Master Thesis:

Collaboration between Utility Systems and Production Plants under Time-sensitive Electricity Prices: Assessing the Economic Benefit

Case Study: An Integrated Steel Mill

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ABB

Energy-intensive industries are increasingly affected by time-sensitive electricity prices

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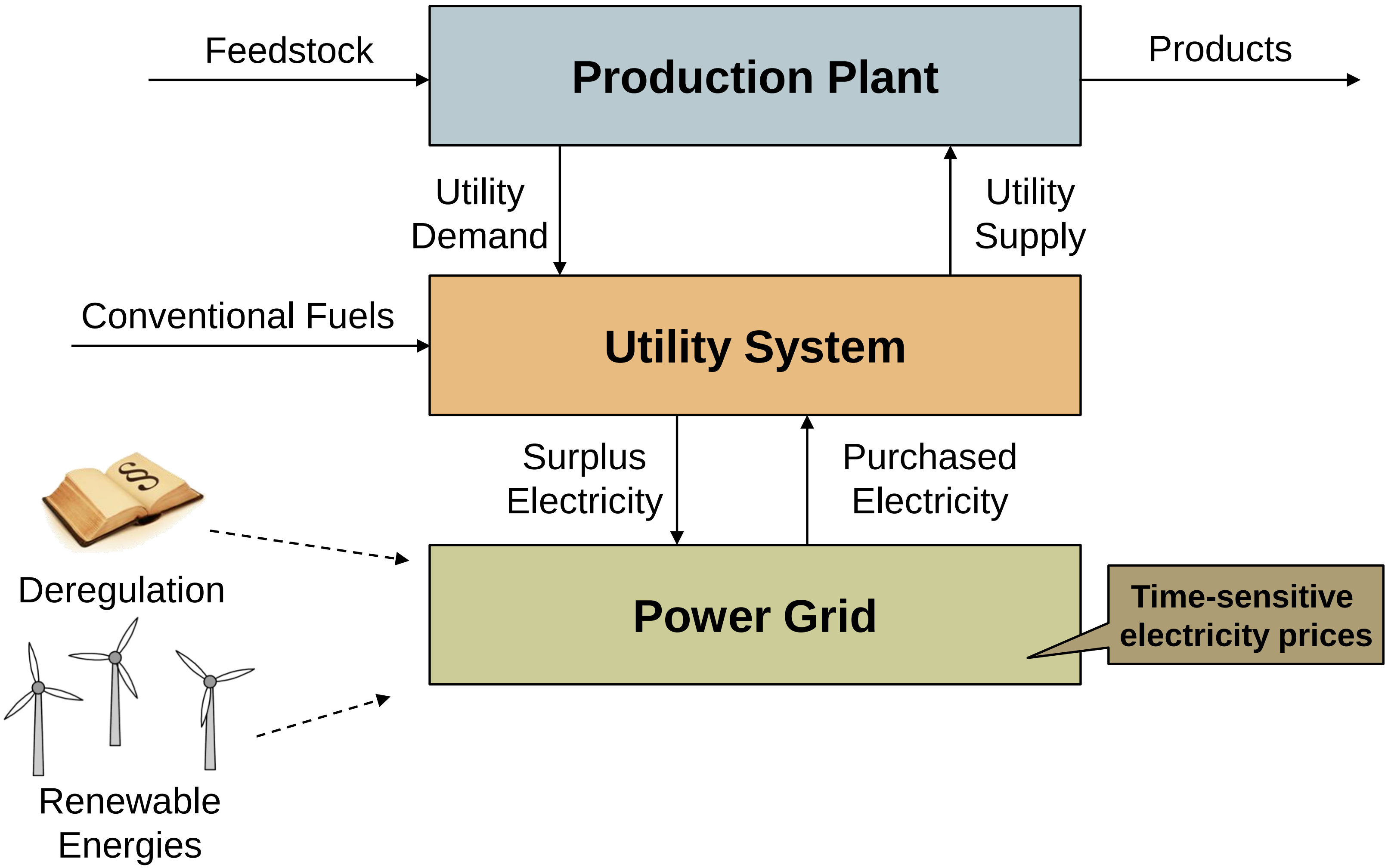
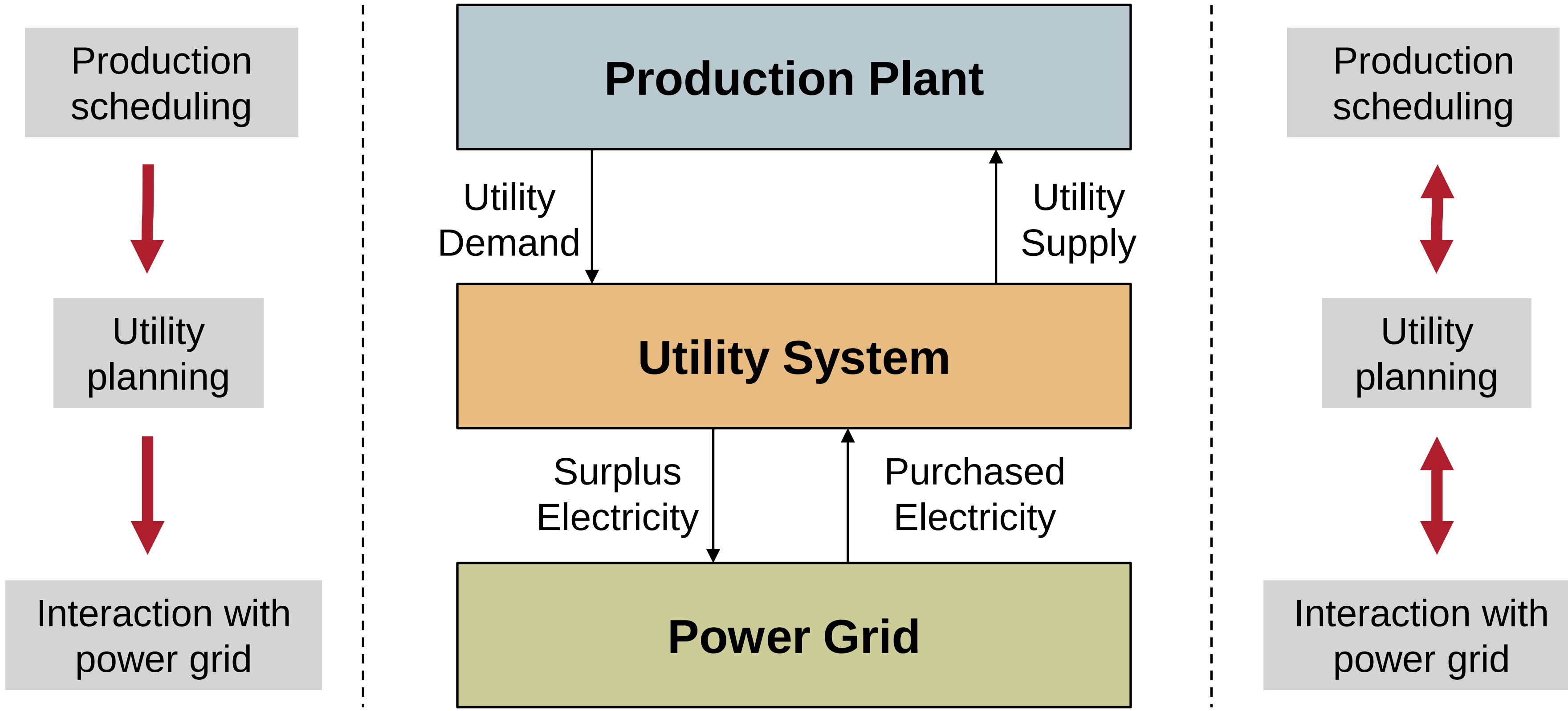


The sequential scheduling approach implies the risk of making suboptimal decisions

Sequential (traditional) scheduling approach

Simultaneous (collaborative) scheduling approach



Collaborative approach: Optimize utility system and production plant simultaneously while considering time-sensitive electricity prices

A collaborative scheduling approach appears promising to the steelfinishing process

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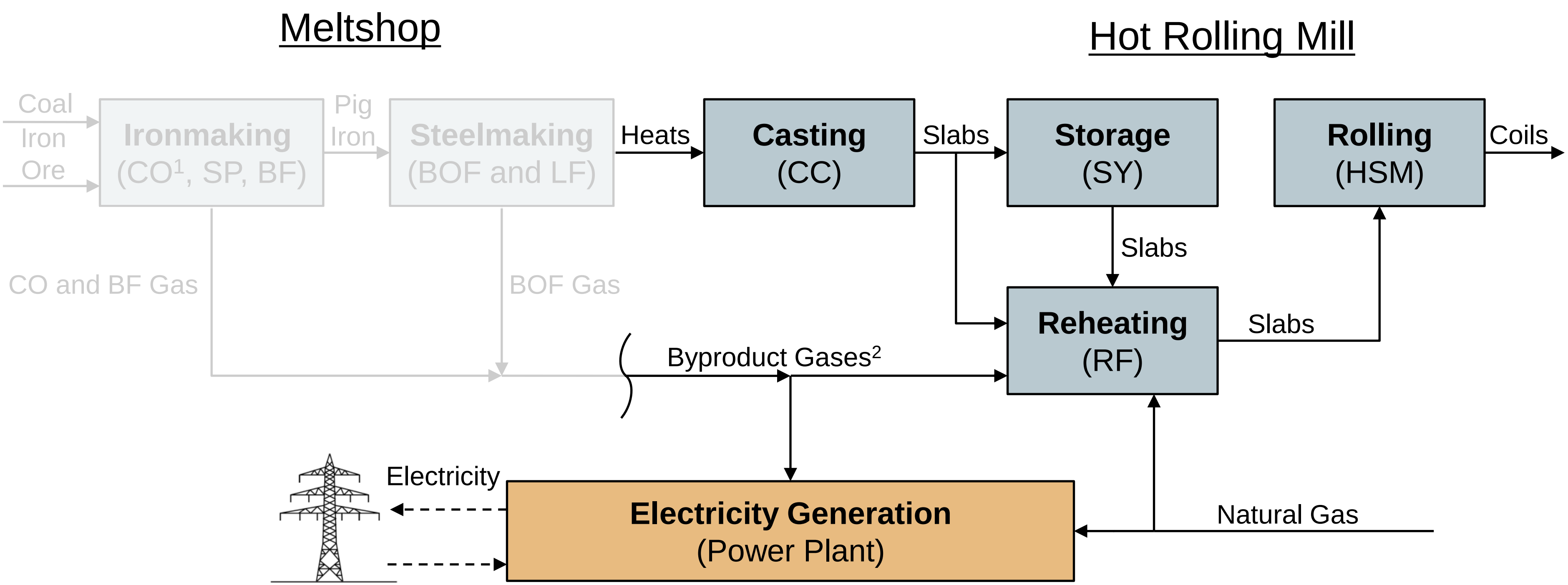

	High Electricity Prices
Use of surplus byproduct gases	Electricity generation
Natural gas consumption for reheating	Increased
Reheating activity	Delayed

1. Abbreviations: CO (coke oven), SP (sinter plant), BF (blast furnace), BOF (basic oxygen furnace), LF (ladle furnace), CC (continuous caster), SY (slab yard), RF (reheating furnace), HSM (hot strip mill)
2. Only excessive byproduct gases (CO gas, BF gas, BOF gas) that aren't required in the CO, BF and BOF units are sent to the power plant

An industrial case study is translated into a generic problem statement

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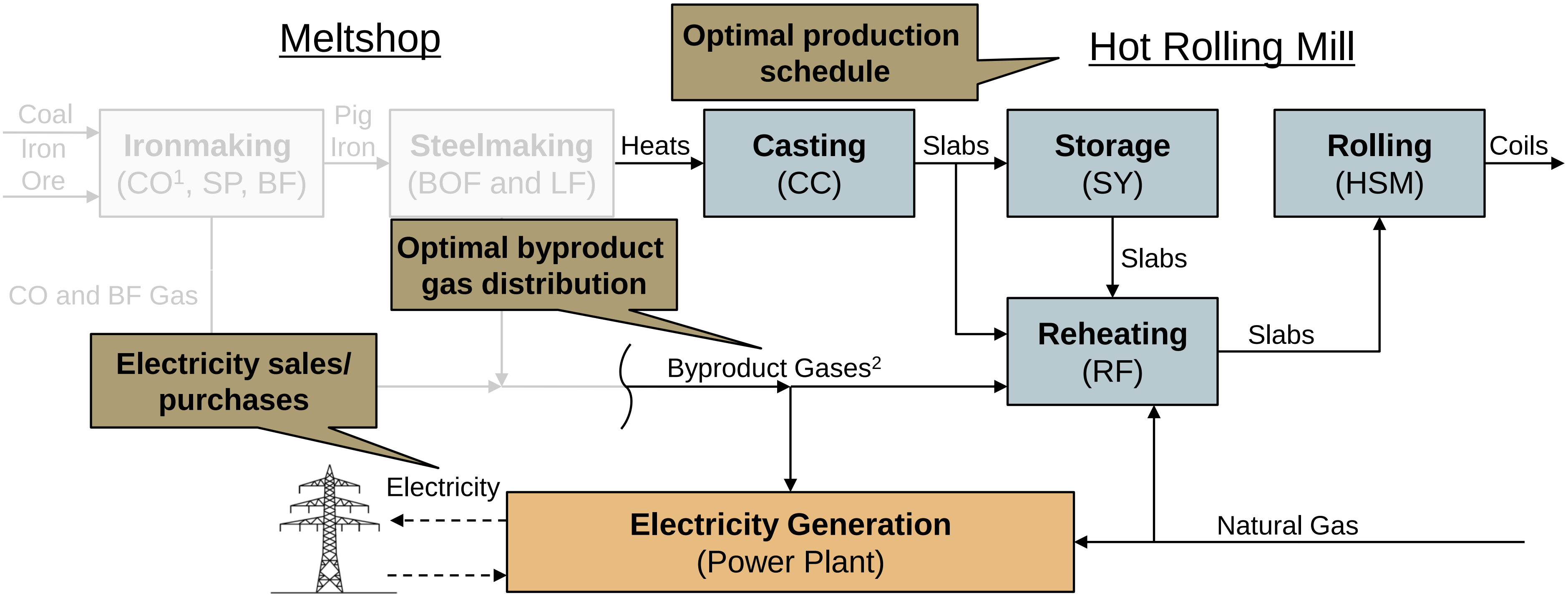

Given:

- Hot rolling mill produces set of products $s \in S$ with equipment $e \in E$
- Byproduct gases $g \in G$ can be used for either reheating or to generate electricity
- Electricity can be purchased from or sold to the power grid at any time $t \in T$

Determine:

- The optimal production schedule for the hot rolling mill while satisfying customer demand at given due dates and meeting all process constraints
- Optimal byproduct gas distribution between the reheating furnaces and the power plant

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2. Only excessive byproduct gases (CO gas, BF gas, BOF gas) that aren't required in the CO, BF and BOF units are sent to the power plant

Objective function:

Minimize operating costs of reheating furnaces and power plant

$$\min \quad costs = c_{Fuel,RF} + c_{Fuel,PP} - r_{EL,PP}$$

Fuel costs reheating furnaces

Fuel costs power plant

Revenues from surplus electricity sales

Objective function:
Minimize operating costs of reheating furnaces and power plant
Hot rolling mill model:
Logic constraints capturing slab transitions and process constraints

Logic constraints are used to translate the scheduling problem into a mathematical model

Objective function:

Minimize operating costs of reheating furnaces and power plant

Hot rolling mill model:

Logic constraints capturing slab transitions and process constraints

- *Demand and initialization constraints*
- *Assignment and capacity limitation constraints*
- *Body section transition constraints*
- *Processing time constraints*
- *Changeover constraints*
- *…*

Logic constraints are used to translate the scheduling problem into a mathematical model

Objective function: Minimize operating costs of reheating furnaces and power plant
Hot rolling mill model: Logic constraints capturing slab transitions and process constraints
Power plant model: Energy balances for the reheating furnaces and the power plant

Objective function:

Minimize operating costs of reheating furnaces and power plant

Hot rolling mill model:

Logic constraints capturing slab transitions and process constraints

Power plant model:

Energy balances for the reheating furnaces and the power plant

- *Energy balance reheating furnaces*
- *Energy balance power plant*
- *…*

Objective function:

Minimize operating costs of reheating furnaces and power plant

Hot rolling mill model:

Logic constraints capturing slab transitions and process constraints

Power plant model:

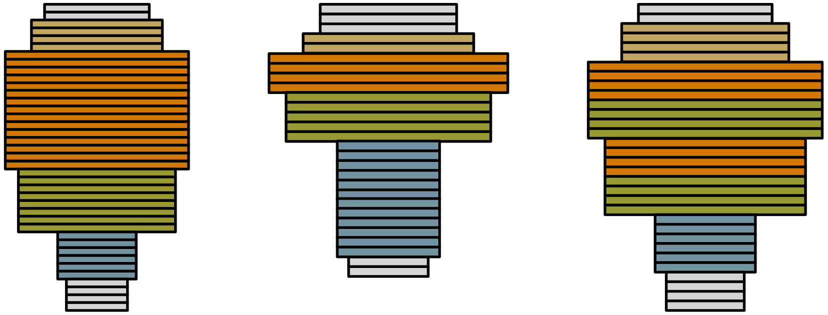
Energy balances for the reheating furnaces and the power plant

Power grid:

Time-sensitive electricity prices affect electricity sales and purchases

Real-world case study:

- 1 day planning horizon (10 min time intervals)
- 3 rolling programs: (2,667 tons per day)
- MILP (≈ 106k 0-1 vars)



Energy Demand Reheating Furnaces over Time
(Collaborative scheduling, **Spring** EL price profile)

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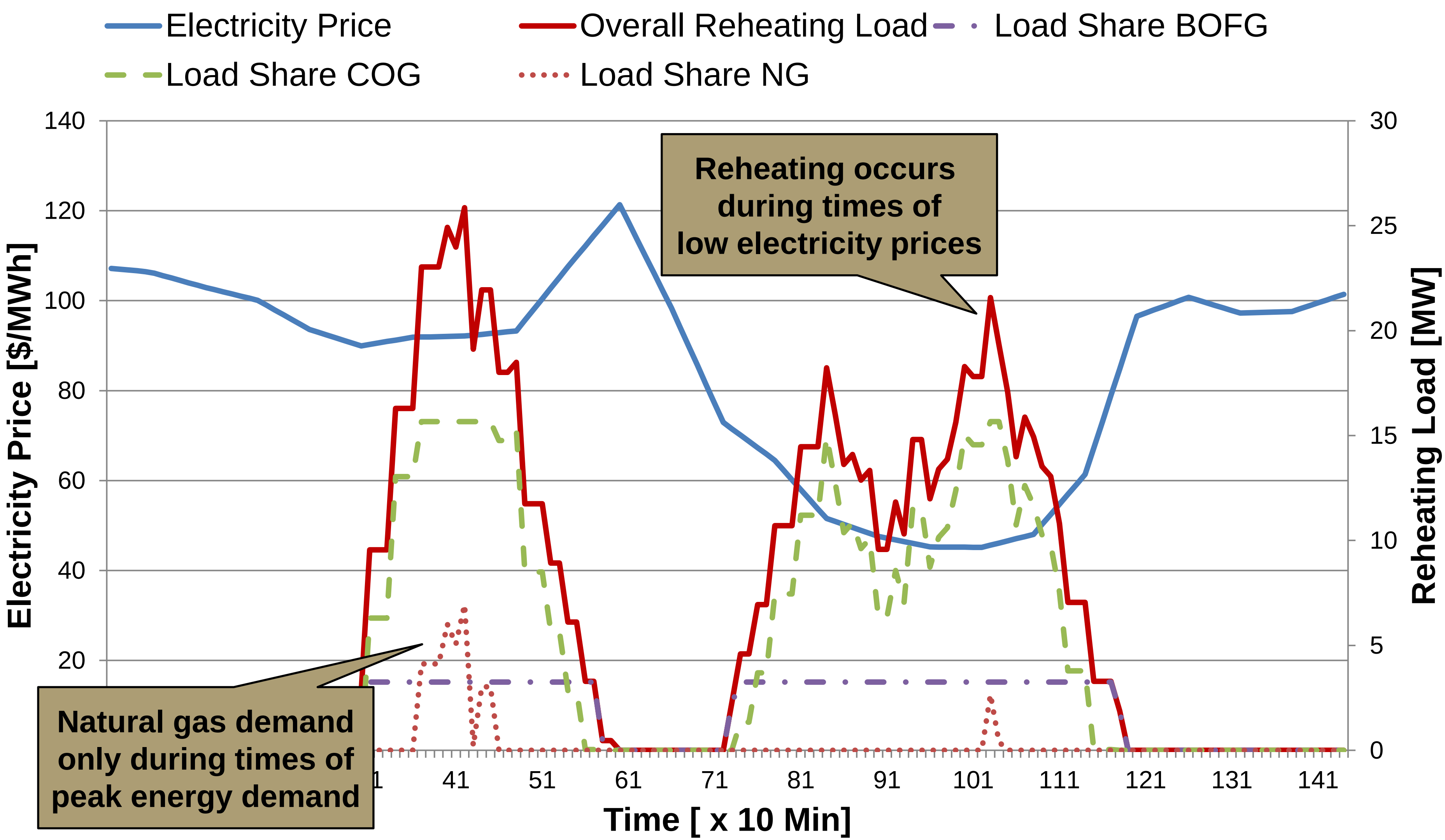

Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas)

Electricity Generation over Time
(Collaborative scheduling, **Spring** EL price profile)

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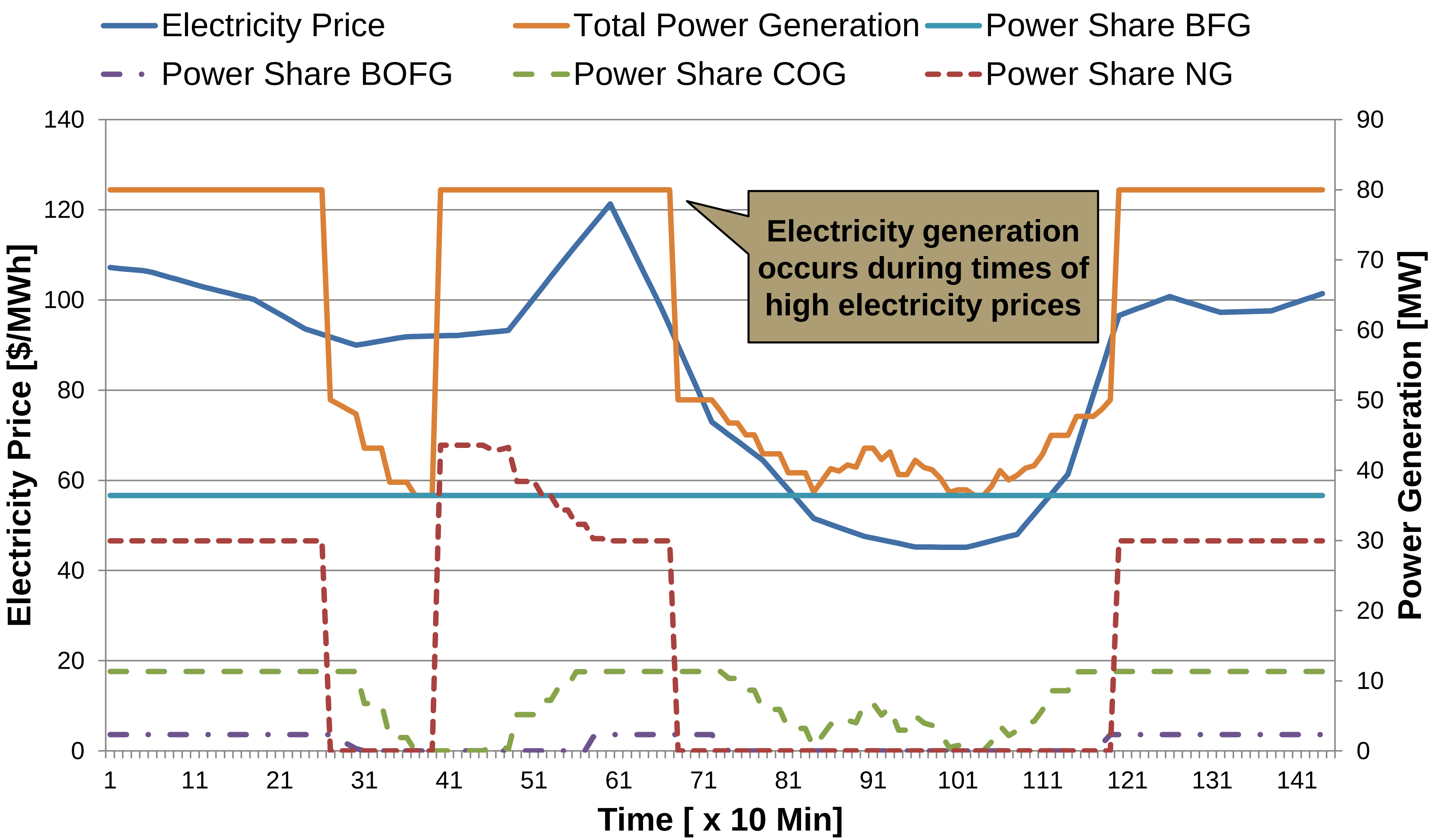
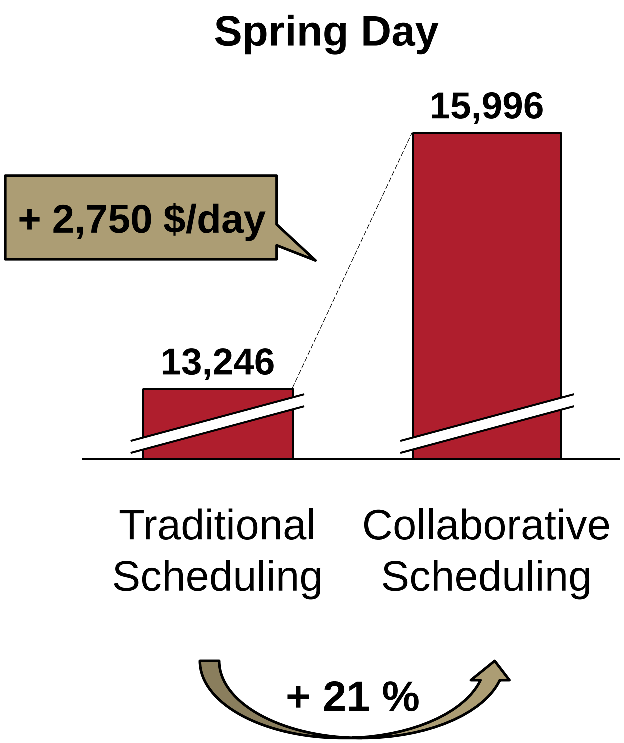


Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas)

Profits generated in [$/day]:



Optimal timing of reheating and electricity generation exploits fluctuations in electricity prices and thereby increases the overall profit.

Energy Demand Reheating Furnaces over Time
Collaborative scheduling, **Summer** EL price profile)

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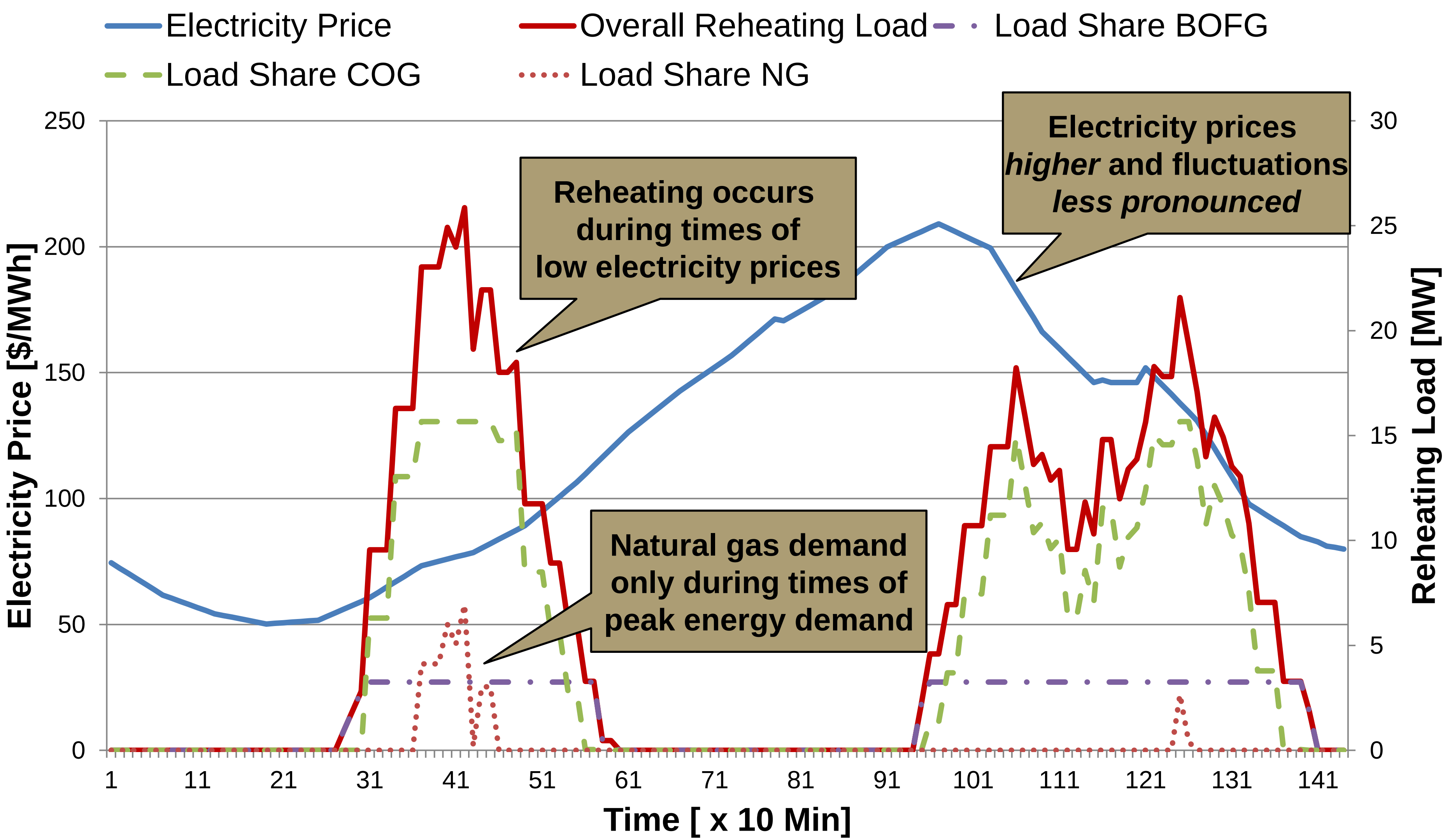

Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas)

The economic benefits due to collaboration can be *marginal*

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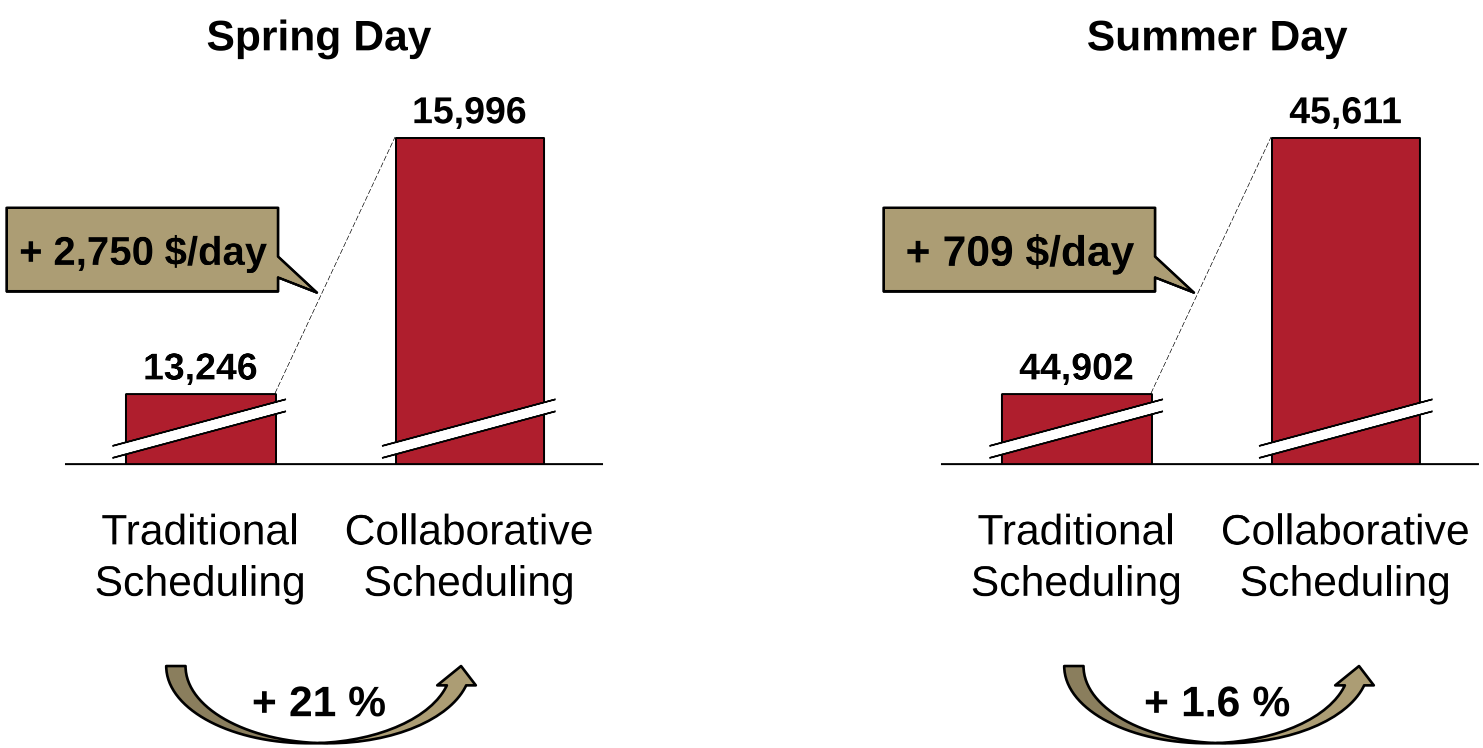
Profits generated in [$/day]:



The economic benefit due to collaboration is very sensitive to the nature of the electricity price fluctuations.

Conclusion

Novelty of the work

- Quantification of the economic benefits of a *collaborative scheduling approach*
- Analysis of the *sensitivity* of the obtained results with respect to time-sensitive electricity prices
- Evidence that the absolute economic benefit is highly sensitive to the *character of electricity price fluctuations*

  → Moderate fluctuations: Small incentive for collaboration

  → Pronounced fluctuations: Significant economic benefit due to collaboration

Impact for industrial applications

- Ability to apply the developed modeling framework to other industries and quantitatively assess the potential economic benefits of collaboration

Thank you for your attention!

Questions, comments?

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