

25 Years of BMW (Forschung und) Technik GmbH. Table of Contents.

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1. Source of innovation. 25 Years of BMW (Forschung und) Technik GmbH. (summary version)

Innovative force entails future capability. The BMW Group owes its status as the world's most successful manufacturer of premium automobiles to an outstanding development concept in all areas relevant to driving pleasure, sustainability and safety. The principles of this pre-eminence have been forged over the last quarter of a century in BMW (Forschung und) Technik GmbH. The researchers operating within the framework of this think tank develop technologies and concepts for individual mobility in tomorrow's world. The subsidiary was created 25 years ago as BMW Technik GmbH. With this company the BMW Group has a centre of competence that is unique throughout the world. It safeguards and expands technology leadership for BMW by providing a constant stream of innovations.

This groundwork is carried out autonomously, but it is by no means uncoupled from the development of series vehicles. The experts working in BMW Forschung und Technik GmbH enjoy a high degree of creative freedom that allows them to take innovative approaches and look for unconventional solutions. They make use of diverse sources of inspiration which can range from bionics to space engineering, and they develop perspectives on the future that extend far beyond the life cycle of a vehicle model. "Our project-related research is not linked to the current product range, although we naturally have the objective of consistently optimising the characteristic features of vehicles coming from the BMW Group and transferring our projects and ideas to series development," explains Professor Raymond Freymann, Managing Director of BMW Forschung und Technik GmbH.

The concept of cooperative research also ensures that the departments responsible for subsequent series development can be integrated within the relevant project at an early stage. This approach guarantees that operations for realisation are already being monitored during the research phase. The initiators of an innovation also support their project after it has been transferred to the pre-production and series development phase. They then move with their project to the series development department at BMW AG. This provides safeguards for ensuring that information is not lost at interfaces, and it promotes a dynamic exchange of ideas on a personal level between research and series development. This strategy facilitates a strategic and efficient use of the innovative force pooled within BMW Forschung und Technik GmbH.



Competence centre in Munich and international network.

The subsidiary company was founded as BMW Technik GmbH in 1985. The main focus of activities in the early years was defined as the development and construction of concept vehicles. The minutes of the Executive Board meeting in January 1985 clearly set out the mission of the fledgling company: “The recently founded company BMW Technik GmbH has the mission to develop innovative, future-oriented and original overall vehicle concepts and sub-concepts away from the constraints of a specific series workflow schedule. However, the objective should always be to develop solutions that have the potential for series development.” The initial aim was to work on projects under the working title “Auto 2000” and “Local Vehicle”.

When the company was rebranded in 2003 as BMW Forschung und Technik GmbH to reflect both research and technology, the focus was shifted to developing technology that encompassed all types of BMW vehicle. The workforce currently has a headcount of around 200 at the Munich site, and BMW Forschung und Technik GmbH has extensive expertise in the areas of vehicle engineering, hydrogen technologies, alternative drive and energy management concepts, active safety and driver assistance systems, as well as information and communication technologies in the vehicle. The research and technology centre also maintains centres in the USA: the Technology Office Palo Alto in Silicon Valley, California, and the Liaison Office Clemson, South Carolina. They enjoy a close relationship with universities such as Stanford University and the Massachusetts Institute of Technology, as well as research institutes and high-tech companies in other sectors. The aim is to harness innovative trends and technologies for deployment in the automobile sector.

There is also an extensive exchange of ideas with universities and research institutes at German and European level. Participation in the Eurécom European communication network – based at the Sophia Antipolis high-tech centre in southern France – ensures that the research subsidiary of the BMW Group has access to leading-edge information and telecommunication technologies. In addition, BMW Forschung und Technik GmbH has a base at the German Research Centre for Artificial Intelligence and drives forward the automation of intelligent behaviour and hence the “Automobile of the Future”. The Munich Center of Automotive Research (CAR@TUM) established as a joint venture with Munich Technical University gives the subsidiary of the BMW Group permanent access to high-flying young academics with great potential for the future and it also ensures access to important results derived from ground-breaking scientific research.

BMW Forschung und Technik GmbH also works on state-financed research projects at national and international level together with other automobile manufacturers and suppliers in order to create industry-wide standards, ultimately for the benefit of all customers. One of the latest examples of this work are the field trials for vehicle-to-vehicle communication in the project entitled "Safe mobility – Test bed Germany", abbreviated to simTD.

Anniversary: Premiere for fascinating concept vehicles and pioneering technologies.

The history of BMW Forschung und Technik GmbH has been defined by a long track record of concept vehicles and technological innovations which generated pioneering impetus for the development of series vehicles, components and systems. The influence of research projects exerts varying effects on series development, depending on the subject focus and complexity. The scope ranges from direct implementation in the form of a concrete project to long-term development of technology competence. BMW Group Research and Technology is presenting a selection of projects to celebrate this landmark anniversary. The specialists working at the centre have developed these projects and some of them will be experienced for the first time outside the confines of the well-guarded laboratories and workshops.

One of the first projects to be launched by the fledgling subsidiary company was the prototype for a BMW Z1 Coupé developed in 1988. This vehicle was created within the framework of a concept development based on the very first project of the new subsidiary – the BMW Z1 roadster produced in a limited series. The development engineers were interested in methods and technologies to facilitate a maximally efficient extension of a vehicle concept to additional derivatives. The knowledge gained from this project was used for the BMW Z3 series model, which was produced as a roadster and coupé, and for the first generation of the BMW Z4, which was also manufactured in open-top and closed versions.

A fuel-cell hybrid vehicle based on the BMW 1 Series is another project being presented in the public domain for the first time. This project developed by BMW Forschung und Technik GmbH shows a highly innovative form of hybrid technology developed within the framework of Efficient Dynamics in conjunction with the use of hydrogen as a fuel. Alongside a four-cylinder petrol engine, the research vehicle has an electric power unit for city traffic. The electrical energy is generated by a small fuel cell in the form of an Auxiliary Power Unit (APU) and stored temporarily in high-performance capacitors. These so-called super caps cover the performance peaks for acceleration and taking off at traffic lights, and store the electricity generated

during braking. Using a comparatively small fuel cell to generate electricity from hydrogen achieves a high level of efficiency for city traffic, while the internal combustion engine is only used for high-speed journeys. This combination could have the capability to provide an emission-free range of several hundred kilometres in city traffic and facilitate “recharging” within the space of a few minutes – this is in addition to the mobility reserves provided by the internal combustion engine for long-distance travel.

BMW Forschung und Technik GmbH is also celebrating its anniversary by providing a unique insight into innovative projects in the area of intelligent networking between driver, vehicle and environment. BMW ConnectedDrive already delivers a package of driver-assisted systems and mobility services that is unique throughout the world. These systems enhance comfort and safety, as well as optimising infotainment functions in the vehicle. The current research projects in this area include the narrow-passage assistant, which assists drivers if they are driving along particularly narrow lanes, for example near building works, and the emergency stop assistant which brings the vehicle safely to a stop if there is a medical emergency.

The latest success of the joint venture between BMW Forschung und Technik GmbH and Munich Technical University (CAR@TUM) is also presented. The project “IT-Motive 2020” involves the researchers developing an innovative architecture for information and communication technology integrated within the vehicle that permits functions previously distributed over a large number of different control units to be pooled in a homogeneous communication network. The aim is to provide a consistent hardware platform for displaying the continually expanding number of vehicle, comfort and safety functions.

Milestones: from the BMW Z1 to the lightweight sports coupé BMW Z29.

BMW Technik GmbH was launched in 1985 with the mission to develop innovative solutions for a large number of aspects associated with individual mobility. The specialists working in the newly established department were able to get to grips with this mission successfully in the very first project they tackled. They developed the BMW Z1 roadster. This vehicle project was intended to trial innovative materials, launch a revolutionary bodywork concept, and highlight opportunities for optimising development processes. The result was so impressive that already three years later the first out of a total of 8 000 series vehicles left the Munich BMW Plant. With its plastic body, vertical sliding doors and fascinating handling properties, the BMW Z1 was not simply the first milestone in the history of BMW Technik GmbH – it also made its mark as an exceptional phenomenon on the road.

Revolutionary body and power-unit concepts were to shape development operations during the years to come. In 1993, the BMW Z13 was presented, a compact vehicle with a sporty design powered by a rear-mounted engine and three seats in an unconventional configuration. The driver was positioned behind the centrally located steering wheel, with seating space being provided behind the driver for two passengers. The study featured the driving pleasure typical of the brand, a high level of comfort, and outstanding safety attributes.

BMW E1: pioneer for electro-mobility.

The same year already saw BMW Technik GmbH presenting the BMW Z15. This first fully functional concept vehicle with pure electric drive was a development of the BMW Z11 electric vehicle presented at the Frankfurt Motor Show in 1991. As a prototype with the model designation BMW E1, the four-seater incorporated a design with pioneering aerodynamic and ergonomic features that provided impressive testimony to the superlative potential of its emission-free drive technology even in normal everyday use. The BMW E1 provided a range of up to 200 kilometres and a top speed of 120 km/h. The prototype generated universal acclaim among members of the public and independent testers. The readers' choice in car magazine "Auto Zeitung" voted the BMW E1 as the winner in the category "Environment and Technology", and trade magazine "Auto Bild" described the BMW E1 as "the most advanced car of the century".

At the time, it was already evident that BMW was in a position to achieve typical BMW driving characteristics and operational capability geared to city driving with a purely electrical power unit. Series development would also be achievable if a battery technology with optimised power and cost could be developed. Today, BMW is continuing to build on this knowledge base in the context of project i: it provided the impetus for the development of a Mega City vehicle designed for emission-free mobility within large urban environments. An innovative vehicle concept and the most recent developments in the area of power unit and energy storage technology form the basis for a state-of-the-art presentation of electrical mobility.

New routes to maximum driving fun: BMW Z18 and BMW Just 4/2.

The development of the prototypes launched in 1995 also saw the specialists at BMW Technik GmbH searching for new and sophisticated approaches to driving pleasure. One of their ideas focused on designing an automobile counterpart to the Enduro motorcycle concept that was so successful during the 1990s. The yearning to explore off-road terrain and the pleasure of mobility under the open skies was combined for the first time on four wheels in the BMW Z18. An eight-cylinder engine, four-wheel drive, a variable interior

concept and elevated seating characterise the innovative driving experience in the robust roadster.

The BMW Z18 had to wait five years after it was created for its public debut – the occasion was the celebration of 15 years of existence for the think tank. Another prototype that offered the prospect of driving fun while having previously been confined to motorcycles captivated the driving public at the Tokyo Motor Show in Japan as early as 1995. Freestanding wheels, a body that abandoned roof and windscreen, and a rear-mounted four-cylinder engine packing 100 hp were the hallmarks of the study where the two-seater concept was already integrated in the model designation – BMW Just 4/2.

Festival of innovations: The BMW Z22.

The BMW Z22 was among the most sophisticated technology platforms that BMW Technik GmbH ever created. The study was presented in 1999, and it bristled with no less than 70 innovations and 61 registered inventions in areas ranging across body concept, lightweight construction, power unit, safety, mechanical systems and controls. The use of carbon-fibre reinforced plastic in an innovative processing procedure permitted compliance with the highest crash safety standards while at the same time significantly reducing weight. Power steering, an electromechanical braking system, cameras instead of wing and rear mirrors, and a cockpit design reduced to the bare essentials defined the mould-breaking, future-proof character of the BMW Z22. Adaptive headlights, Head-up Display and central control unit enabled the prototype to offer innovative functions that were soon implemented further down the line in BMW series vehicles.

Consistent lightweight construction for uncompromising driving pleasure: The BMW Z29.

Optimization of the vehicle weight by deploying the most advanced high-tech materials was the focus of development for the BMW Z29 concept study. The prototype of a two-seater sports car was completed by BMW Technik GmbH in 2001 and represents the culmination of cooperation with another subsidiary of the BMW Group – BMW M GmbH. The vehicle exerts fascinating appeal with flowing lines and lambo-style doors. The principles underlying the outstanding potential of the BMW Z29 for dynamic driving can be found under the engine bonnet and below the surface of the paintwork. The power was generated by the in-line six-cylinder engine of the BMW M3 – at that time a technological benchmark – and the passenger cell was manufactured from carbon-fibre reinforced plastic while the rear axle, and front and rear module were designed in aluminium. The most important results of this combination: a weight-to-power ratio of 3.4 kg/hp and an

acceleration ratio of 4.4 seconds for the sprint from a standing start to 100 km/h.

Research as foundation for Efficient Dynamics.

The Efficient Dynamics development strategy provides the BMW Group with the world's most efficient programme for reducing consumption and emission values in road traffic. The development of power systems with optimised efficiency, smart energy management in the vehicle, and aerodynamic measures form the key supporting aspects of this strategy, complementing lightweight construction throughout. BMW Group Research and Technology has made significant progress in all these areas since the company was established and the results have been channelled into the series development of many different new models.

Intensive fundamental research has also been carried out in the context of the development of innovative and alternative propulsion systems. The spectrum of research ranges from new concepts for the classic internal combustion engine, through hybrid technology and the deployment of hydrogen as a fuel in the vehicle, to electro-mobility. This demonstrates that research covers all the areas that today form the mainstays of the Efficient Dynamics development strategy.

Hybrid concepts: more efficiency, more driving pleasure – right from the start.

The BMW ActiveHybrid 7 and the BMW ActiveHybrid X6 are the first two models of the brand available in 2010 to use a combination of internal combustion engine and electric motor. Each model deploys a unique platform of BMW ActiveHybrid technology while also presenting a characteristic homogeneity: BMW ActiveHybrid presents tangibly enhanced dynamic driving accompanied by significantly reduced consumption and emission values. This twin-track advance is manifested in the BMW EfficientDynamics development strategy, and from the start it shaped the ground-breaking work carried out by BMW Forschung und Technik GmbH in hybrid technology. Hybrid technology in the style of BMW advances efficiency and intensifies driving pleasure.

The hybrid concept car based on the BMW 5 Series and developed in 1994 already facilitated fully electric and hence emission-free driving with characteristic features optimised for city traffic. The car's power-unit technology configured as a parallel hybrid drive combined a four-cylinder petrol engine with an electric drive which generated a maximum output of 26 kW. The energy stored in a nickel-metal hydride battery was sufficient to power the car over a range of eleven kilometres in purely electric drive mode.

Today, hybrid technology in the BMW 5 Series is more relevant to the modern world than ever before. It is well on the way to series maturity, as demonstrated at the Geneva Motor Show in 2010 when the BMW Concept 5 Series ActiveHybrid was featured and bore impressive testimony to the technology.

Within the space of just one year, the researchers had developed another hybrid concept vehicle and significantly extended the range of the vehicle solely under electric power. The BMW 3 Series with serial hybrid technology was primarily intended for city traffic and was able to travel a distance of 38 kilometres with the internal combustion engine switched off. Two electric motors supplemented the four-cylinder petrol engine. One of them provided the propulsion while the other served as a generator within the system.

Researchers presented a hybrid vehicle based on the first generation of the BMW X5 in 2001, and this demonstrated the progress that had been made in the area of drive and energy-storage technology. The study combined an eight-cylinder petrol engine and an electric motor to generate a maximum combined torque of 1000 newton metres. The high-power capacitors known as supercaps were the most important innovation in the first vehicle to be named after the Efficient Dynamics strategy. They were deployed as energy storage devices with particularly high power density.

The BMW Concept X3 EfficientDynamics consistently progressed development of supercaps integrated in the side sills. The technology was presented at the Frankfurt Motor Show in 2005. The specialists at BMW Forschung und Technik GmbH were also able to present new solutions for integrating the internal combustion engine and electric motor. BMW Concept X3 EfficientDynamics integrated the electric motor including performance electronics in a compact active transmission.

Option for the future, already operating today thanks to intensive research: hydrogen as a fuel.

Over the long term, the BMW Group is also committed to using hydrogen as an alternative fuel in vehicles. The use of hydrogen produced with assistance from renewable energy sources offers the option of emission-free mobility for the future. The capability of this power-unit technology for everyday use has already been demonstrated with the BMW Hydrogen 7. This car passed through the complete series development process before being manufactured as a limited series. The world's first hydrogen-powered luxury saloon for use under everyday conditions is powered by a bivalent twelve-cylinder internal combustion engine and has been made available to selected

customers worldwide. They have meanwhile travelled a total of more than four million kilometres driving the BMW Hydrogen 7.

On the way to the BMW Hydrogen 7, BMW Group Research and Technology set up a large number of research projects and concept vehicles, leading to a much better understanding of hydrogen technology and the framework conditions for use in the automobile. A precursor to the BMW Hydrogen 7 was presented in 2000 as the BMW 750hL and used as a shuttle vehicle at the Expo World Exhibition. The following years saw the BMW 750 hL driving more than 170 000 kilometres in a practical test during the "Clean Energy World Tour". Other pioneering achievements were provided by the BMW H₂R hydrogen record vehicle. In September 2004, the model powered by a twelve-cylinder engine set up nine international records for hydrogen-powered vehicles with a piston engine at the BMW test track in Miramas, France. The car achieved a top speed of more than 300 km/h.

Research is currently focusing on the challenges that still have to be mastered for the application of hydrogen. Milestones are the development of a hydrogen-four-cylinder cryogenic test engine and modular hydrogen single-cylinder research engines with combustion chamber geometries similar to petrol and diesel engines that achieved outstanding levels of performance and efficiency for hydrogen engines. The other innovations developed by BMW Forschung und Technik GmbH in the area of hydrogen technology include a variable shape tank with optimised weight made of carbon-fibre reinforced plastic for storing hydrogen in the vehicle and a reformer system for generating synthesis gas as a concept for effective emission reduction in the cold-start and catalytic-converter heating phase.

Another field of research involves tracking fuel cell technology with consistent focus on application for generating electricity to power the vehicle's on-board supply. Use of the fuel cell as an Auxiliary Power Unit (APU) has been undergoing development since 1997 at BMW. Consistent further development over the subsequent four generations of technology has resulted in a continuous increase in efficiency and permanently optimised compatibility with everyday use. These advances are being demonstrated with the fuel-cell hybrid vehicle on the occasion of the anniversary.

Connected Drive: networking as the key to more comfort, security and driving pleasure.

The development of electronic systems facilitates smart networking between driver, vehicle and environment, and BMW Forschung und Technik GmbH has played a major role in enhancing comfort, safety and driving pleasure. Many of today's series vehicles feature driver assistance systems, mobility

services, and systems for integrating external communication and entertainment modules that are based on innovations developed by BMW Forschung und Technik GmbH.

Motivated by the objective of opening up new perspectives for networking with the outside world and creating the foundations for the necessary technology, the specialists at BMW Group Forschung und Technik GmbH are working on assistance systems that extend way beyond the scope of the assistance systems integrated in current series vehicles.

Advanced assistance systems created by the research department of BMW Forschung und Technik GmbH include the TrackTrainer, which is supported by a melding of highly specific data from digital mapping, GPS and video and allows racing tracks – even the North Loop of the Nürburgring – to be negotiated autonomous in an ideal line. This system is used for training purposes during BMW Driver Training.

The emergency stop assistant developed in the context of the research project “Smart-Senior – Intelligent Services for Senior Citizens” uses the capabilities developed for the TrackTrainer to enhance traffic safety. The system is able to change to autonomous drive mode if an emergency situation caused by a health problem with the driver is identified, in order to carry out a safe emergency braking manoeuvre. Apart from reliable localisation of the vehicle within the lane, precise execution of the manoeuvre primarily involves robust identification of all the vehicles in the immediate environment.

Another research project in the area of automatic driving is the garage parker debuted in 2006. This system permits independent manoeuvring of the vehicle. All drive, braking and steering functions are controlled automatically to enable the vehicle to be steered in and out of a garage where space is restricted using remote control by the driver. If required, the system also activates the warning indicators and the headlamps, as well as swinging the wing mirrors in and out. The sensors for stopping the car automatically are naturally also activated if an obstacle is encountered.

More safety and efficiency through targeted communication.

A key area of development for our research subsidiary is interchange of information between vehicles and the traffic infrastructure, known as Car-to-X Communication (Car2X). One example is transmission of information about sequence times from traffic light systems. This means that a driver assistance system can either get information about the optimum speed so that cars can hit an individual green sequence of traffic lights and travel without stopping, or

issue a warning about the possibility of going through a red light. Strategic transfer of data about the traffic situation, conditions on the carriageway and other factors allow early warnings to be broadcast from one vehicle to other drivers in the immediate environment about accidents, traffic jams or the formation of black ice. It is also possible to calculate the risk of collision based on the transmitted vehicle data so that warnings can be given in advance of potential crashes at junctions. As a manufacturer of cars and motorcycles, the BMW Group is in the unique position of being able to integrate both types of vehicle in the communication scenarios.

BMW Forschung und Technik GmbH also carries out ground-breaking work in the development of revolutionary operating concepts and control systems. One example of this is the concept of an entirely innovative cockpit design presented in a second-generation BMW 3 Series compact, with the Drive Stick as the focal point. Instead of steering wheel, accelerator and brake pedal, the concept vehicle has two control levers projecting vertically from the door panel and the centre console. These allow the driving direction, acceleration and deceleration to be controlled using drive-by-wire technology. The Drive Stick Car project provides a particularly vivid example of the abilities of the specialists working at BMW Forschung und Technik GmbH to ask questions about basic assumptions, deploy a high level of creativity in seeking out radically different solutions, and harness the potential of innovative technologies. The knowledge collected in this project played a major role in influencing the development of the electromechanical power steering and active steering marketed for BMW series models. It also provides the typical BMW steering feeling under the conditions of power steering support.

From sailing yacht to car: Optimised Head-Up Display technology.

Their fundamental research and technology development continually encourages the researchers to look at issues that at first glance appear to be way beyond the scope of the automobile. However, over the long term the knowledge gathered in this way is channelled into projects that lead to an increase in comfort, safety and driving pleasure within the context of BMW ConnectedDrive. The team from the Technology Office located at Palo Alto in the US developed a miniature head-up display integrated in the sunglasses of the crew members in the Oracle BMW Racing Team. This system was designed for use in the ocean race for the America's Cup and allows information and commands to be transferred speedily and selectively by projecting it onto the lenses of the sunglasses. This project generated additional know-how that was used for the advanced development of the Head-up Display in the latest series vehicles of BMW.

Identification and integration of new technologies as a recipe for success: BMW ConnectedDrive Services with functionality that is unique worldwide.

Defining principles were also identified by the Technology Office in Palo Alto for integrating external communication and entertainment modules in the vehicle. The first interface for integrating the Apple iPod was developed there and this included the option of using the BMW iDrive System to control the audio function. The pioneering work carried out by BMW Research and Technology has secured BMW a unique position for the integration of external communication and entertainment systems in the vehicle. The systems and services integrated within BMW ConnectedDrive guarantee functionality that remains a world first not matched by any other automobile manufacturer worldwide.

Innovative services for future mobility solutions are already being developed today, including the technology required for these concepts. The BMW Group Technology Office Palo Alto joined forces with other technical departments to develop an iPhone application for the BMW Concept ActiveE vehicle. This application delivers vital information directly to the driver's mobile phone, including data concerning battery charge status and the potential range of the vehicle running on electric power alone.

The prototype of a multifunctional car key was also developed as a means of networking the mobility experience with the driver's lifestyle. The BMW Key is provided with a security chip that allows the driver to make cashless purchases while also enabling other functions such as memorising the e-booking for hotel rooms. The driver's key has integrated credit card functions which offer the possibility of e-booking for bus, train and air travel while in the car and storing the purchased e-tickets on the key. When using hire car or car-sharing systems, the personalised key offers additional potential because it is assigned to the owner of the vehicle rather than to the car itself.

2. Making the force of innovation tangible. The concept vehicles of BMW Technik GmbH.

Liberated from conventional demands, released from the constraints of current series development, and away from the public gaze, projects and visions are created in BMW Forschung und Technik GmbH which are way ahead of their time. Not all the sparky ideas generated by the engineers reach the stage where an actual prototype is built, and most of the knowledge gained only finds its way into the development of series vehicles indirectly or with a certain time lag. There are plenty of instances when reality first has to catch up a few steps in order to keep pace with projects directed far into the future. Sometimes projects that are created in BMW Forschung und Technik GmbH are only presented in the public domain several years down the line.

Another factor is that projects from different areas of research never achieve the status of presentable results in unison. Furthermore, priorities on content are established for the presentation of research results which either lead to an early presentation of individual aspects or result in an overall concept with deliberately longer lead times. One manifestation of the process whereby issues of this kind are decided is the nomenclature of the concept vehicles which have been created in BMW Forschung und Technik GmbH over the past 25 years. Their numbering, starting with the BMW Z1, has gaps and is not always in chronological harmony with the publication date. Some gaps occurred because the associated projects were presented under different names, and a number of gaps arose because the concepts never got beyond the stage of sketches and ideas.

BMW Z1: First project becomes an immediate legend.

The engineers working for the think tank first established as BMW Technik GmbH created a sensation with their first development. They pooled their ideas for a completely new vehicle concept in a two-seater roadster. During this process, they developed a type of car that had virtually been forgotten in the mid-1980s. The first project was therefore already a perfect example of the very special approach being taken by the company.

The highlights of the BMW Z1 went far beyond the body design that was received with such rapturous acclaim by the public and the 125 kW/170 hp six-cylinder in-line engine that served as the power unit. Development of



this open sports car started in the second half of 1985, and ultimately this car was planned as a pilot project for innovative vehicle structures, the manufacture and application of new materials, and the optimisation of development processes.

The structure of the BMW Z1 comprises a monocoque-type steel chassis with a bonded plastic floor. The car's bodywork is made of special elastic plastics that are not sensitive to damage. New thermoplastic materials and sandwich components were used. The comparatively high side sills provide a degree of protection for the passengers that had not previously been achieved in a roadster. The powered vertical sliding doors were the eye-catching visual highlight of the design.

Engineers developed a completely new suspension for the rear-powered wheels in order to ensure that the BMW Z1 with its top speed of 225 km/h also qualified with flying colours in the discipline of future-proof driving pleasure. The so-called centrally spherical double wishbone system used for the rear axle formed the basis for the handling of the roadster, which resembled the performance of a go-kart. This design was later to form one of the key factors in the agile handling experienced in the mid-range models of BMW, when it became the Z-axle in the BMW 3 Series.

The fledgling team at BMW Technik GmbH also achieved the aim of cutting down development times from a standing start. Series production of the vehicle was launched three years after the start of the project. The BMW Z1 has achieved legendary status and was received with open arms by the highly sophisticated roadster fans. In the period between 1988 and 1990, 8 000 vehicles were built. Even today, the BMW Z1 is a model for aficionados – even though the concept was originally not intended for series production.

BMW Z1 Coupé: The base for the platform concept.

The original research project – that was ultimately to bring forth the creation of the BMW Z1 – included fundamental research in the areas of bodywork construction, materials and development processes. Right from the outset, this included pushing out the envelope and applying the newly created methods to several vehicle concepts. The BMW Z1 became a runaway hit with the public as a fascinating roadster, and it had the potential for being joined by other model versions using this approach. Plans included a coupé and a four-wheel drive version of the BMW Z1. The prerequisites for this kind of diversification were engineered into the design of the floor pan, and chassis. And a design was actually created for a BMW Z1 coupé that is virtually unknown in the public arena to the present day.

The plastic model of the BMW Z1 coupé is being presented in broad public for the first time to celebrate the landmark anniversary of BMW Forschung und Technik GmbH. This design demonstrates the potential of a unique platform strategy for roadsters and closed coupés. Benchmarks were defined in the course of this project – designated internally as the BMW Z2 – that included key components with the capability for use in several vehicle concepts. These knowledge assets constituted the platform for innovative development processes that were subsequently incorporated in new BMW models and permitted exceptionally efficient diversification of the model profile. However, the so-called “off-roadster” was to remain a study in wood, clay and plastic resembling the styling incorporated in the Z1, and the concept was not taken any further.

While the BMW Z1 coupé never succeeded in getting on the road, the innovative platform strategy was used for the first time only a few years later during the development of a series vehicle. In 1995, BMW presented the BMW Z3 roadster. The two-seater immediately captured the public imagination as a puristically open symbol of sheer driving pleasure. By contrast, the potential for an expansion of the model range was not, however, obvious at first glance. The concept was realised in 1998 when the BMW Z3 coupé was launched in the marketplace.

This flexibility gained in the development of additional versions was also deployed for the successor model. The BMW Z4 made its debut as a roadster in 2002, and it was joined by the BMW Z4 coupé four years later.

BMW E1: premiere in the sphere of electric vehicles.

The Z at the start of the project name continued to form a characteristic feature of all the concept vehicles developed by BMW Technik GmbH during the subsequent years. At the beginning of the 1990s, the nomenclature of the exceptionally active company had already got as far as number 11. The fact that the prototype designated internally as the BMW Z11 was ultimately launched in the public domain as the BMW E1 bore testimony to its revolutionary power unit: The BMW E1 presented at the Frankfurt Motor Show in 1991 had an electric motor mounted in the rear. The development goal of this project was to carry out research into the advantages and disadvantages of a car propelled entirely by electric motive power when subject to the practical test of everyday conditions on the road. The BMW E1 was also intended to represent a standalone, efficient automobile that was designed according to all the defining principles of driving pleasure while making no compromises with respect to functionality.

Today, the BMW E1 is regarded as the launch pad for holistic development of electro-mobility concepts in the BMW Group. A number of electric vehicles had already been developed on the basis of conventional series models from the start of the 1970s onwards. These vehicles had yielded fundamental insights into the areas of power-unit and energy-storage technology. The BMW E1 was the result of the first vehicle concept based on electro-mobility. The electric motor of the BMW E1 packs 37 kW with power being transferred to the rear axle. The innovative extruded aluminium construction and plastic body produced an exceptionally lightweight city car with a top speed of 120 km/h and a range of 200 kilometres.

The BMW E1 was a prototype that was fully roadworthy with the capability to be used in everyday traffic conditions. The performance and practical qualities of the vehicle with its aerodynamically pioneering design were immediately given a seal of approval by the test drivers at the time. High-grade materials and the quality of finish so typical of BMW definitively set the BMW E1 apart from the few other electric vehicles. Airbags for driver and passenger set a new benchmark for protection of the occupants. The trade magazine "Auto Bild" designated the 2+2-seater that generated zero emissions when driving as "the most advanced car of the century". And the readers' choice in car magazine "Auto Zeitung" voted the BMW E1 as the winner in the category "Environment and Technology".

In the BMW E1, sodium-sulphur batteries are mounted under the rear seat and adequately protected in the event of a crash. A conventional domestic power socket is all that's necessary to recharge the power supply. The BMW Z15 designed as a successor and the slightly bigger BMW E2 based on that platform are powered by a sodium nickel-chloride battery. The basic conclusion from this development series established in the early 1990s was that vehicles powered with electric drive are technically feasible, but the technology for storing electric energy needs more work and sets practical limits for use. Nevertheless, BMW Technik GmbH had already laid the foundation stone for projects currently developing emission-free mobility in urban environments. This has provided a technological lead which the BMW Group is demonstrating today with vehicles like the MINI E and the BMW Concept ActiveE.

BMW Z13: an interior concept that breaks the mould of convention.

In 1993, the engineers at BMW Technik GmbH were given a new and exciting mission: the search was on for a contemporary compact vehicle with mould-breaking active and passive safety, enhanced comfort, impressive performance, and realistic economic and environmental credentials. The brief also included driving pleasure and understated elegance to embody the

inimitable values of the brand. The specialists developed the BMW Z13 on the basis of this specification.

The fully functional prototype combines the advantages of a comfortable touring saloon with the dimensions of a compact car. The engineers involved in this project took an exceptionally unusual route to achieve their goal. The BMW Z13 was given the title of Personal Car and designed principally as a single seater. The driver's seat positioned in the middle allows all the control elements to be positioned with ergonomic perfection, while also offering advantages if the car is involved in a side crash and when entering and leaving the vehicle parked at the kerbside. The left-hand or right-hand door can be used to match the particular traffic situation.

The variable baggage space is located directly behind the driver's seat, and it can even accommodate skis up to two metres in length. Alternatively, two additional seats can be folded down, which are positioned obliquely behind the driver's seat. This unconventional configuration offers unparalleled legroom with an enhanced level of comfort for passengers seated in the rear of the car.

The supporting structure of the BMW Z13 consists of a lightweight chassis made from aluminium extrusions (space frame). The 60 kW/82 hp petrol engine is rear mounted. The low vehicle weight of only 830 kilograms contributed towards achieving average fuel-efficiency values between five and six litres for every 100 kilometres travelled.

The highly unusual vehicle concept is packaged in an extravagant design that outperformed the conventional benchmarks for an automobile at that time. Moreover, the BMW Z13 gave a very concrete perspective onto the future of mobile communications. A satellite navigation system was installed on the instrument panel alongside a telephone and fax.

BMW Z18: The first off-road roadster.

Innovative vehicle concepts create new challenges. These are particularly important for the specialists at BMW Technik GmbH because they inspire unconventional technical solutions. The result of making breakthroughs of this nature is encapsulated in the BMW Z18 concept vehicle. In 1995, this unique car went down in history as the first off-road roadster to be developed by BMW. This was a period when the desire for versatile mobility under the open skies and the yearning to explore off-road terrain had triggered a boom in the segment of Enduro motorcycles. BMW Technik GmbH took the initiative and transferred this expression of sheer driving pleasure to an automobile concept. The BMW Z18 crossed category boundaries by

combining the exhilarating feeling of a convertible with the robustness and versatility of an off-road vehicle.

An eight-cylinder engine packing 260 kW/355 hp powered the roadworthy prototype, while a four-wheel drive designed with technical complexity provided the necessary off-road capability. The plastic body was mounted on a frame structure made from steel extrusions and was not dissimilar to a boat – the BMW Z18 was able to drive effortlessly through flat stretches of water. The variable interior concept – configurations as two-seater, four-seater and pick-up were engineered into the design – made the unusual concept vehicle a true multi-tasker from several points of view.

BMW Z21: fascinating driving fun Just 4/2.

The BMW Z18 was premiered on the public stage five years after it had been created. Another prototype offering the prospect of driving fun that had previously been confined to the realms of the motorcycle captivated the driving public at the Tokyo Motor Show in 1995. The BMW Z21 project launched in the same year saw engineers at BMW Technik GmbH transferring their focus from off-road capability to enhanced driving pleasure on metalled roads. The result was a minimalist two-seater that left its engineering delights exposed to public view and truly lived up to the formulation of “Just 4/2” enshrined in its name.

Only rudimentary vestiges of bodywork can be seen in the BMW Just 4/2, and the wheels are freestanding to emulate a formula racing car. The four-cylinder power unit generating 73 kW/100 hp loaned from the BMW K 1100 model was more than a match for the prototype weighing only 550 kilograms. The two-seater accelerated from a standing start to 100 km/h in around 6 seconds and notched up a top speed of 180 km/h. Specially developed clothing and helmets provided enhanced protection for the occupants alongside airbags for driver and passenger, and side-impact protection, to transform the Z21 project into a complete work of art at the premiere in Tokyo.

BMW Z22: a masterpiece in mechatronic design.

Towards the end of the 20th century, electronic and mechanical functions in automobiles were experiencing a trend towards a harmonized unity. The technology grouped under the concept of mechatronics (mechanical systems with electronic controls) permitted completely new functions. The engineers at BMW Technik GmbH were looking far into the future in this area. The BMW Z22 mechatronic ideas platform was presented in 1999 with a total of 70 technical innovations and 61 pioneering inventions. It represents one of

the most sophisticated projects ever put together by the think tank at the BMW Group.

The steering wheel and the brake pedal do not operate mechanically in the BMW Z22, but use electric impulses (steer-by-wire, brake-by-wire) to transfer the commands from the driver. Cameras replace the rear view mirror and the images obtained are integrated in a panoramic view on a central display instead of being seen in an interior mirror. A fingerprint scanner replaces the conventional ignition key. Important information about speed and instructions from the navigation system are projected into the driver's field of vision on a Head-up Display on the windscreen. This enables the instrumentation in the BMW Z22 to be restricted to two monitors. The rectangular shape of the multifunction steering wheel makes the interior compartment seem almost like an aircraft cockpit. The driver is able to select different shift patterns using an electric rotary switch. The prototype was also fitted with adaptive headlights governed by the steering angle – precursor for the adaptive headlights fitted in today's BMW series models. The Head-up Display and camera functions, such as Side View and Top View are now available in the series vehicles manufactured by the BMW Group – only the rear view mirrors remain a statutory requirement.

A four-cylinder petrol engine generating 100 kW/136 hp was selected as the power unit. The conventional gearbox has been replaced by an automatic CVT drive with variable transmission of power. The engineers took a completely new approach in designing the body structure. They introduced a horizontal separation between the functional framework and the passenger cell. In the BMW Z22, the passenger cell resembles the monocoque chassis found in a Formula 1 racing car and is made entirely of carbon-fibre reinforced plastic. This achieves superlative crash safety, and the ultra-lightweight composite material – weighing some 30 percent less than aluminium – also significantly reduces the vehicle weight.

The wheelbase of a BMW 7 Series car combined with the exterior length of a BMW 3 Series automobile also facilitated a completely new concept for the interior. While the same amount of space was available in the interior, the BMW Z22 weighed around one third less than a BMW 528i touring manufactured in 1999. This innovative design enabled the four-door concept vehicle to set new benchmarks in the area of lightweight construction that is perceived to be a key technology. Average fuel consumption of around 6 litres per 100 kilometres was the quantifiable result of consistent weight optimisation.

Although the vehicle was a feasibility study intended to test the boundaries of technical limits, the BMW Z22 was designed as a fully roadworthy automobile which did not require a greater settling-in period for a driver new to the car than any series vehicle. The revolutionary operating concept was simple and intuitive guaranteeing effortless and relaxed driving pleasure right from the start.

BMW Z29: driving machine made from Formula 1 materials.

Consistent lightweight construction formed the focus of BMW Forschung und Technik GmbH and BMW M GmbH in the BMW Z29 project that was brought to fruition in 2001. The engineers created an emotional, thoroughbred sports coupé as a concept vehicle powered by the in-line six-cylinder BMW M3 engine, which at the time generated 252 kW/343 hp. However, the lambo-style doors clearly marked out the visual appearance of the concept car from all the series models manufactured under the brand.

The BMW Z29 accommodates a maximum number of two occupants in the passenger cell with a structure comprising a monocoque made of carbon-fibre reinforced plastic. A front module manufactured in aluminium is bolted onto the monocoque to accommodate the six-cylinder power unit mounted as a front mid-engine and the double wishbone front axle also made of aluminium. A sequential M six-speed gearbox transfers power to the rear axle. Aluminium for the rear module and rear axle also plays a role in reducing the weight of the vehicle still further.

The engineers garnered further weight savings with innovative structures in the cockpit. The air outlets from the ventilation system were designed as a structural member on which the instrument panel is mounted. This measure and similar design features reduced the kerb weight of the vehicle by some 26 kilograms.

The prototype has a length of precisely 4 metres and a height of 1 265 millimetres. The weight of the vehicle ready to roll is only 1 160 kilograms. The resulting weight-to-power ratio is 3.4 kg/hp and is at the level of a thoroughbred racing car. The axle load distribution achieves the ideal value of 50:50. The performance and handling are equally impressive. The BMW Z29 sprints from a standing start to a speed of 100 km/h in just 4.4 seconds and boasts an impressive top speed of 270 km/h.

3. The future of sheer driving pleasure. **Efficient Dynamics – from research to road.**

The Efficient Dynamics development strategy provides the BMW Group with the world's most efficient programme for reducing consumption and emission values in road traffic. The development of power systems with optimised efficiency, smart energy management in the vehicle, and aerodynamic measures form the key supporting aspects of this strategy, complementing lightweight construction throughout. BMW Forschung und Technik GmbH has made significant progress in all these areas since the company was established and the results have been channelled into the series development of many different new models.

Intensive fundamental research has also been carried out in the context of the development of innovative and alternative propulsion systems. The spectrum of research ranges from new concepts for the classic internal combustion engine, through hybrid technology and the deployment of hydrogen as a fuel in the vehicle, to electro-mobility. This demonstrates that research covers all the areas that today form the mainstays of the Efficient Dynamics development strategy.

In celebration of its 25th landmark birthday, BMW Forschung und Technik GmbH premiered the results of two projects designed to highlight innovative ways of significantly reducing consumption and emission values. These projects relate to a research vehicle with fuel-cell hybrid technology and a concept for using hydrogen technology by a device known as a reformer. The reformer facilitates strategic optimisation of the emission characteristics of internal combustion engines. These two projects offer solutions that are closely associated with the needs of drivers operating in everyday road conditions. The fuel-cell hybrid vehicle was designed with the objective of emission-free mobility in city traffic. The reformer technology allows significantly optimised emission values during the warming-up phase of the engine.

Fuel-cell hybrid technology for emission-free mobility in city traffic.

The fuel-cell hybrid vehicle launched by BMW Forschung und Technik GmbH offers a highly innovative form of hybrid technology developed within the



framework of Efficient Dynamics. Moreover, the prototype developed on the basis of a BMW 1 Series car presents an innovative approach to the use of hydrogen as a fuel. The research vehicle has a four-cylinder petrol engine and an electric motor, as well as a small fuel cell in the form of an Auxiliary Power Unit (APU). The combination of an internal combustion engine with a fuel cell creates the possibility of using both drive technologies, each with optimised efficiency. Hydrogen offers the advantages of conventional fast refuelling and a long range. The size of the fuel cell means it is ideal for use at low speeds, whereas the performance benefits of the internal combustion engine come into their own when the vehicle has to cover long distances at higher speed, delivering the masterly overall performance so typical of BMW. In city traffic, the electrical energy generated by the APU is continuously supplied to high-performance capacitors (supercaps) which have outstanding high power density and cycle robustness. These supercaps cover the performance peaks for acceleration and taking off at traffic lights. The electric motor assumes the function of a generator during coasting and braking phases and feeds electrical energy back to the supercaps. This regenerative braking energy is then available for the subsequent acceleration phases and further reduces consumption. The objective of the researchers in the next stage of expansion is to increase the range provided by electric motive power to several hundred kilometres in city traffic.

All drive components were configured as optimised packages in the 3-door BMW 1 Series. The APU is positioned under the engine bonnet together with the internal combustion engine, the electric motor takes the place of the rear axle differential and drives the rear wheels. An output of 82 kW and a high torque that engages right from a standing start deliver the sporty handling typical of BMW. The supercapacitor battery instead of the gearbox and conventional drive train is mounted in the central tunnel. The force of the 88 kW petrol engine acts on the front wheels. A reduced petrol tank leaves space for the hydrogen tank. This configuration means that no constraints are placed on the interior space of the research vehicle by contrast with the series model. The standard five seats are provided. Moreover, the weight of the fuel-cell hybrid vehicle is only just above the value for a corresponding series model.

BMW has been developing fuel-cell technology since 1997.

The low-temperature PEM (Polymer Electrolyte Membrane) fuel-cell technology has been researched and developed at BMW since 1997. Right from the beginning, the research concentrated on application as an APU with comparatively compact dimensions and a maximally low weight. The hydrogen concept vehicle BMW 750hL presented as early as 2000 had a fuel cell as a source of on-board electricity. The researchers believed that using

the small fuel cell for the supply of on-board electricity was the most cost-effective scenario in conjunction with the internal combustion engine for launching the technology.

Meanwhile, BMW Forschung und Technik GmbH is already bringing the fourth generation of APU units on stream. Apart from the increase in service life under automobile load cycles to the current level of 5000 hours, the complexity of the system has gradually been reduced and a robust fuel-cell unit has been created. This simple system effectively operates at ambient pressure and achieves an efficiency of 58 percent for the system over a broad performance spectrum. The special design enables rapid changes in load, such as those occurring during the APU application, from virtually idle to full loading within the space of five milliseconds.

One of the most important issues relating to introduction of the low-temperature PEM fuel cell is the capability to start under frosty conditions after a long period without use at temperatures below freezing. An ingenious cell design means the external moistening of the gases can be omitted so that the system is in a position to supply the vehicle with energy after a period of only 30 seconds. Intensive tests, in some cases on extremely steep gradients, demonstrated that there was no degradation after several hundred frost starts. This confirms that the technology is ready for use in vehicles on the road.

APU supplies the on-board power – and also provides drive energy for the first time.

The APU supplies the energy necessary for the on-board power supply in the fuel-cell hybrid vehicle, as was already the case in the BMW 750hL. All the units consuming electricity can be supplied in this manner, without having to tap the power of the internal combustion engine. This energy management concept also allows sophisticated comfort features to be displayed. For example, the fuel-cell hybrid vehicle can be fitted with an effective system providing air-conditioning while standing still and it offers virtually unlimited, emission-free energy supply for infotainment applications.

The ongoing advance of the small fuel cell also achieves a premiere by using electricity generated from hydrogen for forward propulsion. The combination of the APU (providing a small but continuous output) and the back-up storage in the supercaps (delivering high outputs over a short period) achieves a highly efficient yet marketable drive system, specially designed for city trips.

Reformer technology: fewer emissions during cold start.

The BMW Group possesses unique know-how in the use of hydrogen. The projects based on this technology being pursued by BMW Forschung und Technik GmbH include the use of hydrogen in internal combustion engines as well as its application in a fuel cell. Hydrogen can also be used with the aim of optimising the emission behaviour of conventional petrol and diesel engines. BMW Forschung und Technik GmbH presents a particularly effective solution in this area in the form of reformer technology in an otherwise standard 5-door BMW 1 Series.

The ambitious emission limits mean that the initial seconds after a cold start present a particularly difficult scenario, because catalytic converters only achieve maximum effect after they have been heated to a specific temperature. The reformer technology intervenes precisely at this point and significantly reduces the level of engine out emissions that are generated during a cold start.

Synthesis gas obtained from liquid fuel is free of residues.

Reformer technology can be used in petrol and diesel engines. The system comprises a mixing zone, an injection valve, a spark plug and a special catalytic converter where fuel is partially oxidised with a limited supply of oxygen. The catalytic process that is initiated in this way selectively splits hydrocarbon chains (C_xH_y) to generate a synthesis gas with a proportion of approximately 21 percent hydrogen and approximately 24 percent carbon monoxide. This synthesis gas is then supplied to the conventional intake manifold of the engine by selectively delivering it into the cylinders via air assisted injection valves. This mixture can completely replace conventional fuel while the engine and catalyst system is warming up. Since the gas mixture burns with virtually no residues, the critical phase for emission behaviour immediately after a cold start is transformed by reformer technology into a particularly clean operating mode.

The lower efficiency of the reforming process is the only disadvantage of using the synthesis gas generated from fuel compared with continuous operation of the internal combustion engine. When combustion of the gas occurs, 15 to 20 percent of the original fuel-energy content is converted into heat. However, this side effect is particularly useful during the warming-up phase. The heat generated in the reformer heats up the engine faster than during operation with petrol or diesel fuel for the increase in engine efficiency as a result of a reduction in frictional losses and complete and very stable combustion.

The reformer system presented in the research vehicle is currently equivalent to the status of a prototype. However, series development is still precluded by the need to reduce the size of the components and the weight of currently some five kilograms to a maximum of one and a half kilos, while optimising the characteristic properties of the system at the same time. Once these requirements have been met, the system could also be used to replace the auxiliary heater currently used in diesel engines or for regenerating the particle filter and for selective catalytic reduction (SCR catalysis) of nitrogen oxides (NO_x). The expense for the exhaust treatment used to date is then reduced accordingly.

Hybrid concepts: More efficiency, more driving pleasure – right from the start.

BMW Forschung und Technik GmbH has carried out intensive and fundamental research in order to lay the foundations for many of the standard efficiency-enhancement technologies used in BMW automobiles today. Comprehensive, thorough and wide-ranging research at an early stage makes a significant contribution to the outstanding know-how of the BMW Group in the area of drive technology. The BMW ActiveHybrid technology available in BMW series vehicles today also owes its unique qualities not least to the experience in this area gathered by researchers over a period spanning more than 15 years.

The BMW ActiveHybrid 7 and the BMW ActiveHybrid X6 are the first two models of the brand available in 2010 to use a combination of internal combustion engine and electric motor. Each model deploys a unique platform of BMW ActiveHybrid technology while also presenting a characteristic homogeneity: BMW ActiveHybrid presents tangibly enhanced dynamic driving accompanied by significantly reduced consumption and emission values. This twin-track advance is manifested in the BMW EfficientDynamics development strategy, and from the start it shaped the ground-breaking work carried out by BMW Forschung und Technik GmbH in hybrid technology. Hybrid technology in the style of BMW advances efficiency and intensifies driving pleasure.

Development of hybrid technology since the 1990s.

The hybrid concept car based on the BMW 5 Series and developed in 1994 already facilitated fully electric and hence emission-free driving with characteristic features optimised for city traffic. The car's power-unit technology configured as a parallel hybrid drive combined an 83 kW four-cylinder petrol engine with an electric drive that develops peak output of 26 kW and a maximum torque of 165 newton metres. This research vehicle was already designed as a Full Hybrid, in other words it permits emission-free

driving only using the electric drive in city traffic. The energy stored in a nickel-metal hydride battery with a capacitance of 3.5 kilowatt hours was sufficient to power the car over a range of eleven kilometres in purely electric drive mode. An Auto Start Stop function was also integrated which switches the internal combustion engine off automatically when the car is stationary at junctions or standing in traffic jams outside suburban areas, in order to prevent unnecessary fuel consumption during the idle phase. Today, hybrid technology in the BMW 5 Series is more relevant to the modern world than ever before. It is well on the way to series maturity, as demonstrated at the Geneva Motor Show in 2010 when the BMW Concept 5 Series ActiveHybrid was featured and bore impressive testimony to the technology.

Within the space of just one year, the researchers had developed another hybrid concept vehicle and yet again extended the range of the vehicle solely under electric power. The BMW 3 Series with serial hybrid technology was also primarily intended for city traffic and was able to travel a distance of 38 kilometres using a sodium nickel chloride battery with the internal combustion engine switched off. The drive train is comprised of an internal combustion engine using petrol as a fuel and two synchronised electric motors. One of them provides the propulsion generating a peak output of 35 kW, and the other motor with maximum output of 32 kW carries out the function of a generator within the system. This research vehicle was also equipped with an Auto Start Stop function.

Researchers presented a hybrid vehicle based on the first generation of the BMW X5 in 2001, and they thus demonstrated the progress that had so far been made in the area of drive and energy-storage technology by the start of the new millennium. This study combined an eight-cylinder petrol engine and an asynchronous electric motor to generate a maximum combined torque of 1000 newton metres at 1000 min^{-1} . The most important additional innovation was the use of the double-layer capacitors known as supercaps, which are deployed to store energy with a particularly high capacitance of 650 kW. In addition to highlighting efficiency benefits, this research vehicle also gave a particularly impressive demonstration of the potential of hybrid technology for bringing about a significant increase in driving dynamics.

The BMW Concept X3 EfficientDynamics consistently progressed development of supercaps integrated in the side sills. The technology was presented at the Frankfurt Motor Show in 2005. The specialists at BMW Forschung und Technik GmbH were also able to present new solutions for integrating the internal combustion engine and electric motor. The electric motor with a maximum output of 60 kW installed in the BMW Concept X3 EfficientDynamics was integrated in a compact active transmission together

with the power electronics. The range of the electric power unit could be expanded using the option of an additional nickel metal-hydride battery. The hybrid technology was again used to optimise efficiency as well as to intensify the driver's level of driving dynamics. The precisely synchronised interaction of the six-cylinder in-line petrol engine with direct injection and the electric motor achieved enhanced fuel efficiency amounting to some 20 percent. A torque of 600 newton metres generated by the two drive sources was available to power particularly dynamic acceleration manoeuvres. This powered the BMW Concept X3 EfficientDynamics from a standing start to 100 km/h in just 6.7 seconds and enabled the car to achieve a top speed of 235 km/h.

Option for the future, available now owing to intensive research: hydrogen as fuel.

Over the long term, the BMW Group is also committed to using hydrogen as a fuel in vehicles. The use of hydrogen produced with assistance from renewable energy sources offers the option of future emission-free mobility. The capability of this power-unit technology for everyday use has already been demonstrated with the BMW Hydrogen 7. This car passed through the complete series development process before being manufactured as a limited series. The world's first hydrogen-powered luxury saloon for use under everyday conditions is powered by a bivalent twelve-cylinder internal combustion engine and has been made available to selected customers worldwide. Meanwhile, the model produced as a limited series of 100 vehicles has covered a total of more than four million kilometres across the world.

On the way to the BMW Hydrogen 7, the specialists at BMW Group Research and Technology set up a large number of research projects and concept vehicles, leading to a much better understanding of hydrogen technology and the framework conditions for use in the automobile. A precursor to the BMW Hydrogen 7 was presented in 2000 as the BMW 750hL and used as a shuttle vehicle at the EXPO2000 World Exhibition in Hanover. The BMW 750hL then drove more than 170 000 kilometres in a practical test during the "Clean Energy World Tour".

Other pioneering achievements were provided by the BMW H₂R hydrogen record vehicle. In September 2004, the model powered by a twelve-cylinder engine set up nine international records for hydrogen-powered vehicles with an internal combustion engine at the BMW test track in Miramas, France. The 210 kW/286 hp engine achieved a top speed of more than 300 km/h.

Other innovations in hydrogen technology being driven forward by BMW Forschung und Technik GmbH include a variably shaped tank with optimised

weight for storing hydrogen in the vehicle. The free-form tank made of carbon-fibre reinforced plastic and developed jointly with partners from the aerospace industry is used to store liquid hydrogen. The variable shape enables the fuel tank to be integrated flexibly within a range of different vehicle concepts. The weight of the tank has been reduced to one third of the weight of an equivalent conventional cylindrical tank. When filled with around 10 kilograms of hydrogen, the free-form tank integrated in an appropriate vehicle would permit a range of more than 500 kilometres.

Because the infrastructure of fuelling stations will not be starting with complete coverage to permit hydrogen to be used as a single source, bivalent engines provide an initial solution. These engines can run on hydrogen and petrol. BMW Forschung und Technik GmbH has successfully confirmed the potential of the monovalent combustion process as regards output and efficiency – for example with the H₂R. This process is optimised without compromise for hydrogen.

The particularly powerful hydrogen-powered four-cylinder cryogenic engine was developed in a joint project between BMW Forschung und Technik GmbH and BMW M GmbH. This engine is based on the four-cylinder engine of the BMW M3 first generation, although it is already fitted with components from the advanced development of one of the two cylinder banks of the V8 engine currently incorporated in the latest M3. A special feature of this drive unit is the mixture formation for super-chilled hydrogen developed by the researchers during the course of this project. On the test rig, the engine achieved a specific output of 67 kW per litre of displacement and set a benchmark for hydrogen-powered aspirated engines.

Another example of the intensive basic research in the area of drive systems is provided by the modular single-cylinder hydrogen engine developed especially for thermodynamic analyses. The HylCE research project sponsored by the European Commission developed a hydrogen-powered engine with the typical geometry of an Otto engine between 2004 and 2007, which generates a specific output of 100 kW per litre of displacement. Another version designed with the geometry typical of a diesel engine was developed between 2007 and 2009, and this power unit has a particularly favourable efficiency. An effective efficiency of 43 percent achieved the level of advanced diesel engines and was virtually free of pollutants.

4. More driving pleasure, comfort and safety through smart networking. Connected Drive – a dynamic concept with fascinating perspectives.

BMW ConnectedDrive contributes a unique, world-class range of driver assistance systems and services for optimising comfort and safety, and innovative application of infotainment functions in the vehicle. No other automobile manufacturer has a similarly comprehensive portfolio of driver assistance systems, packages for using mobile terminals in the vehicle, and mobility services covering traffic information, emergency call, vehicle information and office services, travel and leisure planner, as well as internet access. The leading position taken up by the world's most successful manufacturer of premium automobiles with BMW ConnectedDrive is the result of ground-breaking and consistent development work. BMW Forschung und Technik GmbH has developed an array of different innovations and has made substantial contributions to the outstanding expertise held by the BMW Group in this sphere. The research centre has played major roles in the past in the development of driver assistance systems such as Active Cruise Control, Lane Departure Warning, and it also contributed ideas for the innovative control concept BMW iDrive and for MINI Connected.

Motivated by the objective of opening up new perspectives for networking with the outside world and creating the foundations for the necessary technology, the specialists at BMW Forschung und Technik GmbH are working on additional new infotainment and assistance systems, as well as their control interface. These ideas always extend beyond the scope of the assistance systems integrated in current series vehicles and sometimes they extend way off the radar.

Strategic support in demanding driving situations: the narrow-passage assistant.

The philosophy of driver assistance in the BMW Group is focused strategically on enhancing the mastery of the driver. Strategic processing and presentation of information in demanding traffic situations helps drivers to arrive at an enhanced assessment of the current conditions applicable to each new scenario. Sensors and high-tech camera systems gather data which is evaluated by a powerful computer and then presented in the form of visual, acoustic and haptic alerts for taking action. For example, the systems Lane

Departure Warning and Lane Change Warning flash up graphic warning signals and also generate a subtle but unmistakable vibration in the steering wheel in order to make the driver aware of unintentional departure from the lane or to the potential for a collision when carrying out an overtaking manoeuvre.

BMW Group Research and Technology is currently working on a new dimension of driver support in complex situations based on the Lane Departure Warning. The so-called narrow-passage assistant will be premiered in public to celebrate the 25th landmark birthday of BMW Forschung und Technik GmbH. The system enhances driver control when travelling along particularly narrow lanes. It helps drivers to correctly assess a narrow passage in advance – for example when they are driving through building works – keep to their line precisely when they are driving through the narrow passage, and maintain the optimum safety gap on both sides.

The narrow-passage assistant uses a laser scanner which measures the area in front of the vehicle, and ultrasonic sensors that estimate the lateral gap to obstacles such as crash barriers or other vehicles. The data collected is pooled and an overall picture is generated that is then transmitted to the driver. This makes it easier for the driver to assess the situation on the road before entering the narrow passage or to keep on course while driving through.

In everyday traffic, the narrow passage assistant can be used while driving through motorway building works where two parallel lanes are allocated for traffic travelling in one direction but drivers have to concentrate very carefully because of the reduced width. Overtaking manoeuvres present a particularly difficult challenge. The narrow-passage assistant helps the driver to assess whether safely overtaking a truck driving in the other lane is feasible. If there is not enough room in the driver's own lane in order to carry out the manoeuvre without risk, the driver is given a warning in advance. If the lane is sufficiently wide, the driver also receives instructions while he is overtaking that enable him to keep the ideal gap on both sides. The available gap on both sides is indicated in the Head-up Display with circular symbols. As soon as the gap to the crash barrier or the vehicle in the parallel lane has become reduced beyond a defined dimension, a brief steering pulse is given. If the driver accepts this information, the vehicle returns to the optimum trajectory.

When they were developing the narrow-passage assistant, the specialists at BMW Forschung und Technik optimised data recording using sensor systems and laser scanners as well as enhancing the evaluation of the information gathered in this way. The ideal way of communicating instructions

for action to the driver was also analysed down to the last detail. Comprehensive usability tests using a drive simulator indicated that the combination of optical signals and a brief steering pulse were the most effective method of providing support for the driver in carrying out the manoeuvre. These tests are now also being carried out on cordoned-off roads – in a BMW X5 technology platform structured especially for this purpose.

Automated driving in hazard situations: the emergency stop assistant.

BMW Group Forschung und Technik aims to be ahead of the times. That is why the research includes projects in areas that are investigating the potential applications of highly automated driving in the context of defined situations. The emergency stop assistant provides a particularly impressive example of the technological demands and the applications for systems of this nature. It forms part of an initiative launched in May 2009 by the German Federal Ministry of Education and Research, and deploys innovative technologies for localising and controlling the vehicle, and analysing the immediate environment in order to increase traffic safety.

The emergency stop assistant developed in the context of the research project “Smart-Senior – Intelligent Services for Senior Citizens” is able to change to autonomous drive mode if an emergency situation caused by a health problem with the driver is identified, in order to carry out a safe emergency braking procedure. This aim is achieved by the system activating the hazard warning lights, manoeuvring the vehicle across several lanes to the side of the road in a controlled manner and taking account of the traffic situation in the surrounding environment, and finally bringing the car to a standstill. An emergency call is also made automatically in order to summon the necessary medical assistance and institute any traffic control measures necessary. This procedure permits efficient emergency provision tailored to the needs of a particular situation. It is based on the extended emergency call feature that is already available as standard with BMW ConnectedDrive.

Apart from the sensors required for localisation and plotting the surrounding environment, the emergency stop assistant also has sensors for monitoring the vital data of the driver. Again, these can be transferred to the rescue control centre by the emergency call system. The technologies for calculating applicable vital data are also being developed in the SmartSenior project and implementation is being carried out by the project partners Siemens and the Charité University Hospital in Berlin.

Apart from reliable localisation of the vehicle within the lane, precise execution of the manoeuvre primarily involves robust identification of all the vehicles in the immediate environment. Innovative methods of sensor data fusion from LIDAR, radar, camera and digital map are being used for this purpose. The technology for carrying out the emergency stop manoeuvre is based on already available driver assistance systems, such as Lane Departure Warning and Active Cruise Control with Stop and Go function. However, these systems will have to be expanded and adapted because of the technological challenges of highly automated driving.

Optimised vehicle localisation: with the TrackTrainer on the North Loop of the Nürburgring.

The precision of localising the position, and the dependability of the manoeuvre being carried out automatically, are the key attributes that may enable the emergency stop assistant to contribute to more enhanced safety on the roads. The defining technical prerequisites for this were developed in an earlier project carried out by BMW Forschung und Technik GmbH. The TrackTrainer enables defined tracks to be negotiated in an automated drive mode. The high level of precision provided for localisation means that a dynamic and safe driving performance can be achieved on account of the high level of precision applied in localisation. The TrackTrainer is currently being deployed for BMW Driver Training in order to convey the sense of the ideal line in an immediate experience (behind the steering wheel and not on the passenger seat).

Assisted by a fusion of the data from a highly precise digital map, as well as GPS and video data, the Track Trainer is in a position to negotiate racing tracks in an ideal line for training purposes. The second generation of the system is now already being deployed, and the availability of highly precise position localisation is being further optimised by fusion of redundant sensors. Permanent reconciliation of GPS and video data with the digital map material and the data within the vehicle now enables the "Nordschleife" (North loop) of the Nürburgring to be negotiated in fully automated mode. The achievement is particularly challenging from a technical perspective and was successfully accomplished for the first time on 21 October 2009.

Independent manoeuvring in very tight spaces: the garage parker.

Researchers have been addressing the issue of automated driving in specific situations for a number of years now. BMW Forschung und Technik GmbH had already presented the garage parker for the first time in 2006. This system enables the vehicle to be manoeuvred independently. All drive, braking and steering functions are controlled automatically to enable the vehicle to be steered in and out of a garage where space is restricted using

remote control by the driver. If required, the system also activates the warning indicators and the headlamps automatically, as well as swinging the wing mirrors in and out. BMW Forschung und Technik GmbH developed this system as a technology that saves the driver from having to get in and out of the car in the confined space of a garage. It can also reduce the possibility of damaging the doors.

The garage parker has been integrated in a BMW 7 Series saloon. The system uses a camera attached to the rear view mirror for recording the situation in front of the vehicle. This is complemented by a reflector that is attached to the facing wall of the garage in order to provide a reference point. The images generated by the reflector are recorded by the camera while the manoeuvre is being carried out. If necessary, course corrections are made with the assistance of the electric motor integrated in the steering system. The computer unit for the garage parker controls the steering system and the Auto Start Stop function of the engine, the gearshift selection of the automatic transmission, the braking system and the Park Distance Control. Since the entrance to the garage is often a particularly narrow passage, the system aligns the car on a maximally straight path at an early point. The selected parking line is saved by the system before the engine is switched off. The same line is followed when the car reverses out of the garage.

Safety aspects are already part of this research prototype. During the entire parking procedure, the lock button in the key must be kept pressed down – if it is released, the car stops immediately. If the driver's door isn't opened within a defined period of time after the car has reversed out of the garage, the system automatically stops the engine and locks the car again. And naturally the garage parker reacts immediately to any obstacles encountered while the car is being parked in the garage.

Networking is the future: vehicle-to-vehicle communication for enhanced safety and efficiency.

A key area of development for our research subsidiary is exchange of information between vehicles and between vehicle and traffic infrastructure, known as Car-to-X Communication (Car2X). One example is transmission of information about sequence times from traffic light systems. This means that a driver assistance system can either get information about the optimum speed so that cars can hit an individual "green wave" sequence of traffic lights and travel without stopping, or issue a warning about the possibility of going through a red light.

Strategic transfer of data about the traffic situation, conditions on the carriageway and other factors allow early warnings to be broadcast from one

vehicle to other drivers in the immediate environment about accidents, traffic jams or the formation of black ice. It is also possible to calculate the risk of collision based on the transmitted vehicle data so that warnings can be given in advance of potential crashes at junctions.

BMW Group Forschung und Technik uses this technology to investigate and develop an array of assistance and information systems. The focus of this research is directed beyond the car itself and also integrates motorcycle riders into the communication process within the scope of the BMW Motorrad ConnectedRide strategy.

Research is currently being carried out into systems like emergency vehicle warning, and indicating obstacles, bad weather or abrupt braking action taken by vehicles driving in front.

The emergency vehicle warning gives an early indication of an approaching emergency vehicle with a visual display and additionally provides information about the distance between the emergency vehicle and the own car or motorcycle. The emergency vehicle also communicates its current position, the route and the status of the flashing signals or siren. This enables drivers to take early evasive action and make way for emergency vehicles to avoid critical situations.

The warning about obstacles includes vehicles that have broken down and accidents in the driver's lane, building works and the end of a traffic jam. Different systems are able to trigger this obstacle warning: the broken-down vehicle itself or several vehicles at the end of the jam, by activating the warning indicator or by their braking manoeuvre.

If there is black ice on the road or a severe weather warning, an alert resulting from interventions by control systems (Dynamic Stability Control, etc.) can be triggered. Other severe weather warnings are activated if several vehicles switch on their fog warning lamps, for example, or use their windscreen wipers. Linked with the outside temperature or other sensors (rain sensor, video camera, weather report, etc.), the trigger algorithm outputs appropriate signals in the Head-up Display, on the instrument panel, or acoustically via the BMW Motorrad communication system. Early information about wet conditions is a massive safety factor especially for motorcyclists.

When cars are moving slowly behind each other in a traffic jam, the brake lights of a vehicle are frequently concealed by the following vehicle. This information is also communicated to the road users via the communication system in order to alert the driver behind to heavy braking in good time. The

driver is then in a position to respond appropriately. Here too, the information is communicated by visual or acoustic alerts.

Research project for innovative control systems: Drive Stick.

BMW Forschung und Technik GmbH also carries out ground-breaking work in the development of revolutionary operating concepts and control systems. One example of this is the concept of an entirely innovative cockpit design presented in a second-generation BMW 3 Series compact, with the Drive Stick as the focal point. Instead of steering wheel, accelerator and brake pedal, the concept vehicle has two control levers projecting vertically from the door panel and the centre console. These allow the driving direction, acceleration and deceleration to be controlled using drive-by-wire technology.

The two control sticks linked to each other transfer commands to the drive, braking and steering system electronically without any mechanical link. The sticks are pushed forward to activate the acceleration, and the instruction to apply the brakes to the vehicle is passed on by pulling the drive sticks back. The driver transfers steering instructions by moving the levers to right or left. These movements allow all dynamic movements involving longitudinal or transverse manoeuvres to be carried out by intuitive manual control. Gearshift commands for the automatic transmission can be conveyed by pressing on the buttons integrated in the control levers. The controller of the iDrive system is also integrated in the Drive Sticks. In emergency situations, the passenger could also intervene and take control of the drive, control and steering functions.

Eliminating the pedals and steering wheel opens up new dimensions for innovative concepts in cockpit design. The intensive cooperation between the specialists in drive-by-wire technology and the design department of BMW Technik GmbH led to a revolutionary new design for the interior. The research vehicle has a central rear-view projection display on the centre console. Innovative solutions were also developed in the design of the structural member for the instrument panel and the position of the seats for the driver and passenger. Aside from the general feeling of space in the interior, convenience and comfort were optimised for the driver getting in and out of the car.

The Drive Stick project provides a particularly vivid example of the abilities of the specialists working at BMW Forschung und Technik GmbH to ask questions about basic assumptions, deploy a high level of creativity in seeking out radically different solutions, and harness the potential of innovative technologies. The knowledge collected in this project played a major role in influencing the development of the electromechanical power steering

marketed for BMW series models. It also provides the typical BMW steering feeling under the conditions of power steering support.

From sailing to vehicle: optimised head-up display technology.

Their fundamental research and technology development continually encourages the researchers to look at issues that at first glance appear to be way beyond the scope of the automobile. However, over the long term the knowledge gathered in this way is channelled into projects that lead to an increase in comfort, safety and driving pleasure within the context of BMW ConnectedDrive. The team from the Technology Office located at Palo Alto in the US developed a miniature Head-up Display in the sunglasses of the crew members in the Oracle BMW Racing Team. This system was designed for use in the ocean race for the America's Cup and allows information and commands to be transferred speedily and selectively by projecting it onto the lenses of the sunglasses. This project generated additional know-how that was used for the advanced development of the Head-up Display in the latest series vehicles of BMW.

Identification and integration of new technologies as a recipe for success: BMW ConnectedDrive Services with unique, world-class functionality.

Defining principles were also identified by the Technology Office in Palo Alto for integrating external communication and entertainment modules in the vehicle. The first interface for integrating the Apple iPod was developed there and this included the option of using the BMW iDrive System to control the audio function. This technology went already in series production in 2004. The pioneering work carried out by BMW Forschung und Technik GmbH has secured BMW a unique position for the integration of external communication and entertainment systems in the vehicle. This enabled the BMW Group to be the first automobile manufacturer in the world to punctually introduce fully harmonised integration of the innovative Apple iPhone in the vehicle control systems for the US market launch in June 2007. Further developments in this area also optimise integration of the communication and audio functions of advanced mobile phones in the vehicle control system. Concepts for the latest infotainment innovation – MINI Connected – were also created in the California think tank.

Innovative services for alternative drive concepts.

The concept of a vehicle operated solely by electric power opens up additional possibilities for the integration of innovative comfort features in combination with robust technology for storing electricity. A specific heating and air-conditioning system was developed for the BMW Concept ActiveE, which was supplied with energy from the high-voltage capacitor. This offers the option of

using auxiliary heating or cooling systems to heat up or cool down the interior of the vehicle even when the vehicle is at rest prior to the start of a journey.

The air-conditioning systems developed for the BMW Concept ActiveE can also be activated from outside the vehicle. In addition to the remote control already supplied with the latest series vehicles, control by mobile phone is also possible. This option includes a timer function. It allows the driver to ensure that they will be able to get into the pleasant atmosphere provided by a pre-cooled or pre-heated car in the morning. The climatic pre-conditioning optimises the drive comfort and the operating status of the energy storage capacitor in favour of maximum range. Controlling the heating and air-conditioning system by mobile phone is provided by BMW ConnectedDrive and this capability was developed by the specialists at the Palo Alto Technology Office.

The intelligently controlled operation of the auxiliary heating or air-conditioning activated by remote control is complemented by other services developed specifically for the BMW Concept ActiveE. In particular, drivers are able to get information about the charge status of the lithium-ion rechargeable batteries and the range available at any distance from their vehicle. The remote functions also help drivers to look for a public charging station located nearby.

The idea: Drivers can check the charge status of the vehicle's rechargeable batteries while they are at work or sitting in a café. They can also check the available range. This enables them to find out easily and conveniently whether they can drive to another destination before heading off home without running out of energy. Drivers also have additional flexibility because they can use the remote control to search for public charging stations close to any location. The information transferred to the mobile phone enables drivers to establish in good time whether they can use the planned break in their journey to charge up the batteries of the vehicle.

BMW Key: Additional functions through networking.

The prototype of a multifunctional car key was also developed as a means of networking the mobility experience with the driver's lifestyle. The BMW Key is provided with a security chip that provides personalised access to the vehicle as well as allowing the driver to make cashless purchases, while also enabling other functions such as memorising the e-booking for hotel rooms.

Furthermore, the driver's key has integrated credit card functions which offer the possibility of e-booking for bus, train and air travel from the car and storing the purchased e-tickets on the key. When using hire car or car-sharing systems, the personalised key offers additional potential because it is assigned to the owner of the vehicle rather than to the car itself. A large

number of additional mobility scenarios is also conceivable: In future, car drivers will be able to read off vehicle data, such as number of kilometres travelled, locking status, GPS position, service data and battery charging status using Near Field Communication on the BMW Key. The key owner will even be able to get secure access to personal data in the vehicle. This means that they will have access to authorisation on their ConnectedDrive online access for personal services in the BMW automobile – irrespective of whether they are travelling in their own vehicle or in a BMW hire car. The driver can use the private key to verify their identity, and the vehicle will then adjust to the automatic settings of the user. Access to personal data, e.g. address books, favourite radio stations, or personal service and content subscriptions, is activated using this multifunctional car key.

“IT-Motive 2020”: lean IT architectures for a more robust system in the vehicle.

The continuous increase in the level of electronics in the vehicle is effectively taking the current IT architecture (maximally with more than 70 heterogeneous control units, up to five different bus systems, and a burgeoning volume of software, sensor systems and actuators) to the limits of its capacity. The project "IT-Motive 2020" involves researchers pursuing a new approach for a future lean IT architecture in the vehicle. A BMW 7 Series car has already been fitted with a prototype system. The innovations include a reduction in development expenditure through a lower level of diversity, and optimised use of hardware and software resources as well as creation of scope for the design of new innovations relevant to customers' needs. This approach is focussing on pooling a restricted number of identical and powerful computer units with vehicle-specific peripherals that are linked to each other via an IP-based identical communication network and provided with switches. A central challenge is concentrating functions with radically different requirements – e.g. real-time control algorithms or data-intensive multimedia functions – on a single computer unit, and complying with all future vehicle requirements at the same time.