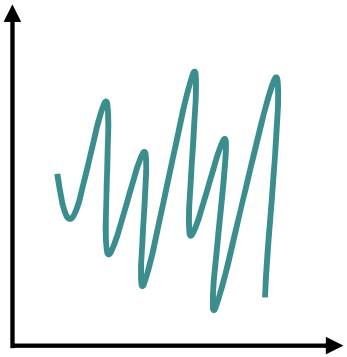

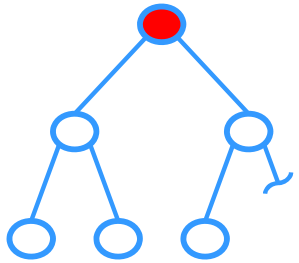

Global optimization of an industrial gas network operation

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CAPD CENTER

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GAS PIPELINE NETWORKS

O_2 network

N_2 network

SCOPE OF WORK

- **Consider a network of 4 plants and 3 pipelines**
  - **Model balancing fidelity and complexity**
  - **Optimize for fluctuating demands and electricity prices**
  - **Ensure small solution times for use as an RTO tool**

- **Assumptions**
  - **Implemented for one time period on rolling horizon**
  - **Instantaneous switching between states**
  - **Uncertainty revealed at the beginning of the time period**

PLANT MODEL

- Model for a single column with 40 trays had size 320 differential equations, 1200 algebraic equations (Huang et al., 2013)
- Regression-based nonconvex models developed at Air Liquide
- 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

COLD BOX MODEL

- **HP column pressure**

$$\mathrm{PMP}_{p,b} = f(\mathrm{airflow}_{p,b}, \mathrm{RN2}_{p,b}, \mathrm{LOXass}_{p,b}, \mathrm{LINass}_{p,b}, \mathrm{runCB}_{p,b})$$

- **Product recoveries**

$$\mathrm{rarg}_{p,b} = \min(0.95, f(\mathrm{airflow}_{p,b}, \mathrm{RN2}_{p,b}, \mathrm{LOXass}_{p,b}, \mathrm{LINass}_{p,b}, \mathrm{runCB}_{p,b}))$$

$$\mathrm{rgox}_{p,b} = \min(0.99, f(\mathrm{airflow}_{p,b}, \mathrm{RN2}_{p,b}, \mathrm{runCB}_{p,b}))$$

- **Material balance**

$$\mathrm{airflow}_{p,b} = \sum_{c \in \mathrm{Aircomp}} \mathrm{Fcomp}_{p,c} - \mathrm{loss}$$

- **Bounds on airflow**

$$\mathrm{airflow}^{lo}_{p,b} <= \mathrm{airflow}_{p,b} <= \mathrm{airflow}^{hi}_{p,b}$$

- **Cold box described with 10 algebraic equations and 10 variables**

INCONSISTENT RESULTS

Solver	Lower Bound	Upper Bound
Antigone	6996	6996
AlphaECP		6075
Lindoglobal	6169	6964
Scip	5086	-
Couenne	6105	6217
Sbb	unbounded	
DICOPT	rminlp unbounded	
BARON 12.7	infeasible	

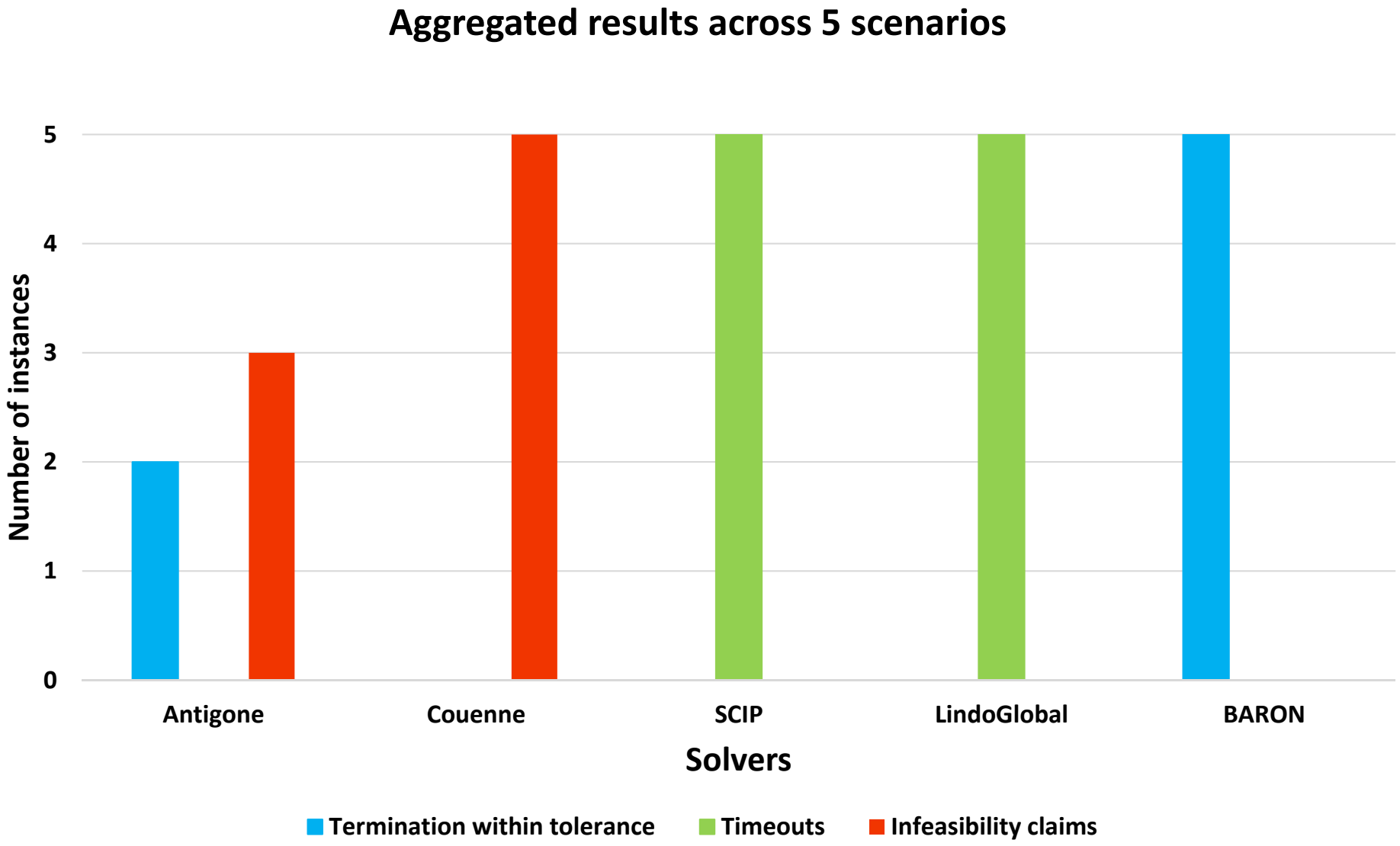
CHALLENGES

- **Infeasibility**
  - **Infeasibility during model formulation difficult to diagnose**
- **Numerics**
  - **Regression models utilizing very small (10^{-31}) and very large (10^{20}) numbers**
- **Nonconvexity**
  - **Global optimization necessary to avoid suboptimal solutions**
- **Combinatorics**
  - **Complicating combinatorics making model difficult to solve**

SIGNIFICANT CONTRIBUTIONS

- **Multi-pronged approach to solve a complex industrial case study of practical interest**
- **Infeasibility analysis**
  - **Systematic infeasibility analysis tool with BARON**
    - **Proposed preprocessing algorithm**
    - **Multiple algorithms and heuristics from literature**
- **Numerics**
  - **Model simplification**
  - **Scaling of model**
- **Combinatorics**
  - **Use of MIP relaxations and associated technology**

RESULTS



Tests were run with an optimality tolerance of 5% and time limit of 500 seconds

IMPACT FOR APPLICATIONS

- **Problem motivated developments in BARON**
- **IIS module for isolation and diagnosis of infeasibilities in models**
- **Scaling strategies for robust and reliable solutions for regression models frequent in industrial applications**
- **MIP relaxations for faster solutions for difficult nonconvex MINLPs**
- **Release of test cases to motivate development of other solvers**