A.N.I.P.L.A.
ASSOCIAZIONE NAZIONALE
ITALIANA PER L'AUTOMAZIONE

I *Big Data* incontrano il Manifatturiero: Opportunità e Vantaggi

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Energy aware supervision for real-time optimization of energy intensive processes

Application to a foundry

A. Brusaferri e S. Spinelli (CNR-STIIMA), G. Cannella e F. Negri (Brembo SpA)

STIIMA
Sistemi e Tecnologie Industriali Intelligenti per il Manifatturiero Avanzato

brembo

Summary

1. Challenges and opportunities:
   Managing flexibility in the most efficient way while increasing energy efficiency and fostering sustainable consumption patterns

2. Flexible energy intensive process example:
   Foundry with melting furnace array and multiple molding lines

3. Developed energy-aware optimization system

4. Results and next (actual) developments

Key targets and challenges – flexibility and efficiency

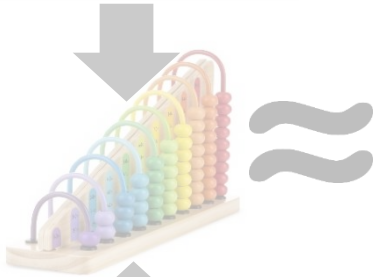
- **Batch-1** needed also **in continuous industries** historically characterized by more «stationary» production as Iron & Steel
  - **Shorter time to market,** reduced times and costs
  - Highly **customized products** and heterogeneous **mixes**
  - Frequent **operating changes** following variable production volumes
- **Energy efficiency**, minimize wastes (e.g. dissipations due to wait-times)
- **Reshape loads**: towards sustainable consumption patterns

New challenges (opportunities) for sustainable I4.0

Fostering sustainable energy consumption patterns

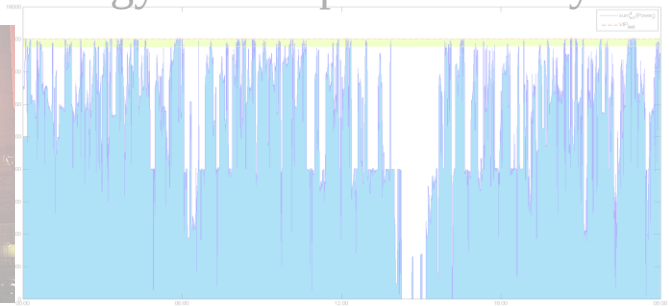
Production

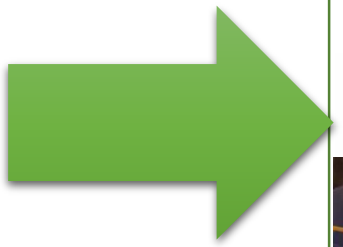
Renewable energy production



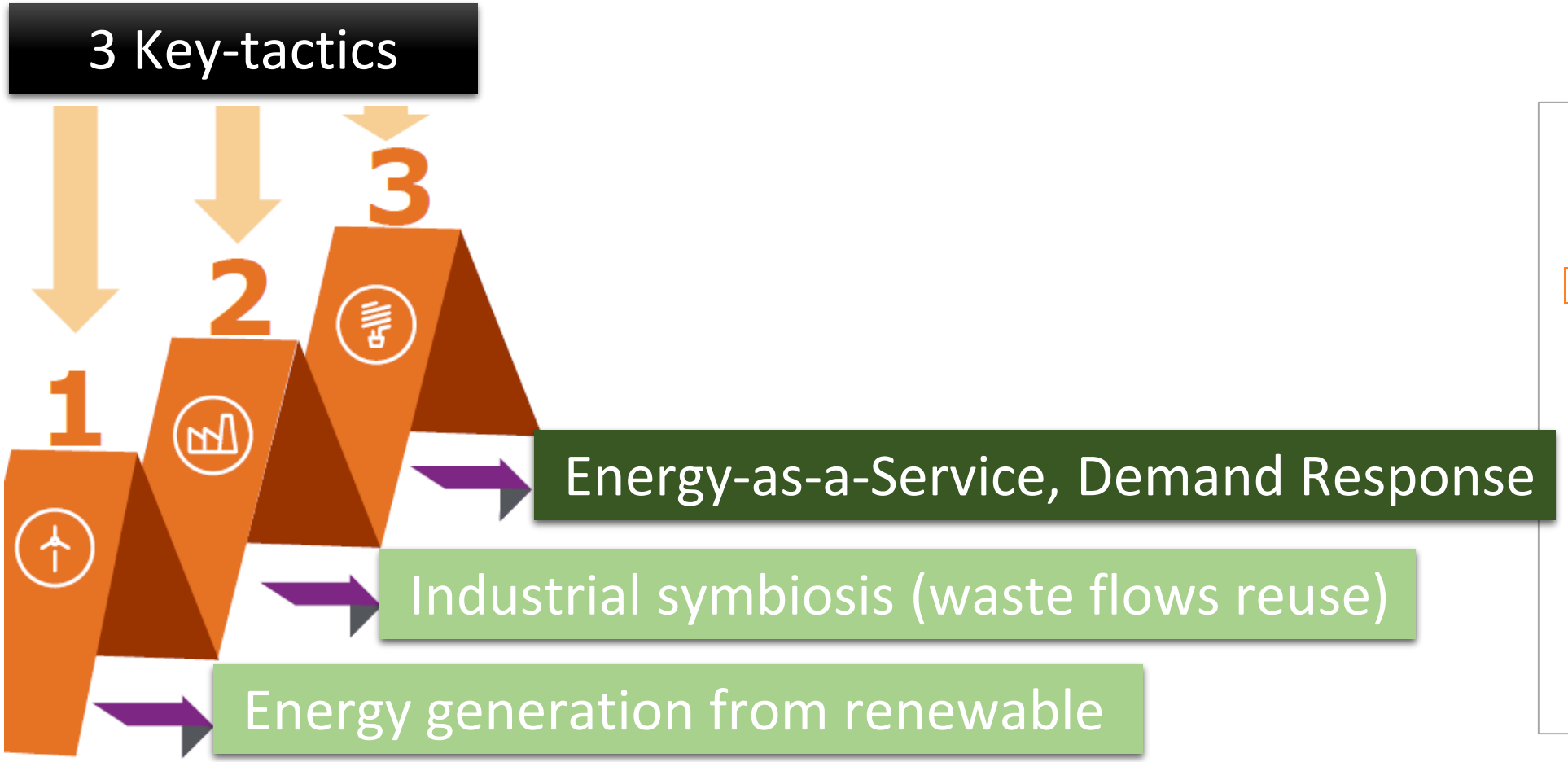
Consumption

Energy consumption on a day





DR as key tactic for energy circular economy



World Energy balance, 2014

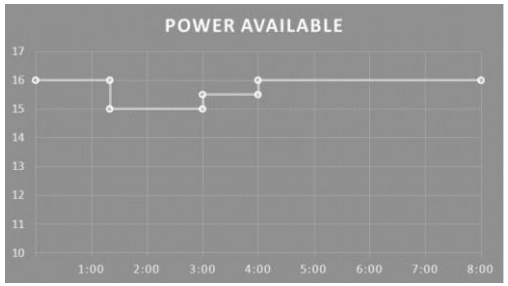
ELECTRICITY CONSUMPTION [Mtoe]	
INDUSTRY	
Iron and steel	101.39
Chemical and petrochemical	100.81
Non-ferrous metals	79.63
Machinery	78.57
Non-metallic minerals	51.78
Food and tobacco	40.51
Paper pulp and printing	33.92
Mining and quarrying	29.52
Textile and leather	28.71
Transport equipment	23.59
Construction	15.02
Wood and wood products	10.20
Non-specified	131.73
TOTAL	**725.37**

source: International Energy Agency

Deloitte.

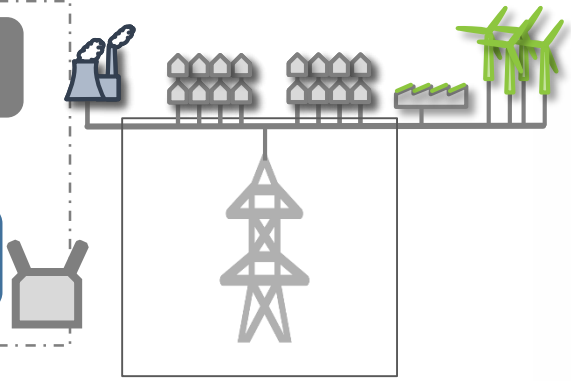
Source: Circular economy in the energy industry. Final report (2018)

Grid optimization with industrial prosumers



Energy and AS
BRP/TSO/DSO

Grid constraints
Contract optimization



Local grid power constraints to be respected

Cluster aggregator

$\delta g_1/\delta\lambda$

$\lambda(t)$

$\delta g_2/\delta\lambda$

$\lambda(t)$

$\lambda(t)$

$\delta g_n/\delta\lambda$

flexibile load

flexibile load

flexibile load

ENERGY INTENSIVE PROCESS

ENERGY INTENSIVE PROCESS

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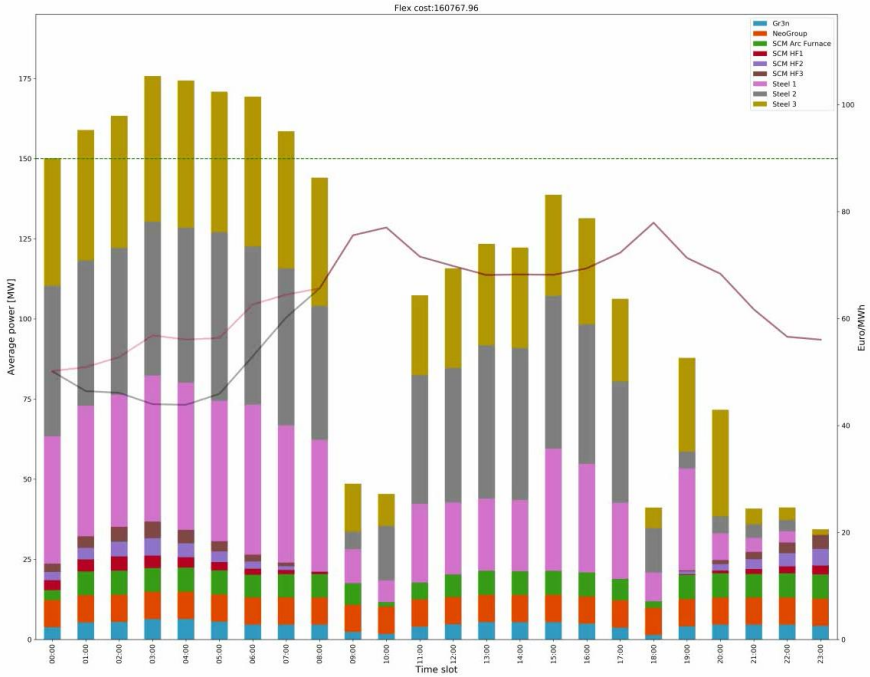
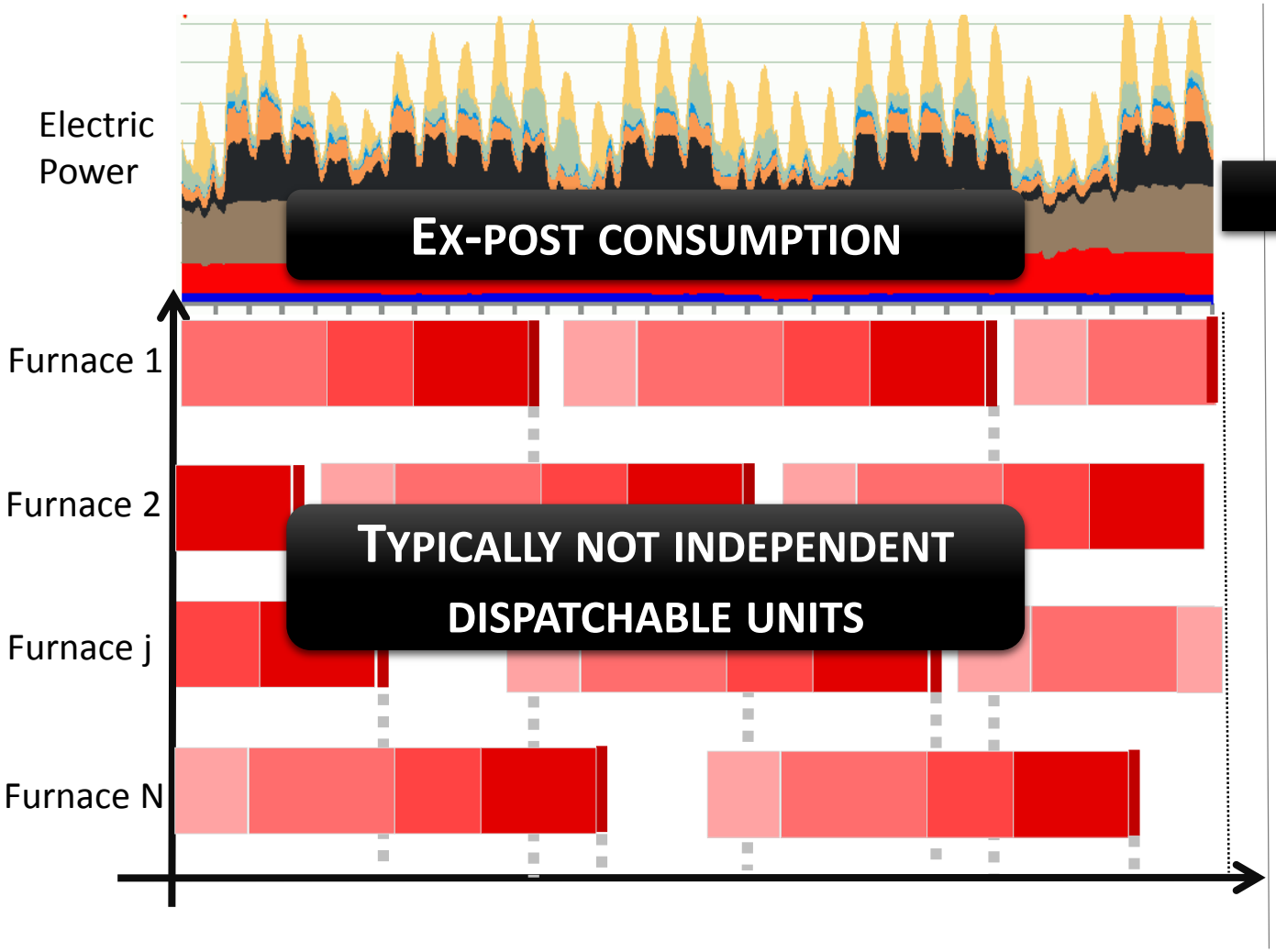


Energy intensive factories
as Smart Nodes
of the Smart Grid

Major open issues limiting the evolution



ADOPTING INDUSTRIAL DEMAND RESPONSE STRATEGIES…

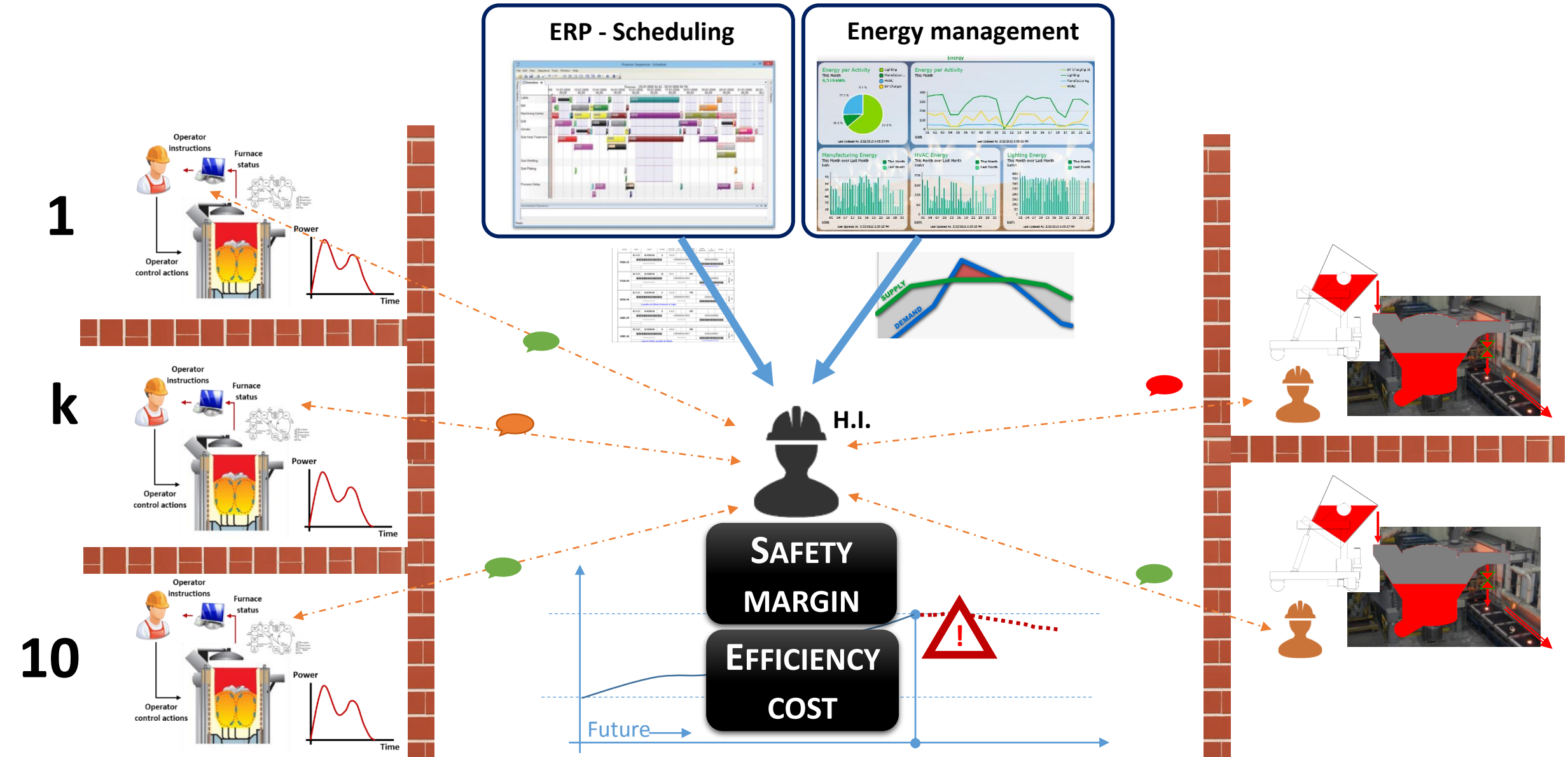
WHICH LOAD TO RESHAPE ?? WHEN ??

IMPACT ON PRODUCTION ?

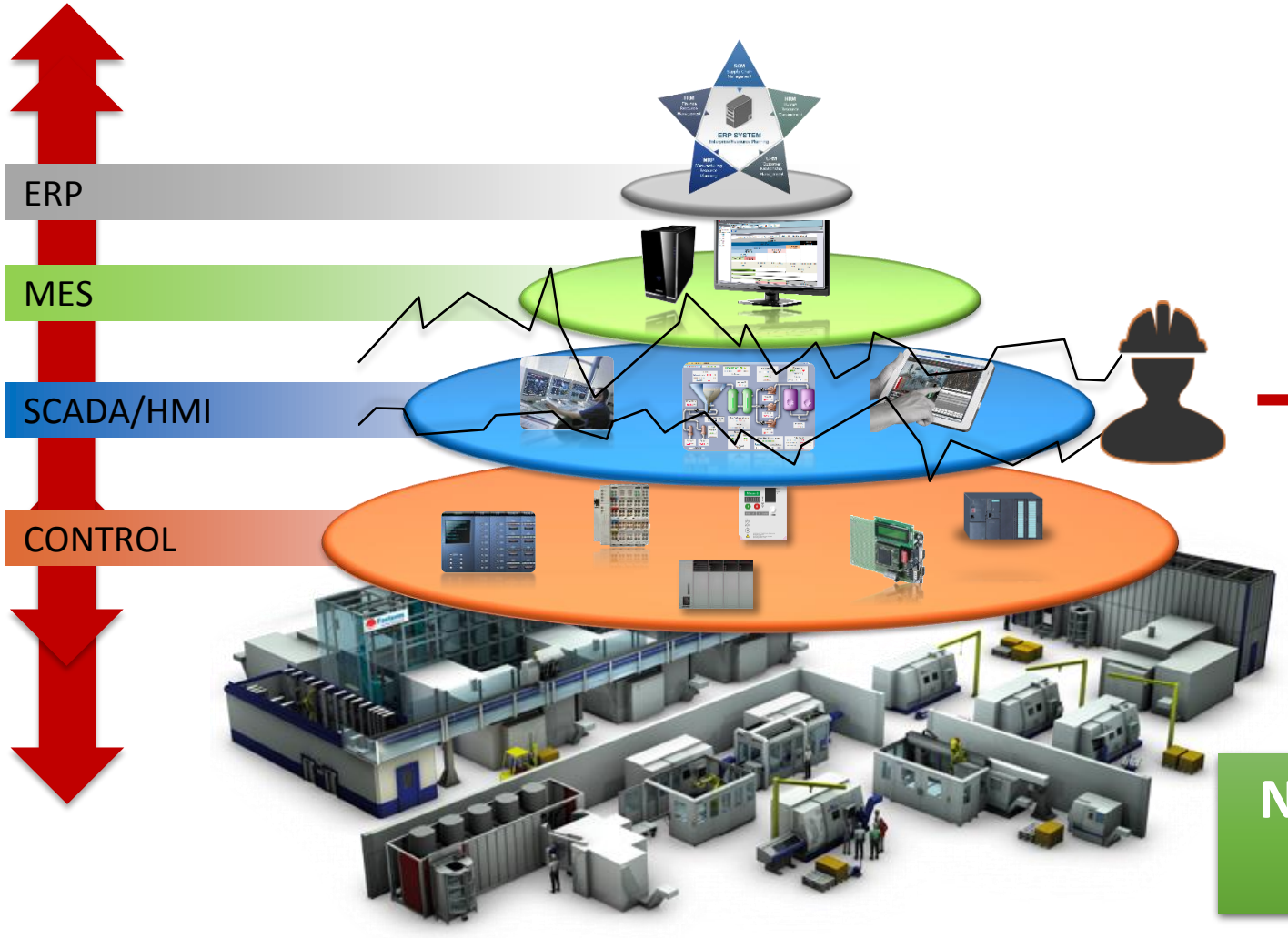
2 – Flexible energy intensive process example:

Foundry with melting furnace array and multiple molding lines

Typical situation today in foundries

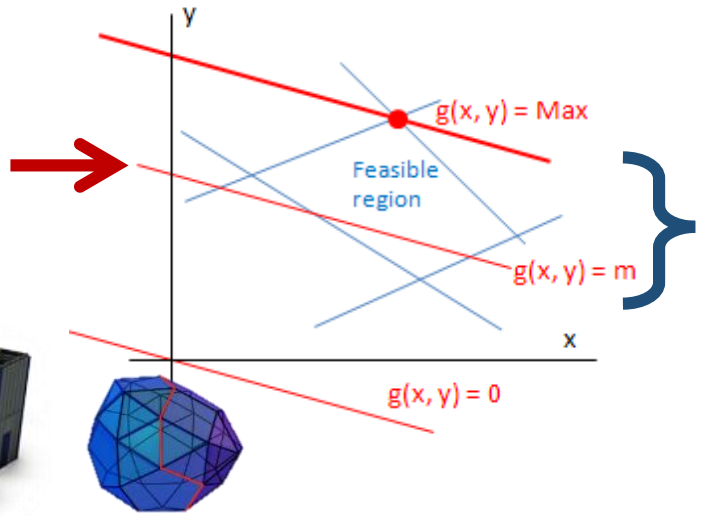


Efficient Agile production in hybrid manufacturing
Need for Level 2.5



HYBRID MANUFACTURING PROCESS

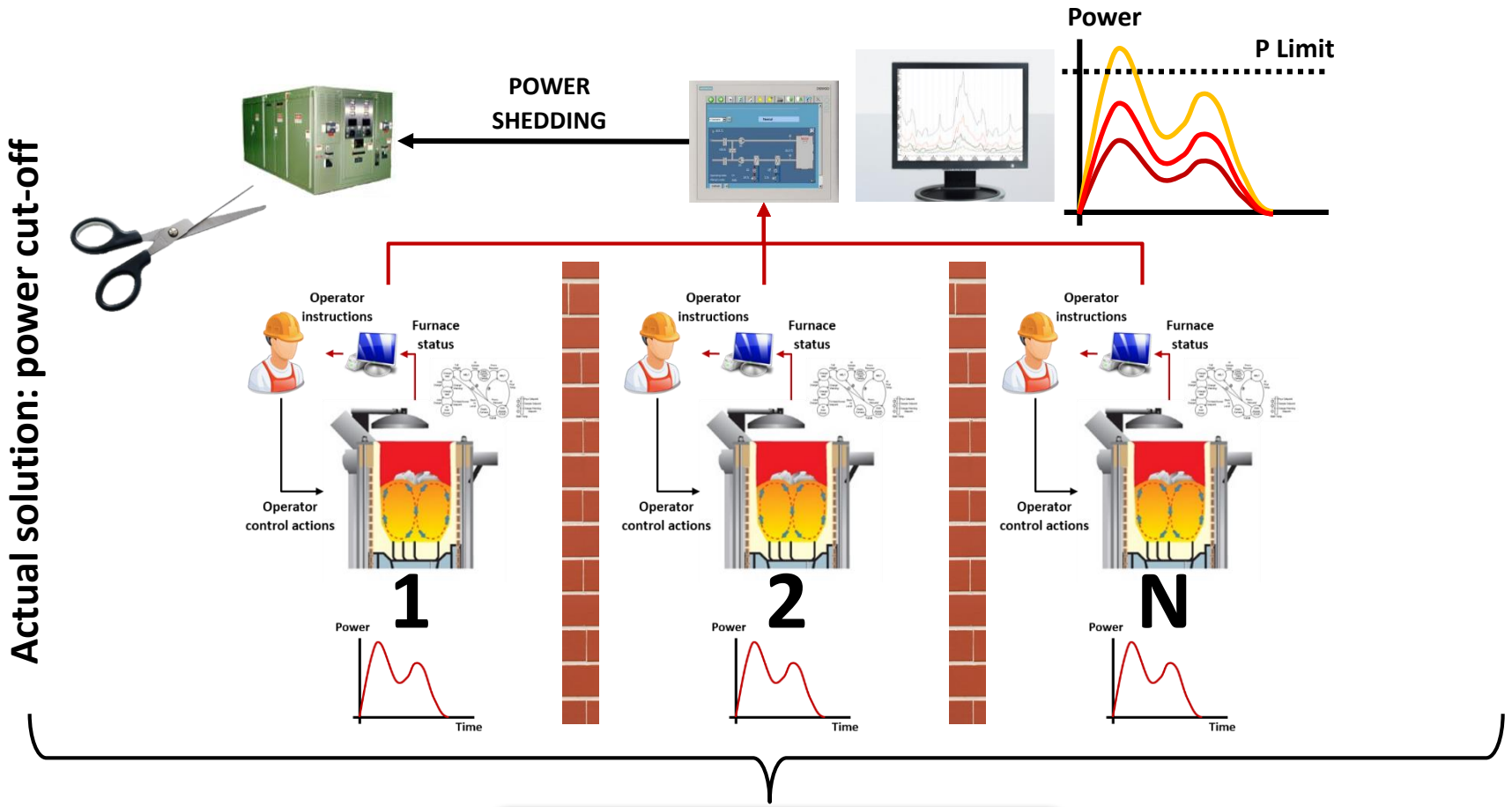
DEALING WITH MASS CUSTOMIZATION



Price of sub-optimality

Need for new tools supporting dynamic solution of the optimization problem

Partial solutions on the market



Respect power constraints

Impact on the melting process

Start before and wait
Lower energy efficiency

3 - Developed energy-aware optimization system

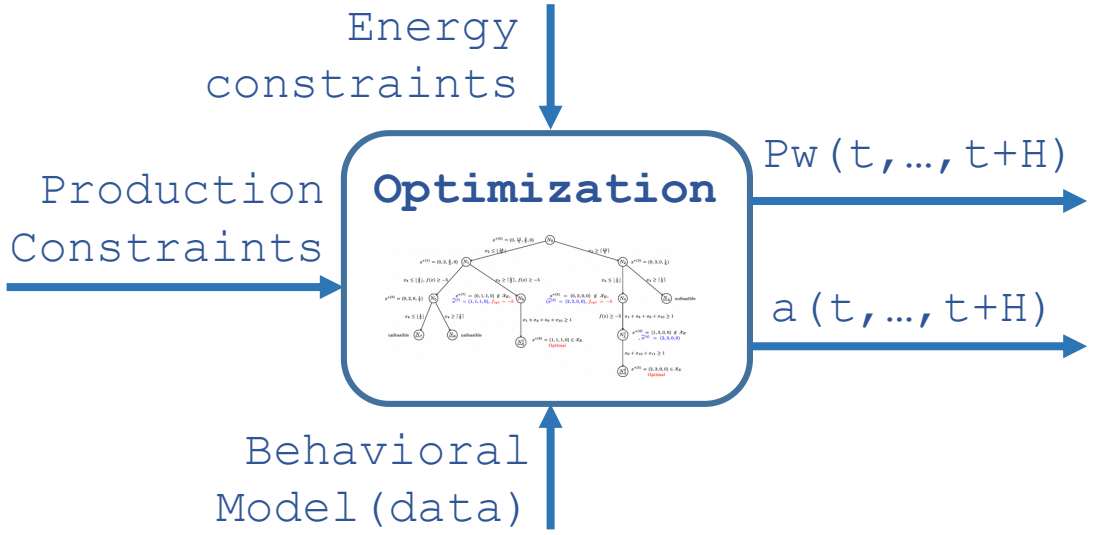
Optimization kernel and implementation in melt-shop SCADA

Addressed issues and adopted approach

- First approach considered: predictive consumption model
- Do not provide a solution to the commitment of furnace and power allocation to address production and Demand Response targets.
- Too complex to find a solution by what-if analysis exploiting prediction models

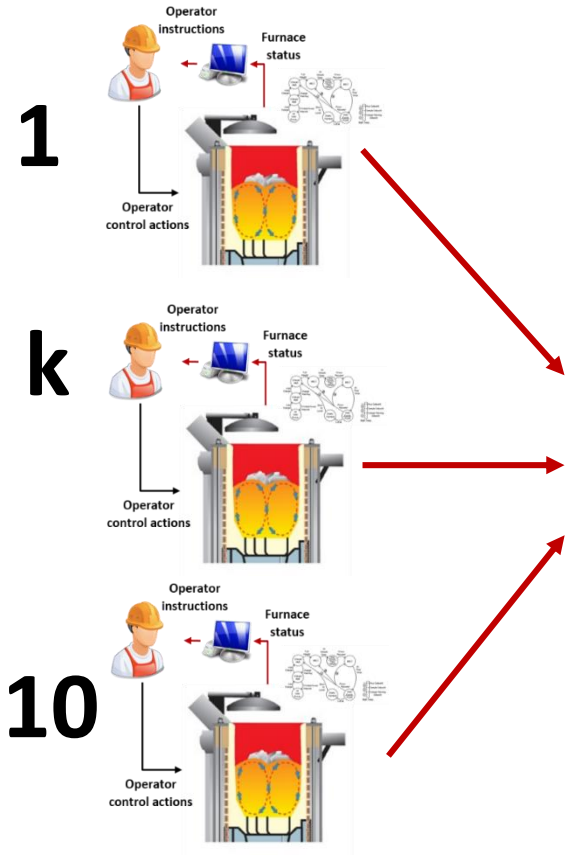
Adopted approach:

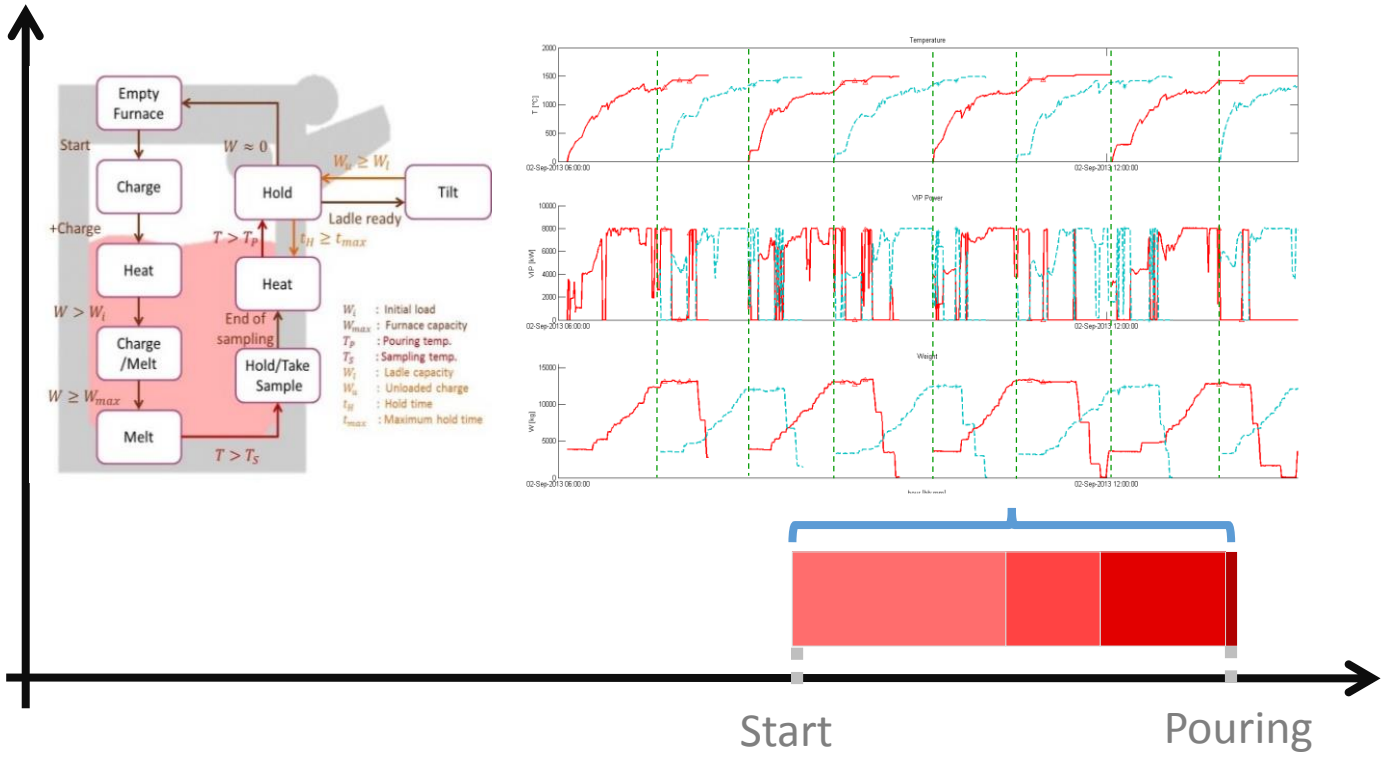
- Exploit models fitted on data within an optimization tool
- Predictive vs Prescriptive analytics

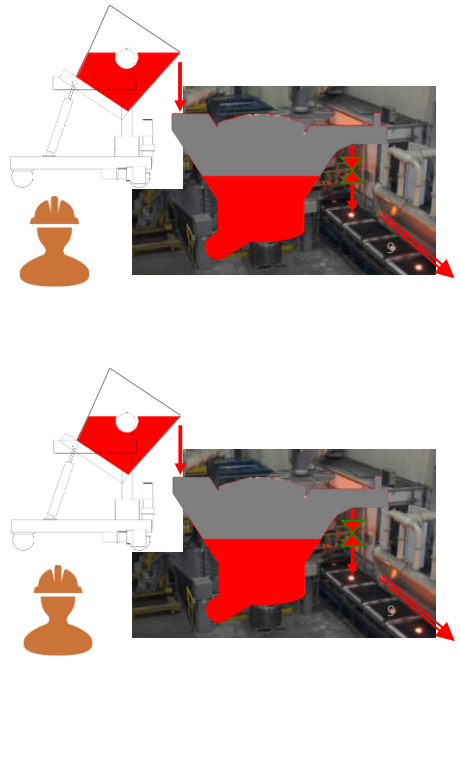


"Data is Dead…Without What-If Models" [2011] - The final phase is prescriptive analytics, which goes beyond predicting future outcomes by also suggesting actions to benefit from the predictions and showing the implications of each decision option

Guarantee molten metal in pouring lines

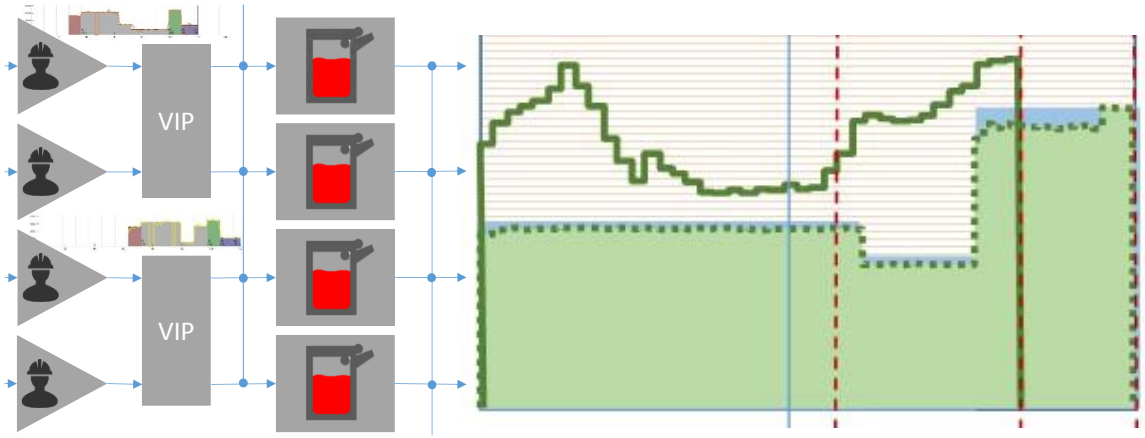


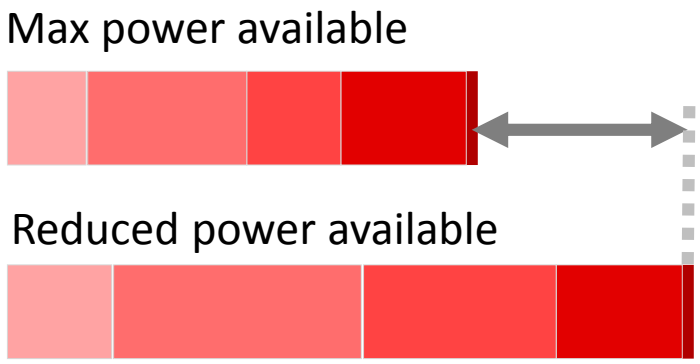


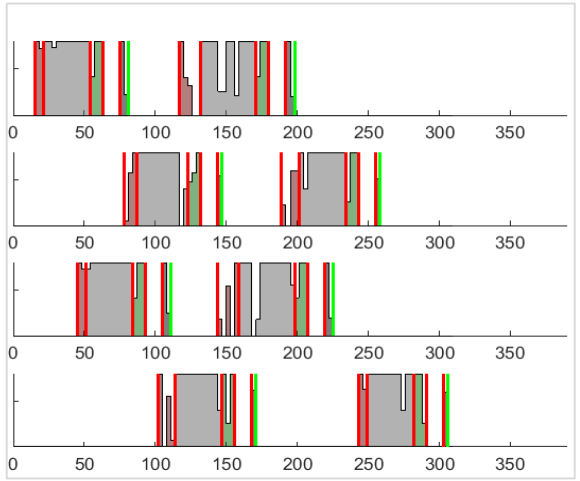


- Choose when to start each melting phase on each furnace
- Hybrid model: phases specific behaviour with guarded transitions
- Furnace commitmnet + power allocation → Mixed integer problem

Overall power consumption policy

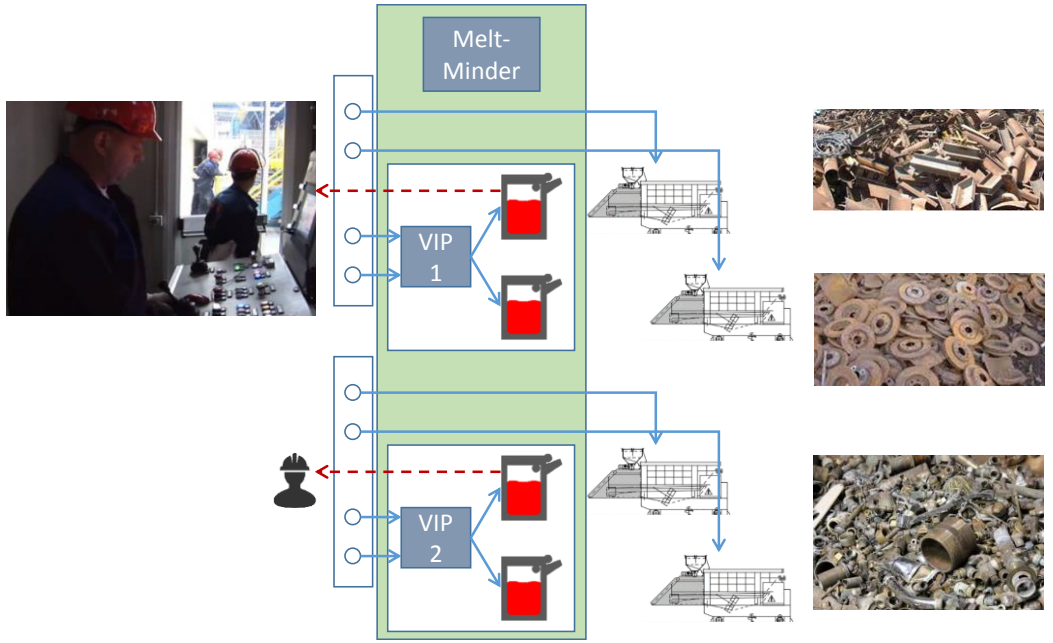






- Respect of overall power constraint (or considering hourly price)
- Minimize overall melting time to minimize dissipations
- Different PW requests depending on the phases (e.g. chargMelt vs test)
- Allocation of Power(t) to each furnace (3 min. discretized optimization)
- Considering multiple meltings over receding horizon (5 hours)
- > 15K continous and discrete variables > 80K constraints = Large MIP problem

Adaptive to time varying conditions



- Run-time variations in absortions of the molding lines
- Scrapt material stochasticity (e.g. impact on induction behaviour)
- Receding horizon solution to compensate deviations
- 30 seconds cycle time adopting mixed discretization

Integration of process constraints

- Modelling of process constraints, e.g., flows, precedences, VIP tandems, etc.
- Both norm-2 on hourly energy profile and min energy cost (market price)
- Optimization kernel and pre/post-process heuristic implemented in Python
- Gurobi solver integrated to solve the dynamically built MIP problem
- Connection to induction furnaces and molding lines by OPC interface
- HMI implemented in Movicon SCADA
- Connection and processing of data from ERP (production plan)

Managing complexity behind the scene

Implemented within Movicon SCADA

$$\min_{x,y} \quad \sum_{i=1}^{n} x_i + \lambda \sum_{i=1}^{l_1+l_2} y_i$$

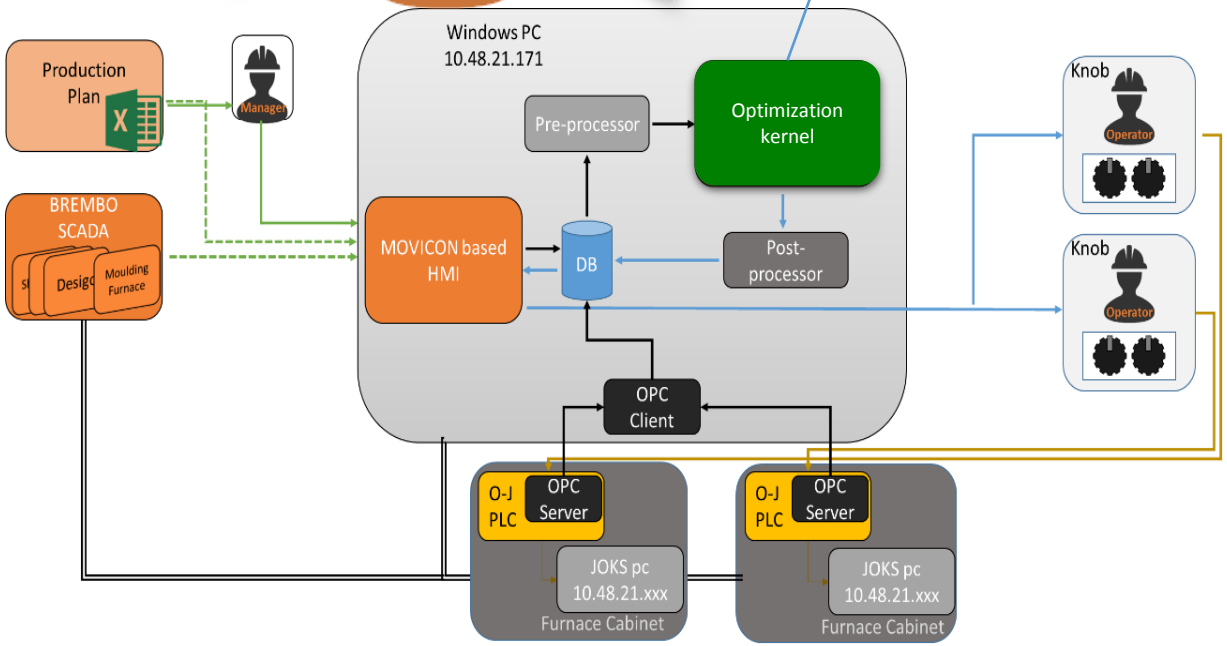
$$s.t. \quad \sum_{i=1}^{n} \left| p_{li} - \sum_{j=1}^{m_1} t_{ji}/m_1 \right| x_i - y_l < \sum_{i=1}^{n} \left| p_{li} - \sum_{j=1}^{m_2} f_{ji}/m_2 \right| x_i$$

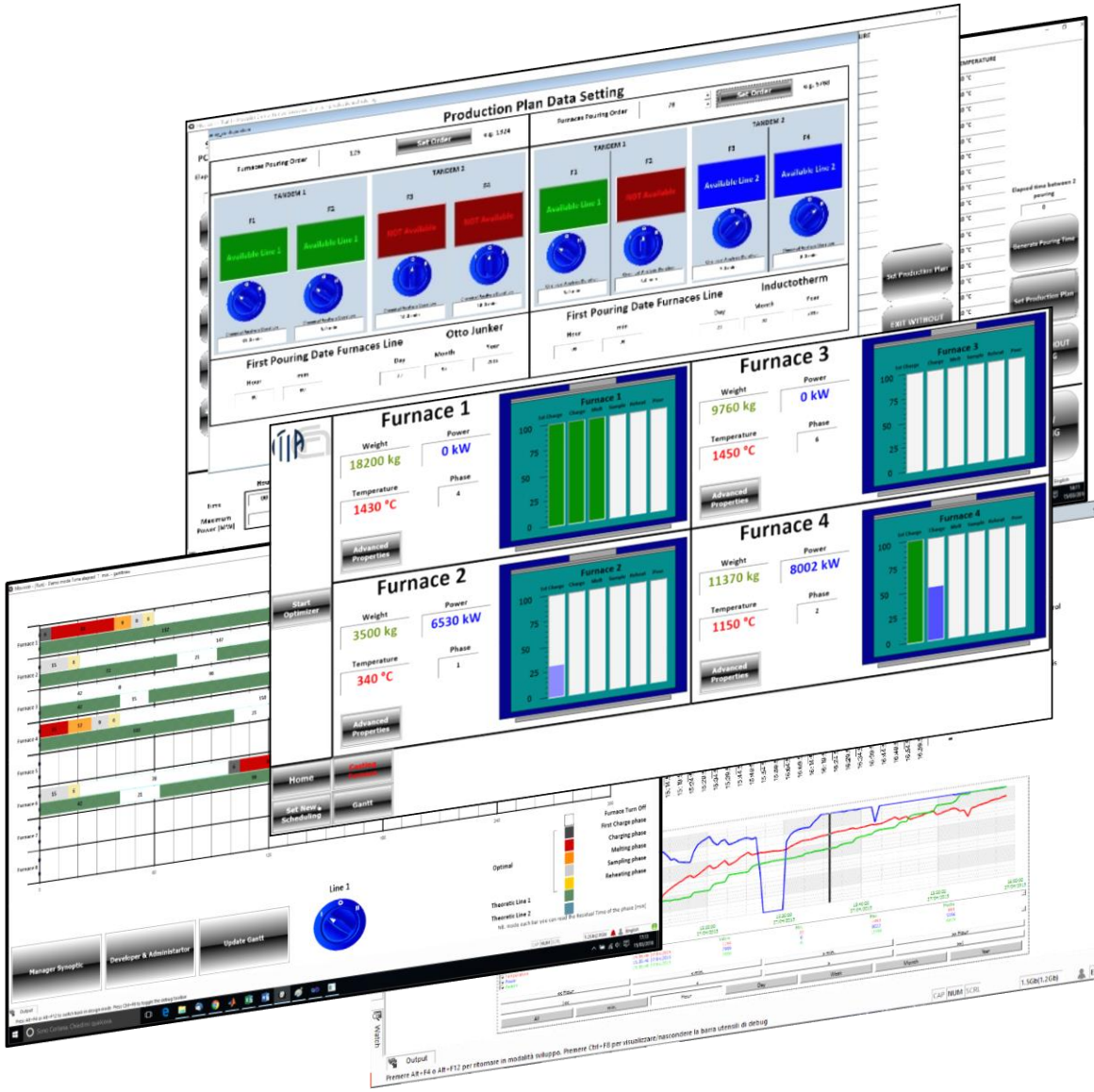
$$p_l = (p_{l1}, s_{l2}, \cdots, p_{ln}) \in U_T, l \in \{1, 2, \cdots, l_1\},$$

$$\left| p_{li} - \sum_{j=1}^{m_1} t_{ji}/m_1 \right| x_i + y_l > \sum_{i=1}^{n} \left| p_{li} - \sum_{j=1}^{m_2} f_{ji}/m_2 \right| x_i$$

$$(p_{l1}, s_{l2}, \cdots, p_{ln}) \in U_F, l \in \{1, 2, \cdots, l_2\},$$

$$i \in \{1, 2, \cdots, n\}, y_j \geq 0, \quad j \in \{1, 2, \cdots, l_1 + l_2\}$$





Achieved results

- Software installed in Brembo plant in Poland, Q4-2018
- Tested over different profiles and regimes
- Achieved savings (without change in electricity contract)
  - 5-7% saving in first 6 months (40% of software usage)
  - 10-13% at full rate (varying operating conditions)
- Now proceeding with second phase (flexible energy contract)
- Expected further savings:
  - 6 % of energy costs due to improved contract

Critical issues and lesson learned

- Getting historical data could take more time than predicted (development of new interfaces, data not available in system APIs, etc.)
- Connection to plants in brownfield could be tricky (e.g. custom driver for IF)
- Fundamental involvement of all company stakeholder from the beginning (e.g. furnace chief operator, plant manager, logistic, IT, furnace operators)
- Involvement of suppliers could be key for a successfull implementation
- Try to avoid new issues/requirements during project execution could be particularly tricky for innovation projects
- Fundamental training of operators as well as further involved personell

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Questions?

contact: alessandro.brusaferri@stiima.cnr.it