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New Technology Horizons: Chemistry as Innovation Driver

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How are we going to adequately supply the growing world population with food and the most precious raw material of all—clean water? How can we ensure medical treatment and care for an aging society? What will the buildings of the future look like? What materials will they be made of? What is the ideal energy mix of the future? What are the mobility concepts of tomorrow?

In the 21st century, it seems that almost every day presents a new challenge. And with the world growing more complex, each challenge represents a chance to show that chemistry can be an innovation driver—even if its role is not always visible.

For chemical companies, anticipating changes and needs, and responding with new ideas and products, has always been self-evident. And this is even more true in the International Year of Chemistry 2011. As an important provider of new technologies, materials, and their precursors, as well as ideas and application know-how, the chemical industry is indispensible for innovations in nearly all industrial sectors.

Fulfilling this mission requires substantial, permanent investment in research and development (R&D). The chemical industry is well aware of this responsibility. Even in the depths of recession, German chemical companies funneled €8.3 billion into R&D in 2009—nearly 25% more than at the beginning of the decade. Most companies increased spending again in 2010 by 4% on average, as recovery took hold.

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Increasing expenditures in R&D or keeping them at an adequate level is not enough. As the challenges become greater and more complex, the players need to take a different—more coordinated and more international—approach to research and development. Currently, the chemical industry is undergoing a paradigm shift. While success in the past depended to a major extent on developing, manufacturing, and selling large volumes of standard products, in the future we will deliver more and more system solutions and functional materials.

In any case, chemistry will play an important role in shaping the future, just as it did in the past.

Chemical innovations are crucial for quality of life

Chemical innovations have always been a prerequisite for improving the quality of life—history is laced with examples. The list of chemical innovations in the first half of the 20th century alone is impressive. The production of indigo dye made the worldwide jeans craze possible. Sulfonamide and penicillin antibiotics offered for the first time a cure for many life-threatening illnesses. And the development of new fertilizers prevented hunger: At the beginning of the last century, academia and industry together developed the Haber–Bosch process to produce ammonia. This process was the key to accessing the large amount of fertilizer needed to boost crop output and has proved to be an enduring invention ever since. More than 100 million metric tons of nitrogen-containing fertilizers are still produced by this process annually, helping to sustain more than 40% of the earth's population.

Fast-forwarding 50 years from there, chemistry fueled another important innovation—polystyrene foam. The need for cheap and easily available materials to insulate buildings may not have been quite as dire as the need for fertilizer was earlier, but nevertheless it made an enormous contribution to personal comfort in *Wirtschaftswunder* Germany in the 1950s and 60s. Today we know that keeping people warm and comfortable is not the only benefit, because insulating homes with plastic foam also improves energy efficiency and thus helps to protect the climate.

The second half of the 20th century witnessed the start of the electronics industry, which is dependent upon chemistry as well. Ultra-pure chemicals are used as cleaning, etching, and polishing agents, which are needed to reduce the size of computer chips and increase storage density and performance. Innovative liquid crystals are making computer and television displays sharper and brighter.

Chemistry will continue to drive innovation

In the 21st century and beyond, chemistry will need to solve problems that we may not be able to envision yet. However, this can't be done with yesterday's or today's concepts. Leap-frog innovations—totally new technological and

Leap-frog innovations will be necessary

chemical concepts for problem-solving—will be necessary.

Some of the challenges we will face in the future are not dissimilar to those tackled in the past—how to cure disease, how to feed and clothe a growing population, and how to keep houses warm or cool.

Other challenges, such as enabling even faster global communication, finding substitutes for fossil fuels, or preserving natural resources, present a new dimension.

We need new ideas for affordable and robust solutions, and the growing world population in developing countries must also be able to benefit.

Several important megatrends are already moving into focus, the most important of which is undoubtedly the strongly growing world population. In 2050, more than nine billion people will be living on earth, two and a half billion more than at present. About 60% of the world population will be living in cities by 2030. Responding to a world population of this size raises numerous questions. We must make sure that everyone can have a safe and comfortable life. Chemistry is already providing the answers.

To supply nine billion people with food, crop production will need to double within the next 20 to 30 years, but technological improvements using conventional methods alone will not be sufficient. Chemical companies are working hand-in-hand with seed producers to produce and jointly market plants with new, favorable properties, such as new drought-resistant crop varieties.

Biotechnology provides solutions

While plant (green) biotechnology contributes greatly to increasing agricultural yields, pharmaceutical (red) biotechnology is bringing about a paradigm shift in healthcare, with recombinant drugs vastly improving the management of diseases.

Industrial (white) biotechnology has already made multiple contributions, one of which involves fermentation processes using fungi or bacteria to produce dairy products, wine, beer, and sourdough bread. And the potential of white biotechnology for future applications will be immense, too. For instance, it permits renewable feedstocks, such as sugar and starch, to be used to manufacture biofuels or chemical products. Although this has been criticized in some quarters for decreasing the food supply and raising agricultural prices, second-generation biofuels based on cellulosic plant components, such as stems and leaves, assure that the plant's fruit and seeds can continue to be used as food.

Nanotechnology enables innovations across a wide range of challenges

Nanotechnology also offers fresh perspectives. The particular importance of this science of the very small—one nanometer is one millionth of a millimeter—is that it enables innovative solutions to an extremely broad range of problems, and many innovations are inaccessible without it. The diverse applications range from healthcare to lighting concepts of the future.

The majority of applications for nanotechnology will be in energy transformation and storage (fuel cells, solar cells, batteries), environmental protection (resource efficiency), and information technology (new types of storage systems and processors). But even in areas that one would not expect, nanotechnology drives innovations. Take, for example, innovative plastics: nanostructures can increase the flowability in the molding process of thermoplastics and thus help to reduce energy consumption.

Self-illuminating displays that generate light only when needed were just a vision a few years ago, but they are now becoming reality. In the second phase of Germany's organic light-emitting diode (OLED) promotion initiative, chemical research focuses on energy- and CO_2-saving OLED systems that do not dazzle and cast less harsh shadows. Innovative materials are being developed for use in display screens (TV or mobile displays), electronic traffic signs, and lighting systems.

Another promising innovation opportunity for nanotechnology is in the construction sector. Even today, high-rise structures such as the 828-meter Burj Khalifa in Dubai and many other projects can only be realized with high-performance concrete admixtures. Nanotechnology is opening up attractive potential to even further improve concrete properties. For instance, BASF has developed and commercially launched a new product that uses nanocrystals to strengthen and accelerate the process of concrete hardening. This lowers energy consumption and CO_2 emissions.

The *lowering* of energy consumption is not the only benefit of chemical innovations. As demonstrated by the above examples, the *transformation* of energy in the future will be driven by new products powered by chemistry as well. Chemistry is finding ways to capture the sun's power with products ranging from silicon to etching pastes for wafers, from electrolytes used in dye solar cells to thin films for solar modules, and these are only a few applications.

The widespread use of solar energy can only be competitive, however, if the costs involved in converting non-electrical forms of energy into electrical power are similar to the costs of other renewable and conventional energy sources. A major challenge here is to further reduce the overall costs by using less expensive materials. Together with their innovation partners, chemical companies are therefore currently exploring organic photovoltaic solutions that deliver good power yields at low material cost and work even under poor light and indoor conditions.

In going from energy *transformation* to energy *storage* of the future, chemical innovations will be the enabler, too. Electromobility is such an example: vehicles driven on tomorrow's roads will be powered more and more by electricity and thus contribute significantly to reducing greenhouse gas emissions. But the technology currently used

for electricity storage still needs to be substantially improved. An ambitious goal would be to produce a battery that weighs less than 200 kilograms and has a driving range of at least 400 kilometers. Chemistry is one of the main technology drivers here, supplying key components such as electrode materials, separators, or electrolytes for future battery technologies.

From energy transformation to energy storage

To resolve the major challenges involved in implementing electromobility successfully, all stakeholders along the value chain need to act together, and national governments are supporting the implementation with substantial funding to secure their berth as frontrunners. To meet the goal of one million electric vehicles on Germany's streets by 2020, the National Platform Electromobility (NPE) was established by the German government, with more than 80 companies and research institutions working together to develop the necessary concepts.

Interdisciplinary and international networks are the key to success

Just from the examples given above, it becomes obvious that the goals are evolving. A paradigm shift can already be observed today: success will no longer be determined merely by new molecules. New system solutions, functional materials, and application know-how will be called for, and only an international, interdisciplinary approach to research can address complex problems efficiently and comprehensively. In the future, chemists engaged in R&D will cooperate even more with specialists from other disciplines, such as engineering, biology, and physics. Global knowledge networks will rapidly become the norm.

Global knowledge networks will be the norm

R&D at BASF also follows this path. We integrated our R&D platforms into a global network of around 1900 cooperations with customers, universities, research institutes, high-tech joint ventures, and industrial partners. Many other internationally active companies are following a similar approach.

Science, industry, and politics must work together

This much is clear: Chemistry can generate the breakthrough innovations necessary to tackle the emerging problems of tomorrow. However, to be successful, our efforts must find acceptance in the population at large. We need to be well aware of our responsibility to evaluate new technologies and products objectively and to make the risks as well as the benefits transparent in an understandable language.

BASF and other chemical companies only launch products onto the market that have been determined safe for human beings and the environment. We make the results of our safety research available to the scientific community, publish them on our internet pages, and discuss them with critical opinion leaders. Engaging in dialog with the public as well as with the political sector is essential if debates are to be guided by scientific facts and not by emotion or ideology.

When the benefits of technological progress cannot be easily seen and understood, the discussion often focuses more on the risks than on the benefits. To implement new technologies and products successfully in the market, we need the acceptance of the potential users. Only a culture of innovation can unlock the potential of new technologies.

This is the basis on which we can find solutions for the challenges of the 21st century together.