An Operational Model for Optimal Non-Dispatchable Demand Response for Continuous Power-intensive Processe

or

An Operational Model for Optimal Production Scheduling under Hourly-varying electricity prices for Continuous Power-intensive Processes

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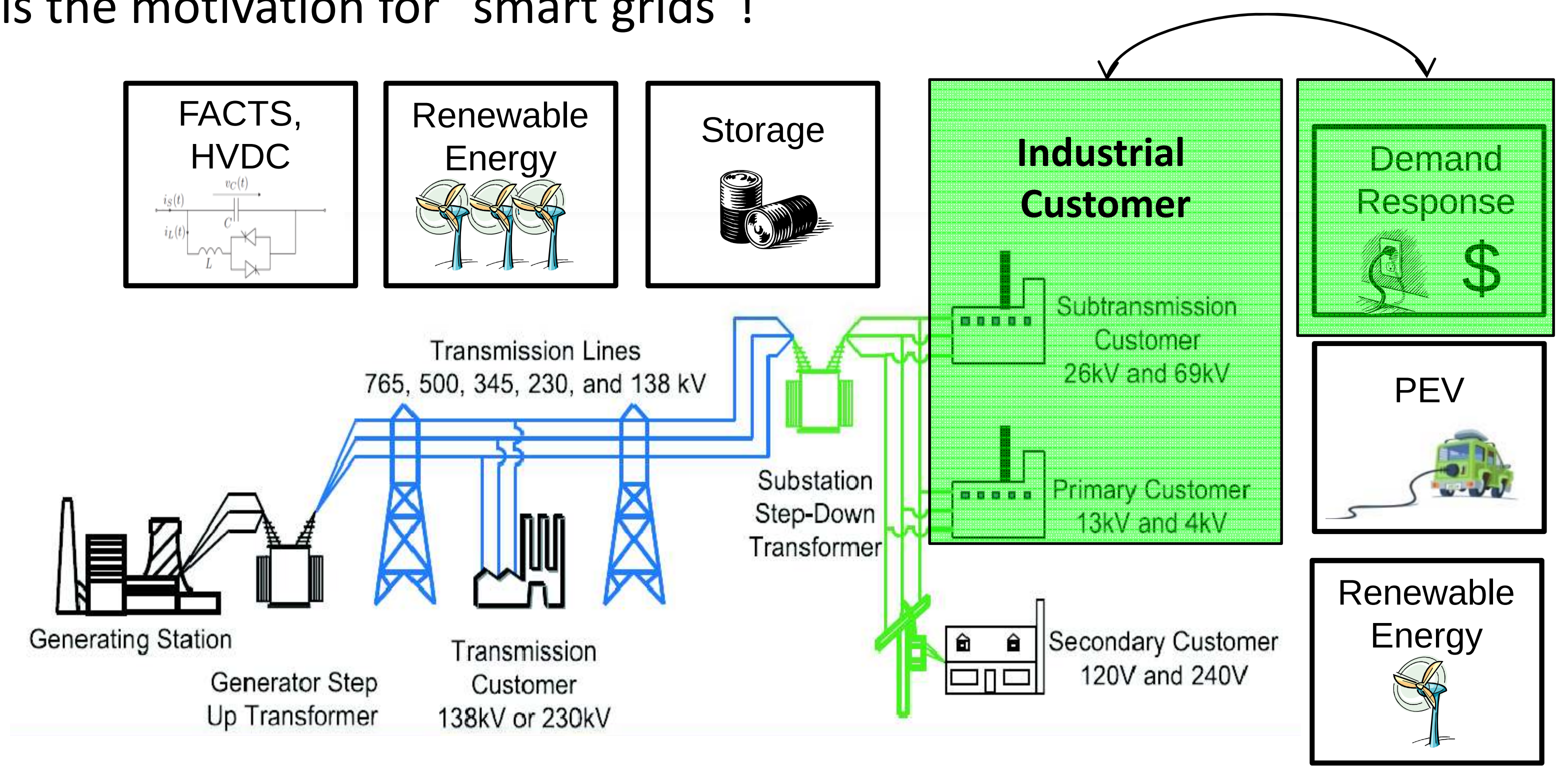
EWO Meeting, 03/09/2011

Perspective of the Future Electric **Power System**

Main challenge: balance supply and demand

→ This is the motivation for “smart grids”!



Source: U.S.-Canada Power System Outage Task Force

High Observability
enabled by increased communication capabilities

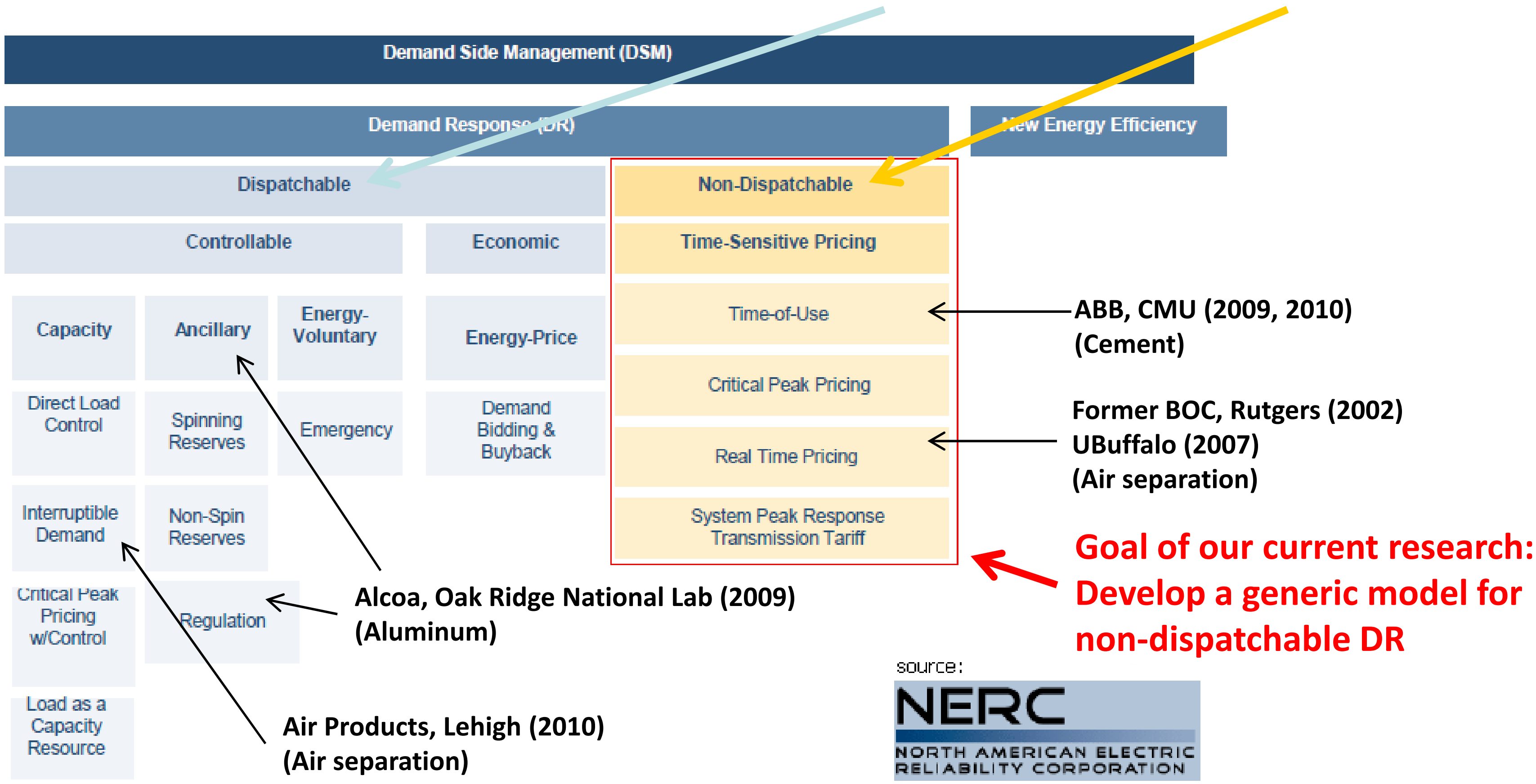
This slide is based on a presentation slide by Prof. Gabriela Hug, Department of Electrical Engineering, Carnegie Mellon University, ESI seminar, January 13 2011

Demand Response (DR): Overview and recent work for industrial processes

Carnegie Mellon

Basic idea: To balance supply and demand of a power system, one can manipulate both: supply and **demand → demand response (DR)**.

Utility provider perspective: distinguish *dispatchable* and *non-dispatchable* DR



Other power-intensive processes:

- Chlor-alkali synthesis

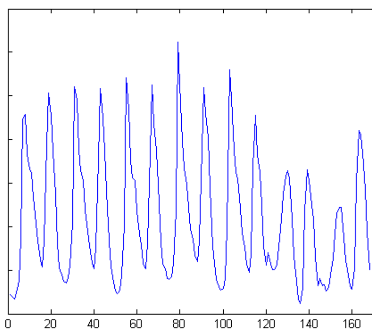
- Paper production

Industrial customer's perspective: Problem Statement for an Air Separation Plant

Carnegie Mellon

Due to compressors!

Electricity costs



Price forecast

Air Separation Plant

Liquid Oxygen

Liquid Nitrogen

Liquid Argon

Gaseous Oxygen

Gaseous Nitrogen

Demand forecast

Operational Decisions

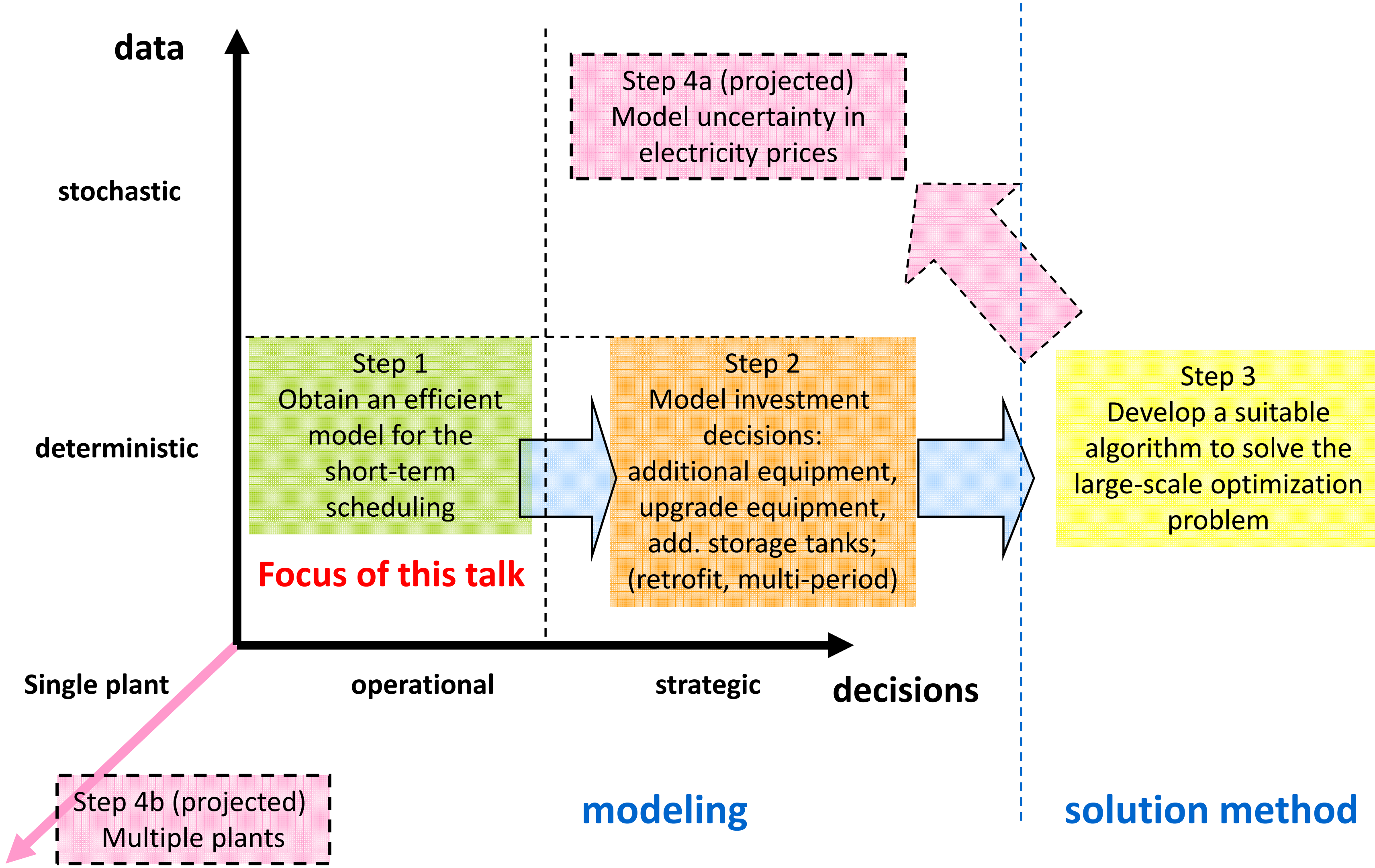
- When to produce and amounts?
- Inventory levels?

Strategic Decisions

- Additional equipment?
- Additional tanks?
- Equipment upgrade?

Investment Costs

Overview: Research Methodology



Operational Model

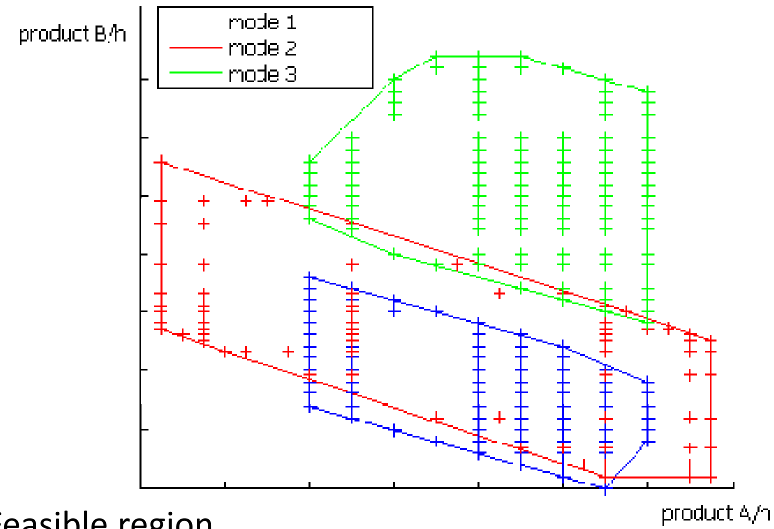
Objective function

Feasible region

Mass balances

Logic constraints for transitions

Operational Model



Feasible region

Feasible region: projection in product space

Modes: different ways of operating a plant

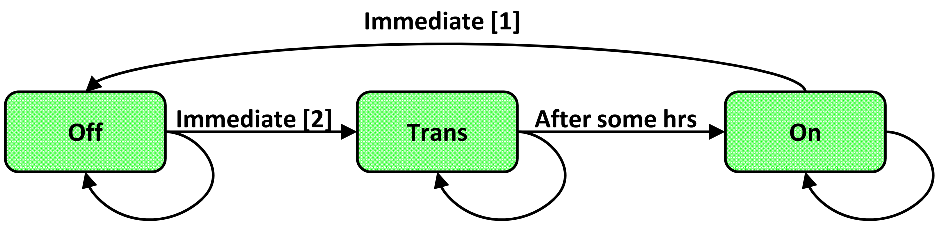
Energy consumption: requires correlation with production levels

Mass balances: differences for products with and without inventory

Feasible region

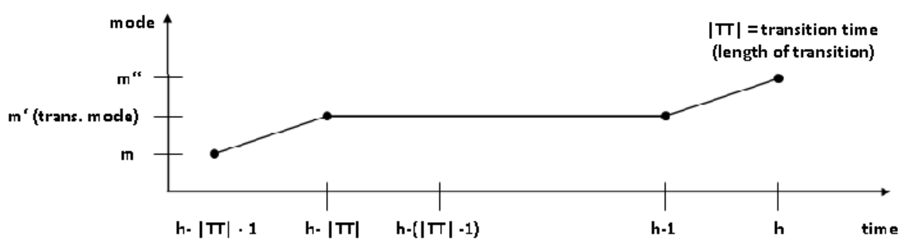
Mass balances

Modeling of transitions



Immediate [1]: Minimum uptime
Immediate [2]: Minimum downtime

State diagram for transitions



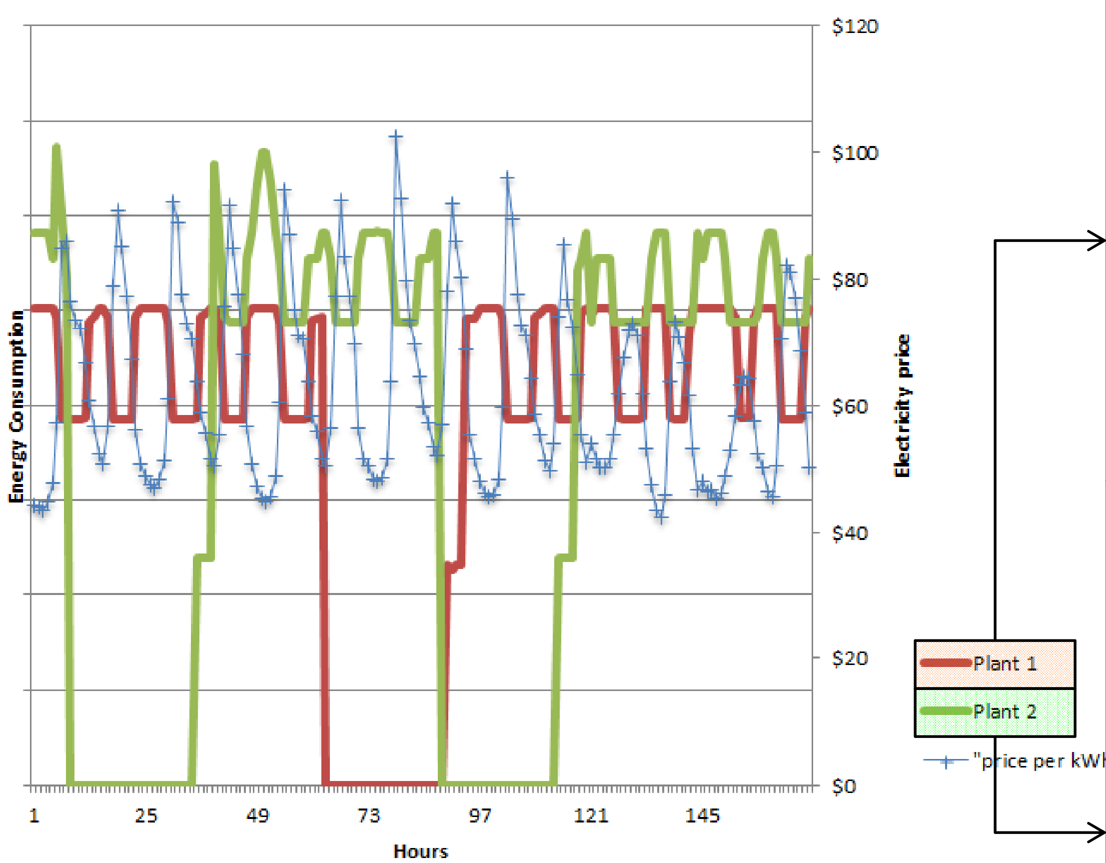
Logic constraints for transitions

Modes: different ways of operating a plant

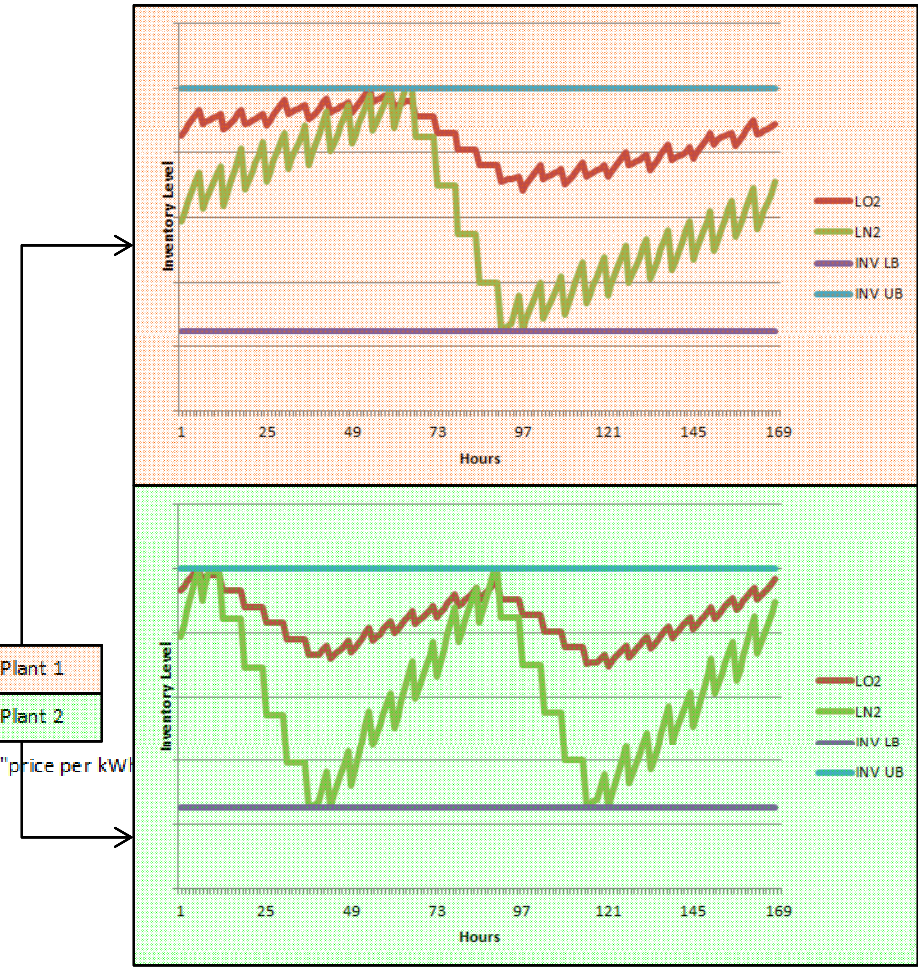
Transitions: between modes to enforce e.g. min. uptime/downtime

Result: Comparison of production schedules

Electricity consumption profiles for test case B



Inventory profiles for test case B



Case studies: Air separation plants

Problem sizes

plant	type of schedule	# constraints	# variables	# binary
P1	noncyclic	21838	16129	1512
P1	cyclic	21841	16129	1512
P2	noncyclic	42163	29401	3528
P2	cyclic	42169	29401	3528

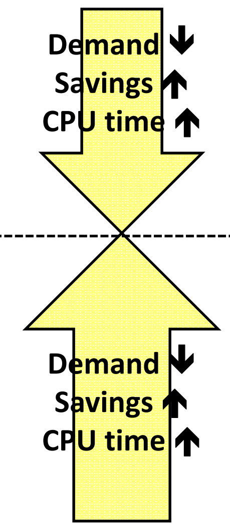
cyclic is the harder problem

For the same demand, P2 can produce cheaper due to higher flexibility

Savings compared to constant operation

case	cyc/ ncyc	RMIP	MIP CPLEX	MIP XPRESS	CPU times (s) CPLEX	CPU times (s) XPRESS
P1A	ncyc	88416	**90129**	**90129**	2	3
P1A	cyc	89197	**90448**	**90448**	3	26
P1B	ncyc	72806	**74932**	**74932**	4	5
P1B	cyclic	73305	**76011**	**76011**	15	27
P2B	ncyc	67659	**70017**	**70017**	135	47
P2B	cyc	67173	**72027**	**72027**	844	462
P2C	ncyc	98645	**100796**	100837	7	10
P2C	cyc	99726	101280	**101242**	6	8
P2D	ncyc	113521	**114715**	**114715**	4	4
P2D	cyc	115173	116125	**116122**	5	6
P2E	ncyc	128019	**128054**	**128054**	4	4
P2E	cyc	130186	**130186**	**130186**	4	4

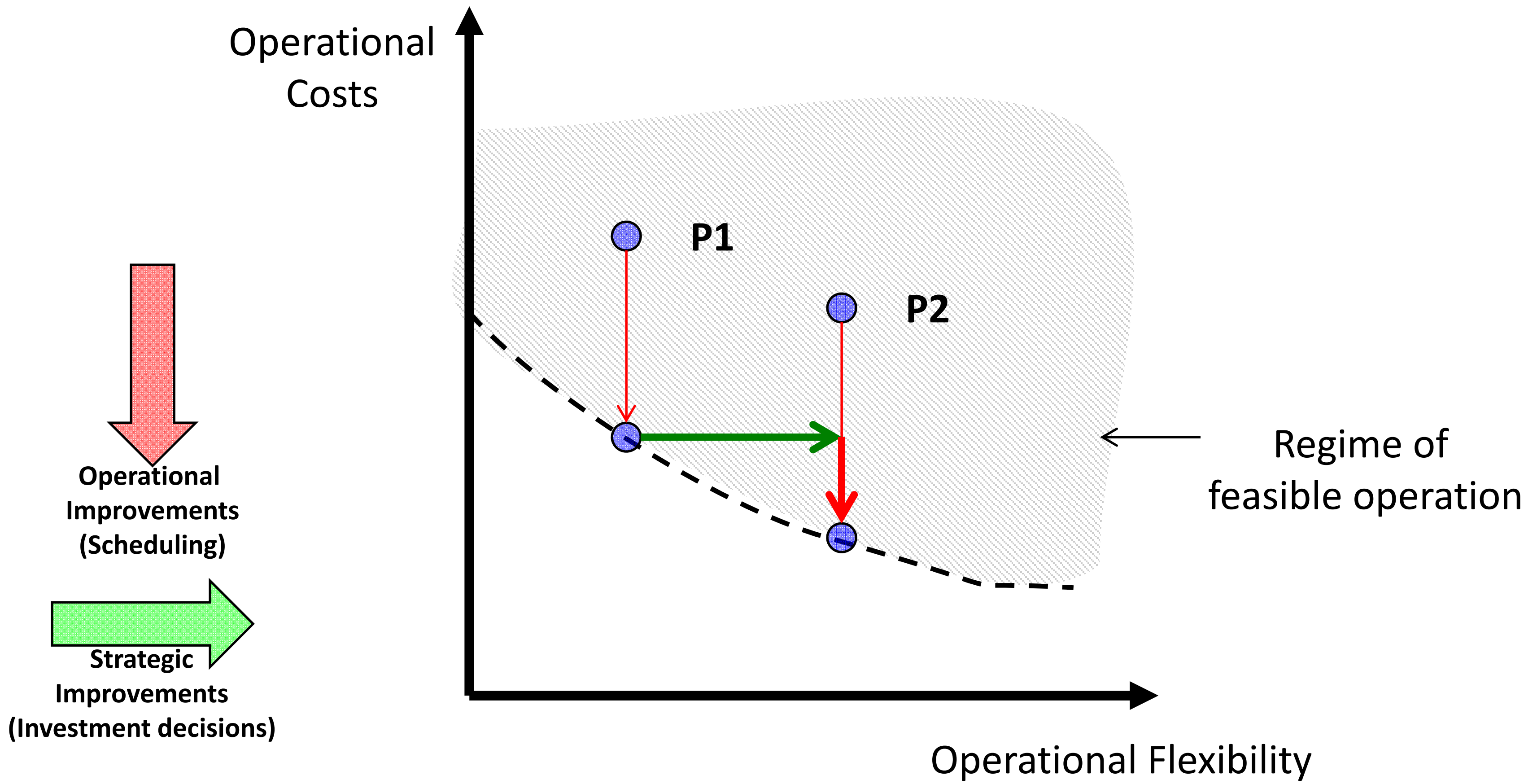
Computational results



case	demand/ capacity	savings
P1A	82%	4.58%
P1B	74%	12.02%
P2B	51%	13.78%
P2C	72%	7.44%
P2D	85%	4.90%
P2E	95%	3.76%

Decreasing demand = harder to solve due to higher operational flexibility

Synergies for integration of operational and strategic decisions



Take-home message:
Operational flexibility is key to achieve economic savings with demand response.