Energy

We need a lot of energy to maintain our standard of living. This makes it all the more important to use it efficiently. Renewable energies and efficiency technologies, smart grids and the digitalization of the energy industry are the focus topics of our institute. The focus is always on the secure and sustainable supply of heat and electricity – including for e-mobility.

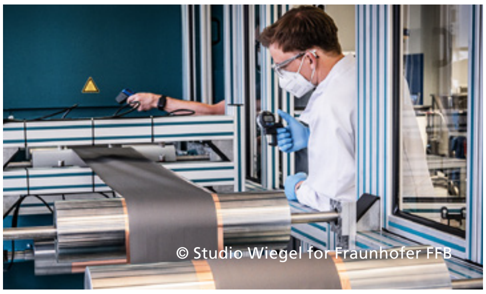
Terahertz Measurement Technology for Checking the Coating of Battery Foils

In the coming years, 1,000 production lines for electrode foils are to be built in Europe; similar figures apply to Asia and North America. Only non-contact systems can be used to monitor quality inline during production. This is why researchers in the "Material Characterization and Testing" department have expanded their expertise in terahertz measurement technology for inline coating control of battery foils.

The production line here refers to the equipment for coating the electrodes. The coating is usually applied as a liquid – called slurry – to copper or aluminum foils. For optimum battery performance, the coating must meet high requirements in terms of layer thickness and homogeneity. Until now, the industry has used beta and X-ray radiation to determine the layer thickness. These have the disadvantage that they only measure the total thickness, i. e. the film including the coating, and therefore require differential measurements before and after coating. If measurements are not always taken at the same strip position, the measurement errors add up drastically.

New Sensor Technology Makes You Flexible

Terahertz radiation can be used to measure faster and more accurately. "This technology measures in reflection and thus directly records the coating thickness; it takes less than five milliseconds for a measurement," explains project manager Dr. Joachim Jonuscheit. The new sensor technology can be flexibly adapted to the respective task in terms of the number and position of the measuring heads as well as the measuring frequency. The optimization to frequencies between 50 GHz and 1 THz, frequency stabilization through improved driver electronics and adapted signal processing enables precise thickness measurements on thin,



highly absorbent and electrically conductive layers.

Coating Thickness Measurement With Terahertz

"We measure the cathode coating with terahertz TDS, as we use it to measure paint coatings in the automotive industry." This allows 1,000 measurements per second. The conductivity of the anode is higher than that of the cathode. Their coating can be measured using photonic terahertz FMCW – a new measuring principle. Several manufacturers are already working on the dry coating of battery foils, which significantly reduces CO_2 emissions by shortening the drying process and thus improves the environmental balance of the manufacturing process. The use of terahertz measurement technology is particularly advantageous here, as beta and X-ray radiation cannot be used for process-related reasons.

The cathode carrier material consists of aluminum, with a layer thickness of between 30 µm and 300 µm. Copper is used as the carrier material for the anode.

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A Look Inside the Battery Cell

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The heart of electromobility is the battery. It powers cars as well as trucks and therefore has to meet a wide range of requirements. Electromobility has been booming over the past five years thanks to political engagement and support. This has only been possible because research into this topic has been going on for a long time – also at our institute. Dr. Jochen Zausch, Team Leader "Electrochemistry and Batteries" and Dr. Falco Schneider explain where the beginnings lie and what level of research has been achieved. Both work in the "Flow and Material Simulation" department.

How long has the Fraunhofer ITWM been doing battery simulation? What was the trigger?

Zausch: It's been around since I've been here, i.e. since 2009, and was triggered on the one hand by the cooperation with Opel and on the other by the Fraunhofer System Research for Electromobility: this research initiative began in the same period, funded by the German government. So battery cell research has been going on for a long time, but most models neglect the microscopic details. We can describe these well with our multi-scale approach.

What does that mean in detail?

Zausch: An electrode consists of porous material, i.e. a powder with particles of the order of five to ten micrometers, and these particles together form the complex structure of the electrode.

Clearly, this microscopic structure naturally has an influence on the macroscopic battery behavior. With a simulation that takes the three-dimensional microstructure into account, it is now possible to draw conclusions about the macroscopic battery behavior. And this is our unique selling point, manifested in the Battery and Electrochemistry Simulation Tool BEST. It allows us to simulate how the battery behaves during charging and discharging and, of course, to optimize it.

Now there is additional aspect to this, namely battery production. Here, for instance, we profit from our expertise in complex flow simulation as electrodes are cast on metal foil in the form of a viscous slurry. In the next step, calendering, i.e. pressing the foil between two rollers,

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we also apply our knowledge in the simulation of mechanical properties and use our FeelMath tool. Going down the production line, we use FLUID to simulate the electrode wetting, i. e.the absorption of the electrolyte liquid into the pores of the porous layers of the cell. With our FOAM software, we can simulate the expansion and curing of a foam in the spaces between the cells, which is intended to ensure mechanical stability and thermal insulation between the cells.

Falco Schneider is working on the new research area of battery ageing. Why has this topic come into focus alongside calendering, wetting and foaming?

Schneider: Like many other products, batteries only have a limited product life. We want to describe what happens at the microstructure level when both charging capacity and battery performance decrease. The underlying electrochemical processes can be investigated only to a limited extend by experiments, which is why simulation is useful here.

What exactly happens during battery cell ageing?

Schneider: Battery cells age both during active use and during storage. There are many factors that influence the ageing behavior. For example, mechanical stress during operation can cause parts of the cell to become inactive so that they no longer contribute to charge exchange. On the other hand, chemical side reactions take place which reduce the cyclable lithium inventory of the cell by binding it in various reaction products. The observed symptoms of these effects are a loss of capacity and an increased internal resistance, which leads to a loss of performance.

We focus on describing the individual effects in order to gain a better understanding of the cells and to investigate how to slow down these special ageing processes in order to save resources and energy in battery production in the long term.

Several departments at our institute deal with batteries; where are the points of contact?

Zausch: Our internal cooperation is best illustrated by the DiBaZ project funded by the federal state government. Together with three other departments, we are working on a digital twin for all process steps in battery production. At the end of the project, we will be able to offer our industrial partners methods and models that not only simulate battery production, but also enable non-destructive quality control and include energy management with predictive control.

Let's venture a prediction: can electric vehicles guarantee the mobility that is desired in Germany?

Zausch: I think so, especially in passenger transportation. The range of current electric vehicles is certainly sufficient for the majority of journeys. What is still being worked on, however, is improving the fast-charging capability of the batteries. This is intended to counter customers' reservations about electric vehicles. In this context, another challenge for the acceptance of electromobility is the sufficient availability of suitable charging points: e. g. on long-distance roads, where high charging capacities are required for fast charging, or in urban areas, where residents do not have the opportunity to charge their vehicles overnight at their own homes. Another obstacle is the relatively high purchase price. It is hoped that costs can be reduced in the medium term through mass production. In addition, new, cheaper cell chemistries, such as those used in sodium-ion batteries, could also help to reduce costs in the long term and become even more sustainable and independent.

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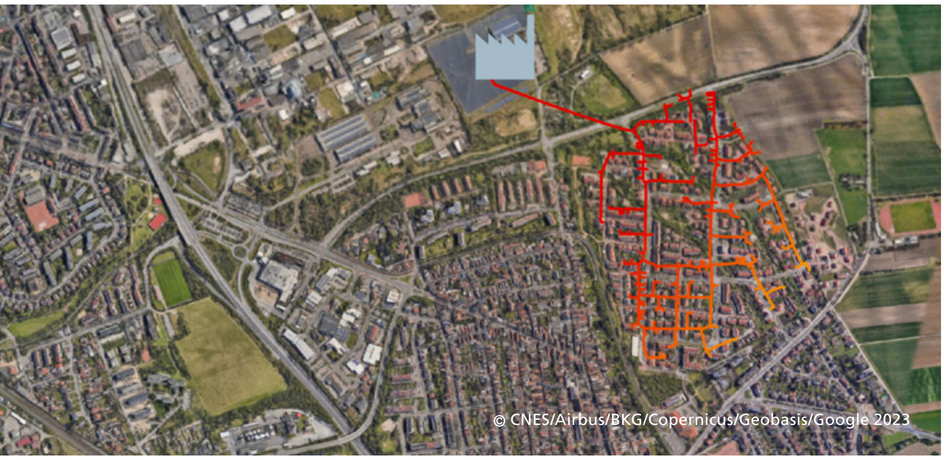
AD-Net – Intelligent Control of District Heating Networks

District heating is considered a central component of future energy supply. The optimal control of networks is currently a lively area of research in which researchers from the “Transport Processes” department are also involved. Their software tool “AD-Net District Heating” dynamically simulates and optimizes the operation of heating networks in real time. The software has been developed since 2015 in close collaboration with Technische Werke Ludwigshafen AG and GEF Ingenieur AG.



Heating network with temperature distribution

District heating suppliers often operate their systems at a constant temperature of around 90° C. In this operating mode, the feed-in power follows consumption, which fluctuates greatly throughout the day. In order to cushion the consumption peaks in the morning and evening, an additional gas boiler often has to be started up, which results in high costs and additional fuel consumption. The researchers therefore looked into the question of whether this additional firing could be avoided, at least during the transitional periods, by feeding water at a variable temperature into the pipe system.

Cut Load Peaks by Preheating

Like the drinking water supply, the district heating network also works via pressure equalization; this means that what is withdrawn by end consumers must be added at the plant at such a pressure that the heat exchangers in the households can work properly – but certainly at different temperatures. “In our model, the producer sends water at a high temperature but low speed into the grid before the consumption peak, which keeps the feed-in rate moderate. When the hot water reaches the customers, the plant feeds in a lot of water, but at a low temperature. This allows a high extraction rate while maintaining a moderate feed-in rate,” explains project manager Dr. Jan Mohring. This principle of pre-heating is well known, but can now be systematically optimized.

AD-Net Plans Two Days in Advance

AD-Net’s data is based not only on empirical values for consumption and temperature curves in the district heating network, but also on weather forecasts. This allows providers to plan even better, usually for two days. This facilitates the reliable supply of heat when large heat pumps or solar parks are also included in the energy mix in the near future.

www.itwm.fraunhofer.de/ad-net-district-heating

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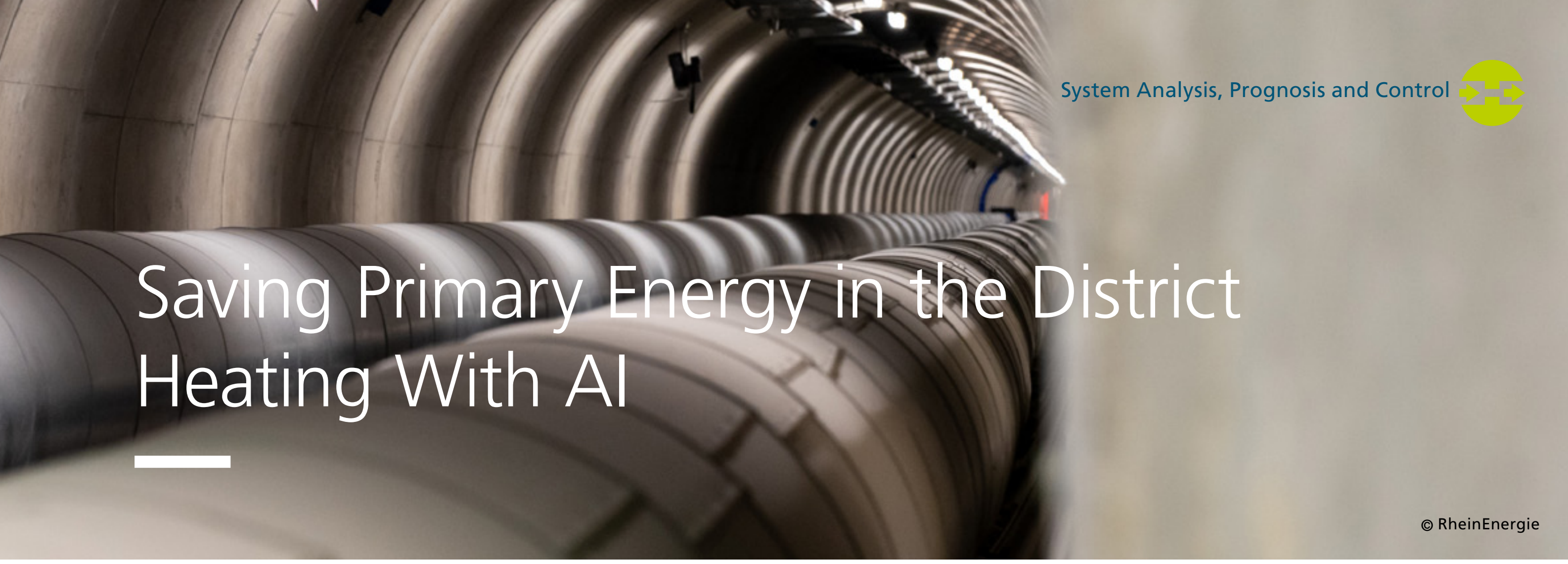

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Saving Primary Energy in the District Heating With AI

The temperature must be right in the heat tunnel.

AI methods can be used not only to optimize consumption in the extensive district heating network, but also to save primary energy at the Fraunhofer ITWM. In a pilot project with the energy service provider RheinEnergie AG, a team from the "System Analysis, Prognosis and Control" department has succeeded in improving the processes around boilers and thus saving a significant amount of primary energy – especially gas.

In general, heating networks are divided into a primary and a secondary side: the boilers are located on the primary side and generate the heat, which is pushed into the secondary side, i.e. into the grid, at a transfer point. "Our task was to control heat generators in such a way that the current demand in the network is covered, but at the same time as little surplus energy as possible is fed into the network," says project manager Dr. Christian Salzig. "The demand at the transfer point is interesting, i.e. where the heat passes from the primary to the secondary circuit. To determine this, we use machine learning methods to create individual, weather-related load profiles." Based on these load profiles, the developed prediction models can forecast the heat demand for the coming hours very precisely and controle the generators accordingly.

Keep Mains Temperature Stable

In addition to demand-based control, another problem with the heat supply was resolved in the project: Measuring points on the grid side report current temperatures, but due to the length of the grid there are runtime delays. It can therefore happen that too little energy is detected in the network and the machines heat up even though the heat currently produced will already cover the demand. This leads to significant temperature oscillations in the grid. For this reason, predictive controllers have been developed that take transport delays into account and almost completely eliminate these oscillations. This allows the energy supplier to controle heat generation precisely to the predicted demand. This allows the temperature in the grid to be lowered without jeopardizing the security of supply, which leads to significant savings in primary energy.

Ensuring Security of Supply

Furthermore, the researchers can use their method to predict whether it is worth starting up an additional heat generator or whether it is better to run the lead boiler at its output limit for a short time in order to compensate for spontaneous fluctuations. External sources, such as electricity-driven CHP units or waste heat from connected businesses, present a particular challenge here. The intelligent control system therefore ensures that the heating plant has a control reserve that can always compensate for unplanned failures of external heat sources.

The ongoing evaluation shows: Depending on the outside temperature, the implemented AI controllers save between six and thirteen percent natural gas. The controllers are currently being implemented in other local heating systems at RheinEnergie AG.

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ENERDIG – Digitalization and Artificial Intelligence for Energy Management 2.0

ENERDIG stands for "ENERGY MANAGEMENT 2.0, DIGITALIZATION, AI, OPTIMIZED PROCESSES" and aims to achieve holistic energy management. Four departments contributed their expertise to the project and worked together to develop new digitalization and AI-based strategies. The focus was on residential and industrial buildings, plastics production, chemical production and nonwovens production.

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For example, the research teams developed AI methods to charge electricity storage units based on weather forecasts, which in turn supply heat pumps and electric cars with as much renewable energy as possible. This is a further step towards energy self-sufficiency, both for private households and companies.

SME Benefit From Research

In the industrial sector, the researchers focused on nonwoven production, which is aerodynamically optimized using software solutions. This leads to more stable product quality and significant energy savings.

This is also possible in plastics production. In order to support SMEs in particular on their way to Energy Management 2.0, the Fraunhofer ITWM is developing algorithms for identifying and evaluating energy consumption and flexibility based on digital twins of machines and production systems.

A similar approach applies in the energy-intensive chemical industry: making energy consumption more flexible means that companies can adapt their processes to changing energy costs at short notice. Thanks to ENERDIG, the availability of raw materials is now also taken into account in plant optimization.

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Other Projects With a Focus on Energy

Hytwin – Hybrid Digital Twin for the Optimization of Plastics Processing Processes

Computer simulations and digital twins offer the possibility of optimizing almost the entire extrusion process. The project team from the "System Analysis, Prognosis and Control" department took a hybrid approach: they developed a digital twin that is both data-based and model-based, which predicts and optimizes using AI. The result is an easy-to-use software platform for quality forecasting that also helps small and medium-sized enterprises (SMEs) to achieve higher production speeds, greater flexibility and higher product quality at the lowest possible cost.

www.itwm.fraunhofer.de/hytwin-en

OpenMeter – Data and Analysis Platform to Increase Energy Efficiency

The availability of consumption data is important for increasing and evaluating energy efficiency, for smart grid planning and for the interdisciplinary development of innovative services and business models. The OpenMeter project created the high-performance digital open data platform "Open Energy Meter Data" – visualization, analysis and comparison of energy consumption data. A team from the "System Analysis, Prognosis and Control" department researched and evaluated mathematical methods of artificial intelligence to derive energy baselines and parametric forecasts of future energy consumption.

www.itwm.fraunhofer.de/OpenMeter_EN

DYNEFF and DingFESt – Efficient Operation of District Heating Plants

In the "DYNEEF" project, researchers from the "Transport Processes" department are working together with GEF Ingenieur AG and Technische Werke Ludwigshafen on "Dynamic network simulation to increase efficiency in district heating generation". The successful collaboration led to the follow-up project DingFESt "Digital twin for flexible and efficiency-optimized control of decentralized district heating networks". With the results, the research team is helping supply companies to ensure highly efficient network operation in the long term without jeopardizing their stability, resilience and security of supply – even under increasingly complex and varying operating conditions.

www.itwm.fraunhofer.de/DingFESt-EN