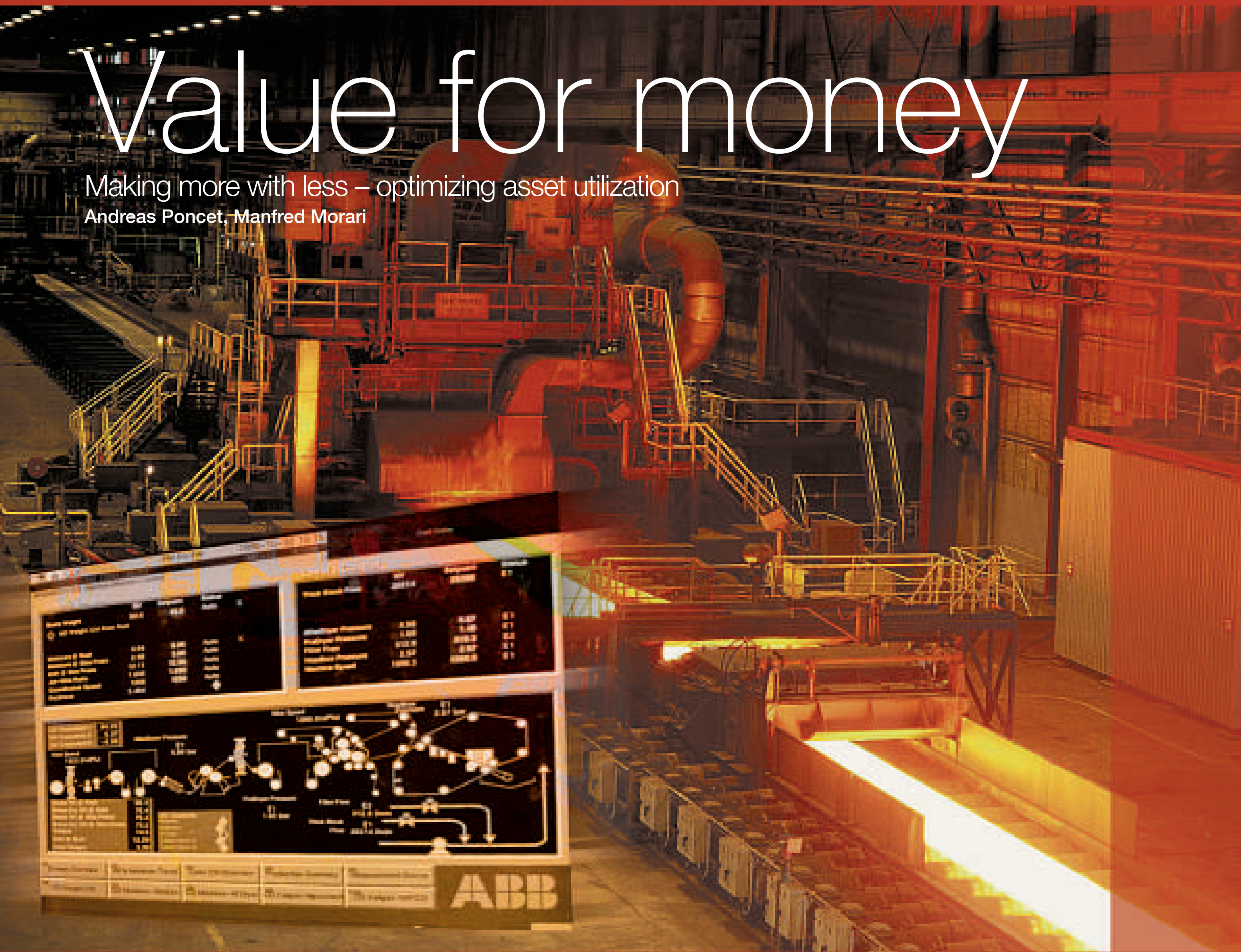
Value for money

Making more with less – optimizing asset utilization

Andreas Poncet, Manfred Morari



Owners of industrial assets are facing tough decisions. Rising competition, accelerated consumption of limited resources and tighter environmental laws are eroding away margins. For asset owners, only one strategy can assure long-term survival: Maximizing return on assets by optimizing operation, while fulfilling ecological constraints. But is it possible to strive for this goal in a systematic way? And if yes, how?

The complexity of the resulting challenge has until recently stood in the way of an analytical solution. This complexity increases with the interconnectedness of the different components. Advances in computing power and algorithms have, however, made genuine optimization graspable.

At the beginning of this decade, ABB launched a strategic university collaboration with the Swiss Federal Institute of Technology, ETH Zurich, to tackle this central question. The issue of how best to operate production assets has been extensively examined in the past. Technological progress, however, has been shifting the spectrum of potential solutions, opening the door for new paradigms.

More concretely, ABB's latest information technology, communication devices, and sensors, now provide direct on-line access to new types of data. Advances in algorithm efficiency and computational speed allow mathematical optimization problems to be handled today that were intractable a dozen years ago. Based on the experience gained in various test cases with assets such as combined-cycle power plants, cement production plants, drives for motors, and power systems, ABB and ETH have jointly reached a decisive stage. The methodology developed will enable an owner to operate assets in an economically efficient and environmentally respectful way. This can be achieved by combining strategies of optimal control theory with econometric models of the industrial assets – to literally make more out of less.

But how does this new ABB-ETH framework for optimization of industrial assets compare to existing solutions? Which type of industrial processes will benefit primarily? And, most importantly, what competitive advantage and financial impact can the asset owners expect?

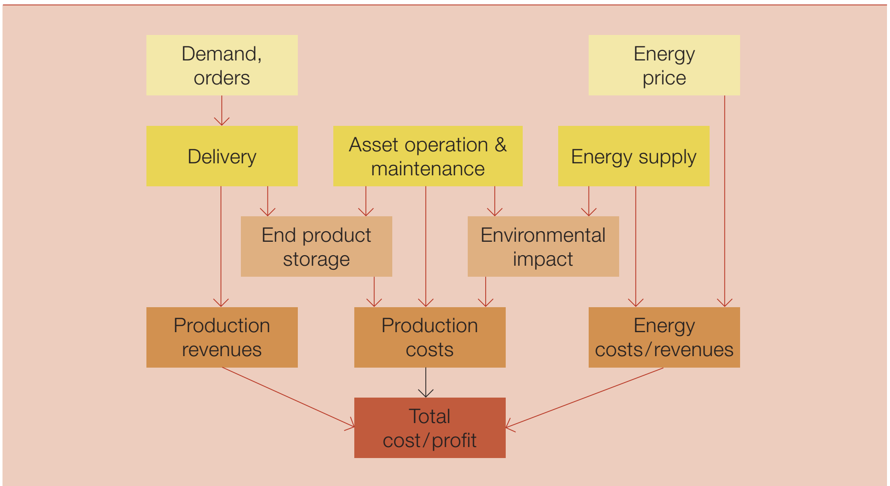
Industrial asset management

An industrial producer wishing to quantify plant performance invariably ends up dealing with economic measures. As with a financial asset, a plant requires investment and, in return, generates revenue from production.

For ABB, industrial asset management has a precise meaning: it is the operational management of equipment to generate or transmit electricity or to manufacture products as efficiently as possible. Schematically the asset performance results from the combination of the following major factors 1:

- The external factors: demand for an end product, energy price.
- The decision variables: delivery of an end product, operation and maintenance of the production assets, generation and consumption of energy.
- The impacted factors: storage of an end product, environmental taxes, energy costs, production costs, and revenues from product delivery.

1 Major factors influenced by the management of an industrial asset. Boxes in the 2nd row represent decisions to be optimized. Boxes in the 4th row represent the economic measures (costs/revenues).



For ABB, industrial asset management has a precise meaning: it is the operational management of equipment to generate or transmit electricity or to manufacture products as efficiently as possible.

The first to be understood is how the operational performance of an asset is linked to the producer's decisions. One possible representation of a managed asset is shown in 1. An arrow denotes direct influence between the factors it connects. This simplified model of an asset illustrates several important points: the underlying drivers of the production process are the demand (ie, orders) and price of energy (and other primary resources). Reliable forecasts of both quantities are therefore crucial. Furthermore, asset management deals with three different decision categories (second row in 1):

- To what extent should demand be satisfied, ie, how much product should be delivered?
- How should the production assets be operated and when should they be maintained?
- How should energy be provided (or possibly generated)?

Usually the producer must consider a certain planning horizon for his decisions, eg, a couple of weeks. For the sake of simplicity, it is assumed here that the delivery target is chosen first – based on the expected demand and the constraints of production assets. This delivery decision will directly impact sales revenues and the inventory level (reduction of storage).

In this simplified model, the producer plans the operation and maintenance of his assets. This decision will directly affect the inventory level (increase of storage) and the production costs, which include contingencies for the environmental impact (eg, CO_2 taxes). For electric utilities, production means power generation. For hydro-power plants, reservoir levels can be seen as inventory.

The third decision that must be taken by the producer relates to the supply of primary resources, especially of energy. Depending on the type of industrial assets, a mix of energy can be consumed (electricity, heat, fuel, raw material). In some applications energy is generated, as in combined-cycle power plants, coal-fired plants, etc.

The decision of energy supply directly impacts costs (or revenues if energy is sold). It also determines the extent of environmental impact. Energy cost, in turn, is a function of the amount of energy supplied and of its price. The latter can be highly time-dependent, especially in the case of electricity.

Finally, production revenues and costs will quantify the overall performance of the asset operation. So how can the producer be assisted in making this series of decisions to aim at the optimum performance?

New mathematical techniques in action

To be applicable in practice, the model introduced in the previous section must be extended and tailored to the specific production assets. The relationships between the decision and process variables must be quantified, thereby providing the metrics according to which asset operation is to be optimized. Building on its domain of expertise accumulated over the years, ABB has developed such detailed econometric models in selected industries. Given an econometric model of an industrial asset, the following state-of-the-art mathematical techniques can be applied.

A framework for modeling systems described by interdependent physical laws, logic rules, and operating constraints, denoted as Mixed Logical Dynamical (MLD) systems, has recently been developed at the Institute of Automatic Control at ETH [1]. MLD systems can efficiently represent dynamic industrial processes subject to operational constraints. They are hybrid in the sense that discrete variables (eg, distinct modes of operation) as well as continuous variables (eg, physical quantities) can be integrated in the same setup.

The MLD framework is combined with an optimal control technique called Model Predictive Control (MPC) [2] to express a cost/revenue objective function over a receding horizon. This combination allows translation of the econometric optimization problem into a mixed-integer program[1)] that can be solved on a computer.

MLD systems can efficiently represent dynamic industrial processes subject to operational constraints.

By contrast, the pre-existing standard approaches calculate a schedule, ie, a plan for the operation of the production assets [4]. The (open-loop) plan is valid under the assumption that the future evolution of relevant variables is known exactly in advance. Unfortunately events in practice often cause changes during the execution of an existing schedule, thereby rendering the initial plan less useful.

With an MLD-MPC approach, however, a mechanism is obtained that takes into account the state of the system and, based on the latest information at each time step, suggests how the operation of the assets should be optimally adjusted – while keeping the numerous constraints fulfilled. Furthermore, by setting appropriate constraints in the MLD model, the extent to which plan changes are allowed can be specified. This is a significant improvement over the current approaches, because the (closed-loop) plan is reactive and is thus a valuable help in facing changes.

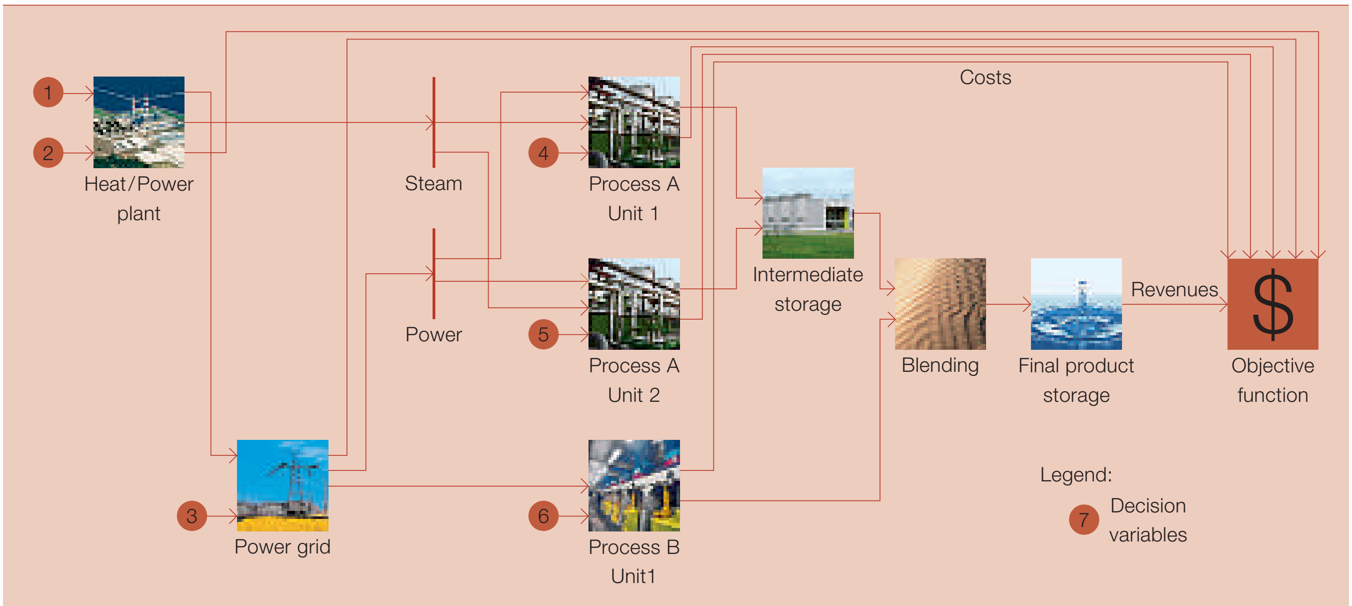
A practical example

The new methodology is illustrated in 2 with a production process that requires both electrical and thermal energy. Electricity can either be generated on site by a combined-cycle power plant, or can be purchased from the power grid. Steam is produced only when the power generation plant is running.

The production consists of five steps: primary process, intermediate storage, secondary process, blending, and final storage. The primary process requires electricity and steam. This process, which can be run on two different units (Process A, Units 1 and 2), creates a first intermediate product. This is accumulated in intermediate storage. A second type of process, which does not need steam, is run in parallel

Footnote:
1) A mixed-integer program is the minimization or maximization of a linear function of continuous and discrete variables subject to linear constraints

2 Industrial production process with power generation. Some of the process units require both electrical and thermal energy. Electricity can be sold to or purchased from the power grid.



(Process B). Both intermediate products are mixed in a blending stage. The end product is stored and finally delivered according to demand.

Several constraints rule the operation of the production units. Starting up an idle unit incurs extra cost. When a unit is operating, the production rate cannot drop below a given minimum bound. If it is shut down, it must remain idle for a given minimum period. The intermediate and the final (limited) storage volumes must be managed in such a way that given mixing proportions as well as orders are respected.

3 Time evolution of: price of electricity (upper plot), generated power (middle plot), and power exchange with the grid (lower plot).

The power generation plant must also fulfill several operational constraints. Startup times, minimum up- and down-times, lower and upper bounds on generation, as well as the time-dependent price of electricity all contribute to the complexity of the optimization problem.

In this problem the decision variables, as shown in 2 are:
1) The amount of electricity to be generated by the local power plant;
2) The amount of steam to be produced;
3) The amount of electricity to be bought from or sold to the power grid;
4) and 5) The operation parameters of both primary process Units;
6) The operation of the secondary process. Delivery of the final product is dictated by the demand (orders).

By optimizing the overall objective function, the best combined operation of the assets (3 to 5) is obtained. All plots correspond to a receding horizon of one week. In 3, the upper plot represents the given price of grid electricity. The second plot shows the power plant generation derived by the optimization procedure. The exchange of electricity can be seen on the lower plot – negative values mean that electricity is sold to the grid. It is interesting to note that the power plant is shut down only during prolongated periods of low price. Conversely, maximum power is generated during high price periods and the excess is sold to maximize revenues.

4 displays the planned operation of the process units. Because it has lower production costs, Unit 1 is run more frequently than Unit 2. *Note:* Because both units require steam, they are active only when the local power plant is in operation (ie, when thermal energy is available).

5 shows how the inventory level of the end product varies over time (middle plot). We can see that the optimization exploits the period of low energy price to increase the storage. The last plot represents the demand for the end product.

The performance of a production system is influenced not only by its controlled variables, but also by unmeasurable perturbations such as changes in machine condition, or input product quality.

Hedging against uncertainty

On which issue of practical relevance should research pursue its efforts? One of the major effects of market liberalization is that industry is increasingly facing uncertainty. It affects various aspects of the supply chain: suppliers, commodity prices, quality, demand, financial market, and other parameters. This is leading to a shift from deterministic planning towards operational risk management.

The shift is not yet complete because the standard formulation of planning and scheduling problems remains deterministic. It is implicitly assumed that the process is free from any disturbance and – consequently – that future evolution can be predicted precisely. In practice, however, this strict assumption does not usually hold – sometimes deviations are considerable. Where does this uncertainty come from?

The performance of a production system is influenced not only by its controlled (hence: certain) variables, but also by unmeasurable (hence: uncertain) perturbations such as changes in machine condition, or input product quality. Another example of uncertain disturbance is related to demand forecasts, which trigger the production plans.

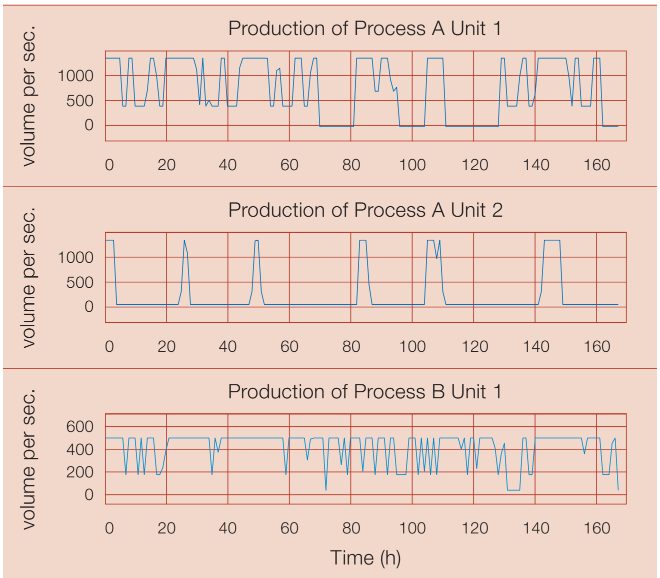
Two examples are considered below:
Cement production: Major decision problems comprise optimizing kiln fuel combustion and scheduling production of different cement grades on different mills. Uncertainty affects demand, outages, process parameters, and production costs.

Power generation: The principle decisions include: scheduling unit commitment, selling electricity, bidding on the spot market, and planning maintenance. Uncertainty is present in demand (load), future spot price, fuel price, and outages. Efficient optimization solutions explicitly taking uncertainty into account are therefore needed.

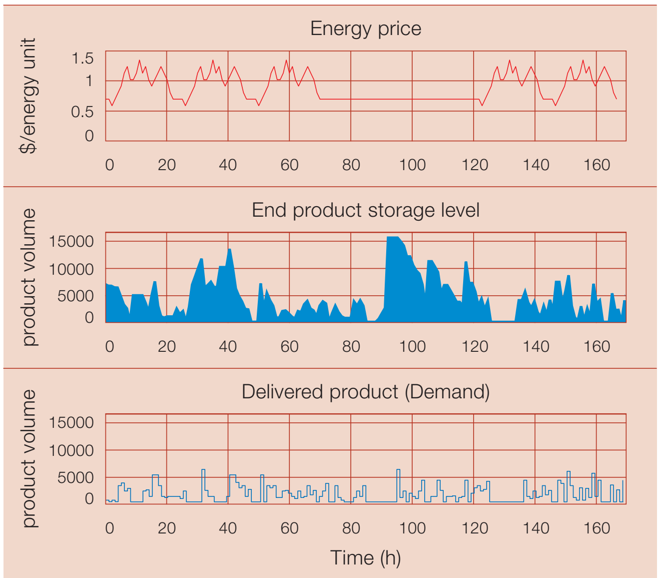
Economical versus ecological impact

What role do environmental aspects play in econometeric optimization? At a first glance, economic objectives often seem at odds with ecological ones. This is not necessarily the case: In fact, the problem of optimally allocating limited resources is, by definition, economics. Moreover, the meaning of "optimality" is strongly influenced by legislation. 1 shows that the

4 Optimized operation of the primary and secondary process units (Unit 2 has higher costs).



5 Price of electricity (upper plot), end product storage level (middle plot), and end product delivery (lower plot).



environmental factor is an element which can impact the overall econometric measure. A somewhat speculative though legitimate question is thus: To what extent can the proposed approach contribute to sustainability?

Again the examples of cement production and of power generation are considered. In the former, a typical plant consumes about 70 kg of coal to produce one tonne of cement. This process creates approximately 175 kg[2)] of carbon dioxide (CO_2). Now if the cement kiln is operated with an optimized combustion strategy (eg, mixing with alternative fuels) leading to a 3% reduction in coal for a plant producing 350 tonnes of cement per hour, the corresponding reduction in CO_2 amounts to 16,000 tonnes/year. Applied to global cement production (1.8×10^9 tonnes/year), the theoretical reduction reaches 10 million tonnes of CO_2 per year.

A standard gas turbine plant (thermal efficiency: 35%) necessitates about 220 kg of natural gas to generate one MWh of electrical energy. Combustion of the fuel creates almost 600 kg of carbon dioxide. It is reasonable to assume that a 1% reduction in fuel consumption is achievable through optimized operation/maintenance. For a plant with an average power of 100 MW, the yearly reduction in CO_2 corresponds to 5,200 tonnes. By extension to all gas turbines (worldwide: 4.5×10^{12} kWh/year [3]), the CO_2 savings would be higher than 25 million tonnes per year.

For a 350 tonne cement plant, the emission value saved each year would be US$ 160,000. In addition, savings achieved from reduced fuel costs would be several times bigger.

An economic quantification of environmental impact, eg, through emission rights dynamically traded on a market, would further increase the weight of the ecological cost component in the overall asset optimization. If one tonne of CO_2 is traded say at a price of $10, then the value of the CO_2 saved by the 100 MW power plant would reach $ 50,000 per year. For the 350 tonne cement plant, the emission value saved each year would be $ 160,000. In addition, savings achieved from reduced fuel costs would be several times bigger.

Conclusion

One major goal of an industrial owner is to secure and consolidate the profitability of its assets. The ability to allocate limited resources dynamically in an optimal way is crucial. Therefore ABB customers will increasingly need solutions that help them to control and optimize their production processes while hedging their decisions against uncertainty. Together with the expertise of ETH Zurich, ABB's technology has entered a new phase: true optimization of production and operational risk management are now much closer.

Dr. Andreas Poncet
ABB Schweiz, Corporate Research
Baden-Dättwil, Switzerland
andreas.poncet@ch.abb.com

Prof. Manfred Morari
Swiss Federal Institute of Technology,
ETH Zurich
Switzerland

Footnote:

2) This figure reflects CO_2 emissions caused by thermal process. The chemical process (calcination) produces several times this figure.

References:

[1] **A. Bemporad, M. Morari:** Control of systems integrating logic, dynamics, and constraints. Automatica 35 (1999) 3, 407–427.

[2] **M. Morari, J.H. Lee:** Model Predictive Control - Past, Present and Future. Computers and Chemical Engineering 23 (1999), 667–682.

[3] International Energy Outlook 2004. Report DOE/EIA-0484, Energy Information Administration, US Department of Energy, 2004.

[4] **M. Pinedo:** Scheduling – Theory, Algorithms, and Systems. Prentice-Hall, 2nd edition, 2002.