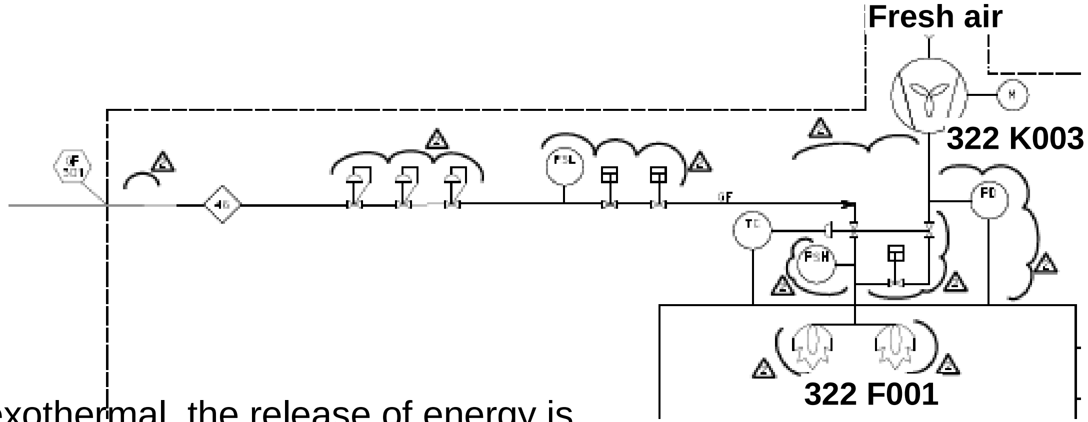
- The oxidation reaction is completed in a 3-step cycle:
  - Initiation: the oxidation is initiated while the gas is heated up during its circulation up to the combustion chamber
  - The oxidation is completed while the gas pursues its way up to the combustion chamber
  - In the combustion chamber, the ultimate traces of CH4 are oxidized.
- The containers have to be purged to evacuate all residues
- Each container follows a 3-step cycle
  - Routing and pre-heating of the gas into the combustion chamber
  - Purge of the container
  - Routing the off-gas to the stake and heat recovery



Process description – Unit 322 – CH4 Oxidizer

Natural Gas
When the burner is on, Natural Gas is supplied to the burner. The gas flow regulation and the combustion air regulation are a coupled control (linked by a Bowden cable).

Combustion Air blower
Provides air for the burner to ensure a reliable flame and to cool the sight port on the unit. A flame trap allows avoiding a flashback from the burner.



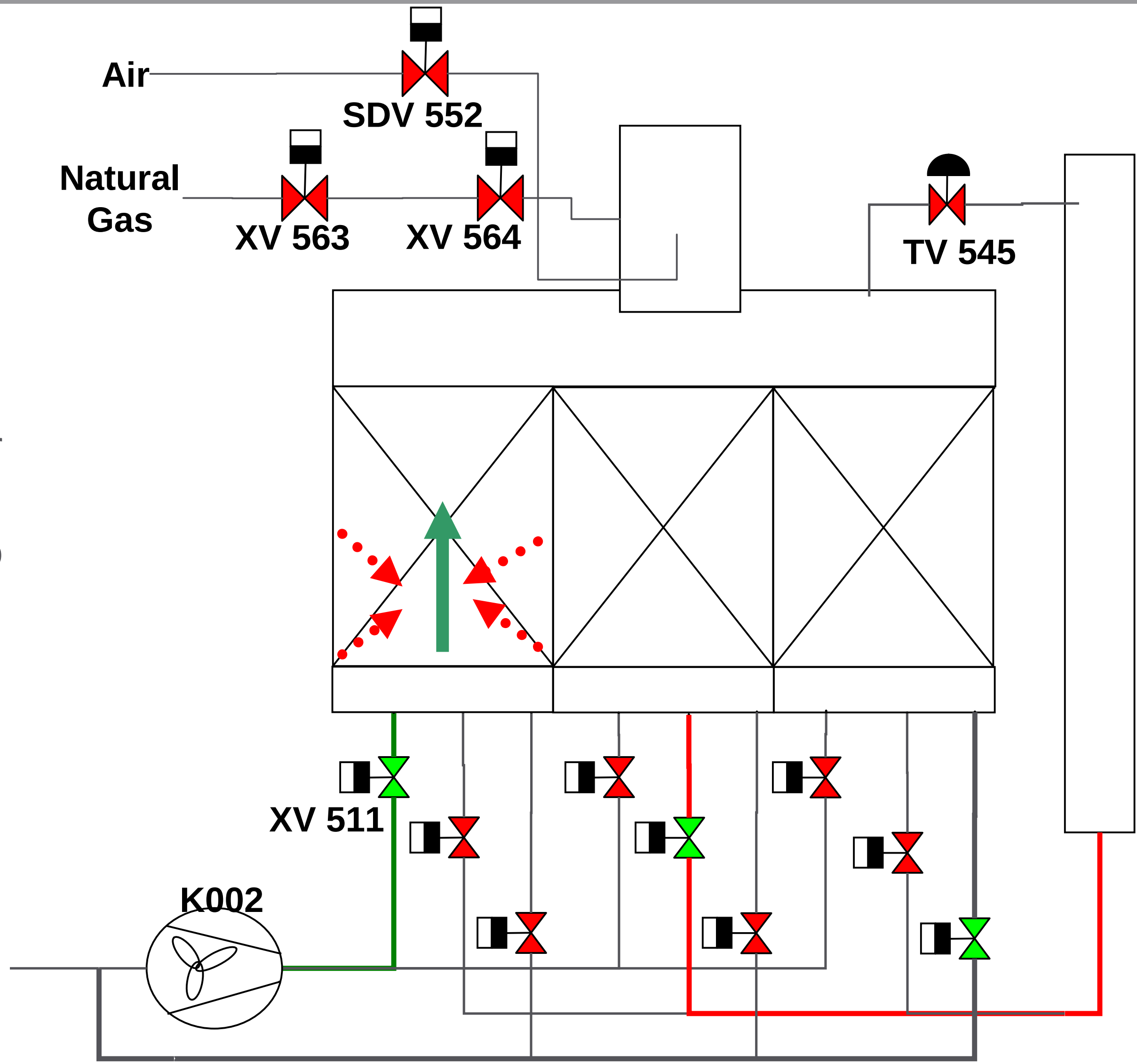
Burner
The reaction being exothermal, the release of energy is sufficient to maintain the temperature of the combustion chamber at high temperature. The burner is switched on at start up in order to ramp up to operating temperature. Then, the burner is switched off.
If during operation the temperature goes down to a low threshold, the burner starts up until the temperature exceeds a high threshold.

Combustion Chamber
The temperature of the combustion chamber shall always be at minimum 850°C.

Process description – Unit 322 – CH4 Oxidizer

PRE HEATING (oxidation initiation)

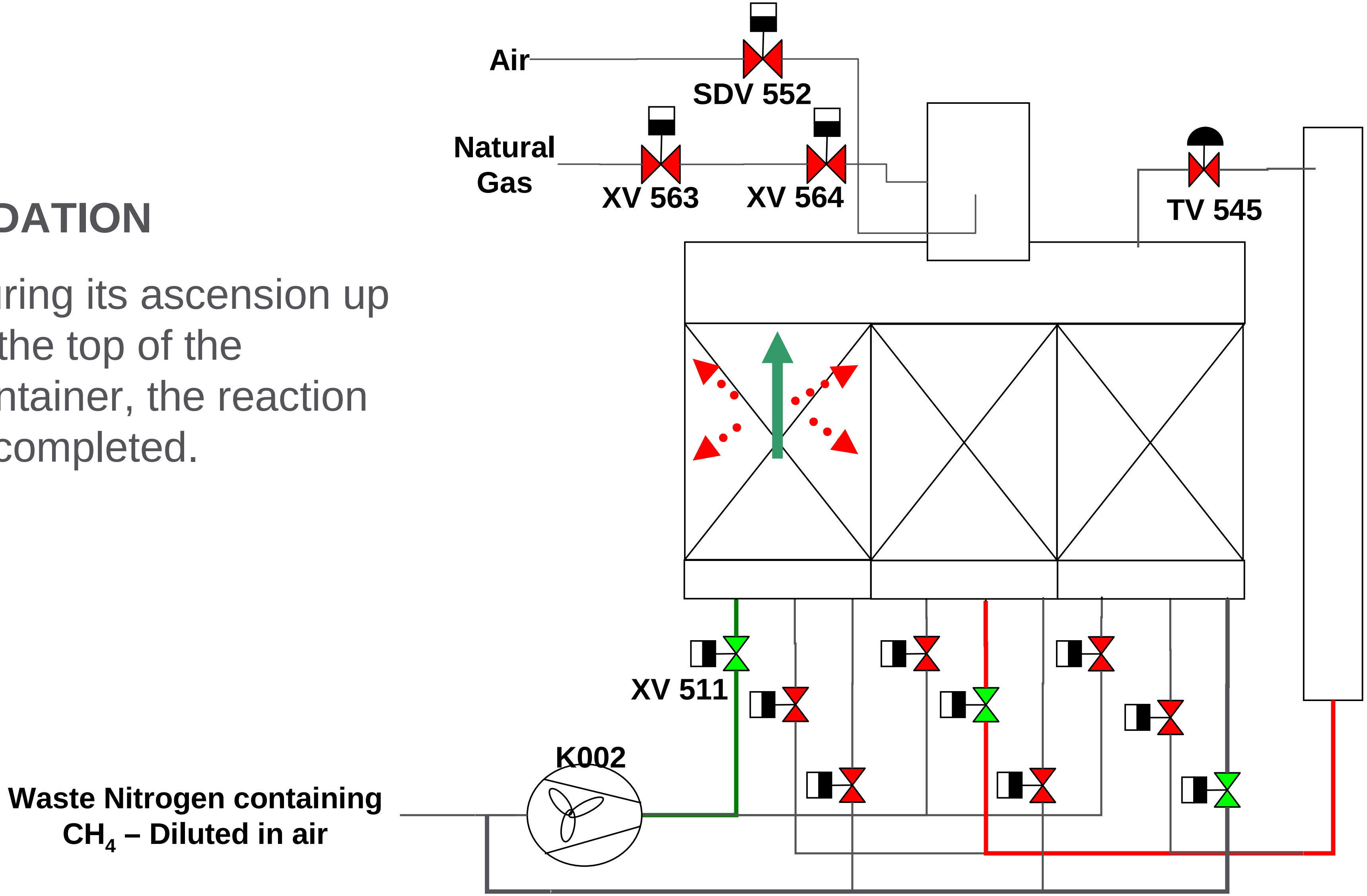
- Inlet gas is injected in container A by the poppet valve XV 511 and circulates up to the combustion chamber
- The container's ceramic material transfers its energy to the gas: the thermal energy comes from the heat recovery step of the previous cycle.
- When the temperature is high enough, the oxidation reaction is initiated.



Process description – Unit 322 – CH4 Oxidizer

OXIDATION

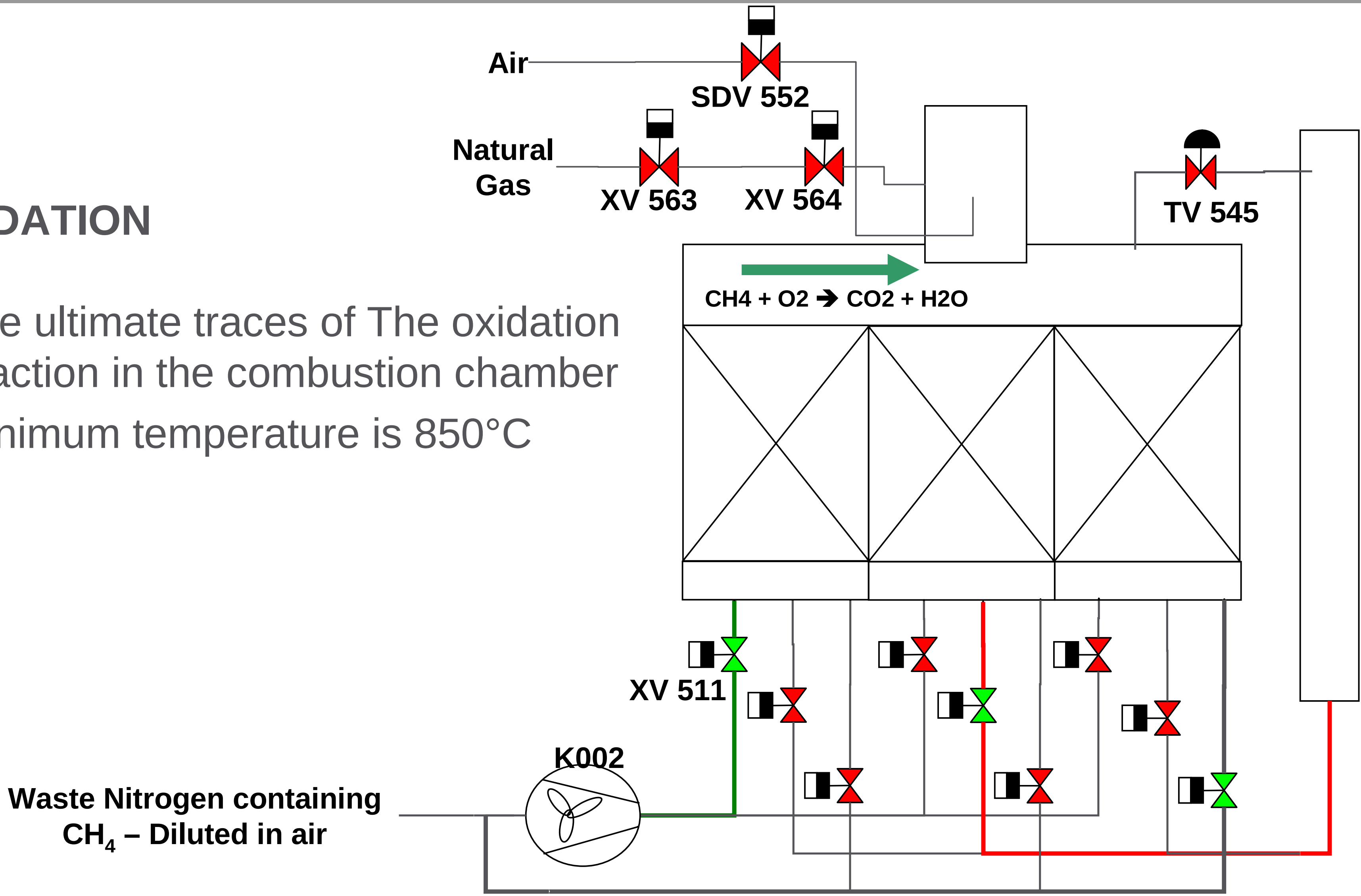
- During its ascension up to the top of the container, the reaction is completed.



Process description – Unit 322 – CH4 Oxidizer

OXIDATION

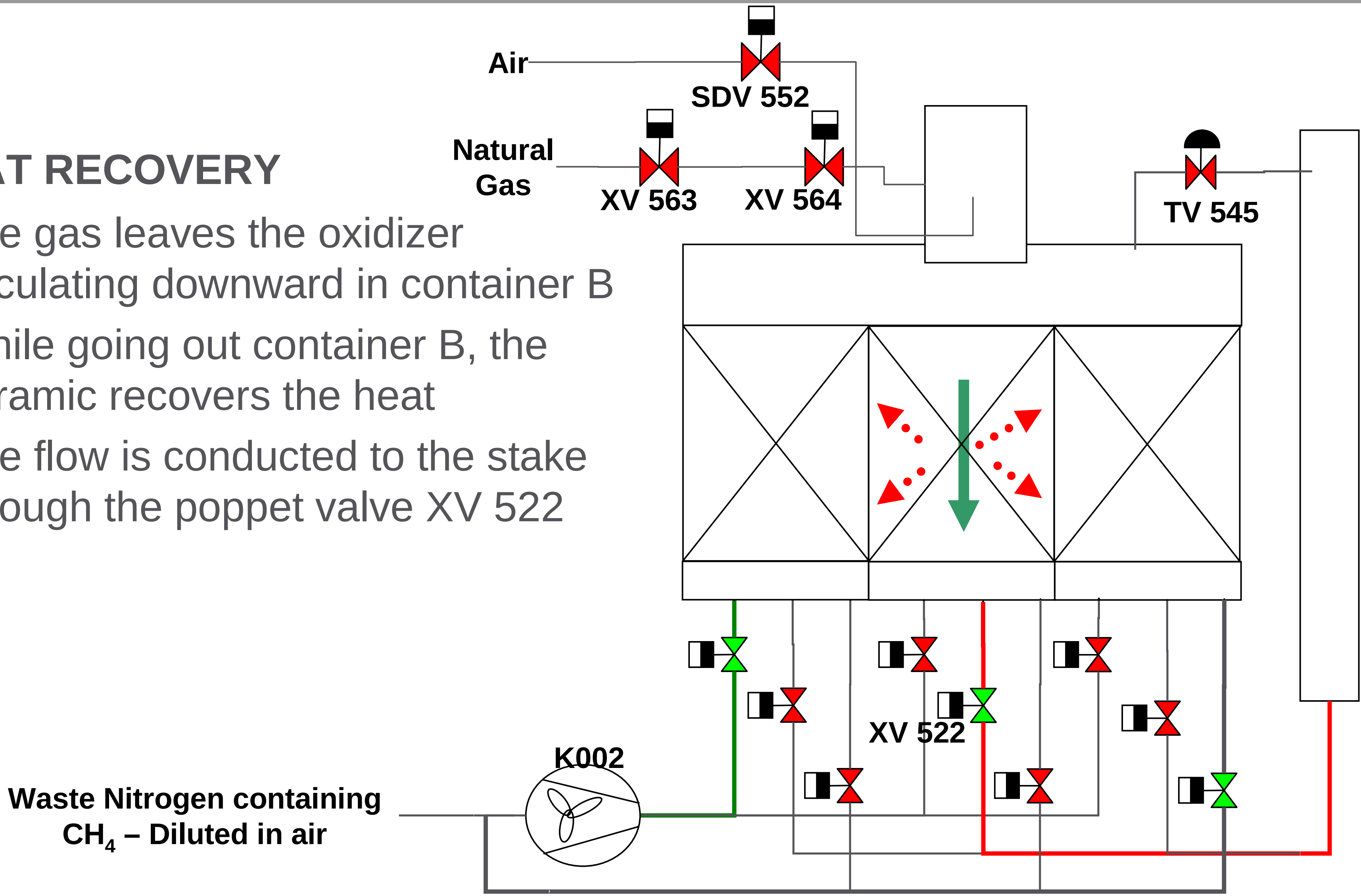
- The ultimate traces of The oxidation reaction in the combustion chamber
- Minimum temperature is 850°C



Process description – Unit 322 – CH4 Oxidizer

HEAT RECOVERY

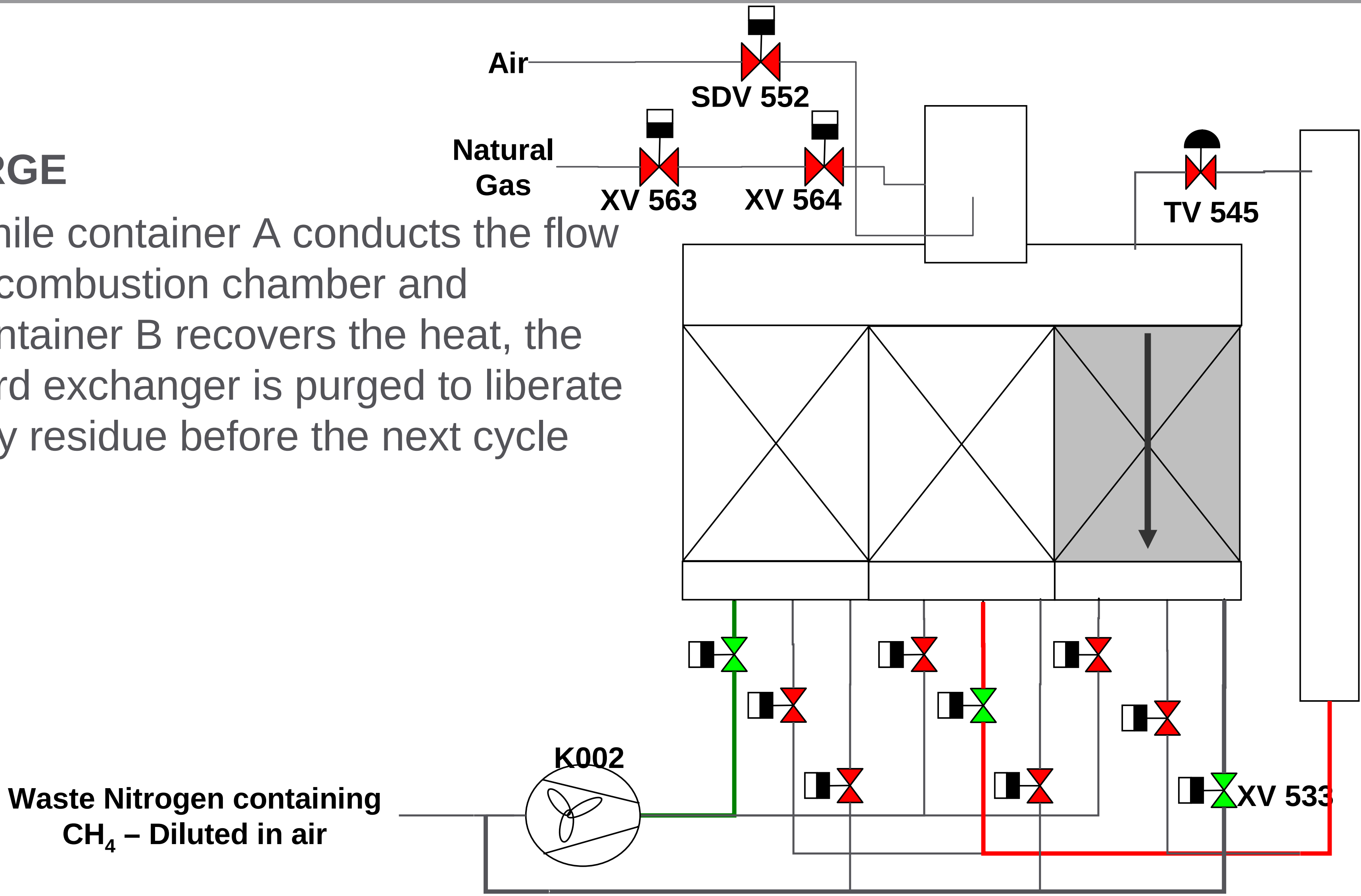
- The gas leaves the oxidizer circulating downward in container B
- While going out container B, the ceramic recovers the heat
- The flow is conducted to the stake through the poppet valve XV 522



Process description – Unit 322 – CH4 Oxidizer

PURGE

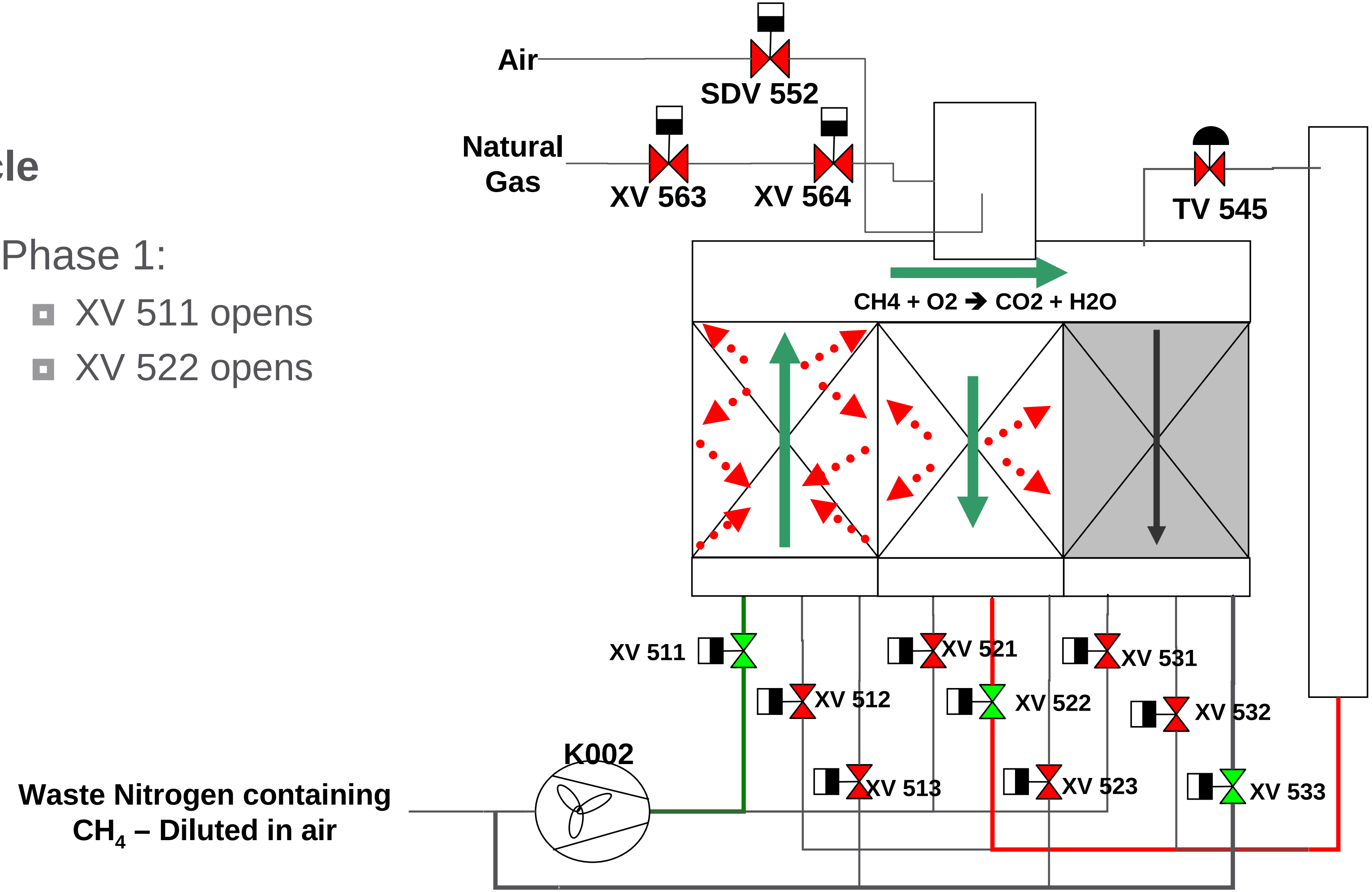
- While container A conducts the flow in combustion chamber and container B recovers the heat, the third exchanger is purged to liberate any residue before the next cycle



Process description – Unit 322 – CH4 Oxidizer

Cycle

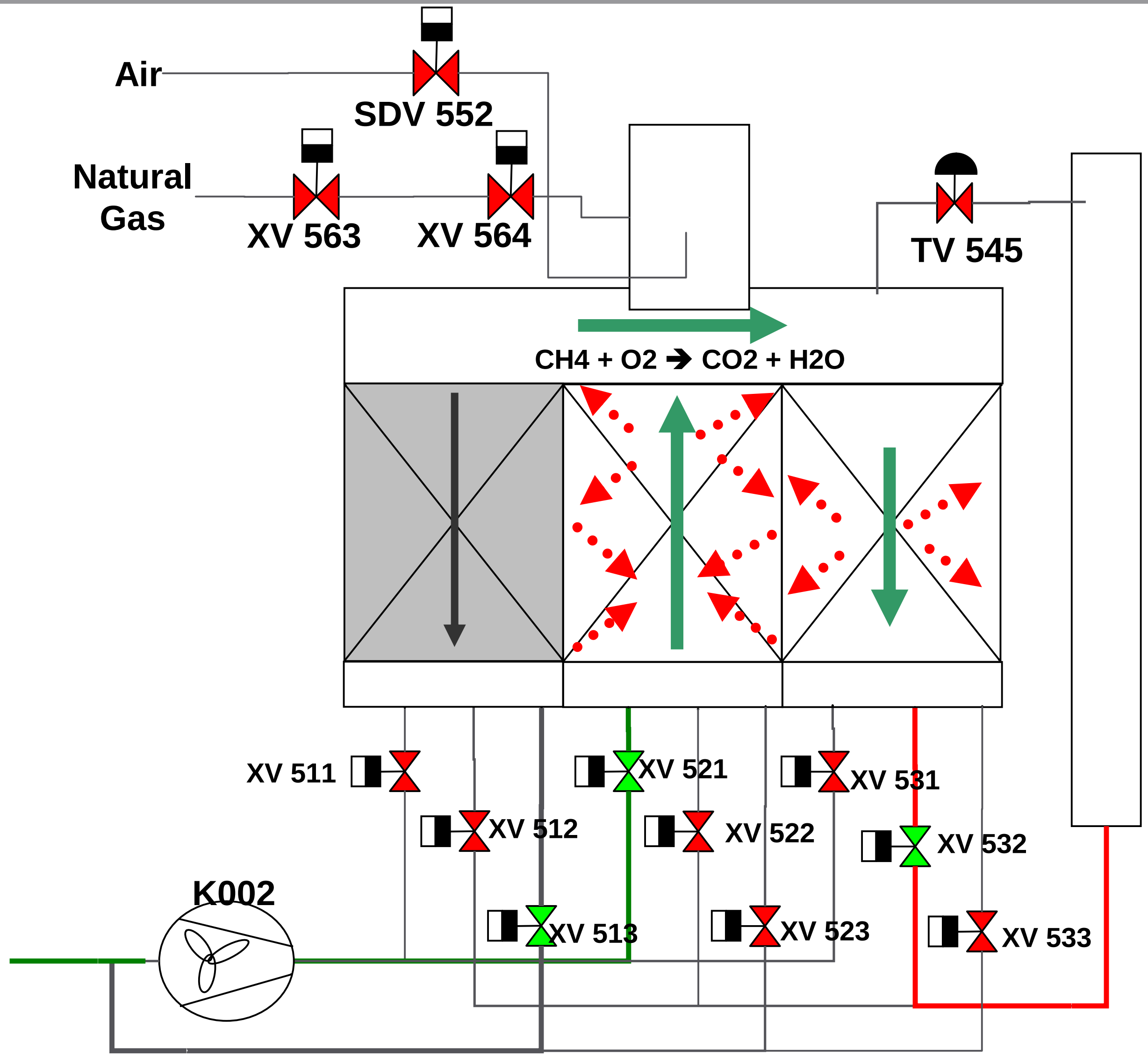
- Phase 1:
  - XV 511 opens
  - XV 522 opens



Process description – Unit 322 – CH4 Oxidizer

Cycle

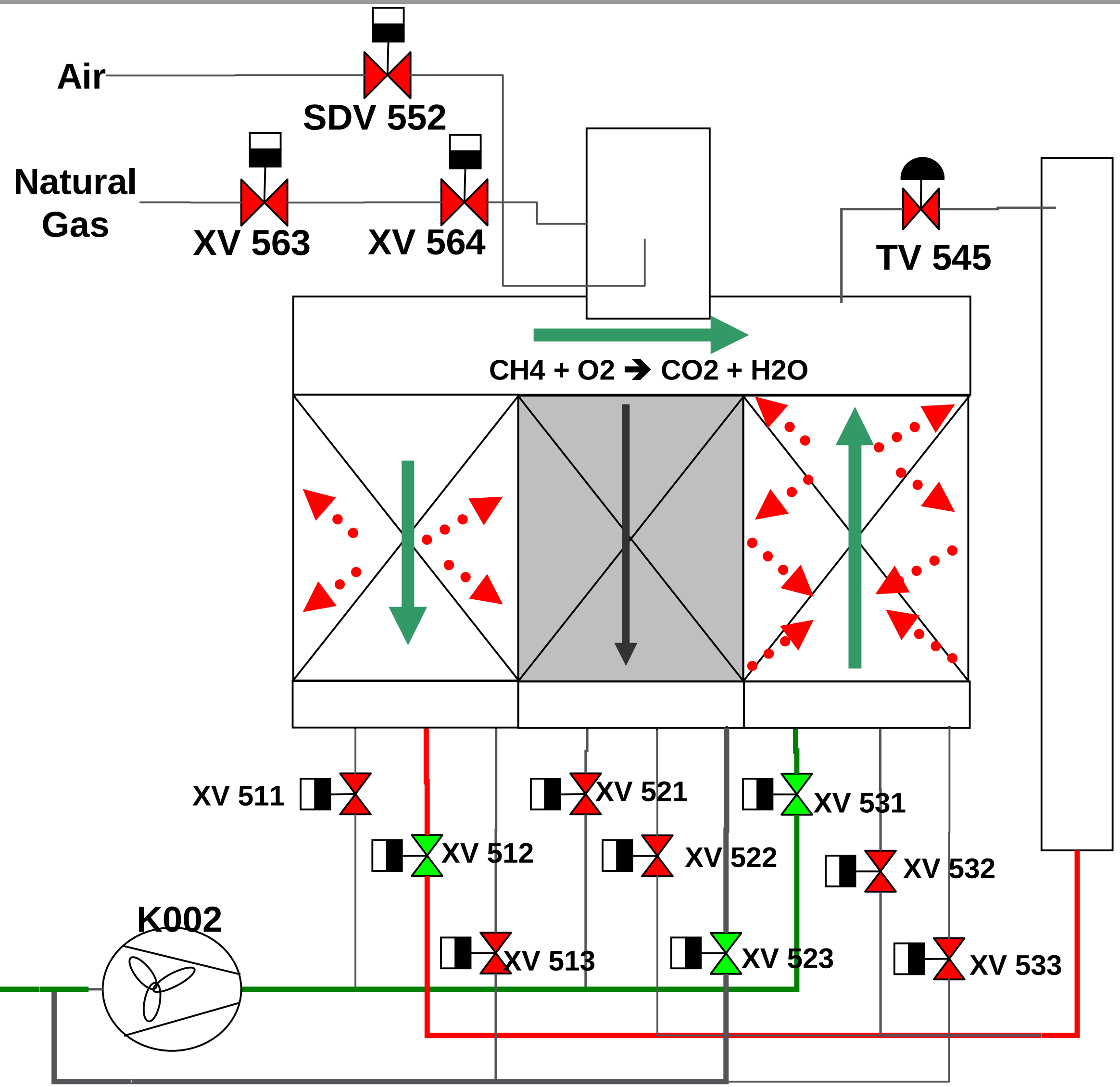
- Phase 2:
  - XV 511 closes
  - XV 522 closes
  - XV 521 opens
  - XV 532 opens



Process description – Unit 322 – CH4 Oxidizer

Cycle

- Phase 3
  - XV 521 closes
  - XV 532 closes
  - XV 531 opens
  - XV 512 opens



Waste Nitrogen containing CH_4 – Diluted in air

Course Agenda

1.Introduction

2.Design conditions

3.Process Description

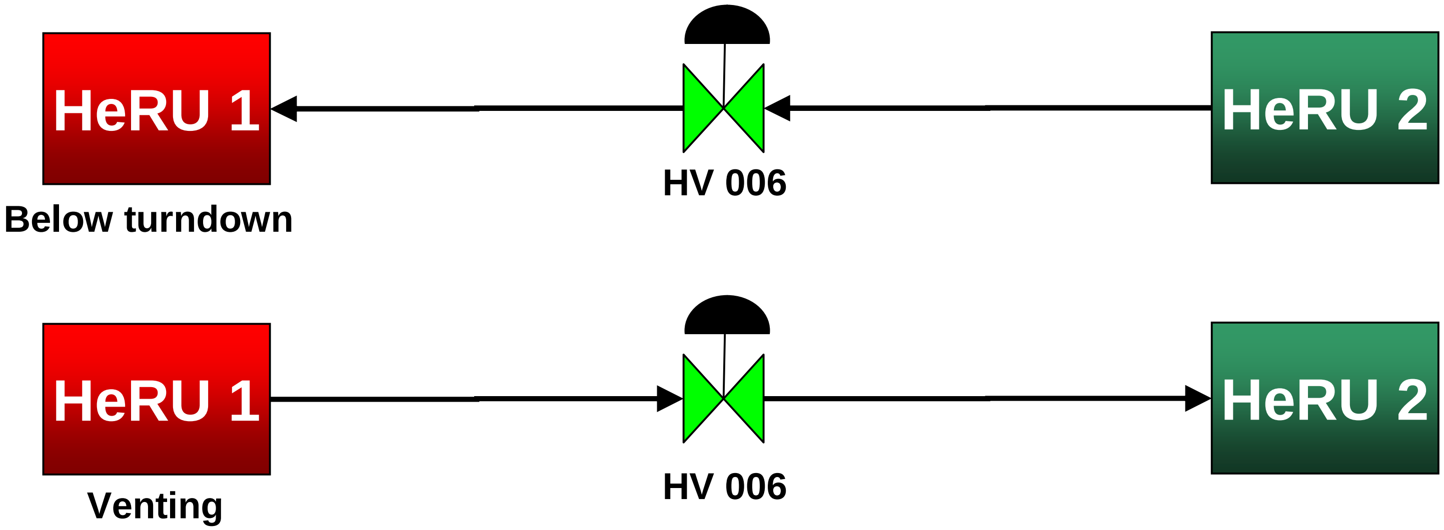
4.Process Variables and Control

5.Hazards and Precautions

4. Process Variables and Control – Feed

Crude helium feeds from RasGas, QatarGas and HeRU 1

- Feeds composition are analyzed in the analysis room
- 321 HV 006 bidirectional line is used on RasGas Manufacturing Managers' approval, and is not meant to be used in normal operation:
  - If one plant is below turndown, the other one tranfers its feed gas to increase availability
  - If one plant is venting, it tranfers its feed gas to the other plant



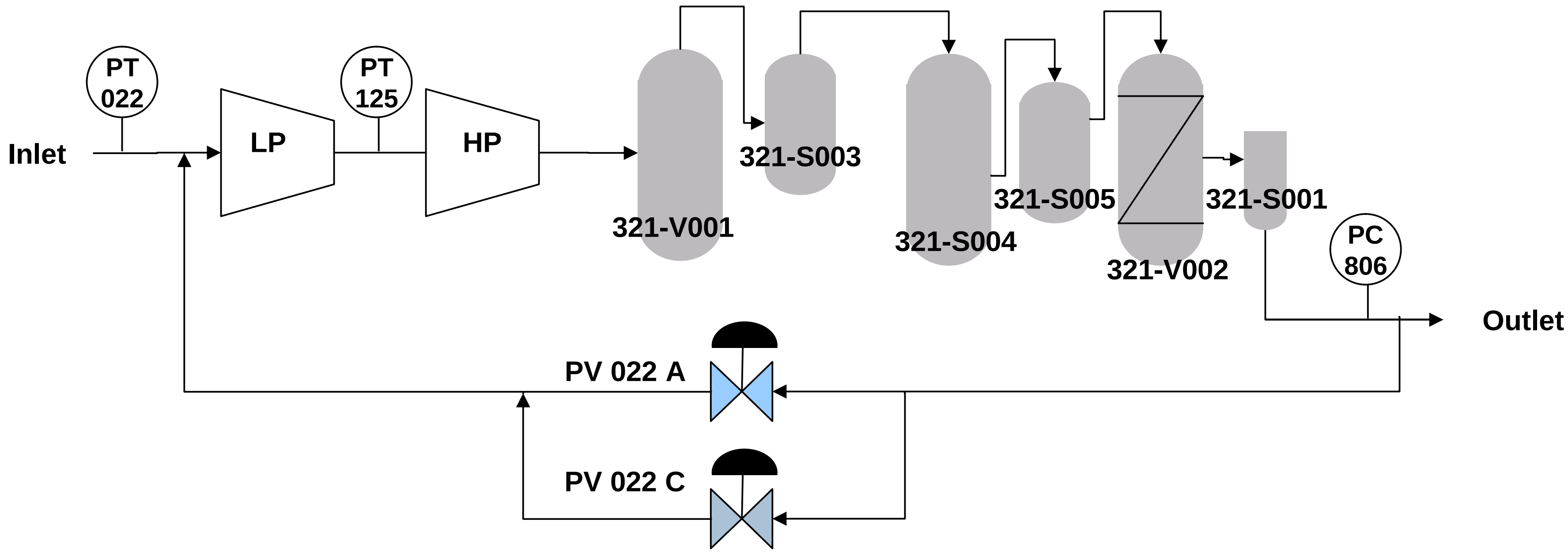
4. Process Variables and Control – Inlet Compressor

LP suction pressure (PT 022)

- Controlled by 321 PC 022A
- Actuators: valves 321 PV 022 A and 321 PV 022 C

HP discharge pressure (PT 806)

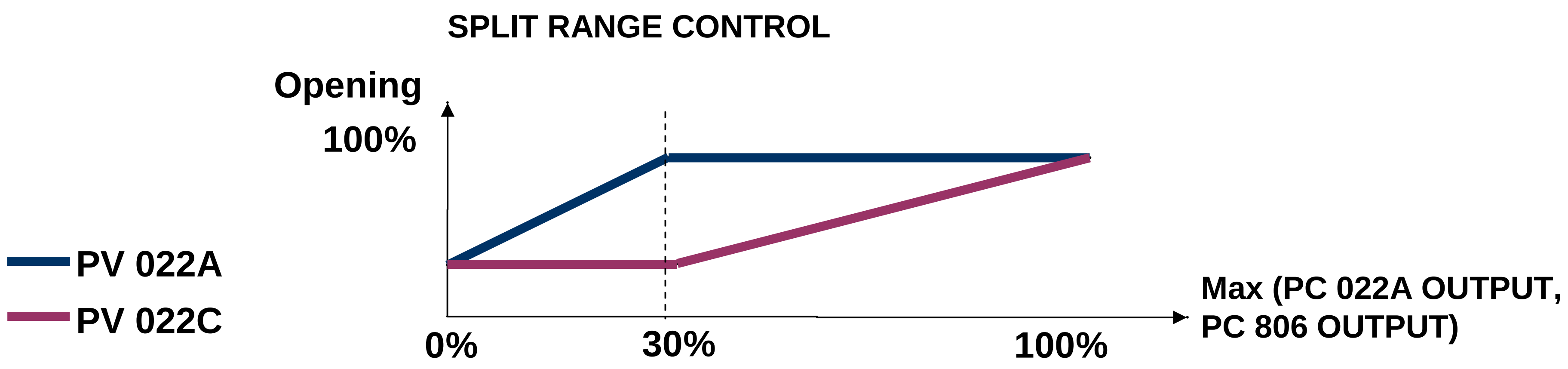
- Controlled by 321 PC 806 A, acting on the same recycle valves



4. Process Variables and Control – Inlet Compressor

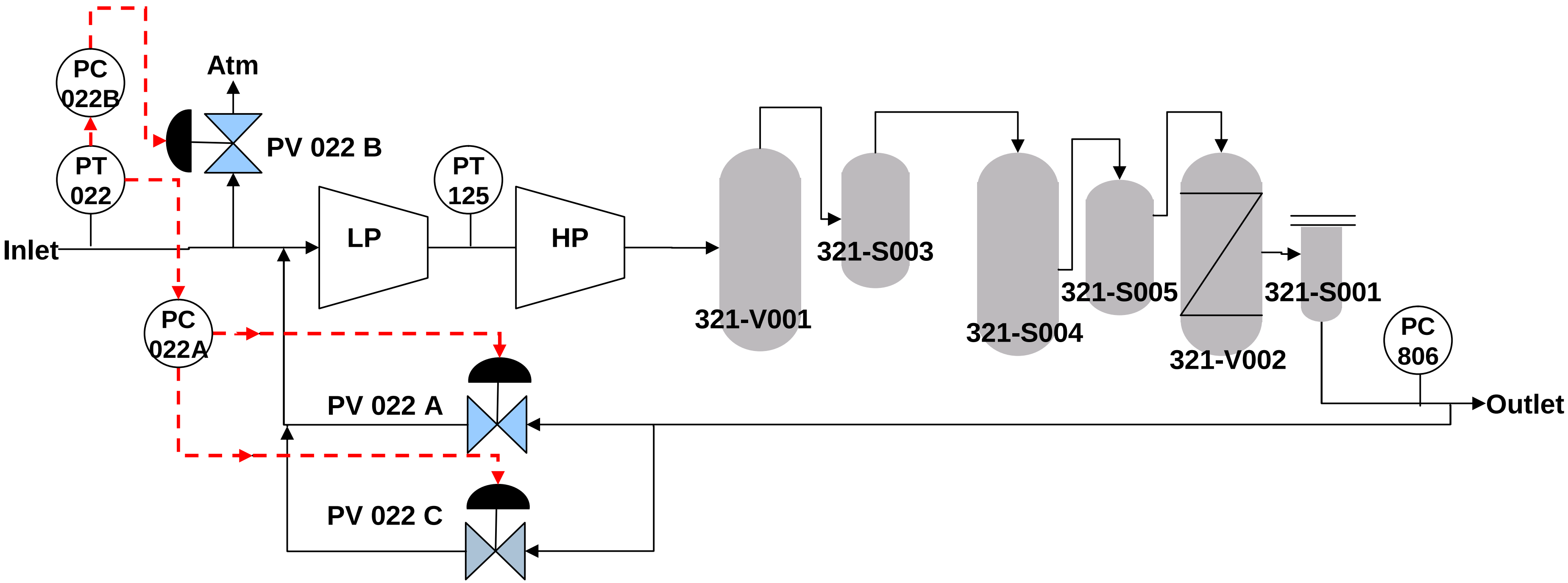
Recycle valves' opening

- 321 PV 022 A and 321 PV 022 C opening is controlled by the maximum output of 322 PC 022 A and 322 PC 806
- In normal operation, the opening is controlled by 321 PC 022 A and 321 PC 806 takes control only in abnormal situation

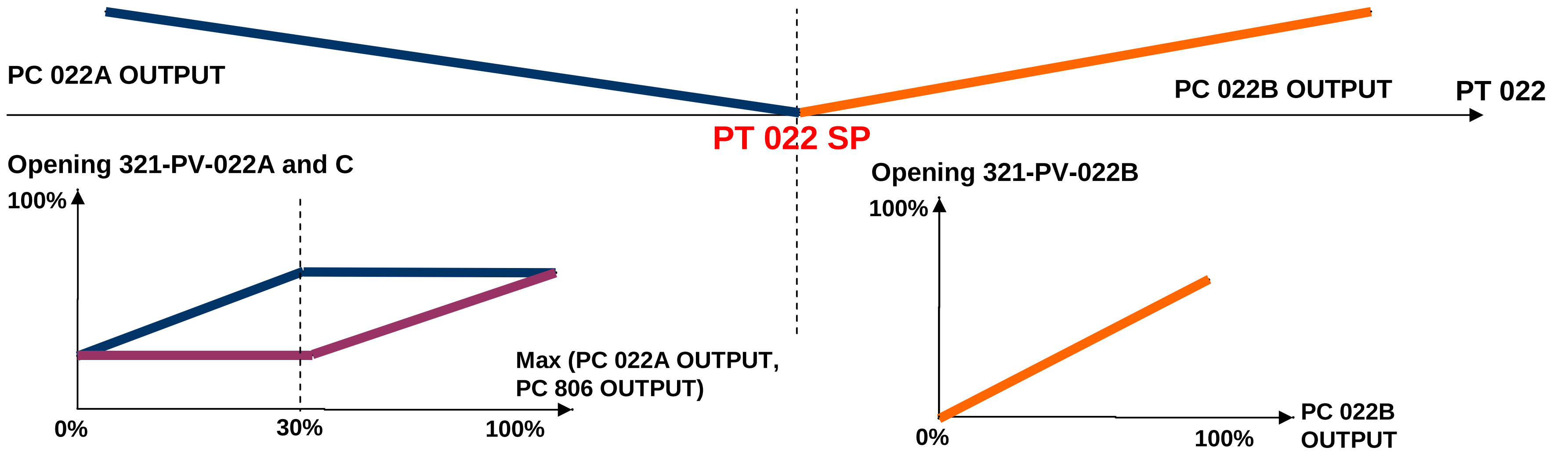


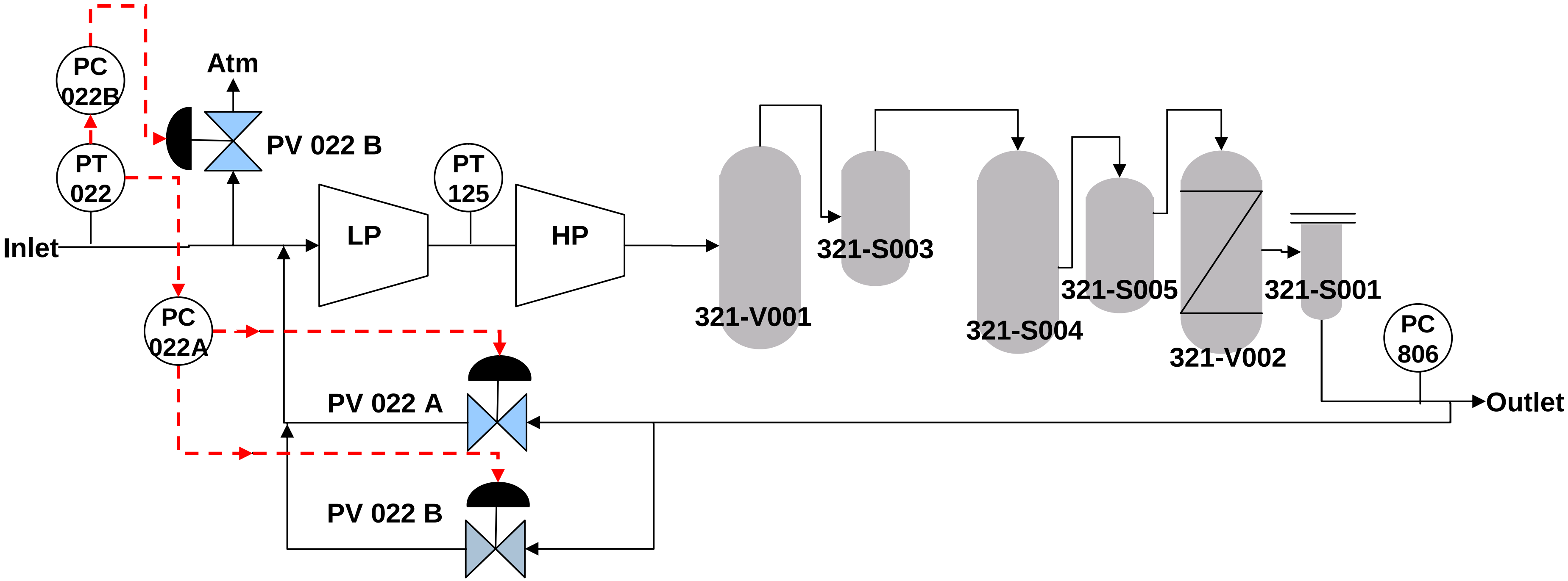
321-PV-022 B

- If 321-PT-022 decreases below its set point, 321-PV-022A and C open
- If 321-PT-022 increases below its set point, 321-PV-022B opens to release the overpressure



4. Process Variables and Control – Inlet Compressor





Process Variables and Control – Inlet Compressor

Spill back valve 321 HV 330

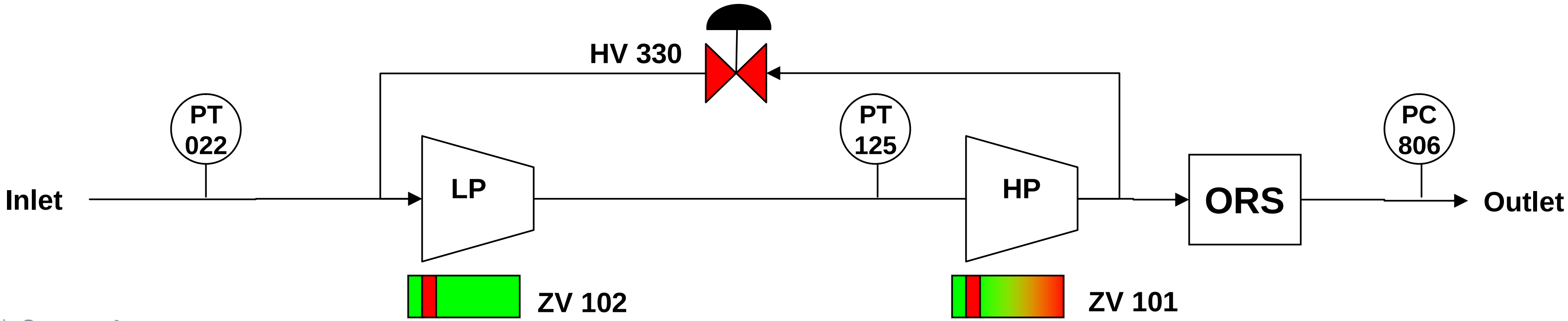
- Spill back valve is used for shutdown and start up
- During shutdown, ramps up to 100%
- During start up, ramps down from 100% (ready-to-start condition) to 0% (operating position in normal operation)

LP slide valve 321 ZV 102

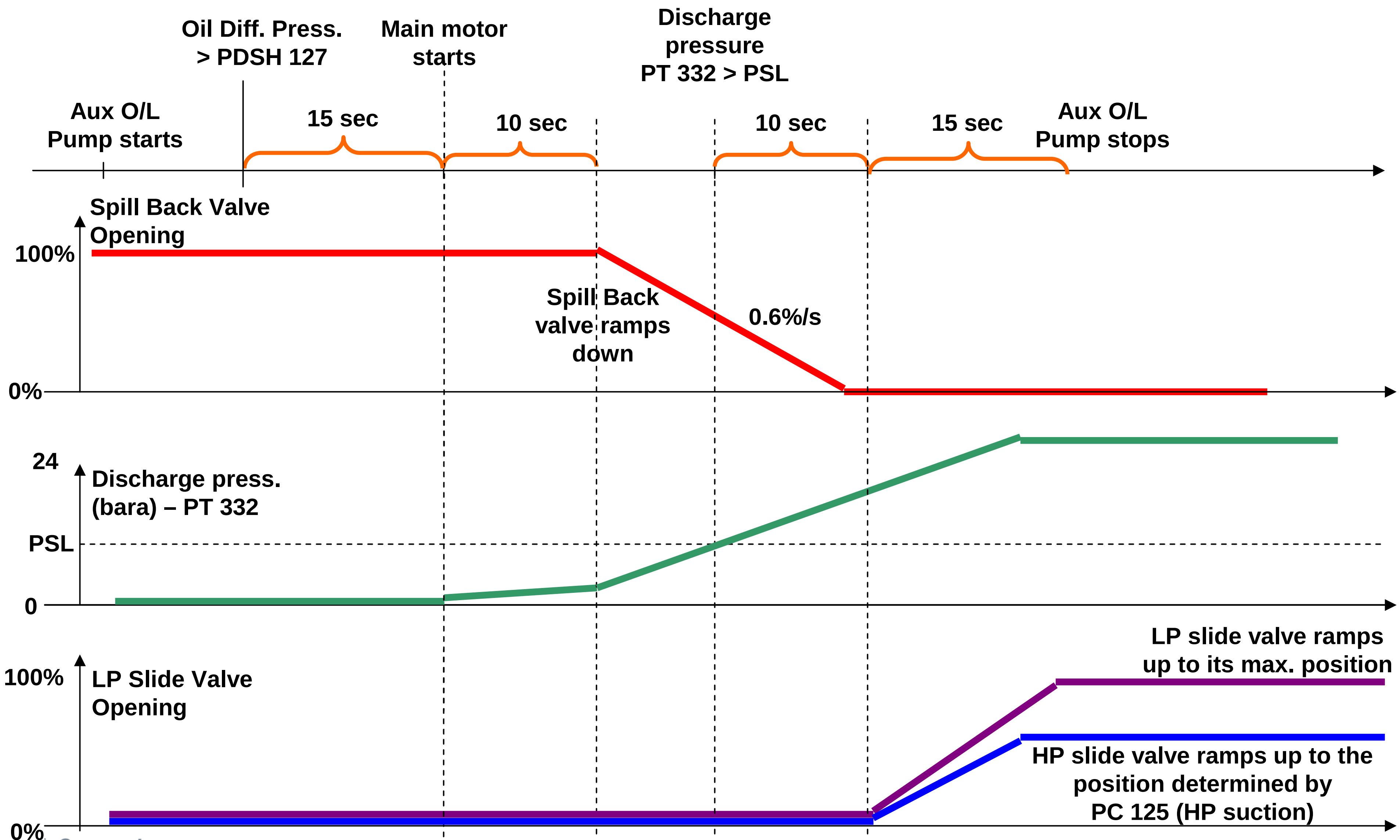
- At shutdown, LP slide valve ramps down to its minimum position
- During start up, ramps up from 0% (ready-to-start condition) to 100% (operating position in normal operation)

HP slide valve 321 ZV 101

- HP slide valve opening controlled by MP pressure controller: 321 PC 125



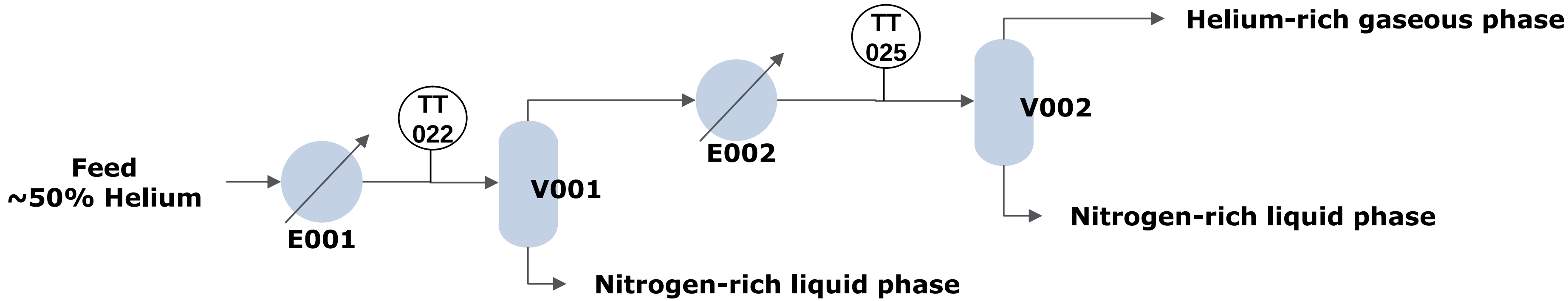
4. Process Variables and Control – Inlet Compressor



4. Process Variables and Control – Upgrader

Helium composition of Upgrader outlet

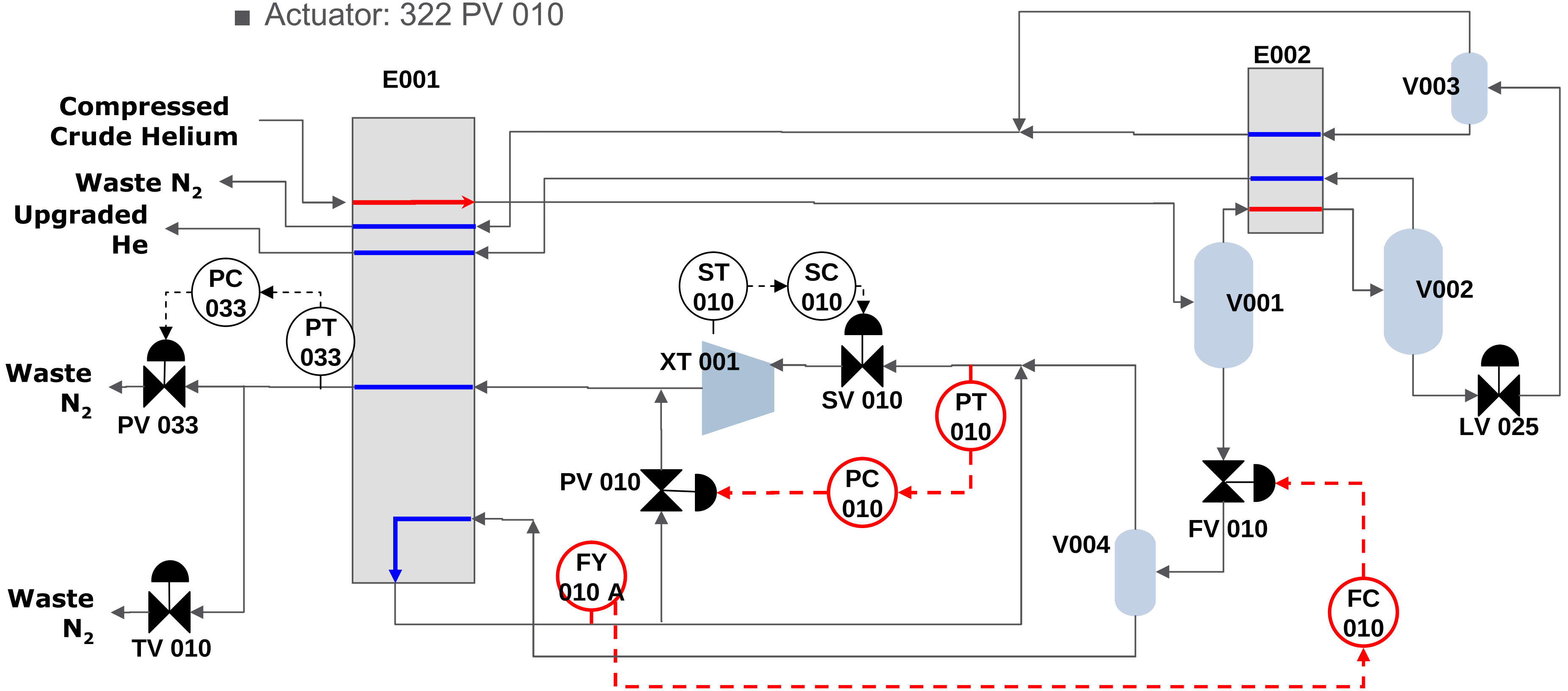
- For a given composition and pressure, the temperatures at 322 E001 outlet and 322 E002 outlet determine the composition of Upgraded Helium.



- If temperature decreases:
  - More Helium will condense and goes in the liquid phase
  - The molar fraction of Helium in vapor phase increases
  - ➔ Purity improvement but recovery rate deterioration
- If temperature increases:
  - Recovery rate improvement but purity deterioration

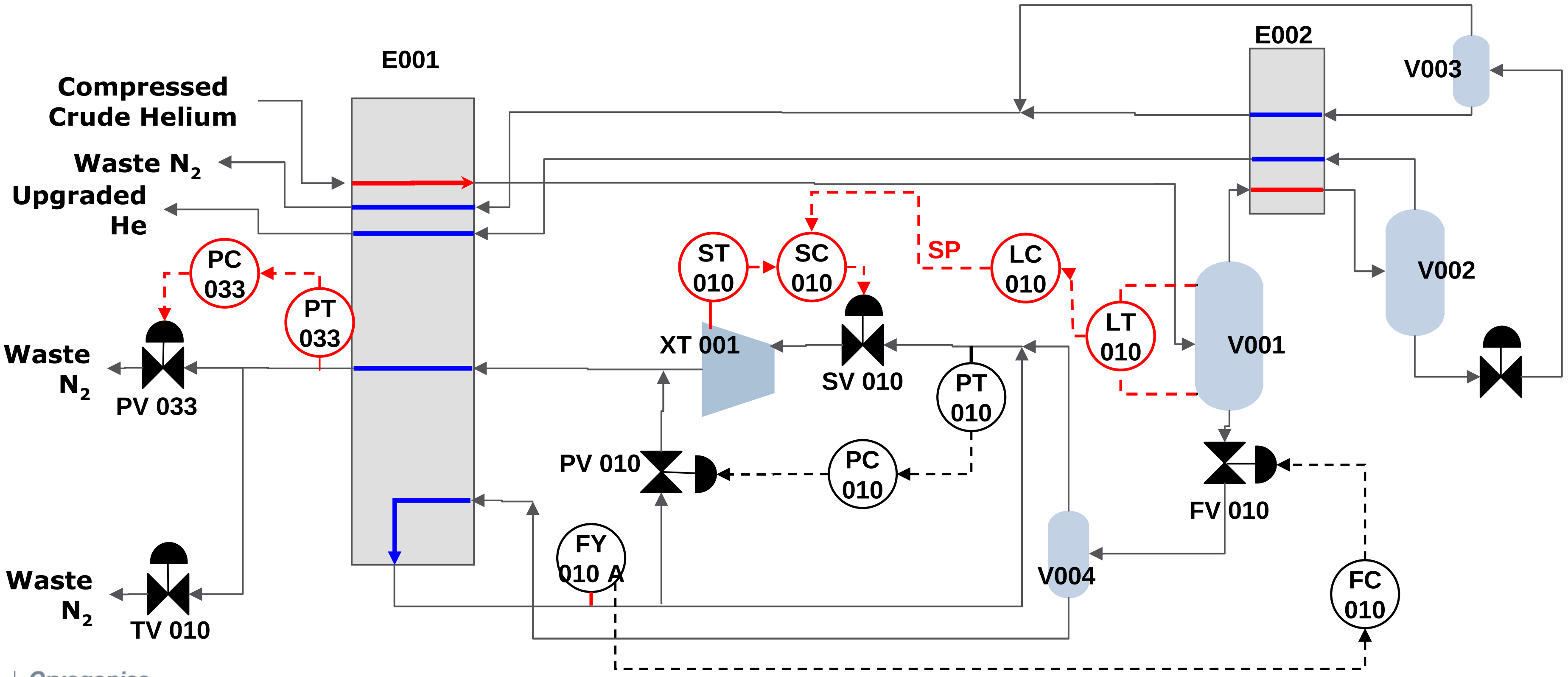
4. Process Variables and Control – Upgrader

- Cold Duty in 322 E001:
  - 322 FC 010 maintains constant Waste Nitrogen flow from 322 V001
    - Actuator: 322 FV 010
  - 322 PC 010 maintains constant turbine inlet pressure 322 PT 010
    - Actuator: 322 PV 010



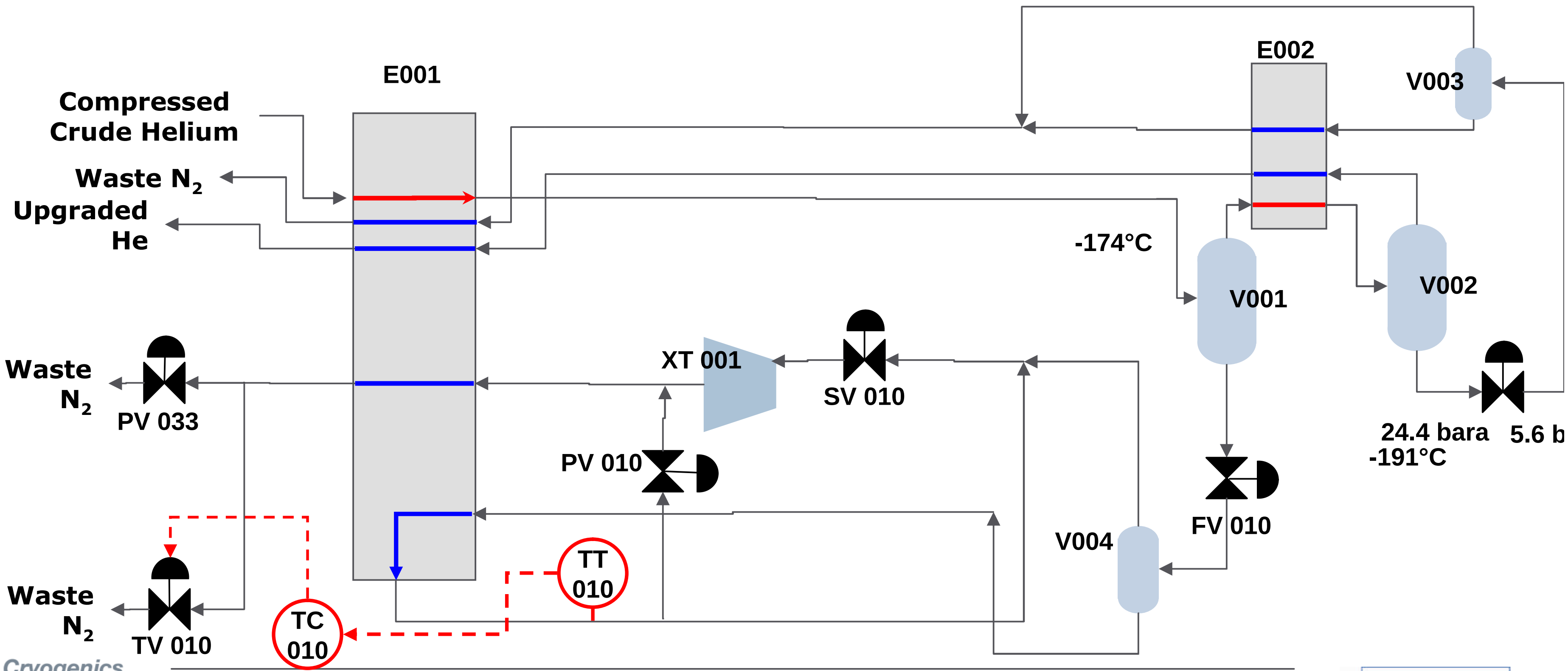
4. Process Variables and Control – Upgrader

- Cold Duty in 322 E001
  - 322 PC 033 maintains constant turbine outlet pressure 322 PT 033 – Actuator: 322 PV 033
  - 322 SC 010 controls turbine speed 322 ST 010 – Actuator: 322 SV 010
    - LC 010 provides SC 010 set point
    - If LT 010 > LC 010 set point, SC 010 set point will decrease and turbine speed will decrease
    - If LT 010 < LC 010 set point, SC 010 set point will increase and turbine speed will increase



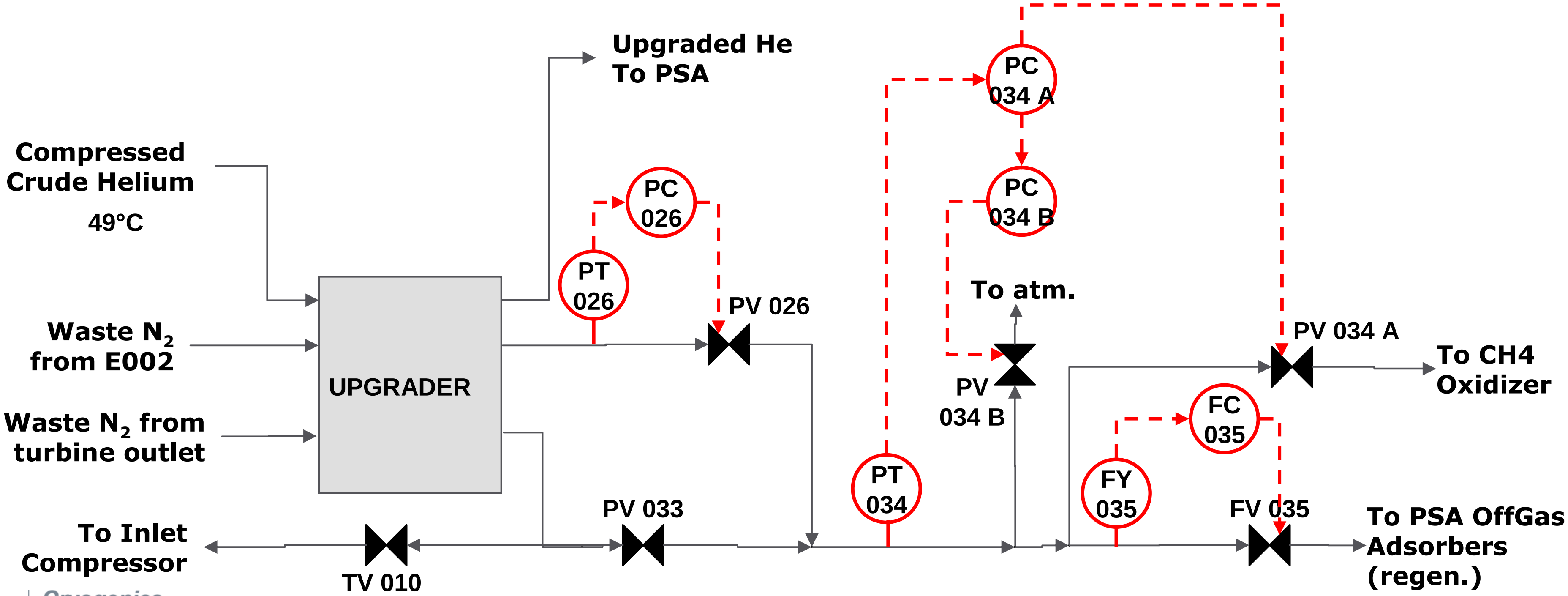
4. Process Variables and Control – Upgrader

- During lower loads or specific runs (low crude helium flow, high helium content in feed), maintaining 322 FT 010 constant leads to very low temperature at turbine inlet (322 TT 010) ➔ Exchanger E001 is very cold,
  - If 322 TT 010 is too low, N_2 flow is recycled at Inlet Compressor suction to reduce the helium content in the feed flow ➔ 322 TV 010 opens

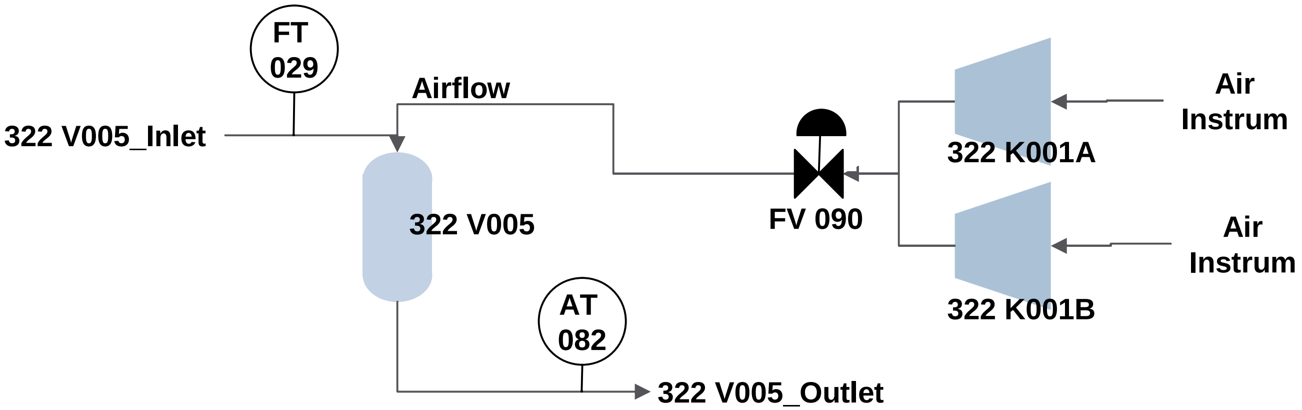


4. Process Variables and Control – Upgrader

- The flow to send to PSA OffGas Adsorber for regeneration is controlled by 322 FC 035 (remote set point calculated in the PSA OffGas sequence)
- When there is no flow to send to PSA OffGas Adsorbers, FV 035 is closed and the Waste Nitrogen is vented to atmosphere through 322 PV 034 A.
- 322 PC 034 A and B control 322 PV 034 A and B to evacuate the excess of Waste Nitrogen



- **Air flow** injection is controlled by 322 FV 090
  - Theoritical air flow:
    - H2_inlet = H2 molar content at 322 V005_ Inlet x Molar flow at 322 V005_Inlet



$$Airflow = \frac{\frac{1}{2}.H2\_inlet}{20.96\%}$$

- As there is no H_2 analyzer at 322 V005_Inlet:
  - H_2 content in 322 V005 ~ H_2 molar flow at Inlet Compressor suction (no H_2 removed in Upgrader) ➔ Given by 321 AT 022.
  - H_2 Inlet ~ 321 AT 022 x 321 FT 029
- All H_2 is removed if O_2 is in excess at 322 V005_Outlet:
  - 322 AT 082 measures O2 content and air flow sent in Catalytic Reactor is adjusted in order to maintain a slight O_2 excess at 322 V005 outlet

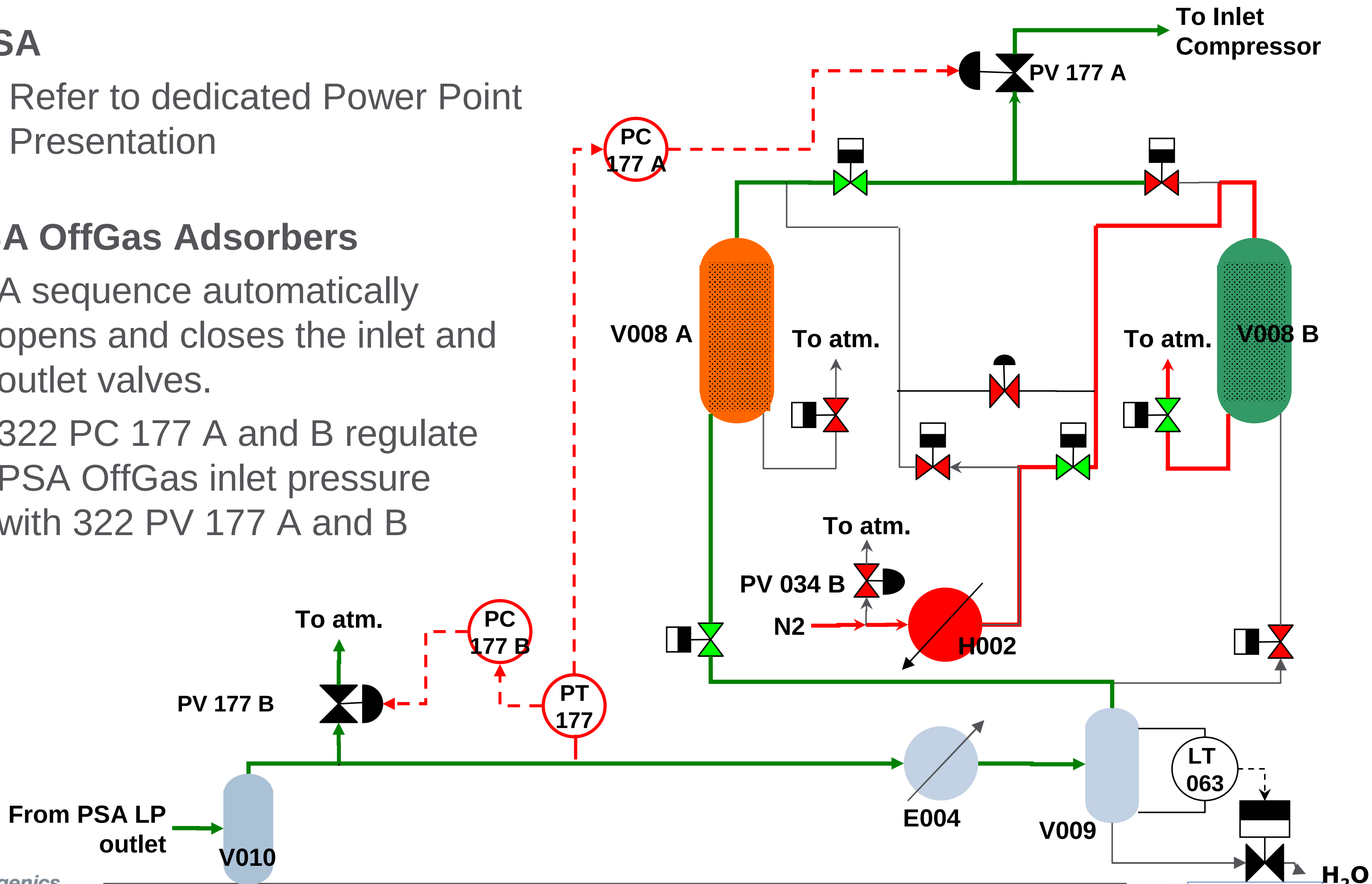
4. Process Variables and Control – PSA and PSA OffGas Adsorbers

PSA

- Refer to dedicated Power Point Presentation

PSA OffGas Adsorbers

- A sequence automatically opens and closes the inlet and outlet valves.
- 322 PC 177 A and B regulate PSA OffGas inlet pressure with 322 PV 177 A and B

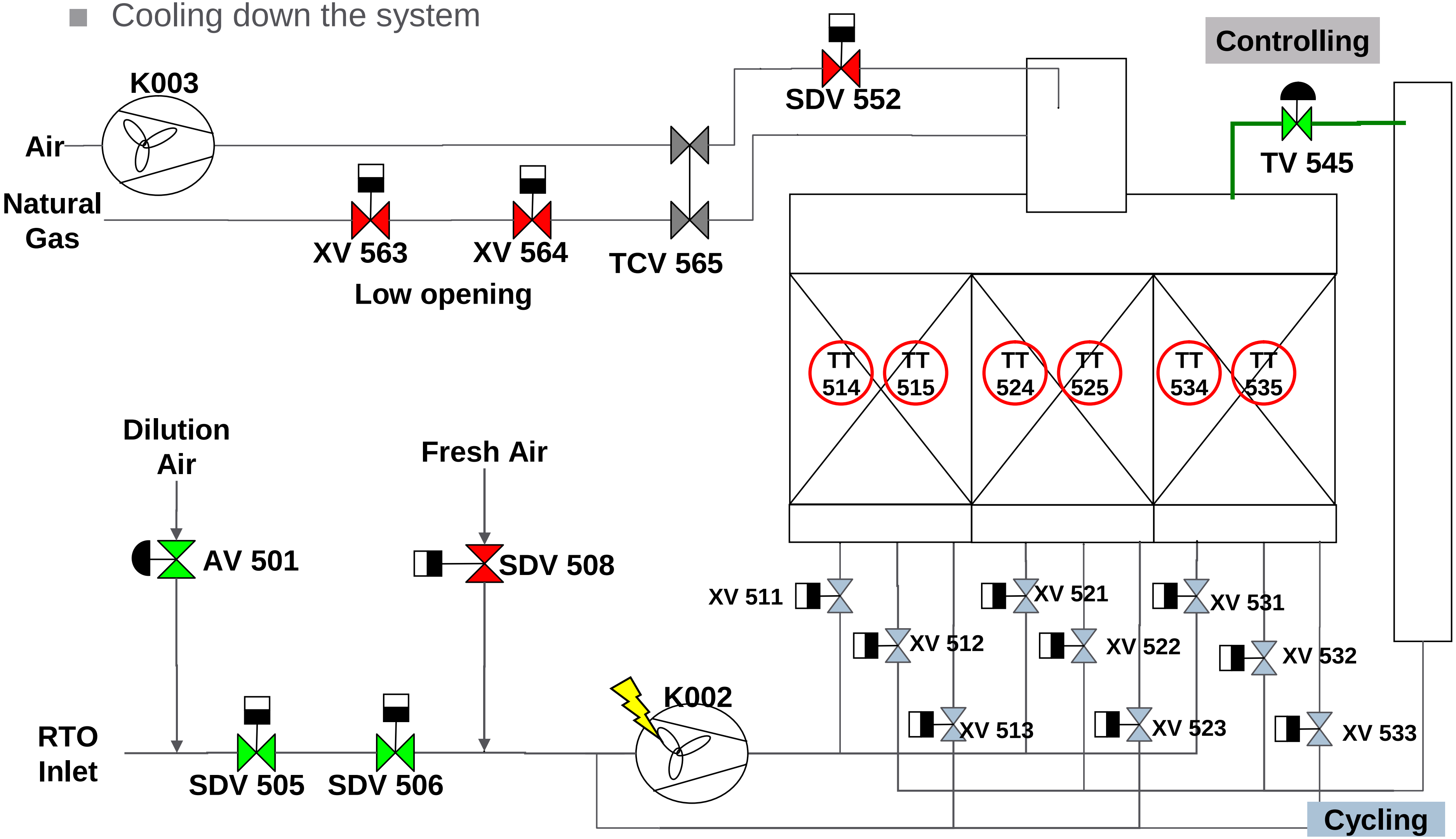


4. Process Variables and Control – CH4 Oxidizer

- **Temperature control: hot side bypass and burner**
  - The temperature is controlled with a hot side bypass (322 TV 545) and the Fuel Gas combustion in the combustion chamber
  - The hot side bypass allows evacuating heat energy directly to the stack if one of the containers' temperature increases above its high threshold. The amount of energy stored in the ceramic during the circulation of the flow from the combustion chamber to the bottom of the outlet container is reduced.
  - The burner regulates the mean value of 322 TT 541 and 542. If the temperature goes below ~850°C, the burner starts to heat up the system.

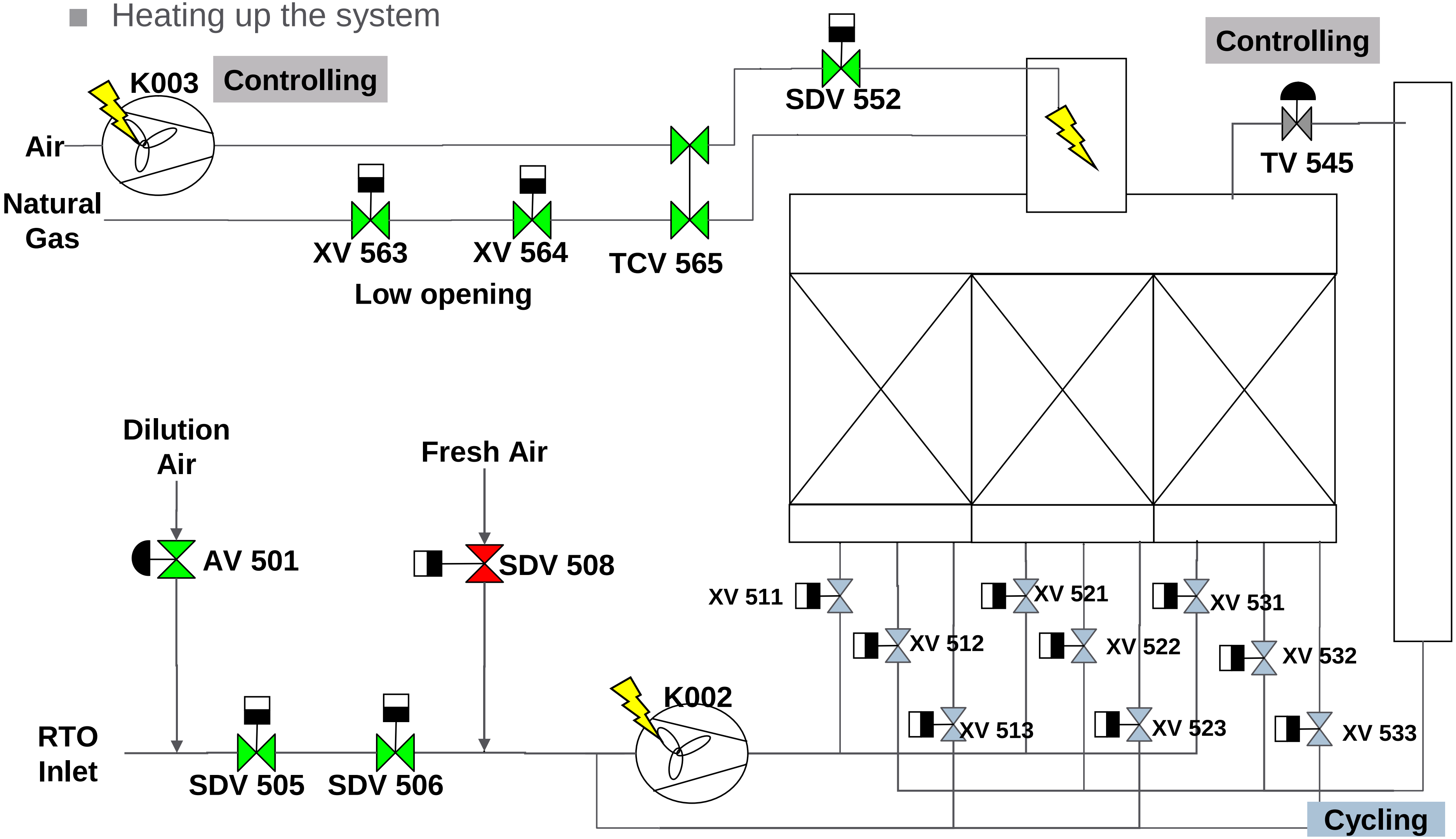
4. Process Variables and Control – CH4 Oxidizer

- Cooling down the system



4. Process Variables and Control – CH4 Oxidizer

- Heating up the system



Course Agenda

1. Introduction

2. Design conditions

3. Process Description

4. Process Variables and Control

5. Hazards and Precautions

5. Hazards and safety – General

- Regular EPI are mandatory on site:
  - Coverall
  - Safety boots
  - Helmet
  - Eye protection
  - Ear protection
  - Toxic Clip
  - Gloves.

5. Hazards and Safety – Main risks

- Cryogenic burns:
  - Leaks on cryogenic pipes can lead to cryogenic burns.
- N_2:
  - Pure or highly-concentrated N_2 can lead to anoxia (< 19.5% O_2)
  - An O_2 analyzer should always be worn on site.
- Heat:
  - In case of leaks on hot pipes, hot burns can occur.

Confined spaces:
  - The main risk is anoxia
  - Confined spaces' O_2 level must be monitored.

Thank you for your attention

Questions?