Optimal Design Approaches for Rapid, Cost-Effective Manufacturing and Deployment of Chemical Processes

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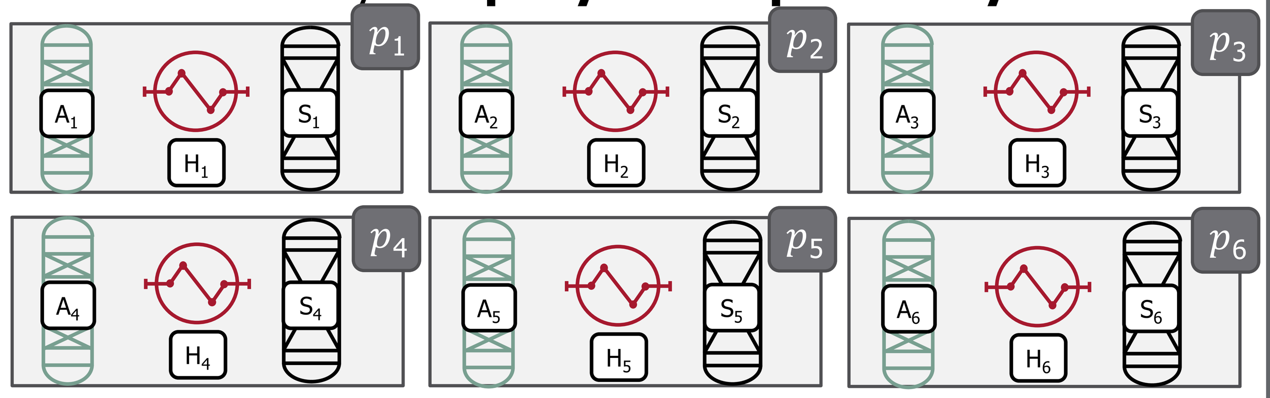
Motivation

Goal Install a process technology across a range of sites with different design variables

Example Carbon-capture facilities for multiple plants with different environmental & operating conditions

Conventional Approach

Design and **manufacture each** plant's carbon-capture facility **uniquely & independently**



- One-off design → time consuming
- Unique parts → manufacturing cost & complexity

Problem

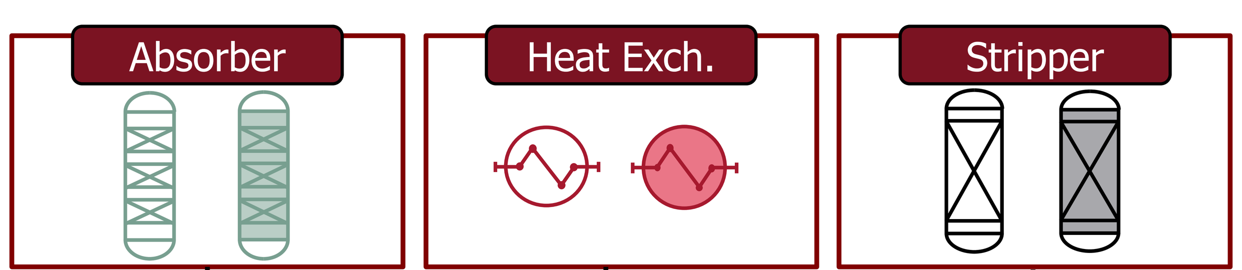
A new process technology needs to be designed and deployed, quickly and cost effectively, at many sites with different core design conditions & requirements.

- ☑ **Simultaneously design** the process technology across a range of installations
- ☑ Exploit efficiencies by **utilizing common components** shared across installations

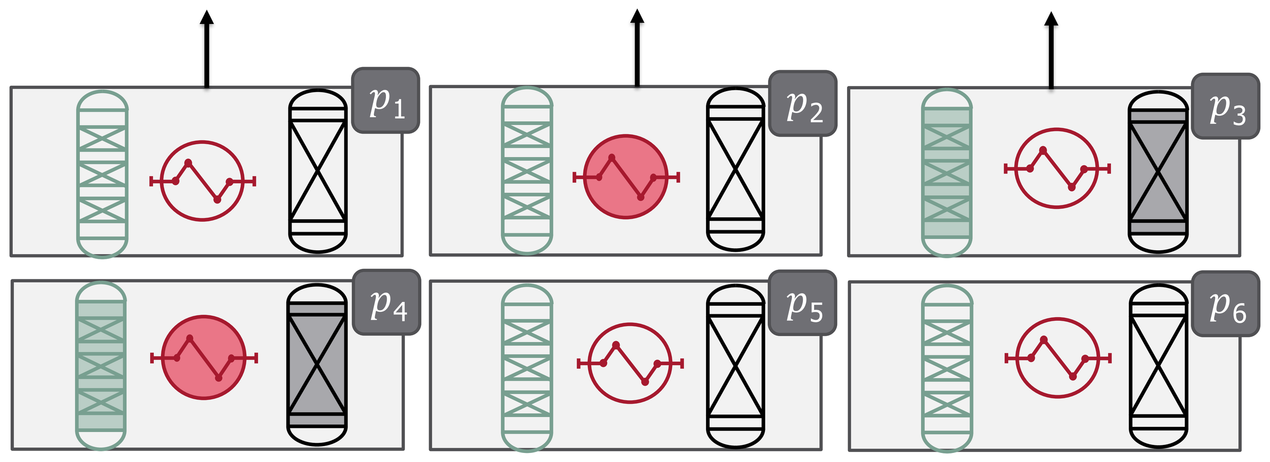
Approach

Process Family Design

- Identify the superset of units
- Select size ranges for units in superset
- Pre-compute performance of every design combination



Optimally select the **size of each unit** based on the **range of design conditions** simultaneously assigning unit sizes to each design



Problem Formulation

Definitions

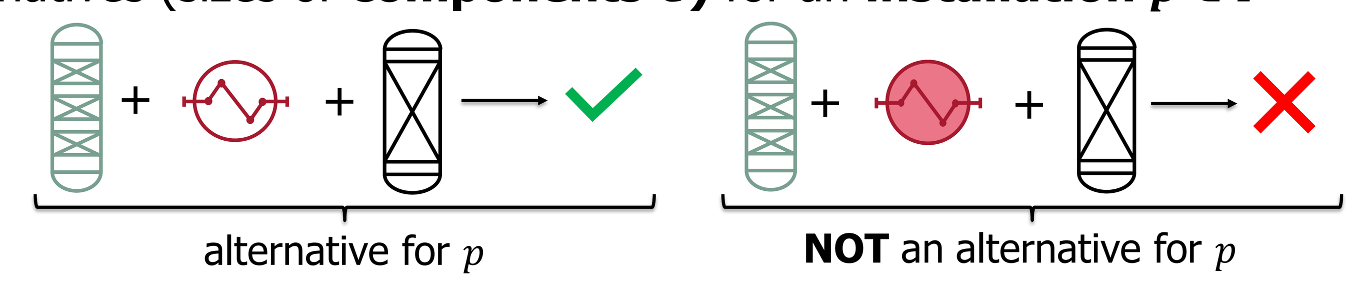
P: set of installations identified by unique **performance targets** & **feed conditions**

Flue Gas Flow Rate ← (plant) → Flue Gas CO_2 Conc.

C: Set of **unit** types considered for shared design across installations in **process family**

A_p: Set of **feasible** alternatives (sizes of **components** C) for an **installation** $p \in P$

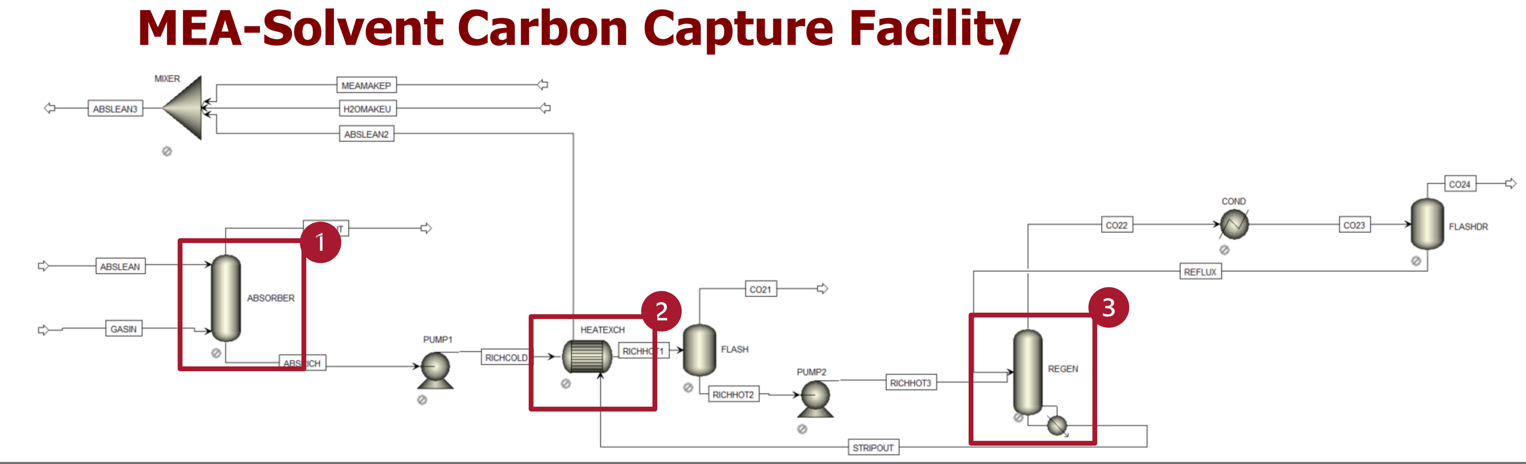
p: FG Flow$_p$ = F, FG $CO_{2,p}$ = x_{CO2}



Process
Flow, CO_2 conc.

Components
Absorber
Heat Exchanger
Stripper

MEA-Solvent Carbon Capture Facility



which **alternative** is chosen for a particular **process**

which **sizes** of each **components** selected for manufacturing

$$\min_{xz} \sum_{p \in P} w_p \sum_{a \in A_p} \alpha_{pa} x_{pa} + \sum_{c \in C} \sum_{s \in S_c} \beta_{cs} z_{cs}$$

(1a) $\sum_{s \in S_c} z_{cs} \leq N_c$ → **Constraint:** Manufacturing — Manufacture certain number of sizes of each component

(1b) $\sum_{a \in A_p} x_{pa} = 1$ → **Constraint:** Process Design — Select 1 alternative for every process

(1c) $x_{pa} \leq z_{cs}$ → **Logic:** Component Selection — Components in altern. must be manufactured

$$0 \leq x_{pa} \leq 1$$
$$z_{cs} \in \{0,1\}$$

Formulation Remark

The P-Median Location Problem

Decide locations of P facilities + assignment of each facility to demands

$$\min \sum_i \sum_j a_i d_{ij} x_{ij}$$

s.t.

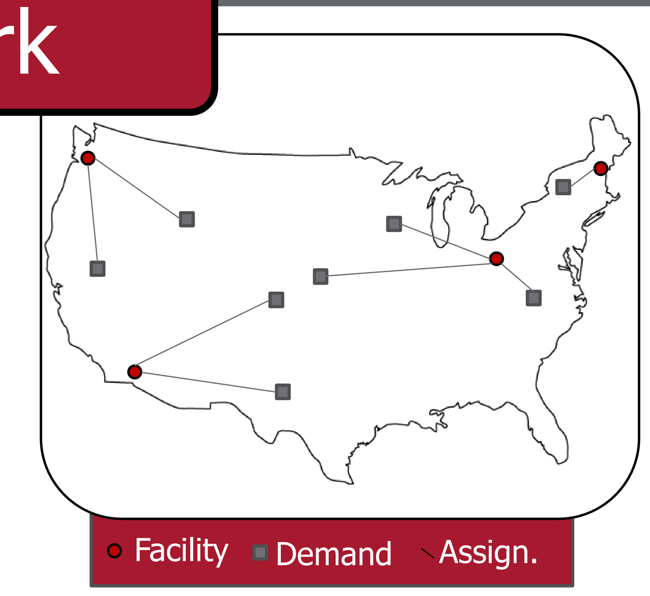
(2a) $\sum_{j \in J} y_j = P$ → Select P facilities to build

(2b) $\sum_{j \in J} x_{ij} = 1$ → 1 facility fills 1 demand

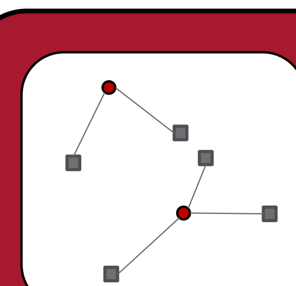
(2c) $x_{ij} \leq y_j$ → Select a facility that is built

$$0 \leq x_{ij} \leq 1$$
$$y_j \in \{0,1\}$$

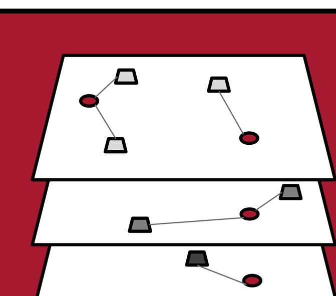
y_i **binary** & x_{ij} **relaxed** → x_{ij} will converge to binary at optimality



In this problem
Facility location → unit sizes
Demand nodes → processes



Each **unit decision** is a P-Median problem



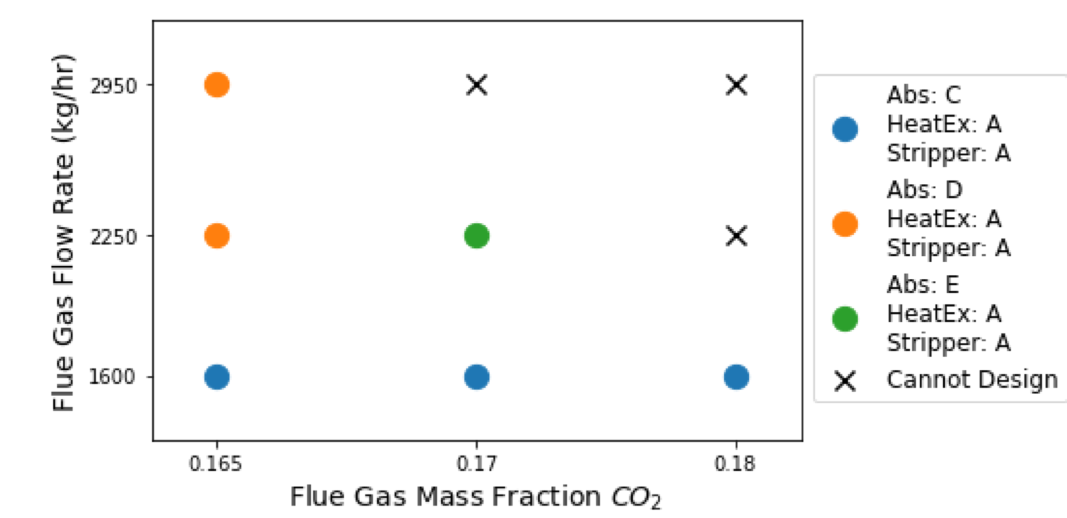
Multiple unit decisions → **multiple** P-Median problems

Results & Discussions

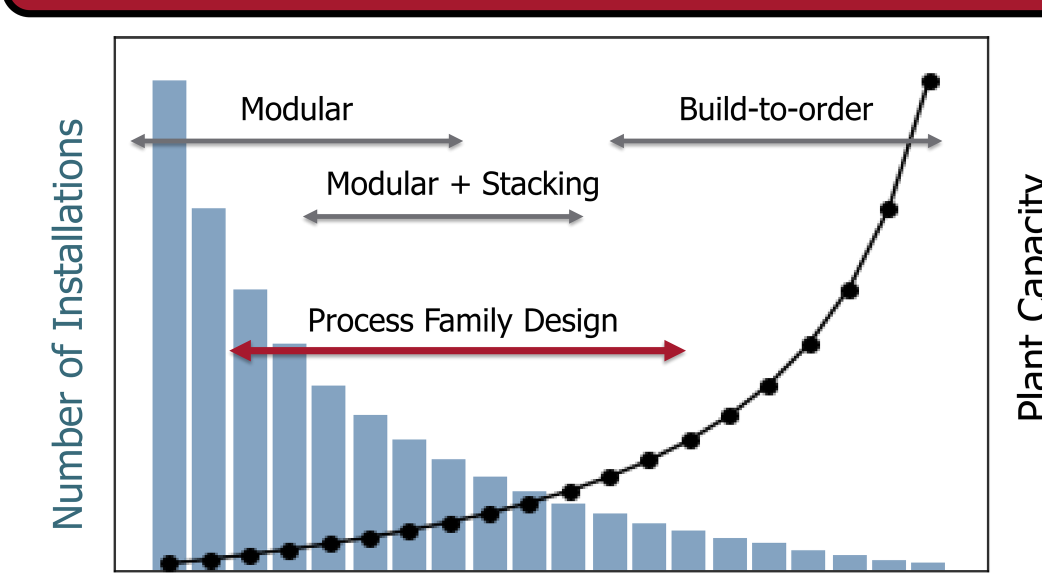
MEA Facility

Process
- **3** flue-gas concentrations
- **3** flue-gas flowrates

Components
5 options for absorber, stripper, & heater exchanger
- **Select:** 1-3 absorbers, 1-2 heaters, 1-2 strippers



Conclusions & Future Work



- Scalable optimization on this and other examples
- Reduces manufacturing cost, retain economies of scale
- Expand ranges & improve simulation reliability
- Investigate strategies to reduce simulation requirements (simulation time is the bottleneck)

References

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