H. Hadera[1,2], I. Harjunkoski[1], G. Sand[1], I. E. Grossmann[3] , S. Engell[2], AICHE 2014, Atlanta, US, 16-21.11.2014
[1]ABB Corporate Research Germany, [2]Technical University of Dortmund Germany, [3]Carnegie Mellon University US

A bi-level heuristic for steel plant scheduling under complex time-sensitive price structures

energy smartOps
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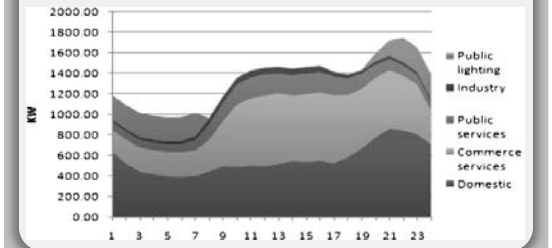
Challenges of Present and Future Grid
Interest in Active Load Management

Renewables Expansion

GRID STABILITY AND RELIABILITY

Demand & Supply

Need for peak load (1)



ENVIRONMENTAL POLICIES AND INVESTMENT COSTS

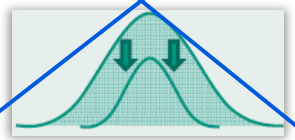
Market Liberalization

Variable electricity prices (2)

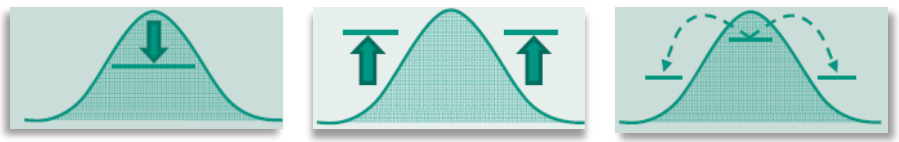
NEW MARKETS

Demand-Side Management

Energy Efficiency



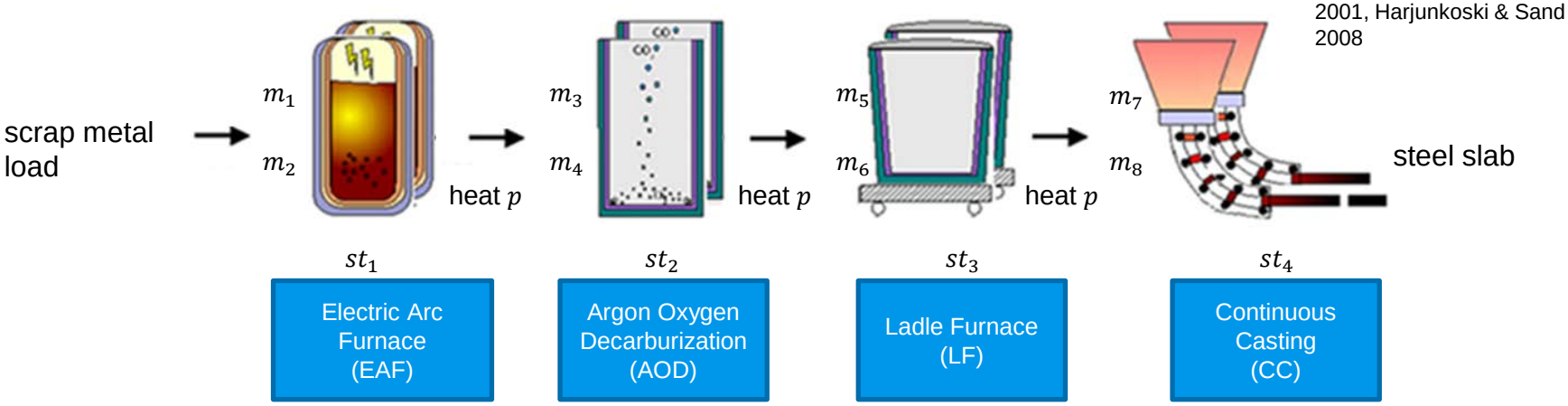
Demand-Side Response

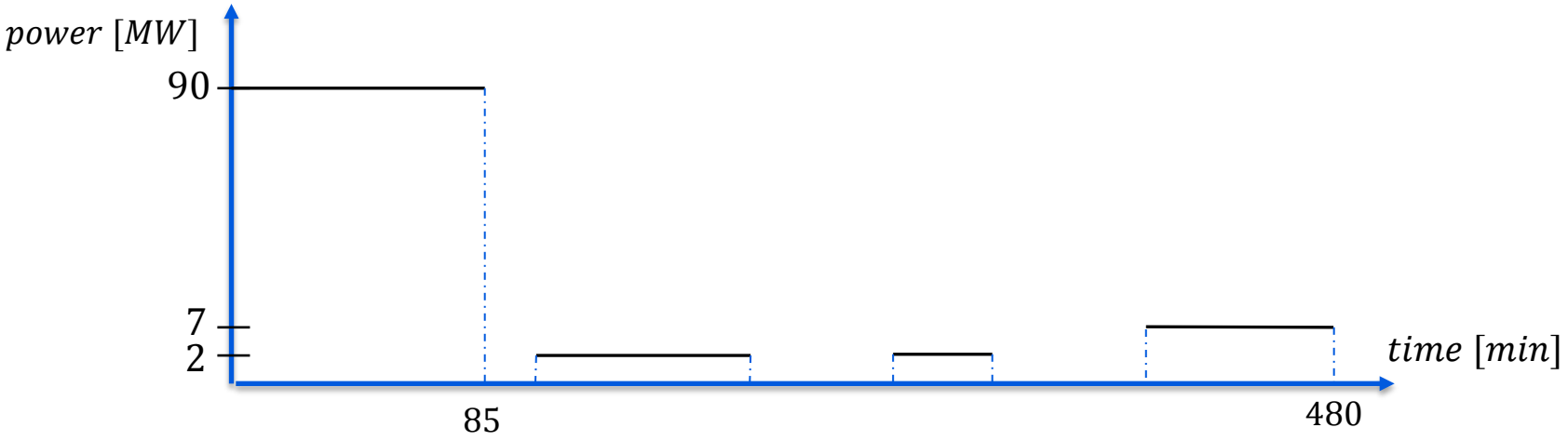


Sources:
(1)Pina et. Al, 2012
(2) EPEX SPOT France, 2012

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

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





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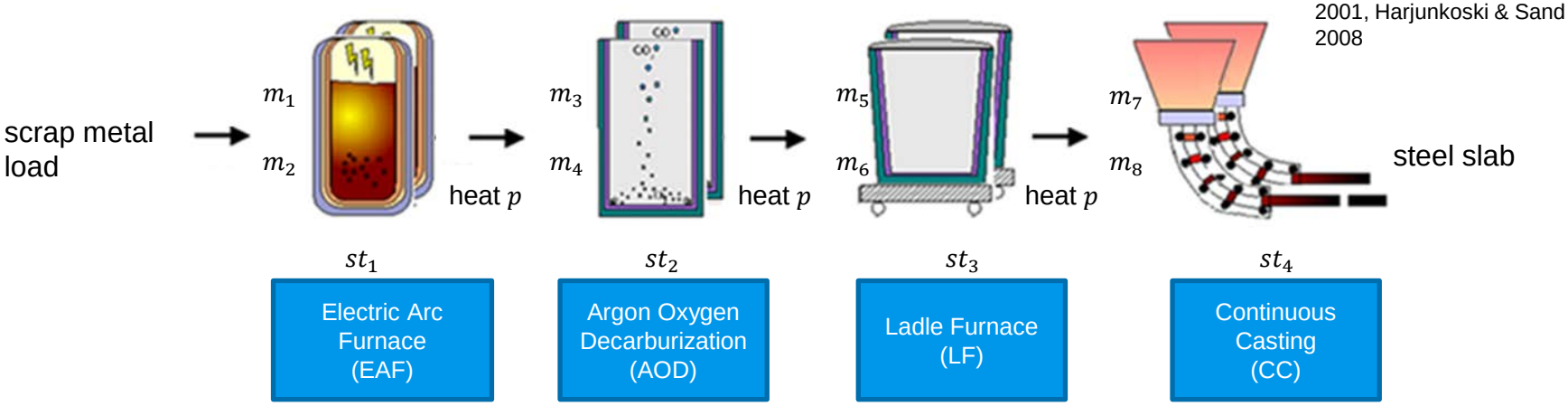
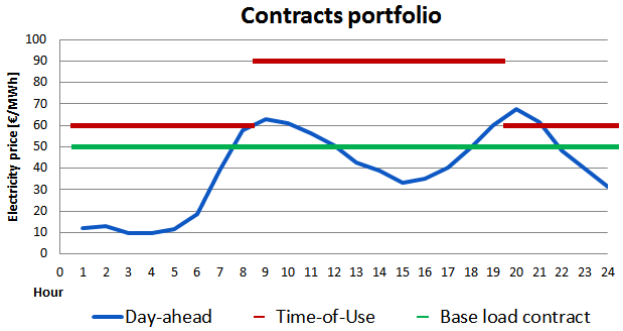
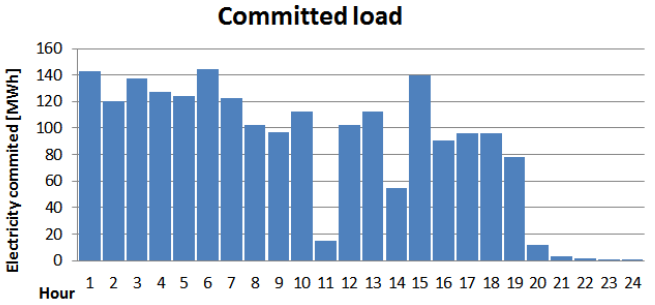


- Batch process with semi-continuous stage st_4 (CC)
- Parallel, non-identical equipment m
- Equipment specific setup t_m^{setup} and transportation times $t_{m,m'}^{min}$
- Max hold-up times $t_{p,st}^{max}$ between stages

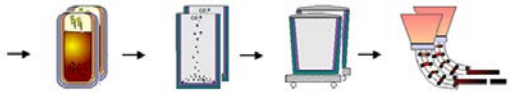
Scheduling of Energy-Intensive Processes
Energy Management Aspects



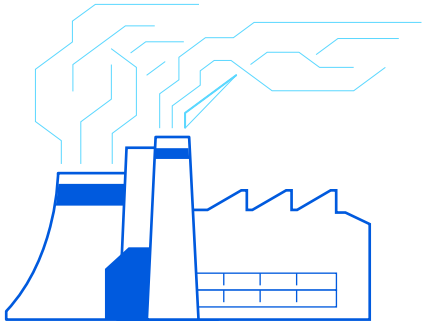
Multiple contracts – time dependent price levels



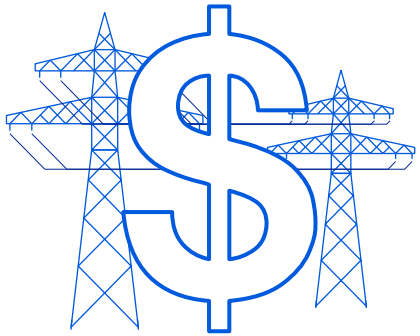
Pre-agreed load curve – penalties for deviation



Demand from production process



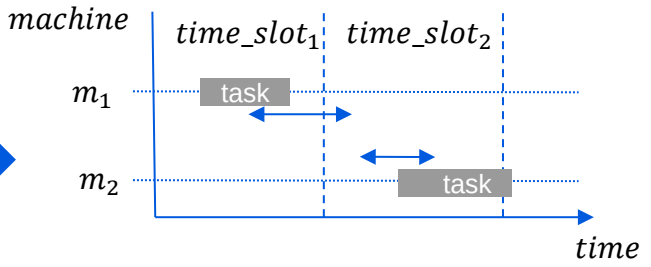
On-site generation – with special constraints

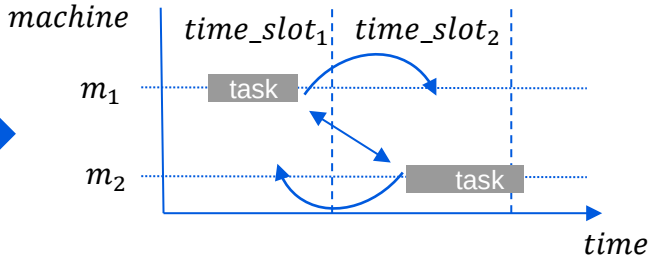


Selling back to grid

Problem statement
Questions to be answered

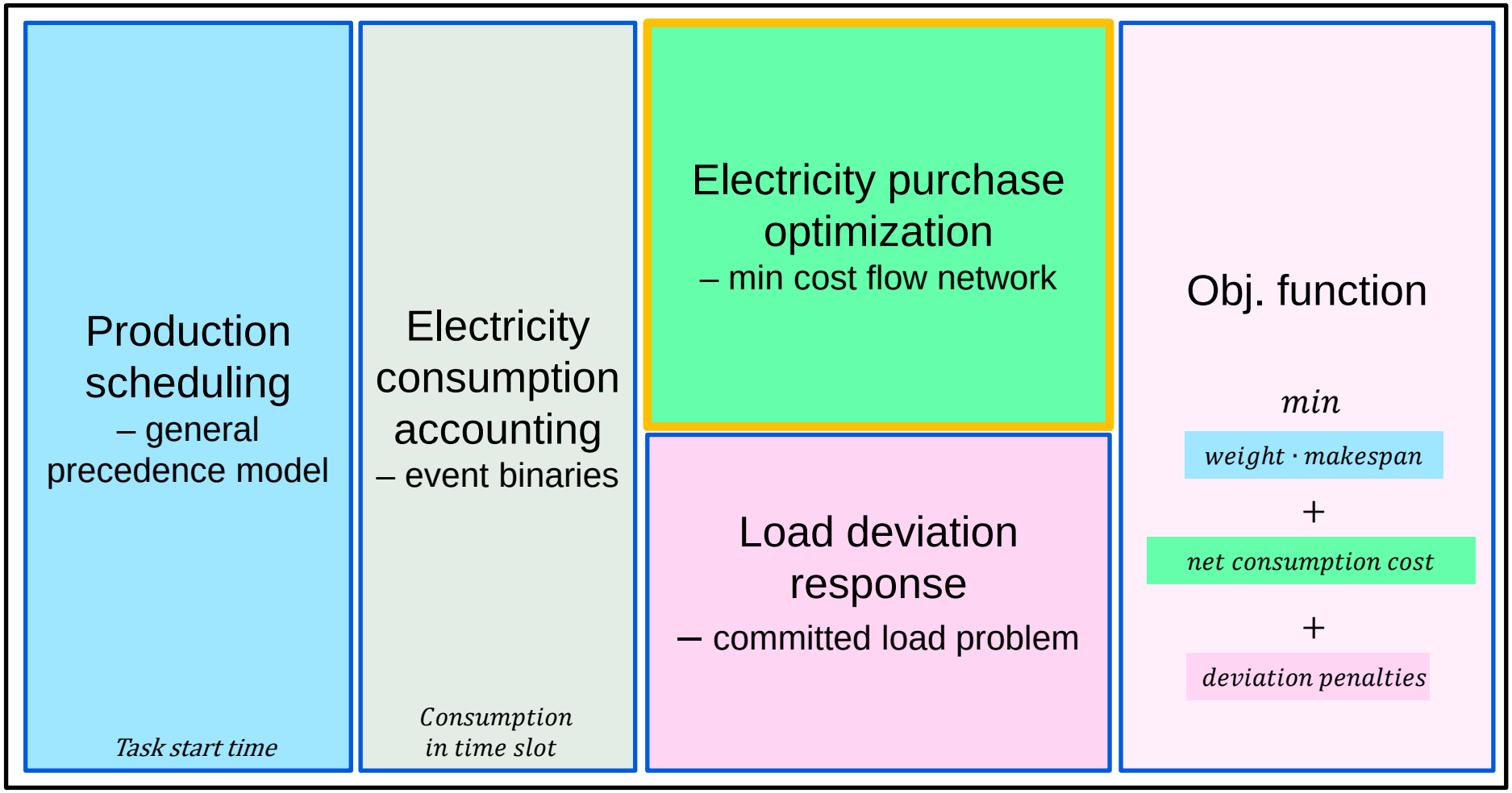
- Problem complexity
  - Approach 1: Energy-aware scheduling with fixed assignment and sequencing
  - Approach 2: Scheduling decisions are also optimized
- Modeling challenges
  - Extending the continuous-time formulation with energy-awareness
  - Embedding the energy purchase optimization into the problem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





Note: $time\_slots$ due to electricity cost accounting

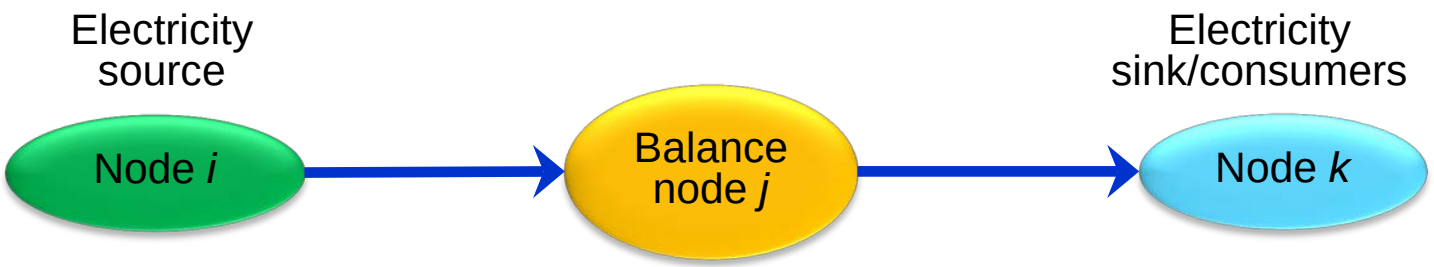
Solution Approach
Monolithic Model Structure



Energy Purchase Optimization
Electricity Flow Network

- Each arc is defined by parameters and flow volume variable

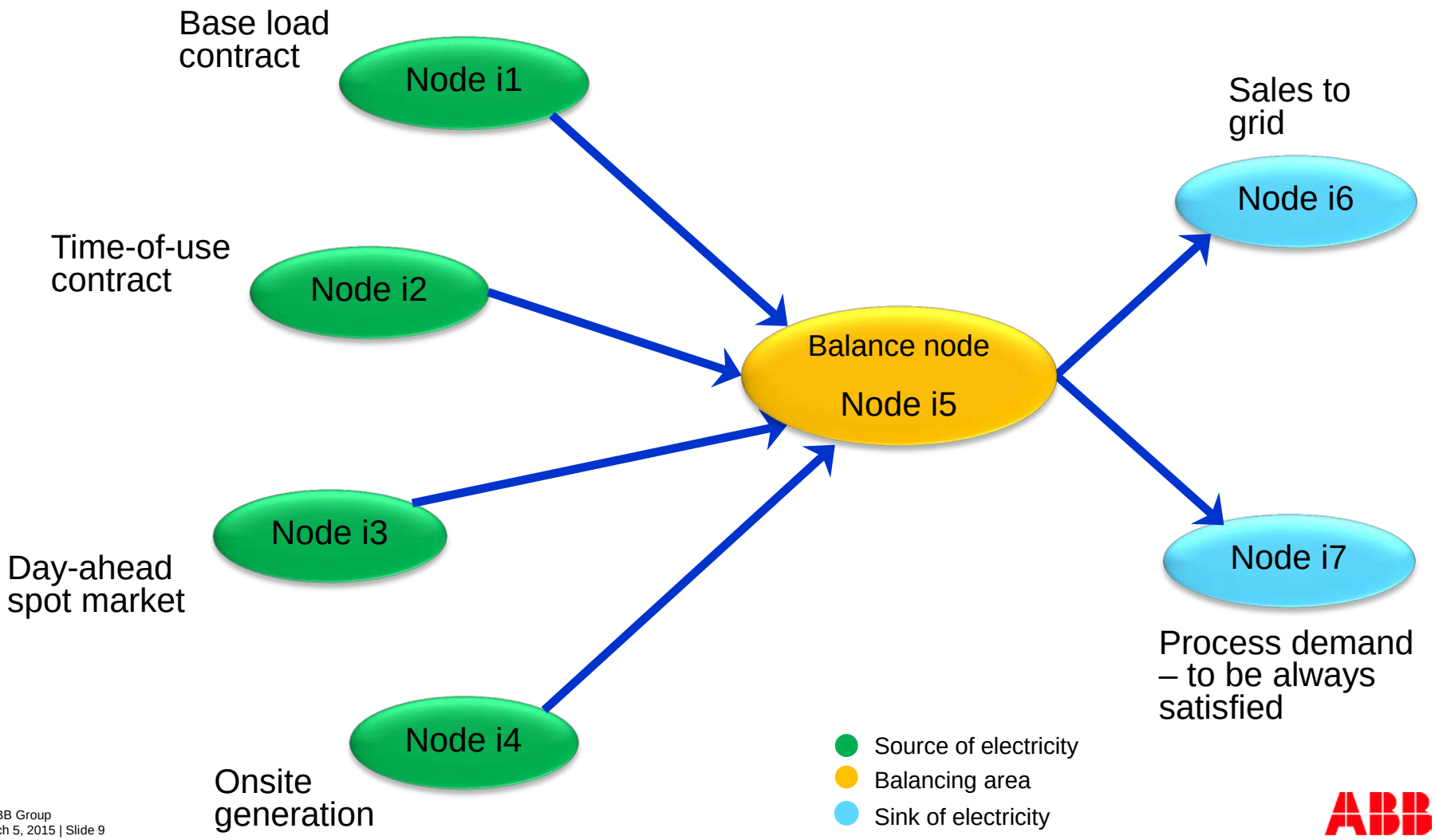
$$[TimeSlot, MinFlow, MaxFlow, Cost, Flow]$$



$$\sum_{i \in Sources} flow_{i,j} = \sum_{k \in Sinks} flow_{j,k} \quad \forall j \in Balance$$

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

Energy Purchase Optimization
Electricity Flow Network



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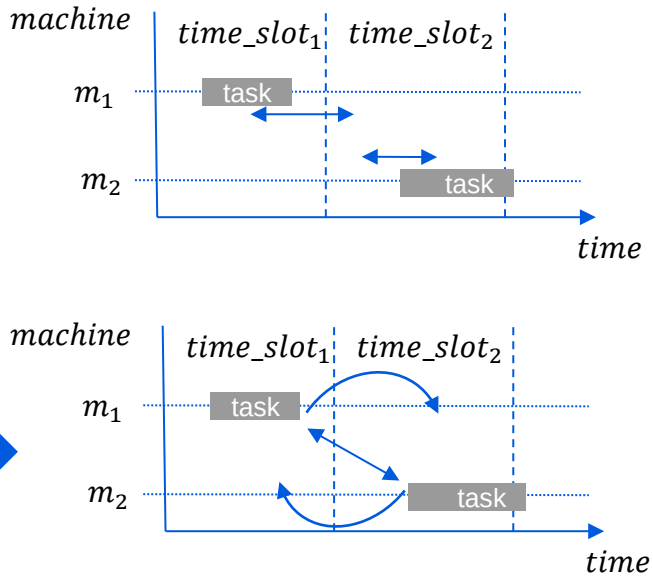
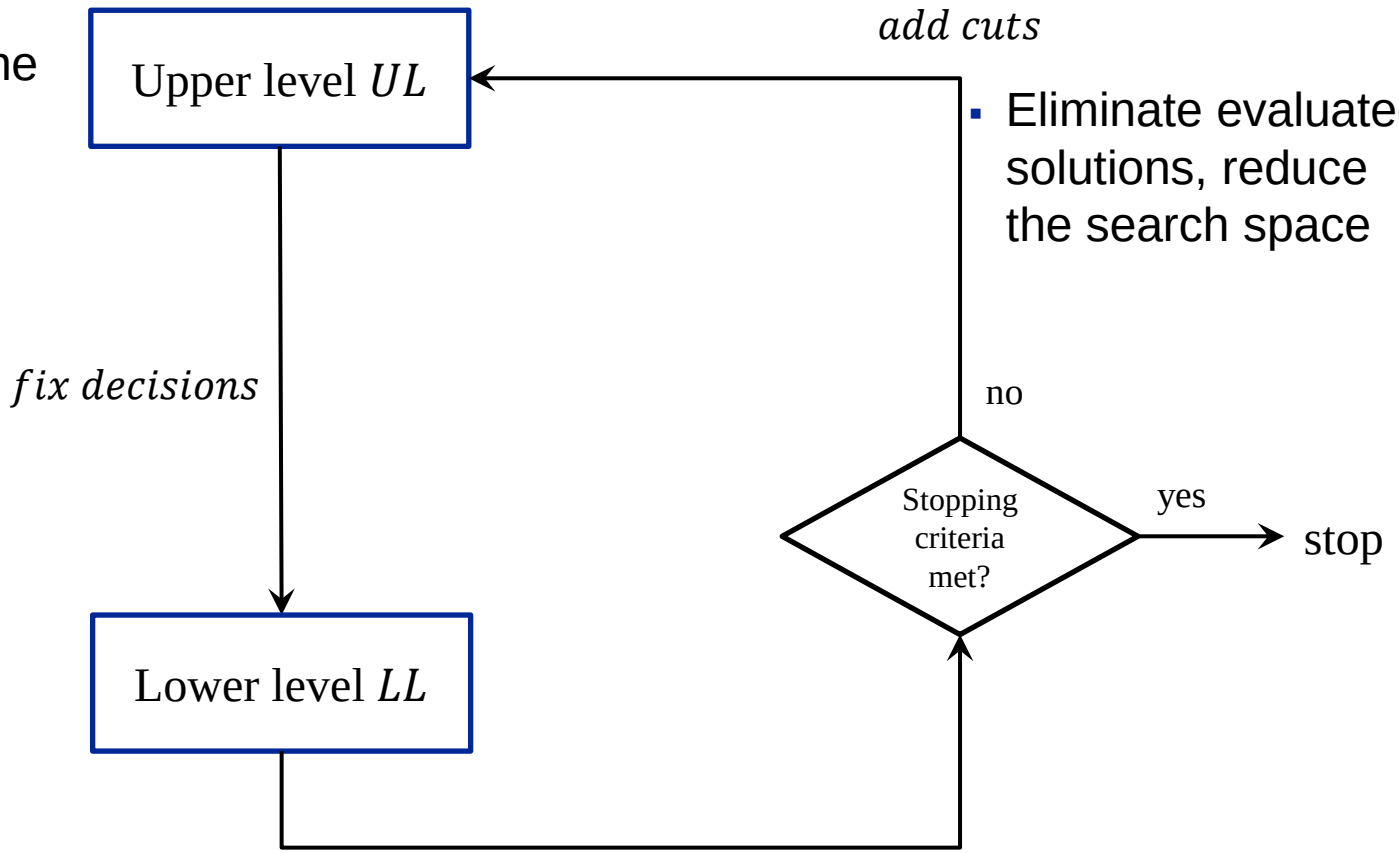


Note: $time\_slots$ due to electricity cost accounting

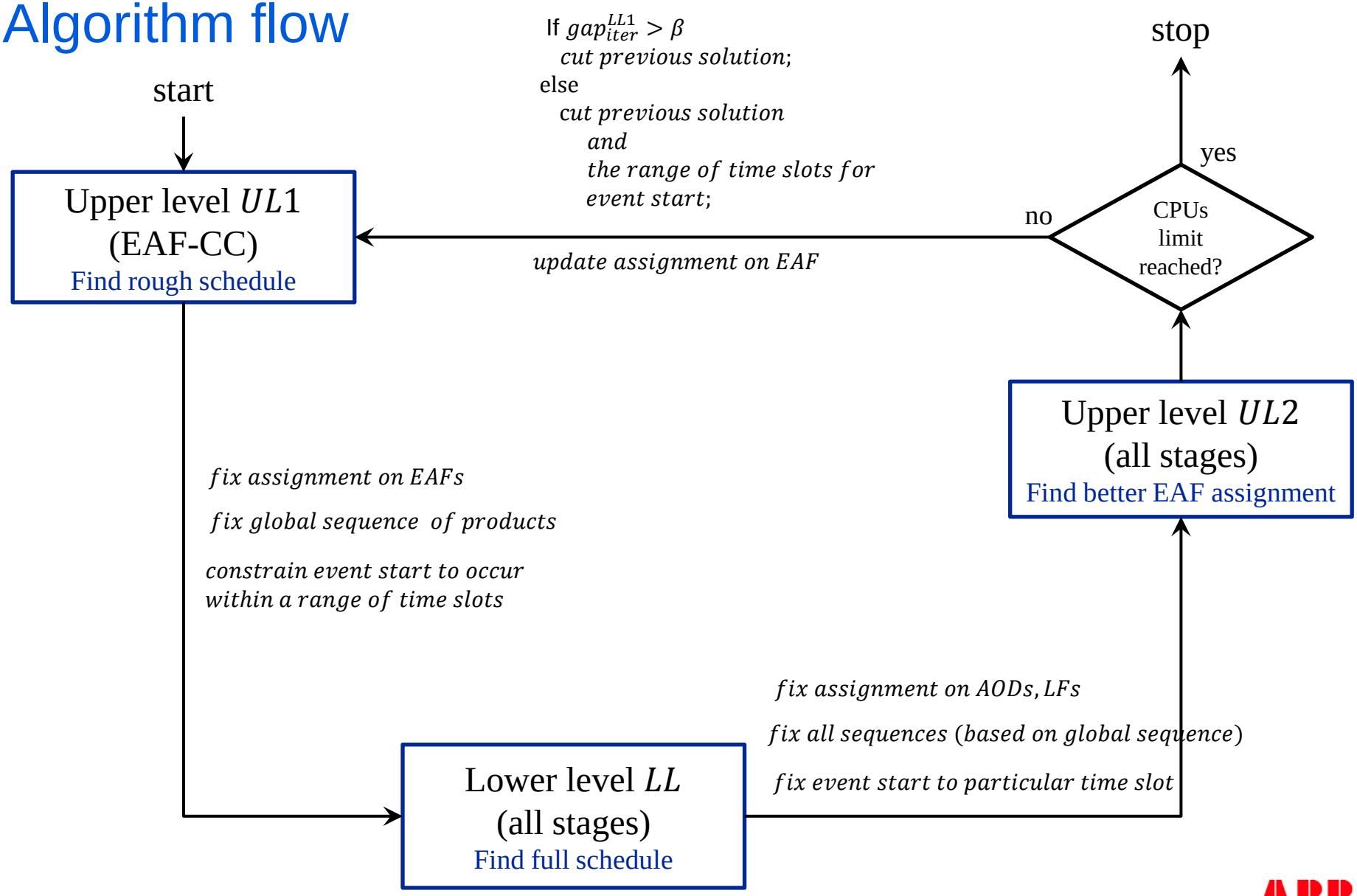
Bi-level heuristic
General approach

- Approximation of the original monolithic problem



- Full problem with fixed difficult binary decisions

Bi-level heuristic
Algorithm flow



Approach 2: Scheduling Decisions to be Optimized– Industrial Case Study

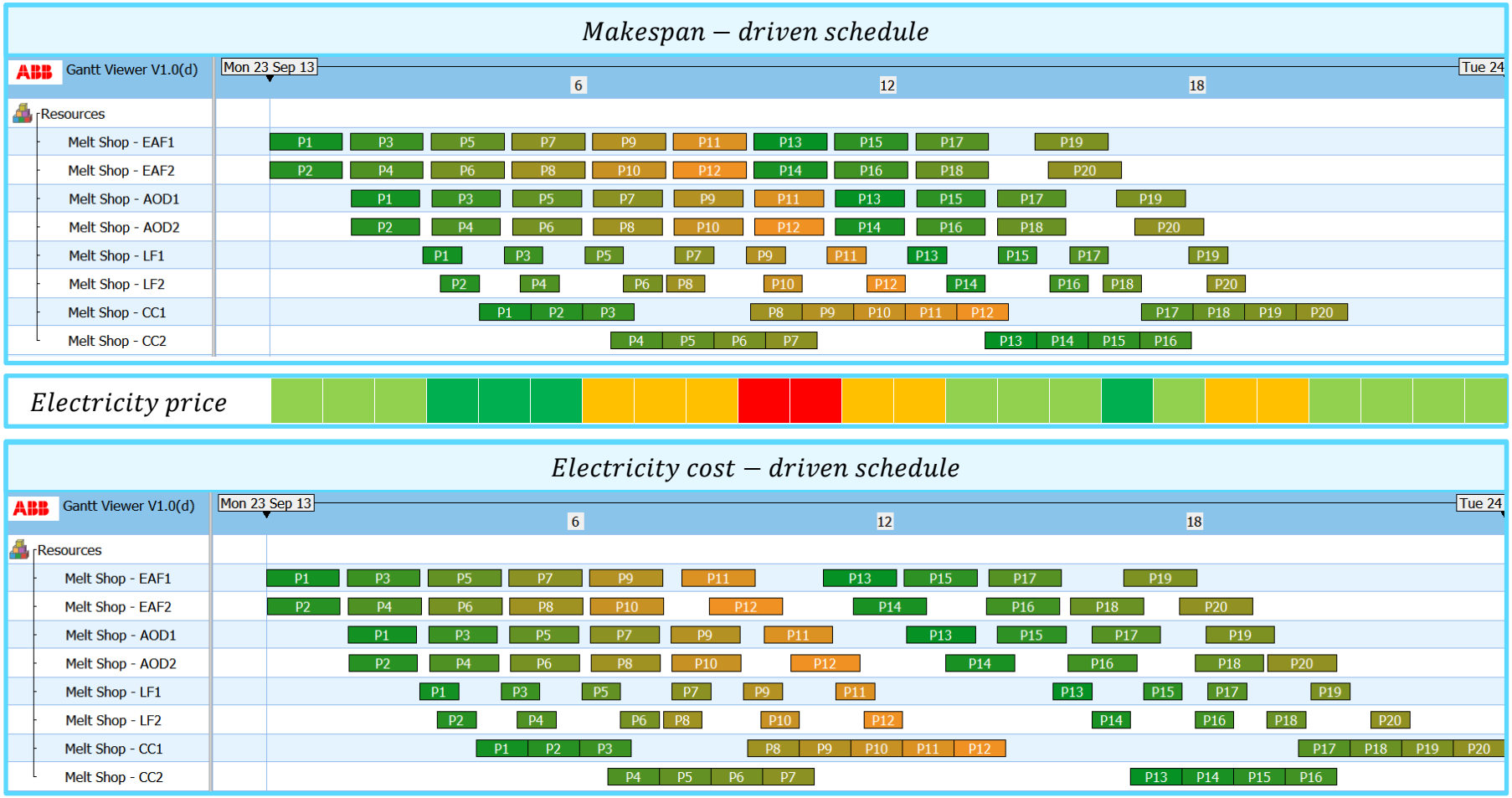
Heuristic vs Monolithic (GAMS/CPLEX v23.7)

Instance	Model type	Model statistics			Min objective 600s	Relative gap 600s	Heuristic Iterations (Best)
		Binary vars	Cont vars	Equations			
24 h, 20 products, high prices spot	**Monolithic 1**	4 065	25 443	102 335	247 838	**29,30%**	-
	Heuristic 1	UL2: 1 458	UL2: 28 050	UL2: 102 335	193 845	**9,89%**	5(5)
24 h, 20 products, low prices spot	**Monolithic 2**	4 065	25 443	102 335	200 038	**24,90%**	-
	Heuristic 2	UL2: 1 458	UL2: 28 050	UL2: 102 335	165 196	**9,09%**	5(3)
24 h, 16 products, high prices spot	**Monolithic 3**	3 229	20 199	80 528	155 226	**22,81%**	-
	Heuristic 3	UL2: 1 276	UL2: 22 152	UL2: 80 528	134 588	**9,87%**	3(1)

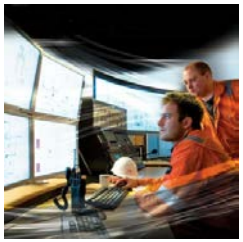
- What if the plant over-commits expected electricity consumption?

24 h, 16 products, high prices spot, agreed load as for 20 products	**Monolithic 4**	3 229	20 199	80 528	204 173	**22,50%**	-
	Heuristic 4	UL2: 1 276	UL2: 22 152	UL2: 80 528	176 006	**8,71%**	4(3)

Model Results
Gantt Chart example



Summary Discussion
Conclusions and Further Work



- Benefits and limitations
  - Cost reduction realized by energy-aware scheduling
  - Very large instances still intractable, even with heuristic
  - No lower bound from upper level problem results in no convergence behavior
- Further work
  - One-sided Mean Value Cross-decomposition on monolithic formulation to functionally separate energy purchase from production scheduling
  - Application to pulp and paper industry
- 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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