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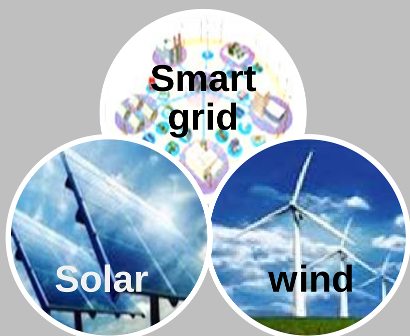
Bi-level Heuristic for Steel Production Scheduling with Electricity Costs Optimization

Power and productivity
for a better world™

Challenges of Present and Future Grid
Interest in Active Load Management

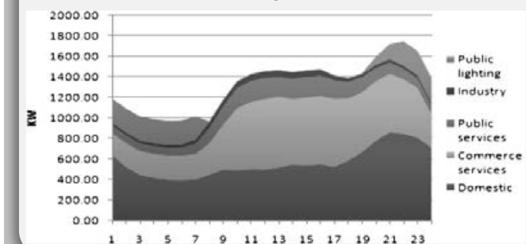
Renewables Expansion



GRID STABILITY AND RELIABILITY

Demand & Supply

Need for peak load (1)



ENVIRONMENTAL POLICIES AND INVESTMENT COSTS

Market Liberalization

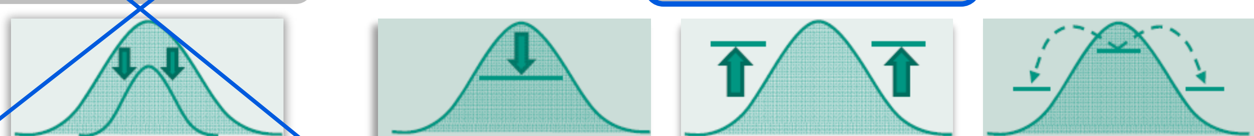
Variable electricity prices (2)

NEW MARKETS

Demand-Side Management

Energy Efficiency

Demand-Side Response



Sources:
(1)Pina et. Al, 2012
(2) EPEX SPOT France, 2012

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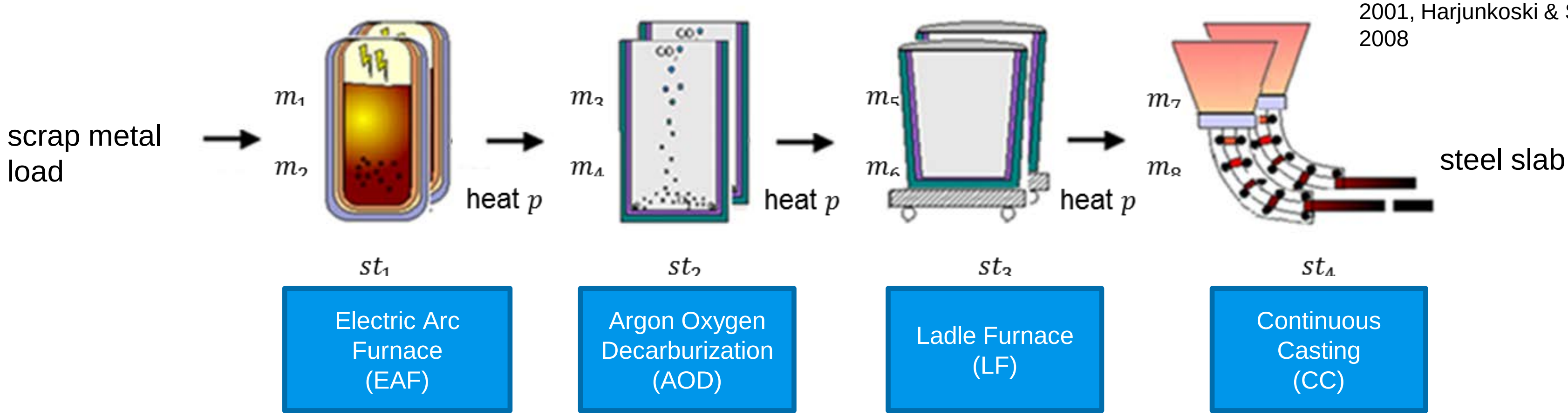
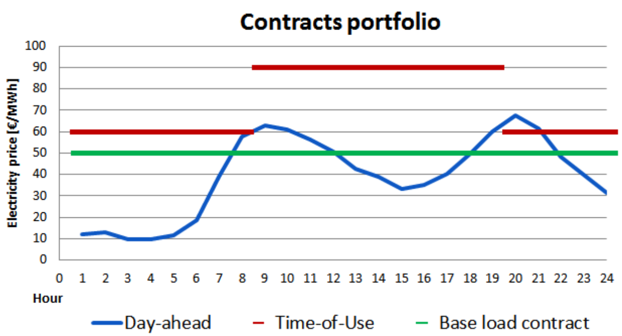
Scheduling of Energy-Intensive Processes
Melt Shop of Stainless Steel Plant

Continuous-time scheduling model based on Harjunkoski & Grossmann 2001, Harjunkoski & Sand 2008

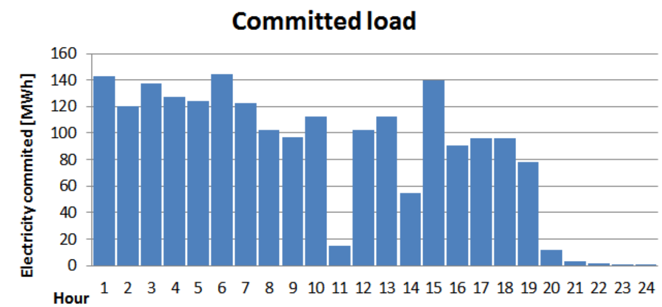


- Batch process with semi-continuous stage st_4 (CC)
- Parallel, non-identical equipment m
- Equipment specific setup t_m^{setup} and transportation times $t_{m,m'}^{min}$,
- Max hold up times t^{max} between stages

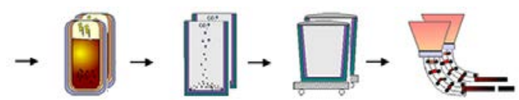
Scheduling of Energy-Intensive Processes
Energy Management Aspects



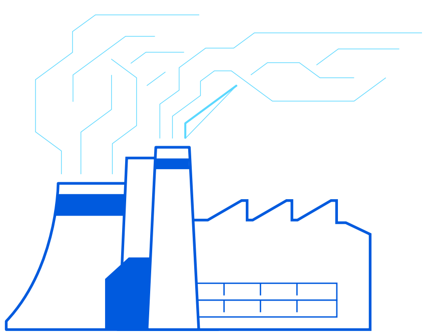
Multiple contracts – time dependent price levels



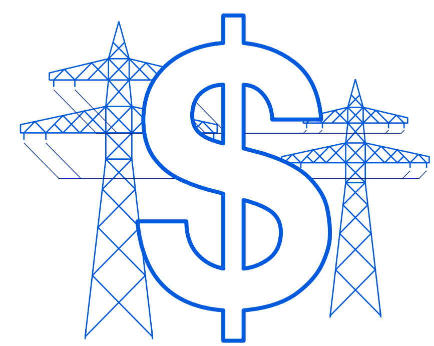
Pre-agreed load curve – penalties for deviation



Demand from production process



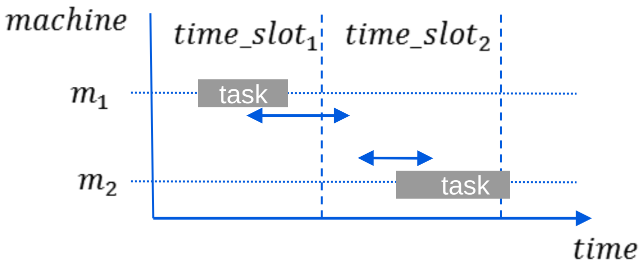
On-site generation – with special constraints

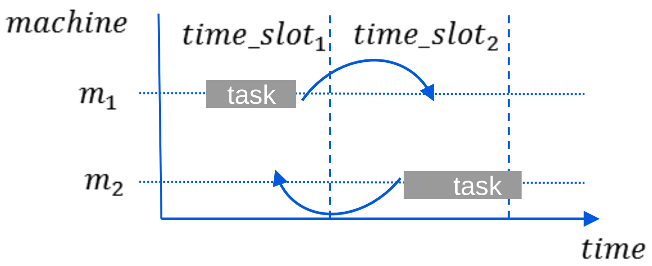


Selling back to grid

Problem statement
Questions to be answered

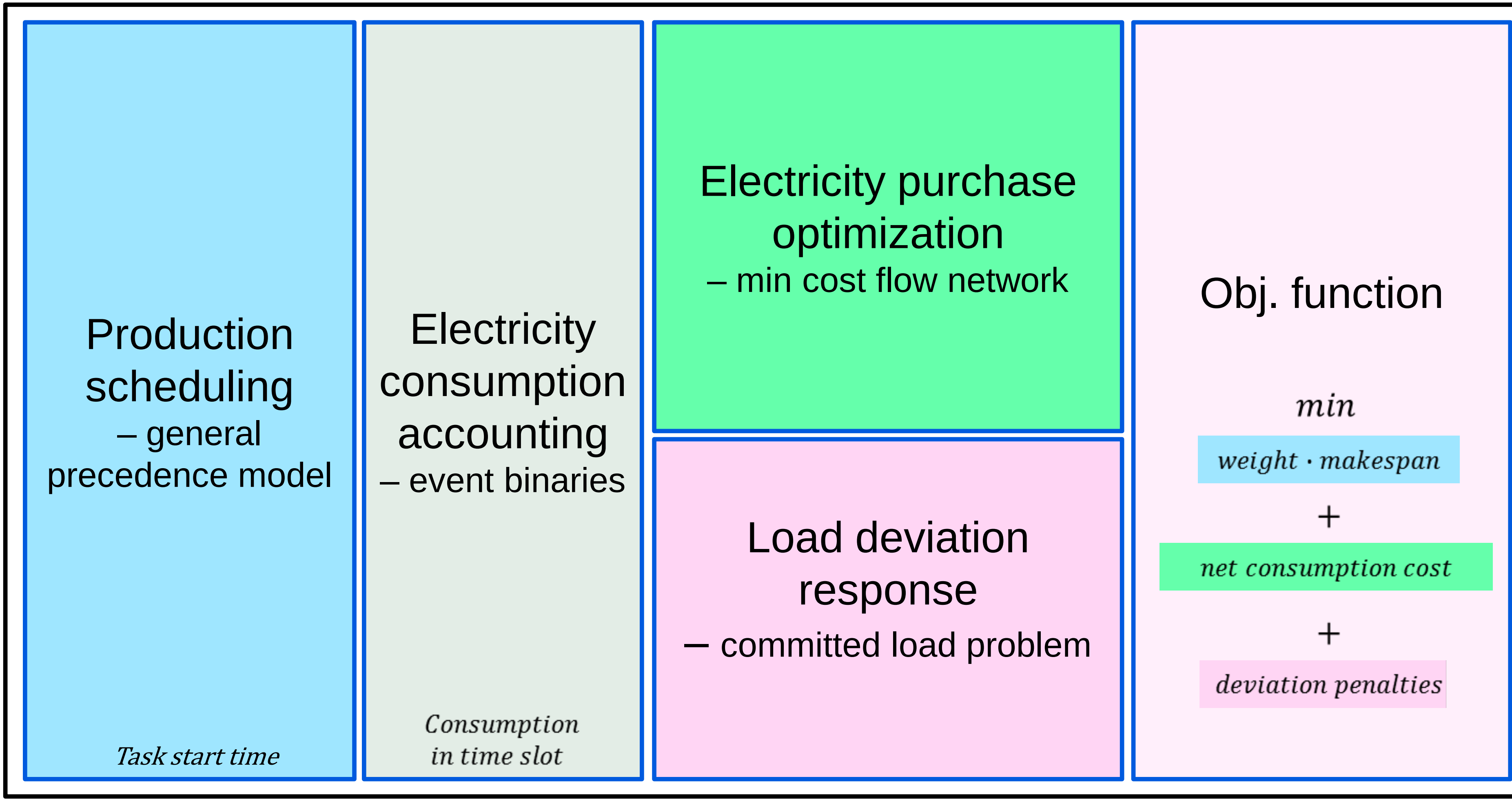
- Problem complexity
  - Approach 1: Energy-aware scheduling with fixed assignment and sequencing
  - Approach 2: Scheduling decisions are also optimized
- Modeling challenges
  - Extending the continuous-time formulation with energy-awareness
  - Embedding the energy purchase optimization into the problem
  - Decomposing the problem for large scale instances





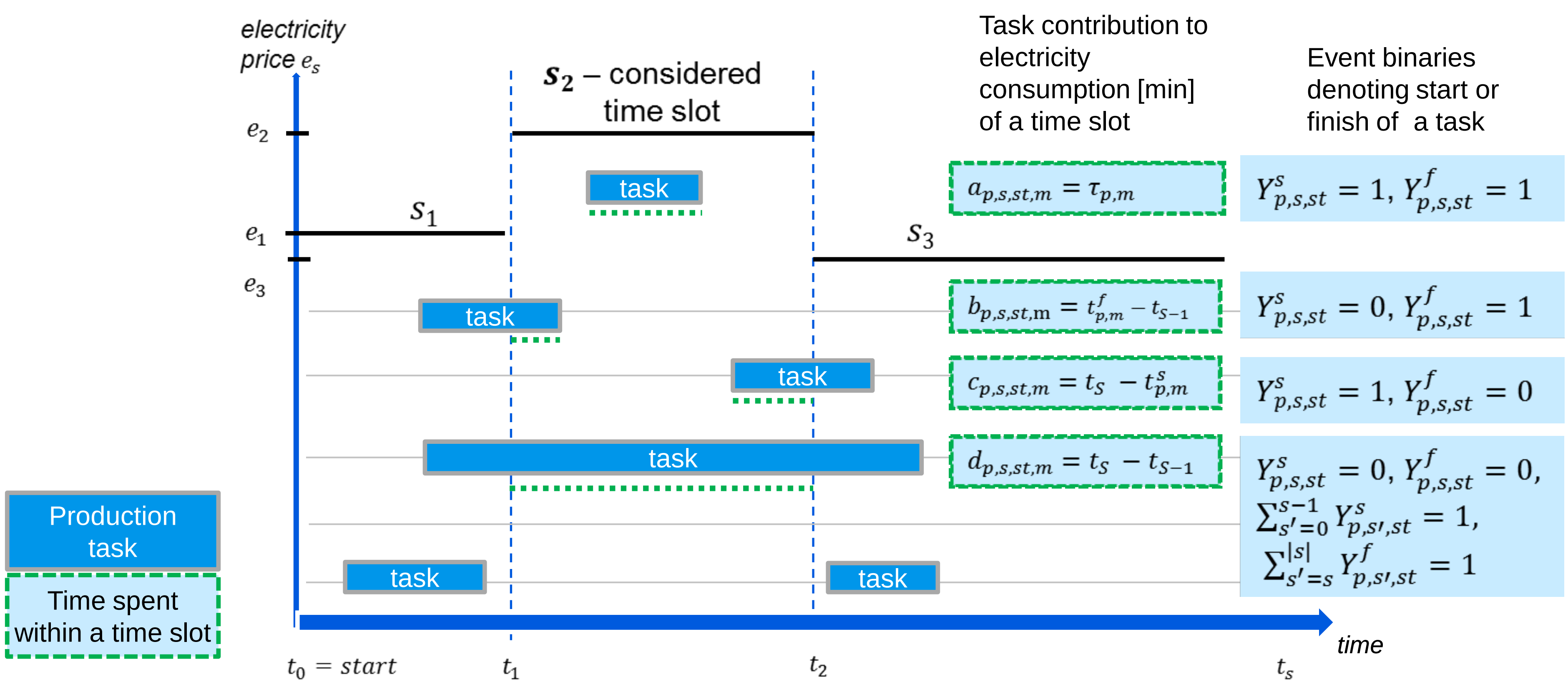
Note: *time_slots* due to electricity cost accounting

Solution Approach
Monolithic Model Structure



Energy Awareness
Accounting for Electricity Consumption

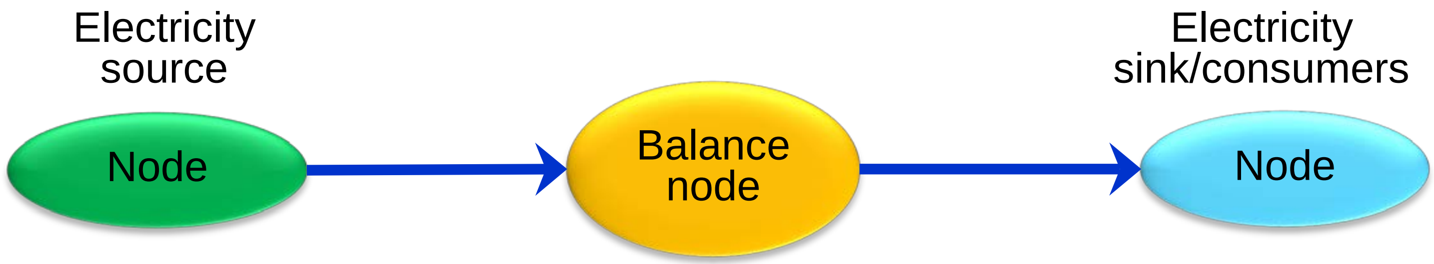
- Model the relation between tasks and time slots through a discrete time-grid (*MILP*)



Energy Purchase Optimization
Electricity Flow Network

- Each arc is defined by parameters and flow volume variable

$$[TimeSlot, MinFlow, MaxFlow, Cost, Flow]$$



$$\sum_{i \in Sources} flow_{i,j} = \quad {}_{k \in}$$

$$\forall j \in Balance$$

- Source of electricity
- Balancing area
- Sink/consumers of electricity

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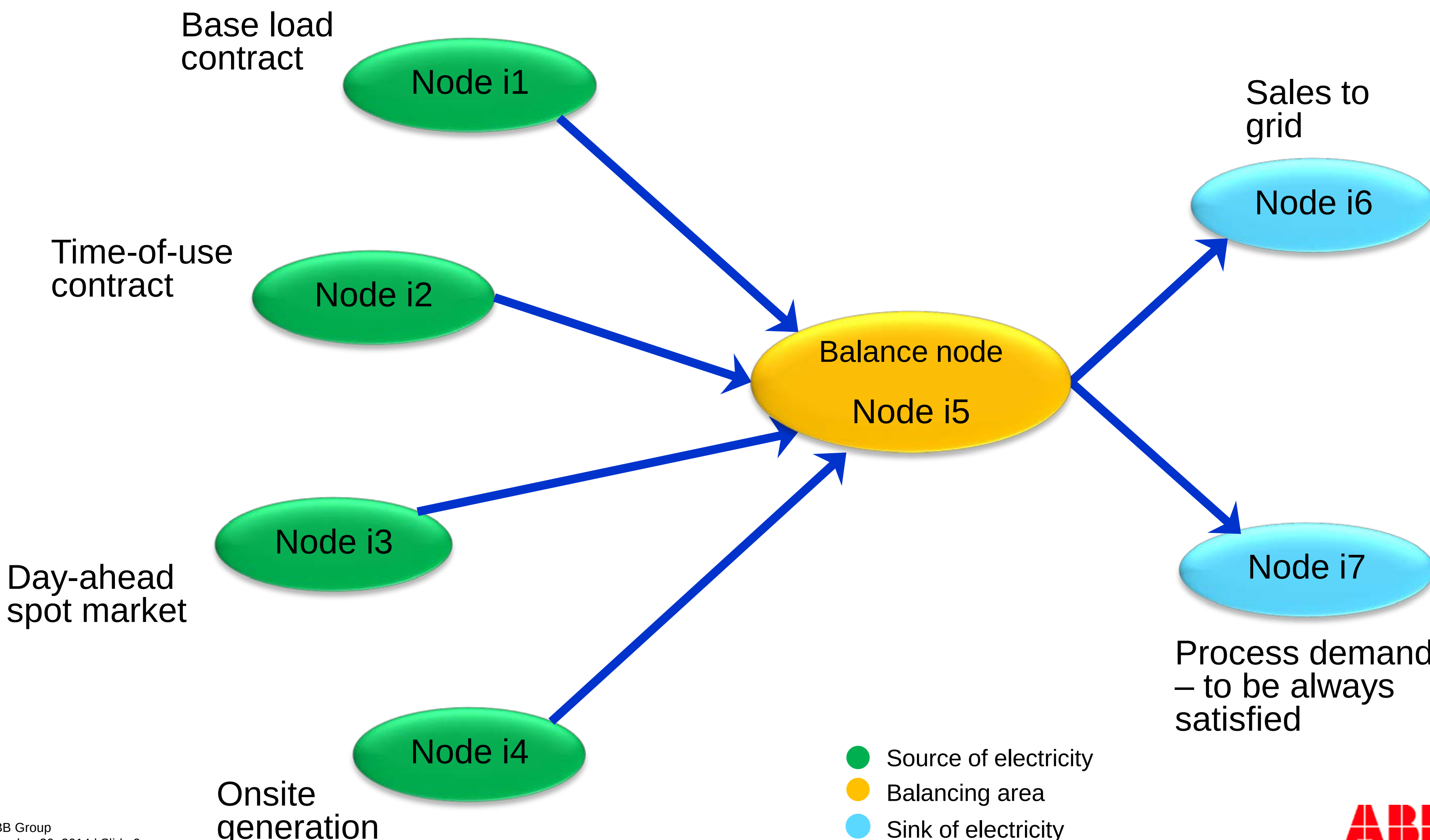
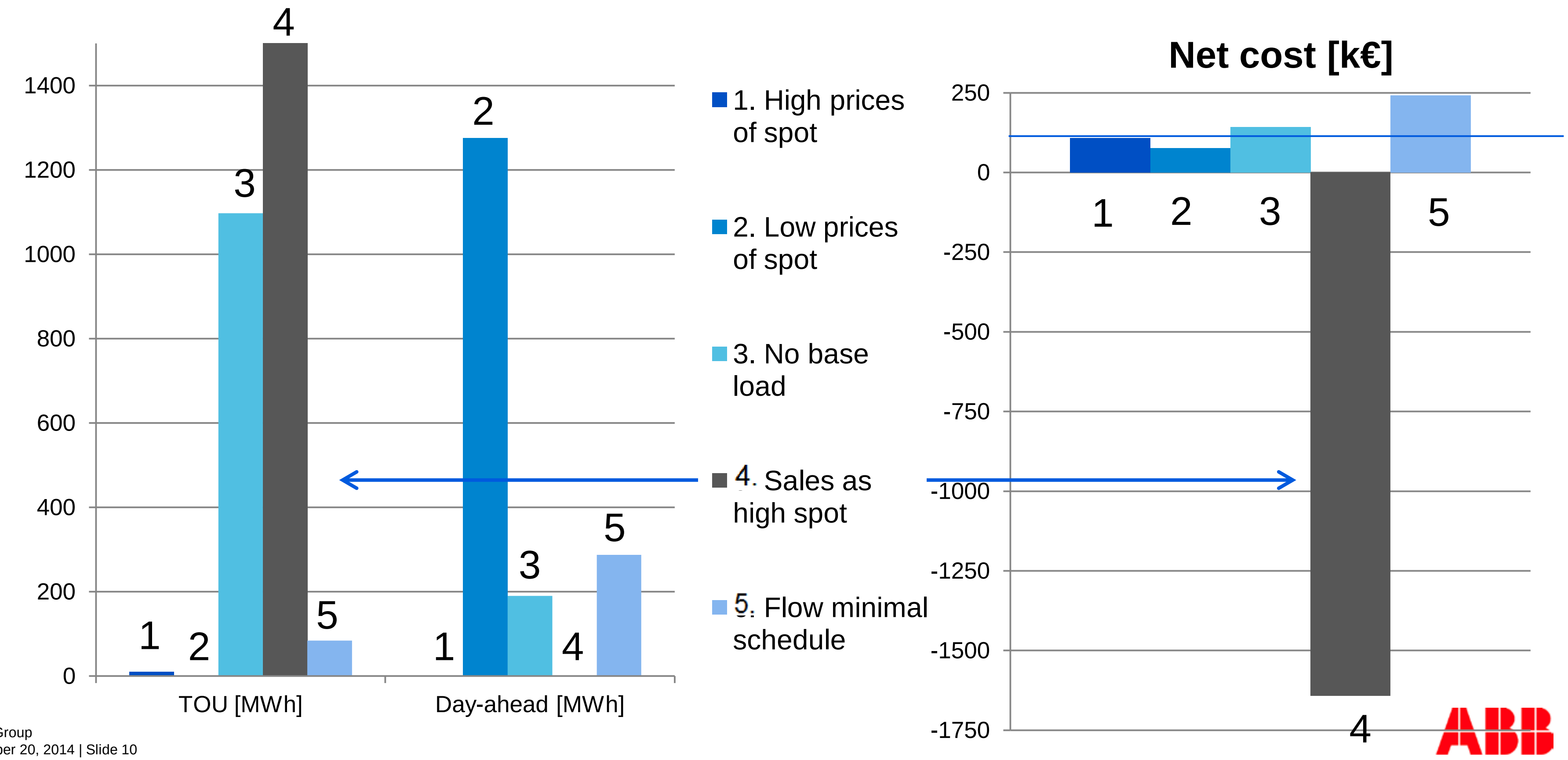
Energy Purchase Optimization
Electricity Flow Network



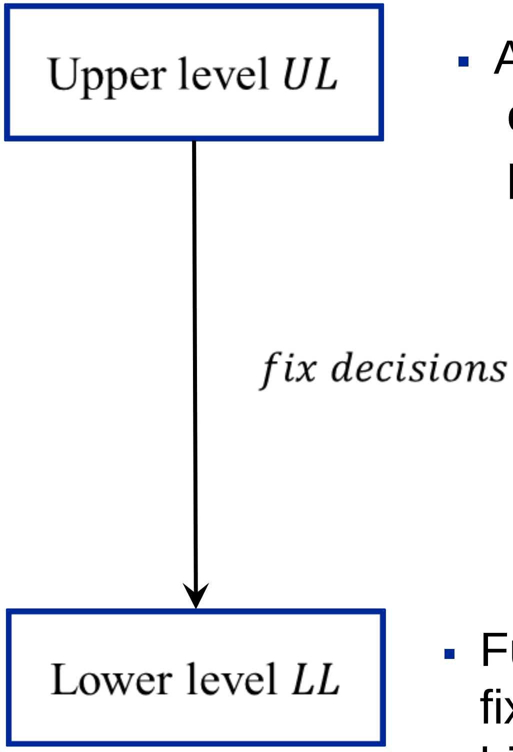
Approach 1: All Scheduling Binaries Fixed – Industrial Case Study

24h horizon and 20 products

- Good quality solutions (gap<2%) obtained always in few seconds
  - ~109k equ, ~29k var, ~5k binaries, solving to optimality: 2~700s
- Computational problems when product sequence not known



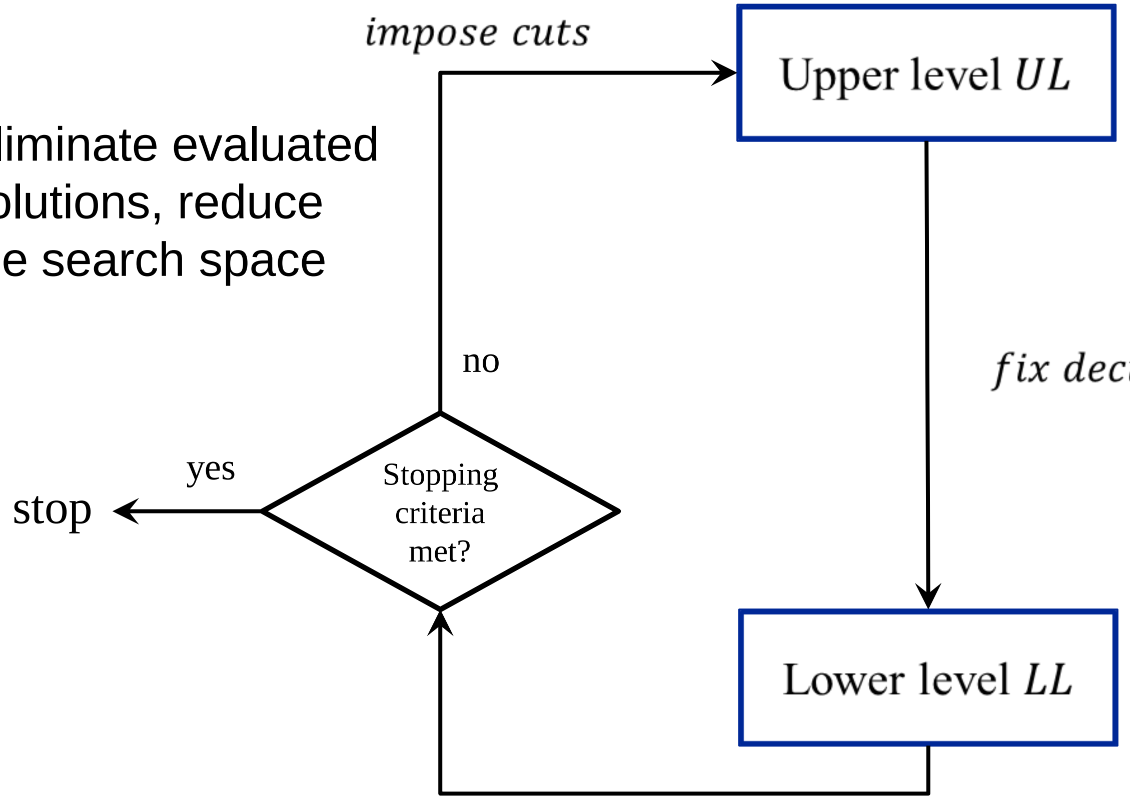
Bi-level heuristic
General approach



- Approximation of the original monolithic problem
- Full problem with fixed difficult binary decisions

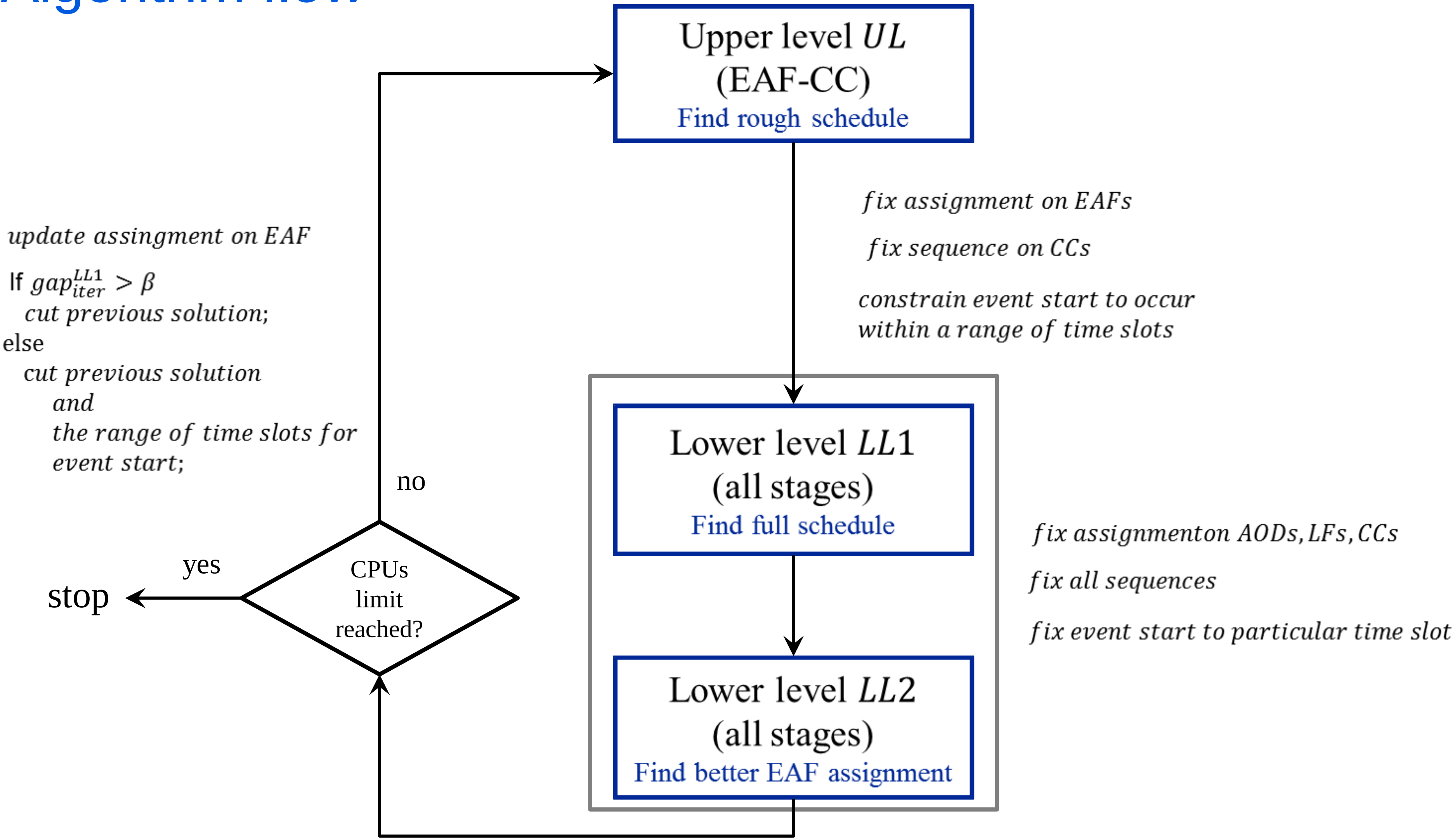
Bi-level heuristic
General approach

- Eliminate evaluated solutions, reduce the search space



- Approximation of the original monolithic problem
- Full problem with fixed difficult binary decisions

Bi-level heuristic
Algorithm flow



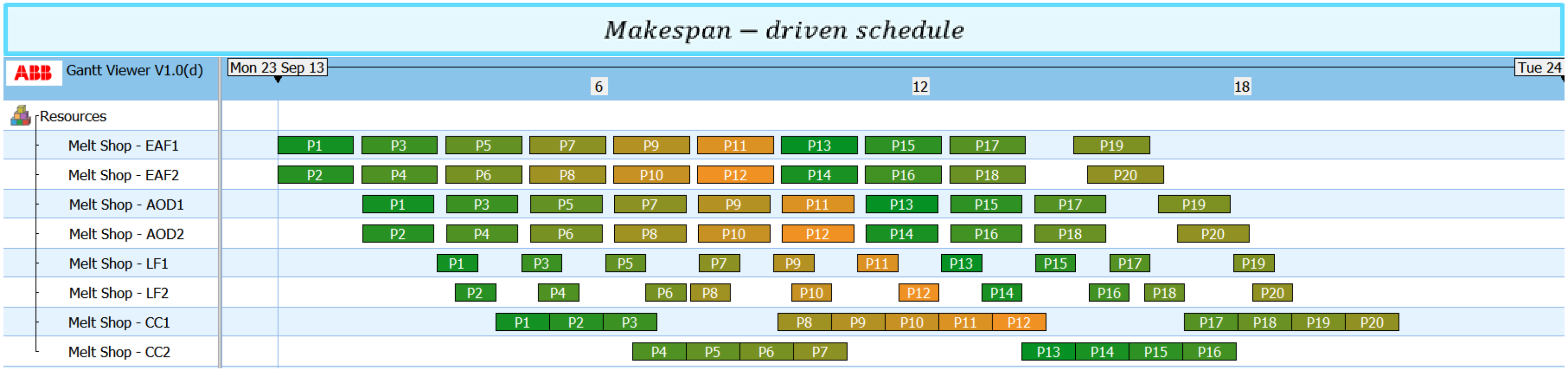
Heuristic vs Monolithic

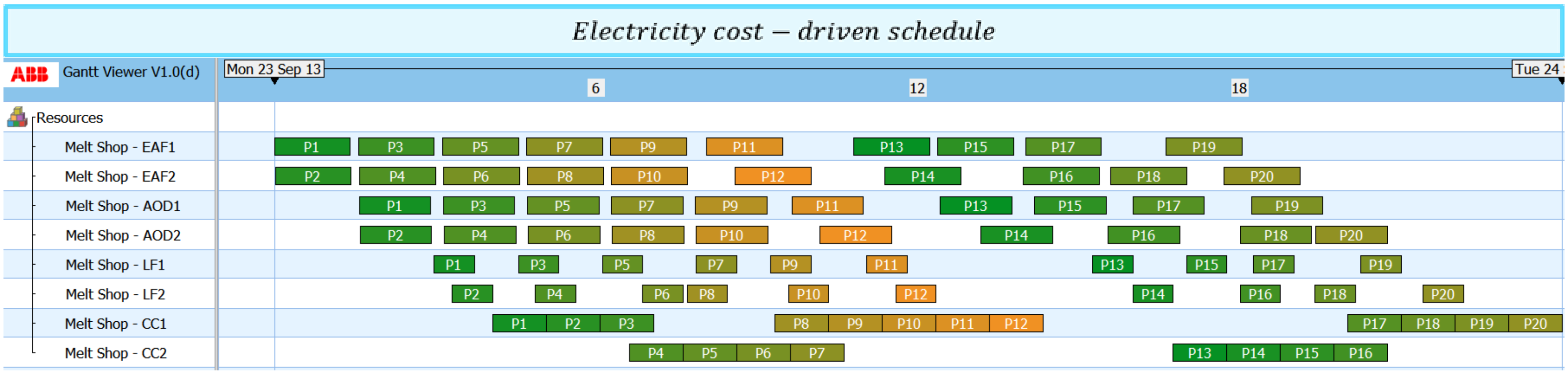
Instance	Model type	Binary vars	Total vars	Equations	MIP solution 600s	Relative gap 600s	Heuristic Iterations (Best)
24 h, 20 products, high prices spot	Monolithic 1	3 921	29 508	102 335	239 195	**26%**	-
	Heuristic 1	LL2: 1 458	LL2: 29 508	LL2: 102 335	193 852	**9,3%**	5(4)
24 h, 20 products, low prices spot	Monolithic 2	3 921	29 508	102 335	193 626	**21%**	-
	Heuristic 2	LL2: 1 458	LL2: 29 508	LL2: 102 335	165 198	**7,2%**	5(3)
24 h, 16 products, high prices spot	Monolithic 3	3 205	23 428	80 528	182 065	**13%**	-
	Heuristic 3	LL2: 1 276	LL2: 23 428	LL2: 80 528	174 249	**8,5%**	3(1)
18 h, 12 products, high prices spot	Monolithic 4	2 055	13 348	45 509	201 961	**10%**	-
	Heuristic 4	LL2: 856	LL2: 13 348	LL2: 45 509	195 160	**4,2%**	4(1)

- Objective function value always better than monolithic
- Gap always better than monolithic

Model Results
Gantt Chart example

- Fixed sequence and assignment





Summary Discussion
Conclusions and Further Work

- Benefits and limitations
  - Continuous-time is challenging but benefits from exactness
  - Cost reduction realized by energy-aware scheduling
  - Very large instances still intractable, even with heuristic
- Further work
  - One-sided Mean Value Cross-decomposition on monolithic formulation to functionally separate energy purchase from production scheduling
  - Application to other industrial cases
- Acknowledgment

  - We would like to acknowledge the Marie Curie FP7-ITN project "Energy savings from smart operation of electrical, process and mechanical equipment– ENERGY-SMARTOPS", Contract No: PITN-GA-2010-264940 for financial support

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