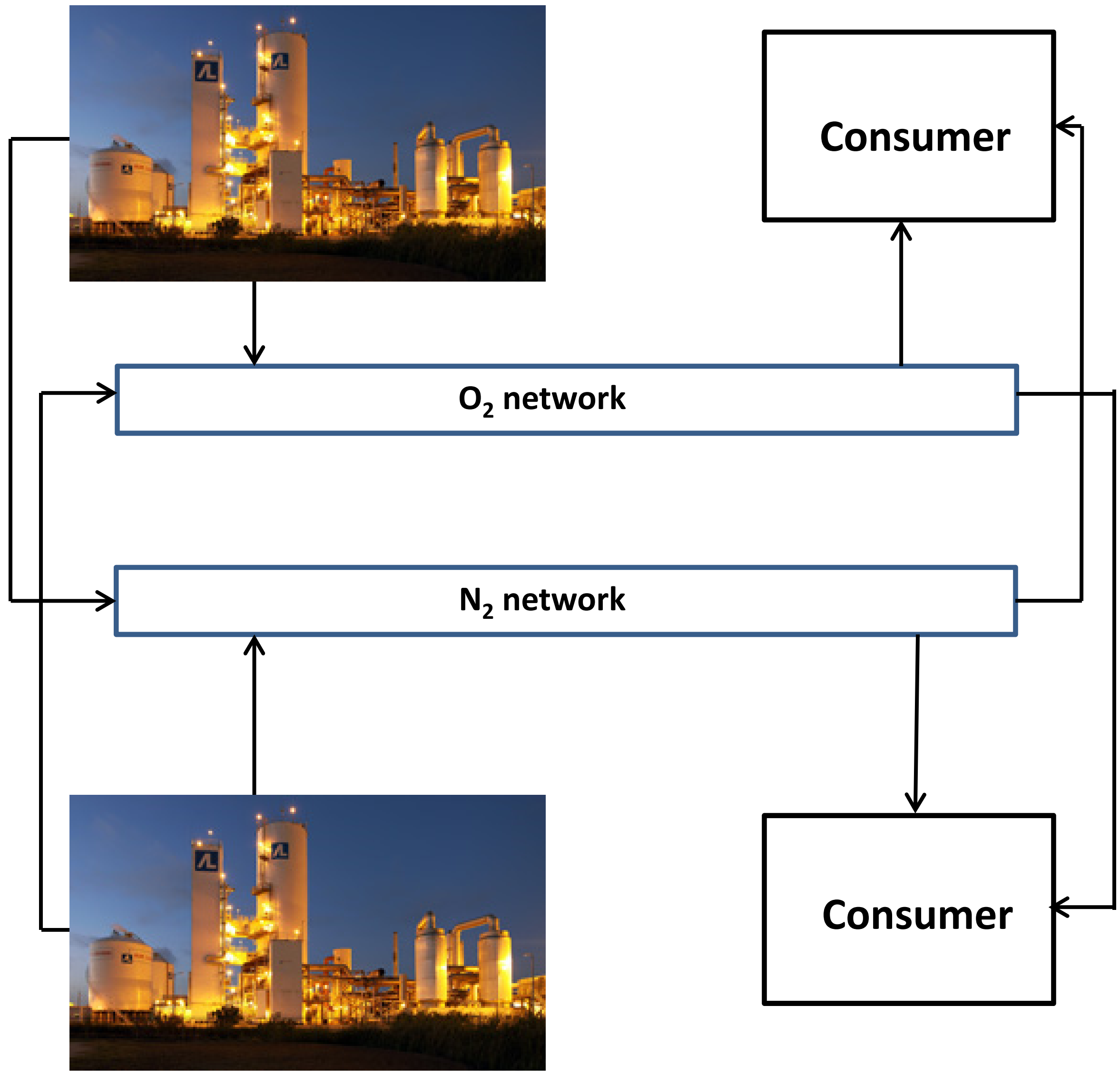
GLOBAL OPTIMIZATION FOR REAL-TIME OPERATIONS OF AN INDUSTRIAL GAS NETWORK

Yash Puranik and Nick Sahinidis (CMU)

Tong Li, Ajit Gopalakrishnan and Brian Besancon (Air Liquide)

GAS PIPELINE NETWORKS

Pre-existing network of gas pipelines connecting air separation units and consumers



SCOPE OF CURRENT WORK

- **Consider operation of a network of 4 plants, 3 pipelines, and external sources**
- **Optimize operations under changing demands and fluctuating electricity prices**
- **Ensure small solution times for application as a real time optimizing tool**
  - **Select and tune solvers**
  - **Reformulate the model to be friendlier to solvers**
  - **Simplify the model if necessary to account for important interactions while maintaining reasonable complexity**

ASSUMPTIONS OF THE MODEL

- **Consider operation for a single time period**
  - **Implemented on a rolling horizon basis**

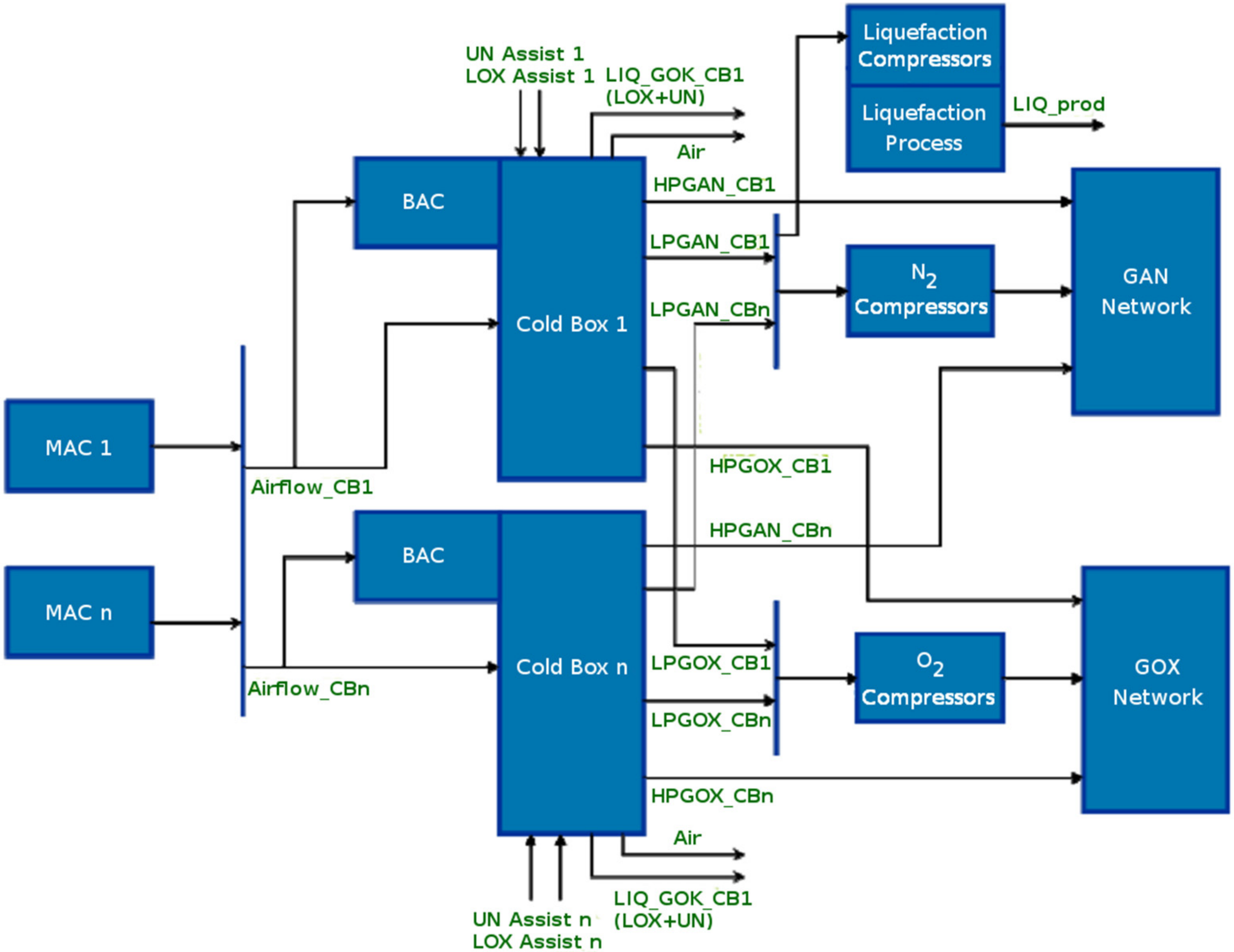
- **All demands are necessarily satisfied**

- **Demands and electricity prices revealed at start of the period**

- **Instantaneous switching between states**

Previous experience at Air Liquide shows presence of multiple local minima. Global optimization techniques essential

GENERIC PLANT DIAGRAM



NETWORK MODEL

- Model for a single column with 40 trays had size 320 differential equations, 1200 algebraic equations (Huang et al., 2013)
- Regression based models developed at Air Liquide
- Nonconvex models necessary to capture system characteristics
- Logic conditions
  - Conjunctions – Certain equipment must be used in concert
  - Disjunctions – Certain equipment cannot be used together
  - Reformulations with binary variables
- Problem Size - ~150 binaries, ~600 continuous variables, ~800 equations

MODEL CHALLENGES

- **Infeasibility: combining different submodels led to feasibility issues not easily diagnosed**
- **Numerics: regression models contained very small (10^{-31}) as well as very large numbers (10^{20})**
- **Nonconvexity: global optimization techniques necessary to ensure we are not trapped by suboptimal solutions**
- **Combinatorics: presence of integrality restrictions in the model**

SIGNIFICANT CONTRIBUTIONS

- **Infeasibility**
  - **Irreducible Inconsistent Set identification to help speed up diagnosis process for infeasible models**
  - **Novel preprocessing algorithm along with four other filtering algorithms implemented in the IIS isolation module in BARON**

- **Numerics**
  - **Model simplification through reformulations and scaling**

- **Combinatorics:**
  - **Solution of MILP relaxations in BARON for stronger lower bounds**
  - **Coefficient reduction, strong branching, cutting planes…**

RESULTS

Tests run over 6 different scenarios of demands and other input parameters.
Tests were run with an optimality tolerance of 5% and time limit of 3600 seconds

Solver	# of failures/ no solution	# of infeasibility claims	# of times converged within tolerance	Average computation time
Antigone	-	6	-	1
AlphaECP	6	-	-	3600
Lindoglobal	1	-	-	3600
Scip	1	-	-	942
Couenne	1	-	-	3600
SBB	-	6	-	1
DICOPT	-	6	-	1
BARON 14.3	-	-	6	105

CONCLUSIONS

- **Developed an optimization model for the operation of a gas pipeline network**

- **Can quickly and reliably solve the model for multiple scenarios**

- **Impact for other industrial applications through BARON**
  - **IIS isolation automates model diagnosis**
  - **Model reduction and dynamic scaling strategy allows for robust and reliable solutions for regression models frequent in industrial applications**
  - **MIP relaxations allow faster solutions for difficult nonconvex MINLPs**