Setting the Standard for Automation™

Real Time Optimization of Air Separation Units

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Standards
Certification
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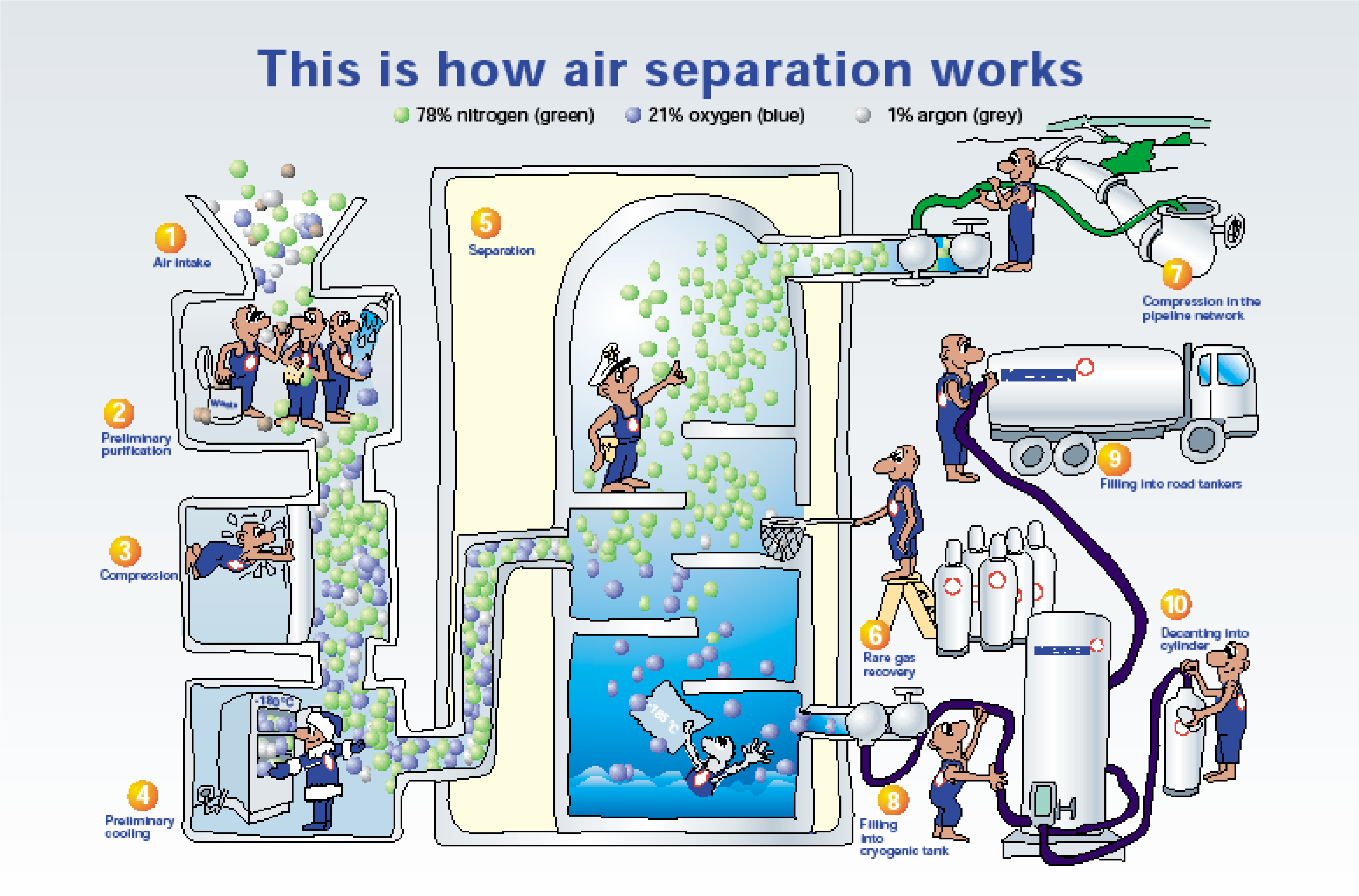
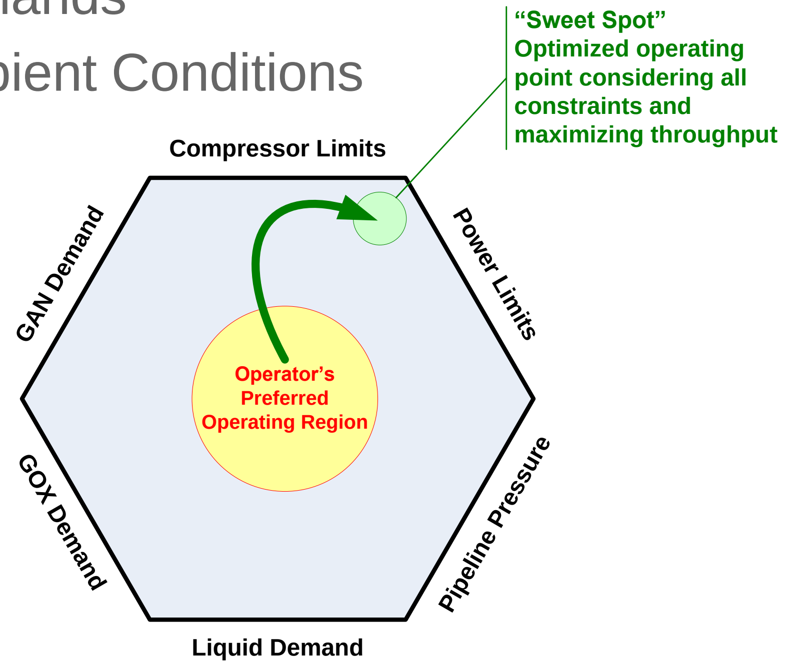
Cryogenic Air Separation

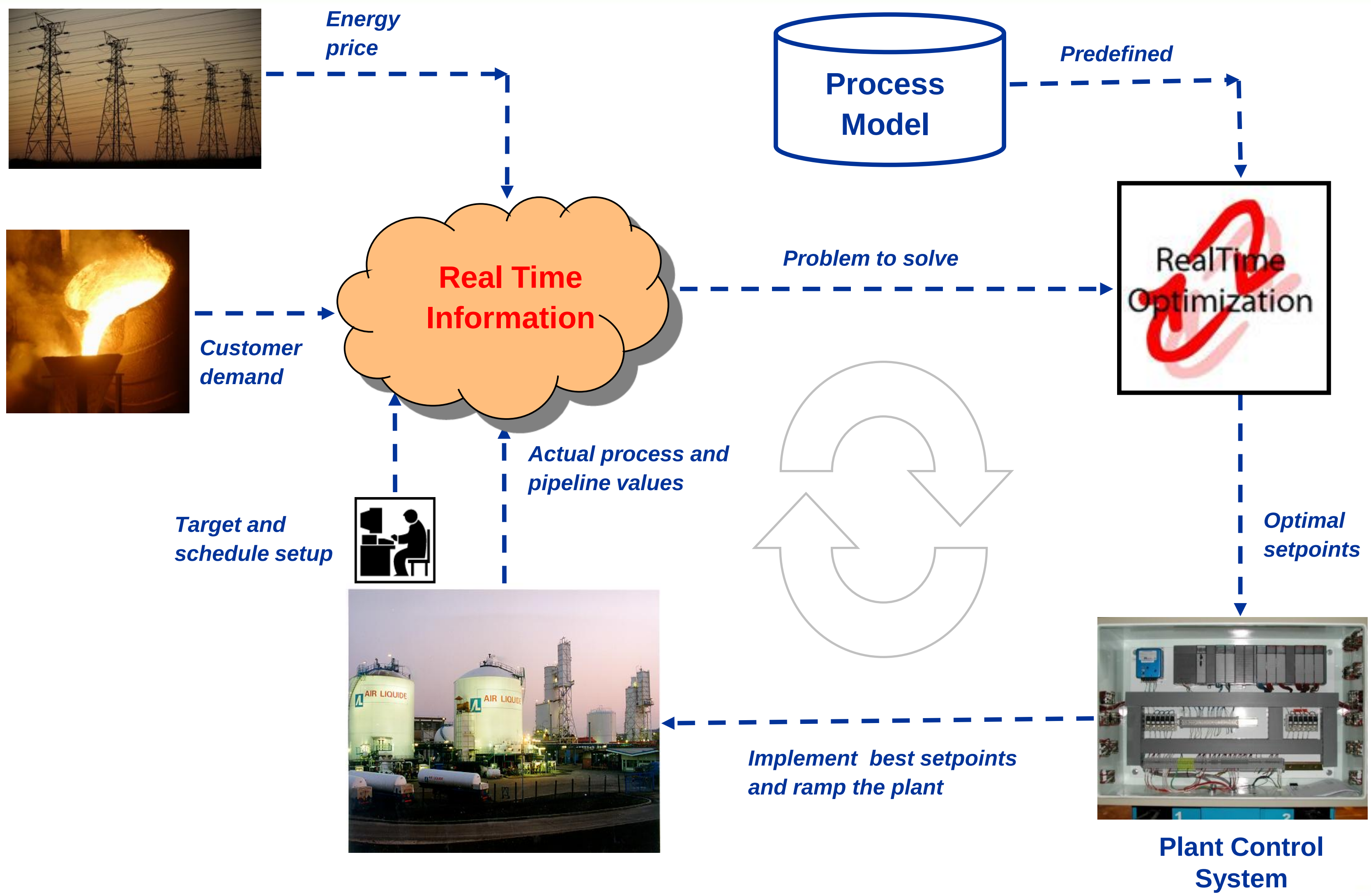


Motivations

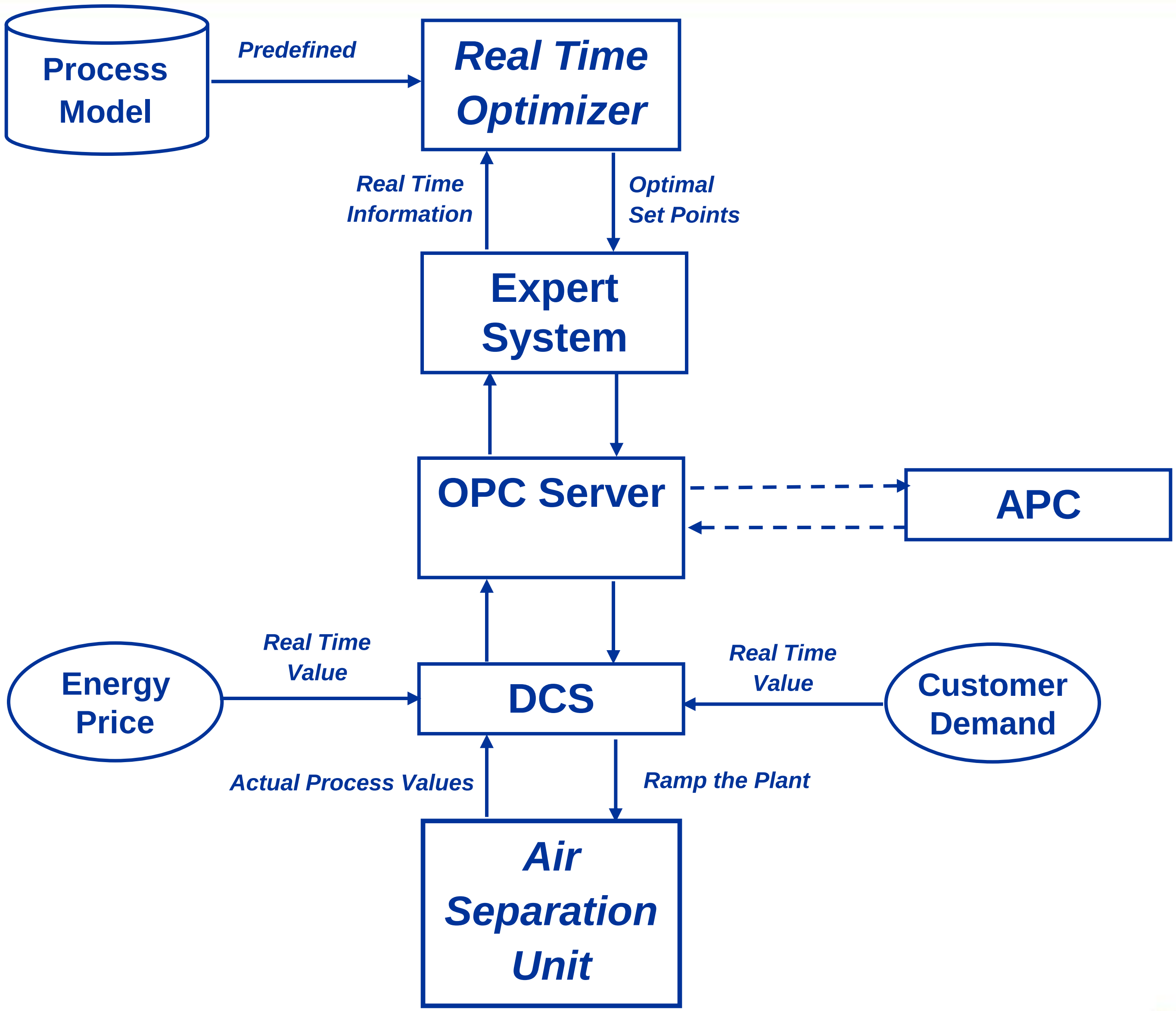
- Energy Intensive
  - Air Liquide consumed more than 0.1% of the world's electricity in 2010
- Dynamic Operating Environment
  - Energy price
  - Customer demands
  - Plant and Ambient Conditions



RTO Technical Solution



RTO IT Structure



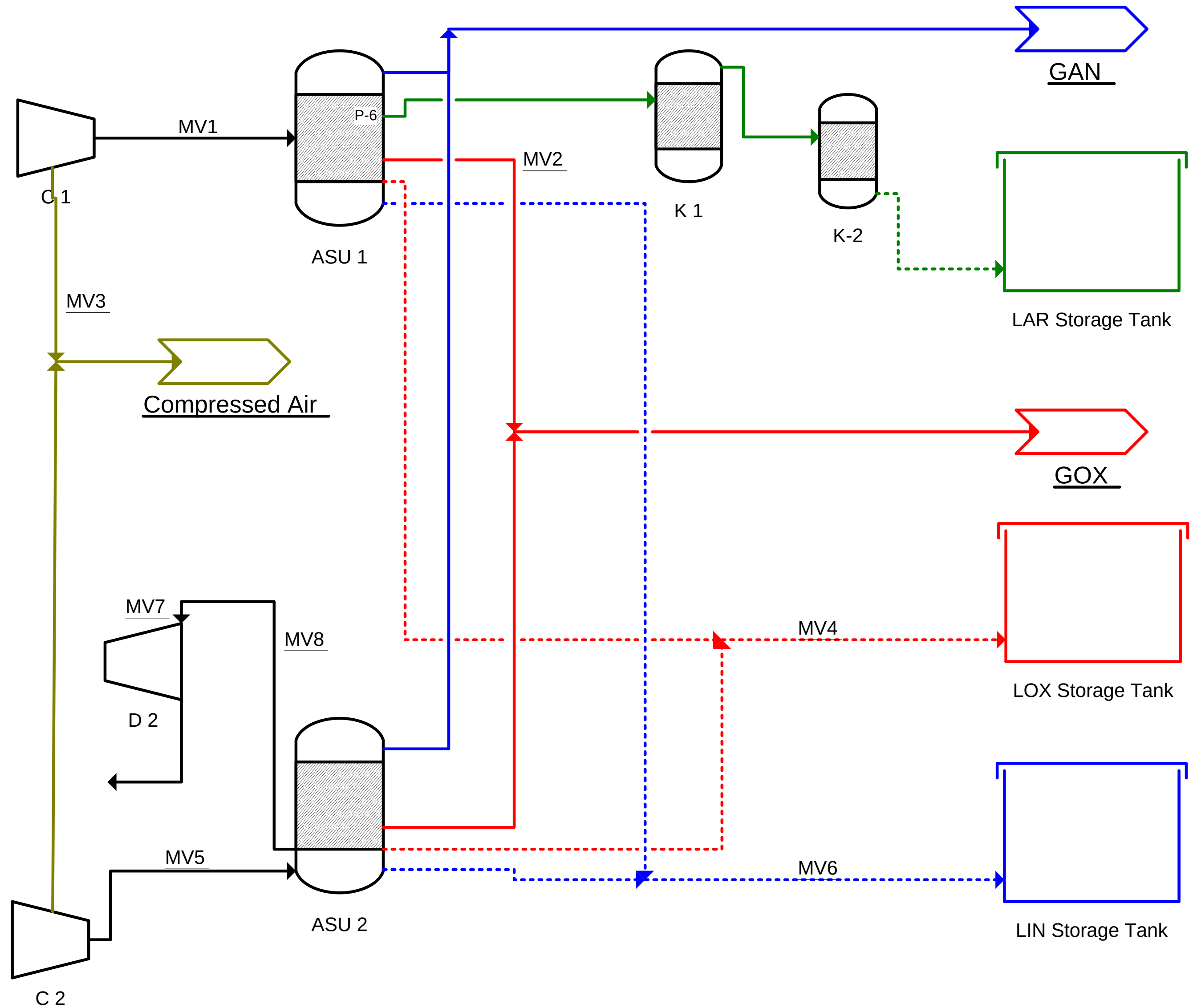
RTO Project Workflow

- **Step 1**: Plant Evaluation and Project Justification
  - KPI
  - Operating Environment
- **Step 2**: Scope Definition
  - Degrees of Freedom
  - Identifying Manipulated Variables
- **Step 3**: Plant Modeling
  - Controlled Variables, Objective Function, Constraints
- **Step 4**: Offline Optimization
  - Selection of Optimization Solvers
- **Step 5**: Online Implementation
  - Configuring Sampling Time, Solving Frequency, etc.
  - Designing Expert System
  - Connecting to DCS through OPC

Collaboration of a Cross-function Team

- Sponsor/Management
  - Project Justification
- Process Expert
  - Scope Definition
  - Process Modeling
- Operations
  - Expert System
  - Online Implementation
- Optimization Expert
  - Selection of Optimization Solvers
  - Model Configuration and Debugging

Case Study



GAN
MV1
P-6
MV2
K 1
K-2
C 1
ASU 1
MV3
LAR Storage Tank
Compressed Air
GOX
MV7
MV8
MV4
D 2
LOX Storage Tank
MV5
MV6
ASU 2
LIN Storage Tank
C 2

Plant Model

- Manipulated Variables
  - Air flow rate to the ASU I (MV_1)
  - GOX production rate of ASU I (MV_2)
  - Compressed air production rate of ASU I (MV_3)
  - LIN production rate of ASU I (MV_4)
  - Air flow rate to the ASU II (MV_5)
  - LIN production rate of ASU II (MV_6)
  - The status of the turbine (MV_7)
  - The flow rate through the turbine if it is on (MV_8)
- Objective Function

$$\max \begin{bmatrix} \left(Q_{LOX,I} + Q_{LOX,II}\right) \cdot P_{LOX} + \left(Q_{LIN,I} + Q_{LIN,II}\right) \cdot P_{LIN} + Q_{LAR,I} \cdot P_{LAR} \\ + \left(Q_{GOX,I} + Q_{GOX,II}\right) \cdot P_{GOX} + \left(Q_{air,I} + Q_{air,II}\right) \cdot P_{air} - \left(k_I + k_{II}\right) \cdot P_e \end{bmatrix}$$

Model Equations

- Controlled Variables (CV)
  - Mass Balance

$$Q_{GOX,II} = Q_{GOX,customer} - Q_{GOX,I}$$

$$Q_{air,II} = Q_{air,customer} - Q_{air,I}$$

  - Regression from Historical Operation Data

$$Q_{LOX,I} = f_1(MV_1, MV_2, MV_4)$$

$$Q_{LOX,II} = f_2(MV_5, Q_{GOX,II}, MV_6, MV_7, MV_8)$$

$$Q_{LAR,I} = f_3(MV_1, MV_2)$$

$$k_I = f_4(MV_1, MV_3)$$

$$k_{II} = f_5(MV_5, Q_{air,II})$$

Optimization Features and Online Implementation

- Optimization Features
  - Mixed Integer Nonlinear Programming (MINLP)
    - Solver: *AOA* of *AIMMS*
  - Nonconvex
    - Multi-start technique of *AIMMS* for global optimization
- Online Implementation
  - Model Configured in *OnOpt*
  - Connected to DCS through *MatrikonOPC Data Calculator* as the expert system
- Performance
  - Both solver and communication are robust
    - Being online most of the time since 2010
  - Expected savings have been achieved

Conclusions

- Real time optimization can increase an air separation plant's gross margin in a dynamic environment
- Investment is mainly software license and manpower
- Cross functional team is needed.
- The methodology can be easily applied to other process plants