Uniform mass and energy balance for the entire process chain of steel plants

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A fully-integrated automation system in metals production and processing is enormously important for achieving product quality as well as process efficiency, and cost-effective production. Fault tracking and retracking back to the source are only possible with heuristic automation systems based on a new model architecture for thermodynamics.

The demands being placed by customer product requirements on system architecture and thermodynamics models in electric steel plants are growing at a breathtaking pace. Steel plant operators are also being forced to innovate their procedures in response to changing market needs. The innovations, providing optimization of process steps or sequences as well as entirely new approaches are revolutionizing the automation landscape. Because traditional models are typically tailored to a specific plant type and can be adapted to the process innovation only with difficulty and regard for intermediate process steps such as logistics is lacking altogether, Siemens Iron & Steel Technologies (I&S IP2) has developed an open model structure, which enables the plant operator to adapt innovations to the process across its entire length.

The need for innovations

Fierce competition on the world's steel markets with regard to product price and quality is moving system suppliers and steel plant operators inexorably toward highly-sophisticated automation systems capable of satisfying requirements for data acquisition, process control, logistics, and dynamic optimization. Siemens recognized early on that not only intelligent data acquisition, management, and evaluation systems would soon be needed, but innovations in the technology of the production process – metallurgy and metals making – would soon become of great importance.

For two decades, Siemens has been working to meet these customer needs with its own process models and those of technology partners in the process automation area. A number of reference projects underscore this experience. As can be seen in Figure 1, Siemens covers the entire model spectrum in iron and steel manufacturing (including models for downstream processes not listed here).

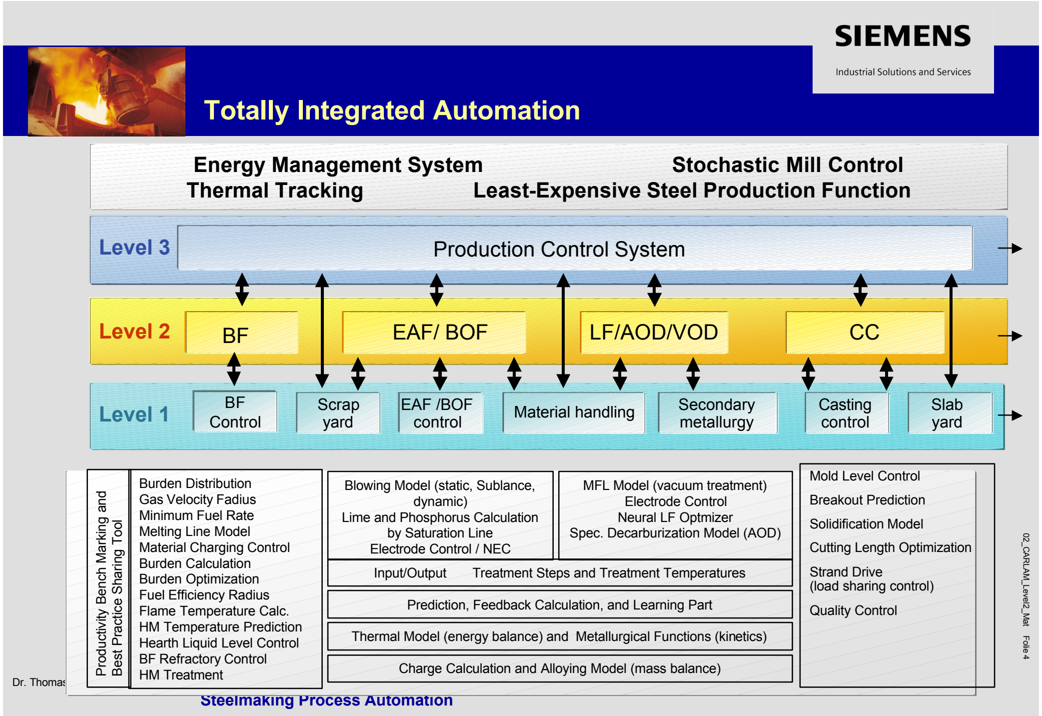

Figure 1: Totally Integrated Automation; Siemens as a full line provider including technological models

The traditional automation landscape relies on partial process sequences with individual models of a largely empirical nature.

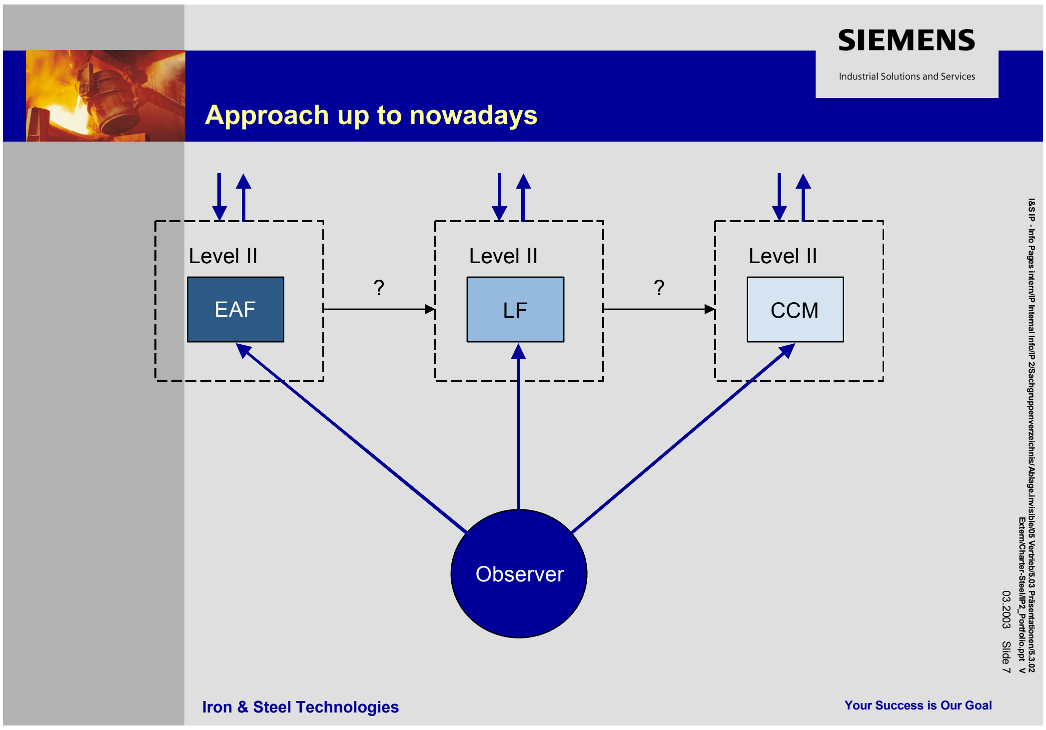

Fig. 2 Principle behind process automation solutions available today

Figure 2 depicts the principle behind the process automation solutions currently available. The *stationary observer* views process sequences from a fixed standpoint outside the process. Auxiliary sequences, such as transport actions, are typically not observed.

What is more, current models are adapted only to the needs of a process particular sequence. The models run on a process computer and are protected in such a way that the plant operator can influence them only with great difficulty. Adaptations to process changes or process innovations can only be realized with source code manipulated by specialist personnel.

Introducing a new model architecture

The new model architecture introduced by Siemens I&S IP2 returns to the fundamental principles of classical thermodynamics, in which the first law of thermodynamics for open and stationary systems provides two points of view. The first involves an external, stationary observer, as is found in previous solutions on the market (Fig. 2). The second, however, provides for a *traveling observer* (Fig 3.) who, himself, experiences the changes in the process chain. This later type of observer is the basis for Siemens new model architecture.

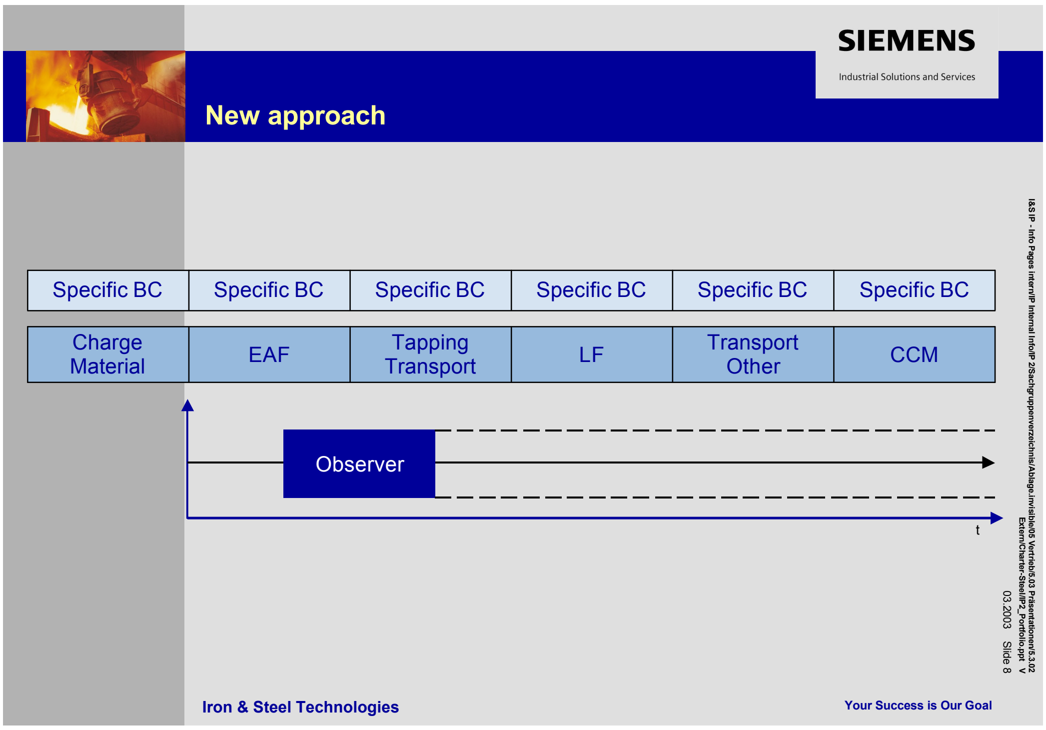

Figure 3: New Approach

Under the Siemens approach, there is only one uniform model core for the steel in the entire process chain – the models for the Electric Arc Furnace, ladle furnace, vacuum process,also other processes like BOF and their equipment are one and the same, which can be seen in **figure 4**. The structure is purely object-oriented, meaning that specific process components, such as metallurgical and process functions, are implemented over time as boundary or start conditions.

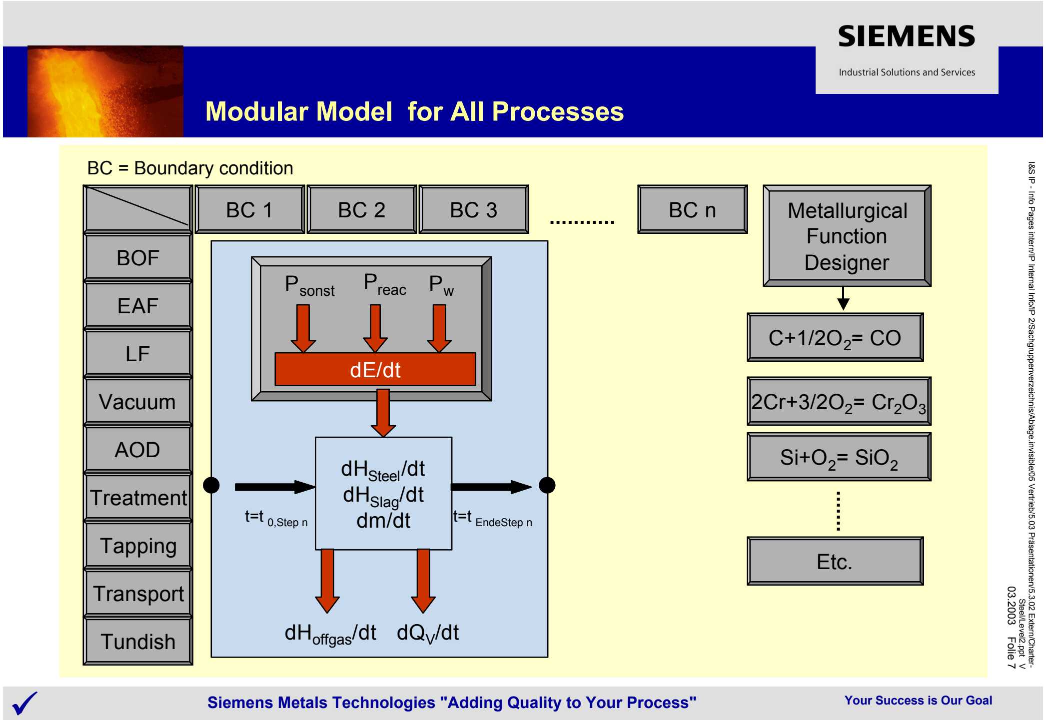

Fig. 4 One model for all process steps

These functions are not situated in the model core, but can be injected from outside. The flexibility of this new approach is such that the plant operator can enter dynamic variables into the system or design them himself (**Fig. 5**).

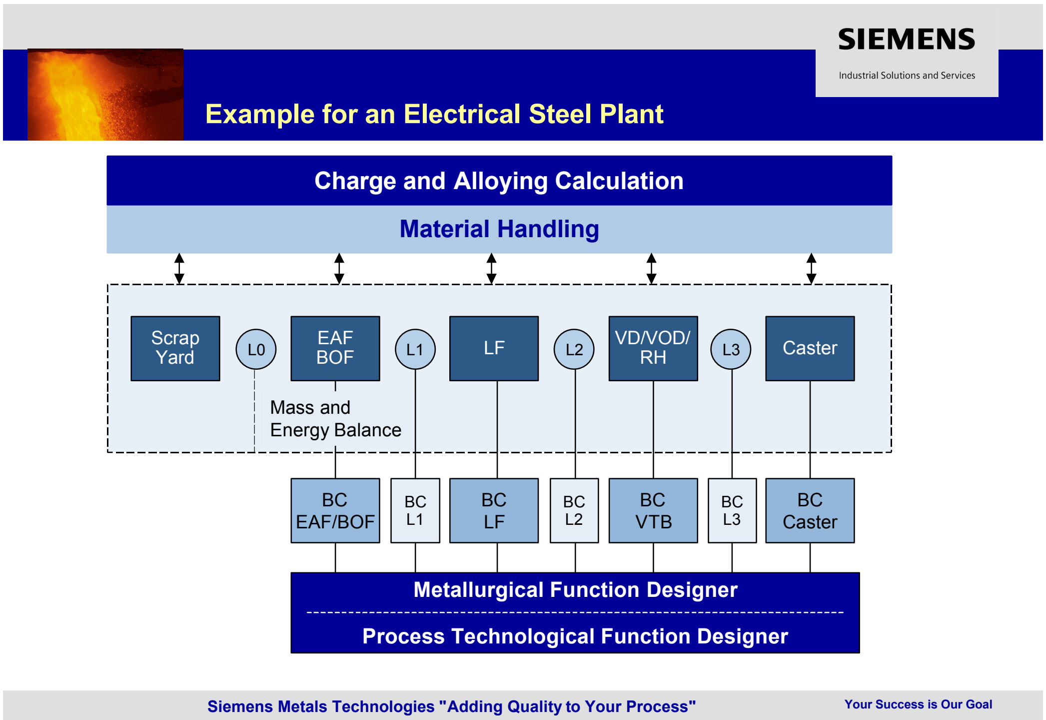

Figure 5: Model implementation in a Electrical Steel plant

The new model bases on a so called volume balance model, which is the base for all features like:

- mass and energy balance (temperatures, energy consumption etc.)
- Material Flow (based on Fick´s laws etc.)
- Impulse exchange
- Metallurgical behaviour
- Heat exchange (Heat losses, heat input etc.)

The development was done together with the Technical University of Clausthal, Germany consist in the three departments, metallurgy, process technology and mathematics.

In **Figure 6** one can see an example for a 2 room model in between a heat and a second medium e.g. slag and or gas. The vector $\bar{\psi}_I$ stands for a medium condition in the room I, which represents temperature, concentration, energy content and impulse. For the balance room I these variables dependend on time are proportional to the sum from energy, material and impulse exchange at the boundary to room J and all the energies, material and impulse sources $\bar{S}_{\psi,I}$ coming into the balance room. One boundary condition is, that the exchange at the boundary in between I and J is the same.
Each kind of effect can be injected in the resulting multi layer matrix, like example the material flow dependend e.g. on convection. Knowledge can be put in as real physical equation and/or as a experienced based with an empirical nature.

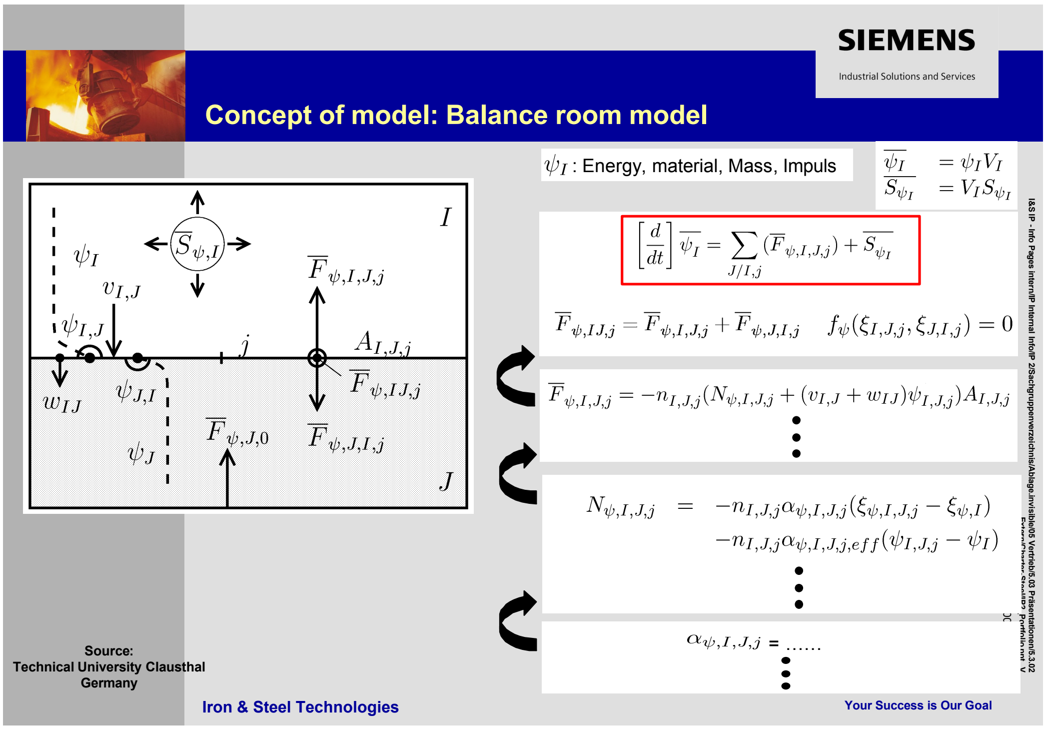

Figure 6: Balance room model

The differential equations in the multi conservation variable matrix can be extended by thermodynamic and material data banks for the consideration of the free Gibb´s enthalpies and material properties in the temperature dependend system (**figure 7**).

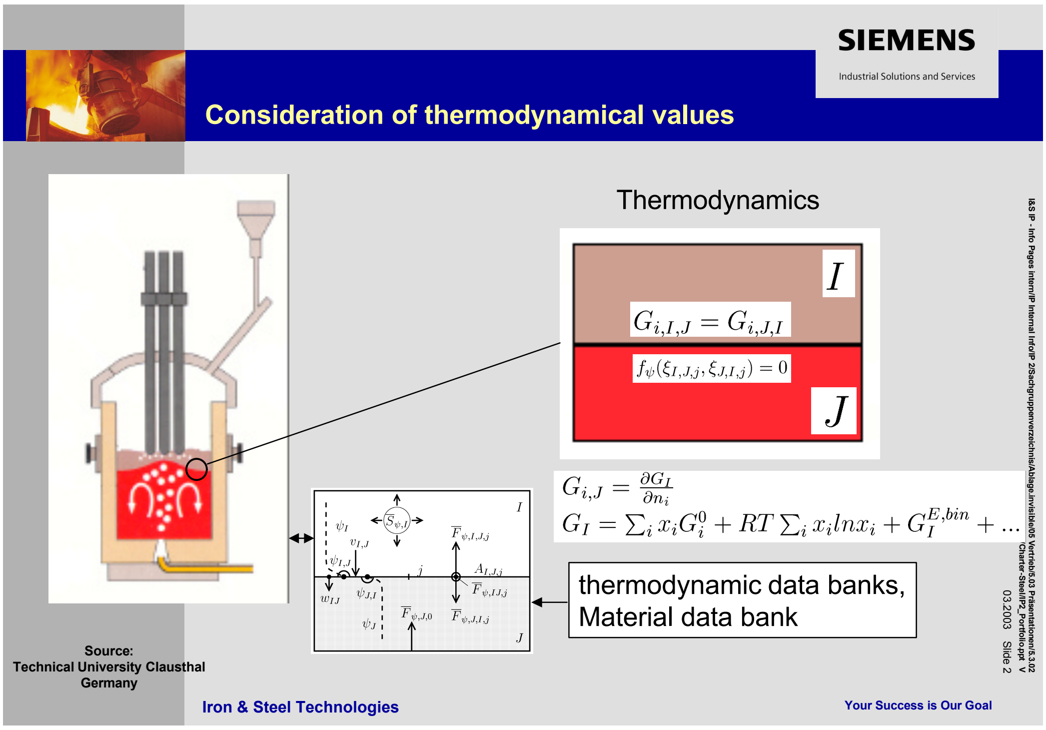

Figure 7: Consideration of thermodynamical values

Also the material flow can be considered **(Figure 8)**, by injecting kinetic data, correlations and coefficients for flow boundary layer, renewal of surface by purging e.g. and emulsioning of iron / steel droplets in the slag. Last item is also very important for the oxygen steel making converter, due to the fact, that a big part of the decarburisation depends on emulsioning of iron droplets in the slag.

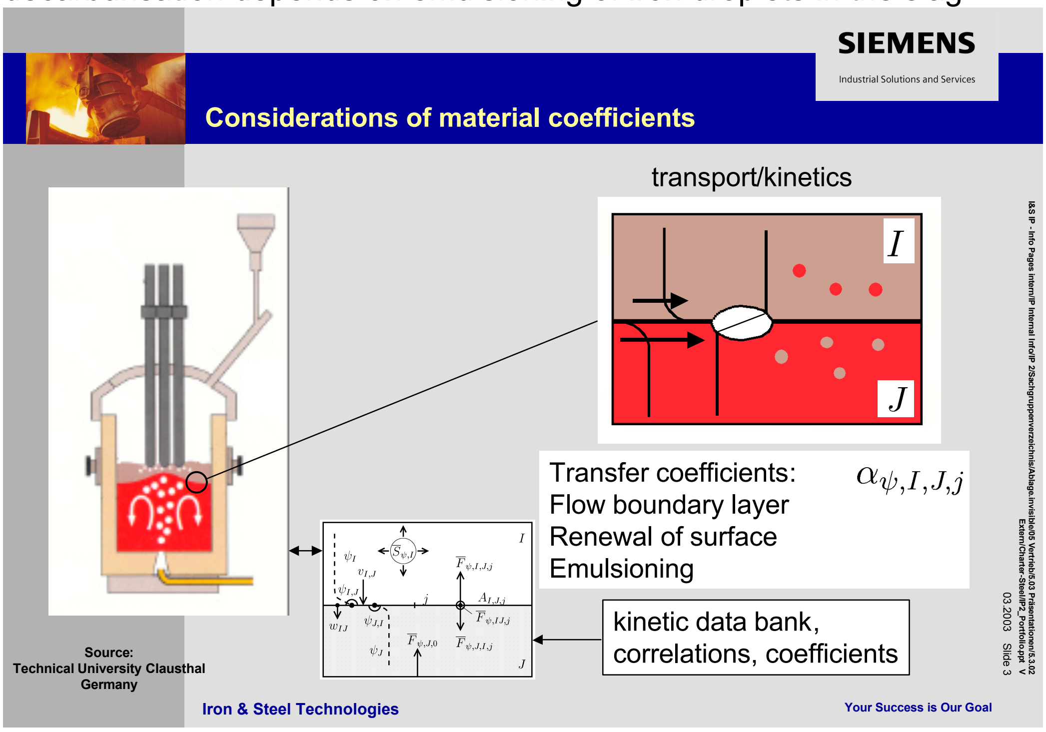

Figure 8: Consideration of material coefficients

Example for the Electric Arc Furnace

In a simplified manner the example for the Arc Furnace is described in **figure 9**. Here one can see for energy and mass balance depended on time the input and out put energies like reaction energies, electrical power, other energies (place holder for possible additions), offgas energies and heat losses.

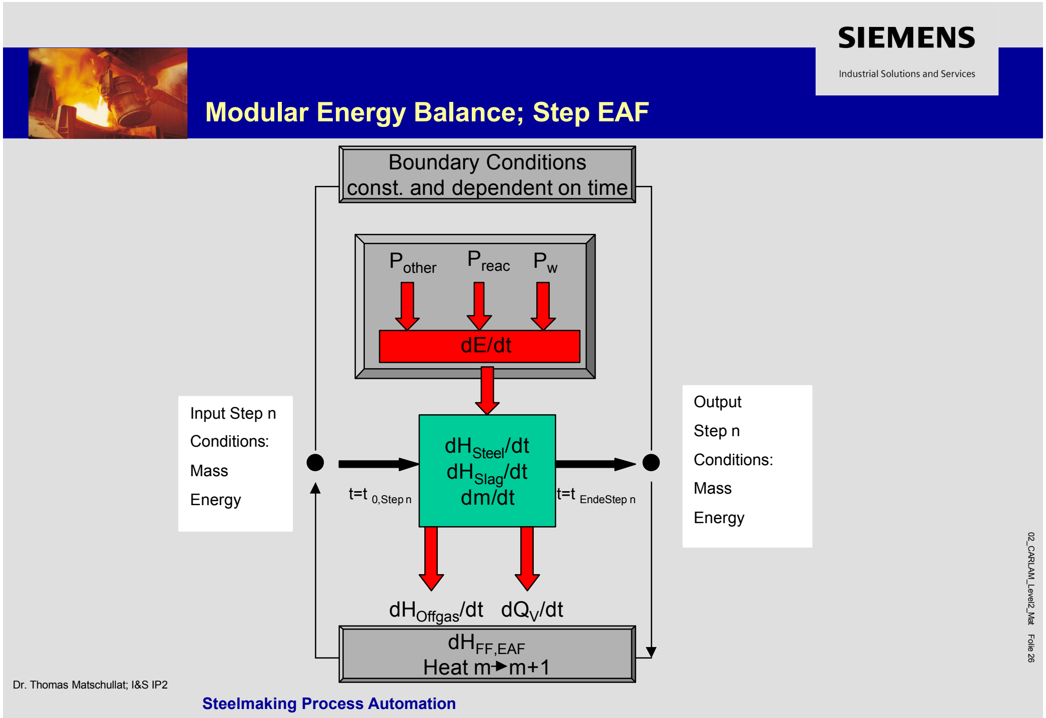

Figure 9: Modular Energy balance, Step Electric Arc Furnace

In the Arc Furnace the input energies can be divided furthermore (**figure 10**) in electrical and reaction energies. The reaction energies also can be divided into burning of fossil fuel, carbon lancing and last but not least into metallurgical reactions, which will produce or destroy energies. One example is the decarburisation. This reaction not only for the converter processes is also very important for the energy input into a heat of an Arc Furnace.
These functionalities are or can be considered as input in the multi variable matrix due to energy, material, mass and impulse.

In **figure 11** a more entire schematic view of the model technique is shown. It can be seen, that the heart of the model is always the same. The functionalities depend at least from the partial process like e.g. Electric Arc Furnace, Ladle Furnace, converter and so on.

Functionalities are e.g. power input by electrodes, energy input by fossil and metallurgical reactions, charging and alloying and all the different heat losses.

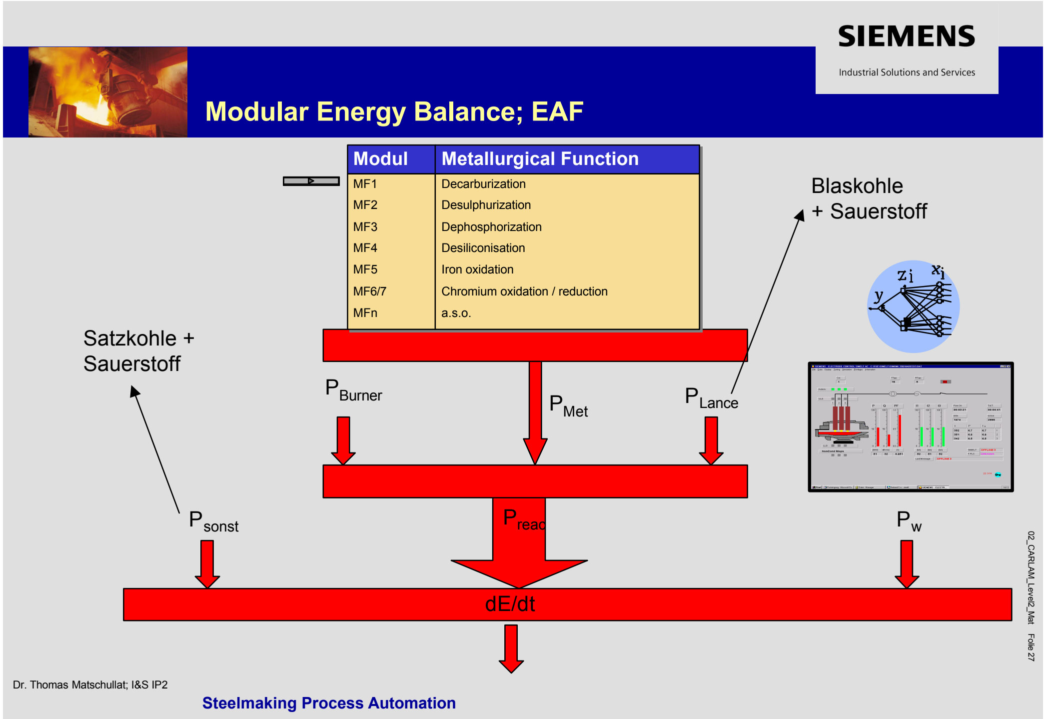

Figure 10: Modular Energy Balance; Electric Arc Furnace

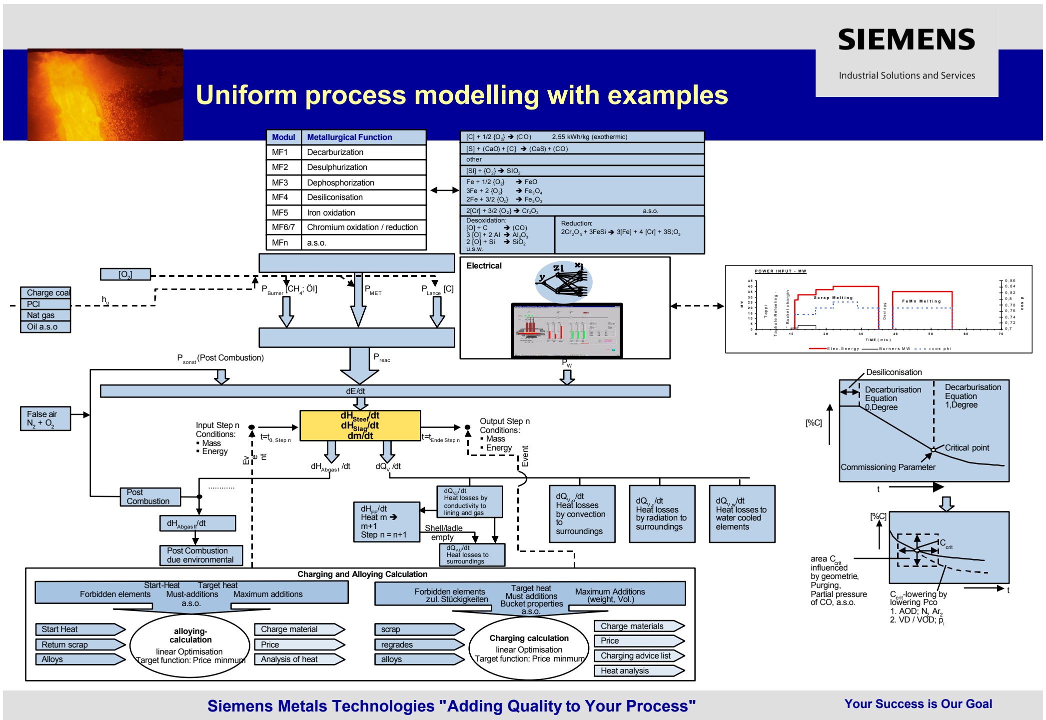

Figure 11: Uniform Process Modelling with examples

Up to now the structure for the process chain, as described in **figure 12**, is developed. The first reference for real operation is in an engineering stage. Comissioning will be in spring 2005. Additional projects are in negotiation.

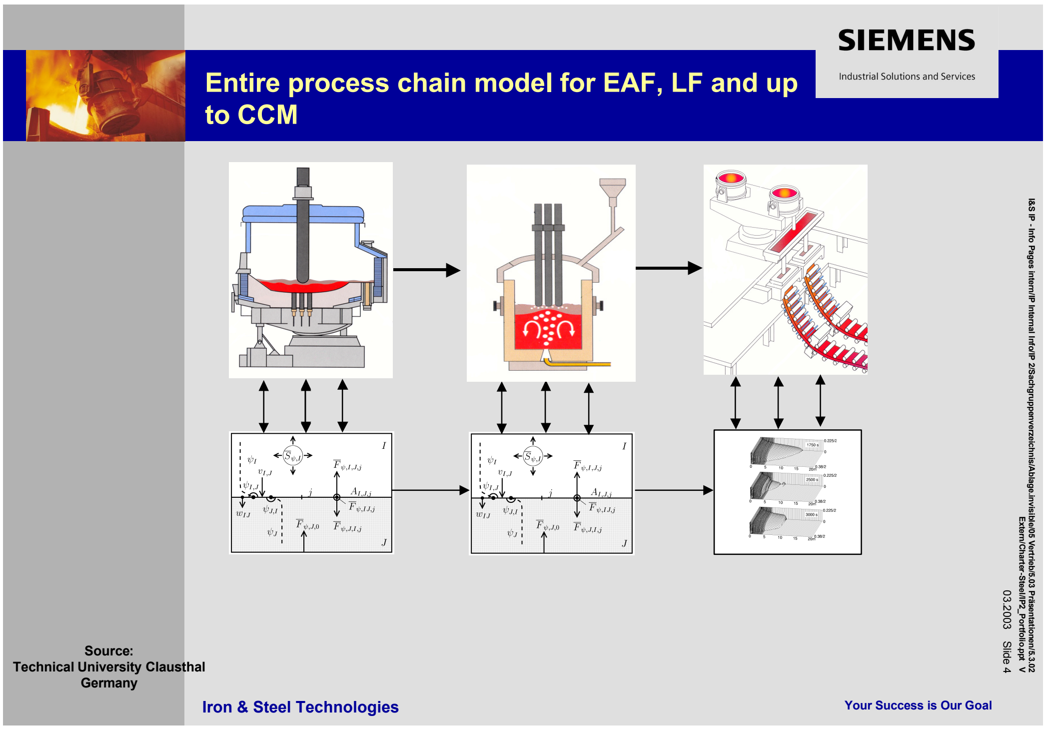

Figure 12: Entire process chain model for EAF, LF and up to CCM

New Automation structure

Based on the new functions and high performance of the new SIMATIC generation, there is now the chance to implement the process optimization function in a complete new design (**figure 13**).

In the traditional process optimization system, the two main basic requirements

- the **online** control loop and online calculation and
- the **offline** optimisation functions

are running on the same hardware with different system requirements.

The new generation of the Siemens process optimization is designed in this way, that the functions are distributed due to there performance requirement.

All online functions like material, energy models or the process sequencing are implemented in the controller area nearby the process itself. This ensures a real-time reaction and control due to process events without confronting the operator.

The set point generation, complex optimization calculation and metallurgical functions will be done automatically in the computer, supported by a database and the process engineer optimize the complete process automation via a graphical interface.

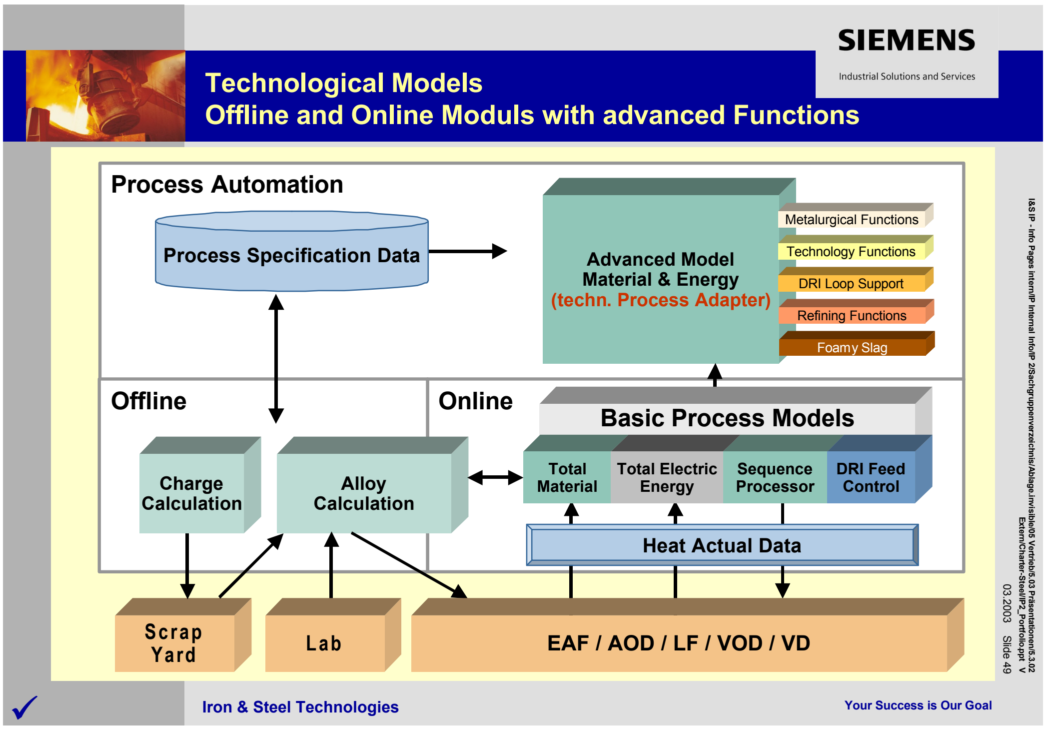

Figure 13: Technological models; Offline and Online Moduls with advanced functions

All in all, joining together the forces of Siemens in field of automation and technology and the core competences of the University of Clausthal in metallurgy, process technology and mathematics will lead to a lot of benefits, not only for the market also for Siemens as Full line provider of Totally integrated Automation Solutions.

The benefits (**figure 14**) of the new model architecture and automation structure include:

- One basic model for all process steps
- Easy parametization via metallurgical / process function designer
- Easy integration of new process steps
- Easy deletion or substitution of existing process steps
- Easy adaption of new process expertise
- Lower engineering and maintenance costs by customer personnel
- Open and object-oriented structure
- More stable and reliable operation by operating models on a FM in a PLC

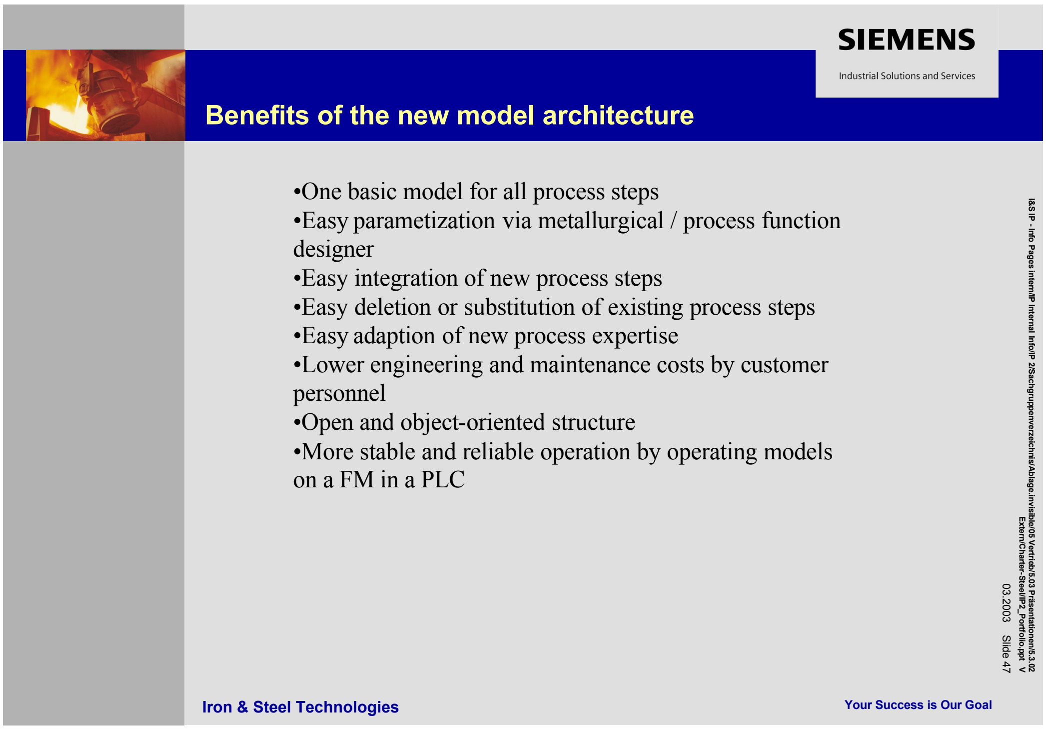

Figure 14: Benefits of the new model architecture