BMW Group Innovation Day 2011: Efficient Dynamics.
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1. BMW Group Innovation Day 2011: Efficient Dynamics. (Short version)

With its Efficient Dynamics strategy, the BMW Group has at its disposal the most effective concept in the world for sustainably safeguarding individual mobility, by single-mindedly reducing fuel consumption and emissions. With the introduction of innovative technologies which support the responsible use of natural resources, the company, the most successful manufacturer of premium automobiles worldwide, takes a leading position in this field. Efficient Dynamics is a central element in the BMW Group's comprehensive strategy of sustainability, setting a framework and safeguarding the future in terms of ecology, economics and society. Sustainability was defined as a central company principle back in the year 2000. The Number ONE group strategy further reinforces the link between profitable growth and taking responsible action.

This commitment to sustainability, in addition to product stewardship, environmentally friendly manufacturing processes and modern recycling procedures also entails long-term company development as well as multifaceted social involvement. In 2010, for the sixth time in a row, the BMW Group was named the most sustainable automobile manufacturer in the world by the Dow Jones Sustainability Index.

Efficient Dynamics is the guiding principle in all areas of vehicle development. The main pillars of this strategy include the continuous increase in the efficiency of internal combustion engines, the further development of BMW ActiveHybrid Technology, innovative concepts for electric mobility and the long-term use of renewably generated hydrogen as an energy source, as well as intelligent lightweight construction technology and the optimisation of aerodynamic vehicle characteristics. At the BMW Group Innovation Day 2011, the latest innovations and concepts representing the underlying ideas of Efficient Dynamics particularly well will be presented, from the development areas of internal combustion engines, BMW ActiveHybrid, electric mobility and lightweight construction.

Sustainability by commonality: the new BMW Group Efficient Dynamics family of engines.

With the development and production of future drive units with six, four and three cylinders, the BMW Group continues to bank on its independence as well as on the use of innovative technologies in the largest possible number of vehicle concepts. The new BMW Group Efficient Dynamics family of engines uses a standardised set of design principles and a significantly increased number of common components for both petrol and diesel engines. The new BMW modular engine system is based upon the in-line engine principle as well as on the BMW TwinPower Turbo technology package. The high degree of commonality within the BMW modular engine system strengthens sustainability in terms of both economy and ecology.

The new BMW modular engine system allows three, four and six-cylinder power units to be developed, with various power outputs. This scalability lays the groundwork for a broad performance spectrum and thus for diverse, worldwide application in vehicle concepts within the BMW Group. Independent of the number of cylinders, the type of engine and power output, each power unit meets the excellent standards which define engine development in the BMW Group in terms of efficiency, power delivery and running smoothness.

These petrol and diesel engines of the future with three, four and six cylinders will be manufactured with a maximum degree of flexibility at the BMW facilities in Munich and Steyr. By 2012, the BMW Group will have invested almost 300 million Euros in at both production locations.

The latest innovations deliver the highest efficiency: four-cylinder petrol engines and six-cylinder diesel engines with BMW TwinPower Turbo technology and anticipatory transmission control system.

BMW has further increased its lead in the reduction of fuel consumption and emissions, underlining its pioneering role by deploying BMW TwinPower Turbo Technology in additional engines in the current range of models. At the Innovation Day 2011, the BMW Group will present the new 2.0-litre four-cylinder petrol engine in addition to the new version of the 3.0-litre six-cylinder in-line diesel unit, equipped with this technology package. In the new BMW X1 xDrive28i, this engine has improved the acceleration of the vehicle from zero to 100 km/h, taking just 6.1 seconds and has reduced the average fuel consumption in the EU test cycle to 7.9 litres per 100 kilometres – an improvement of 1.5 litres or 16% compared with the previous model. The new, sportier and yet more efficient diesel enables the BMW 530d xDrive to accelerate from zero to 100 km/h in 6.1 seconds at an average fuel consumption in the EU test cycle of 5.7 litres per 100 kilometres.

An anticipatory transmission control system for the eight-speed automatic transmission is a further innovation which will be presented by the BMW Group. This system, which is currently in the advance development stage, allows the shift characteristics to adapt to the current driving situation by networking with other vehicle components and incorporating data from the navigation system. In this way, efficiency and driving comfort as well as dynamics are increased appropriate to the situation.

Hybrid technology and electric mobility: the BMW Group banks on in-house development.

The BMW Group is single-mindedly forcing electrification forward, with the further development of hybrid technology and electric drive systems. The goals anchored in the company's strategy for sustainability are being most effectively pursued with the deployment of BMW ActiveHybrid Technology and electric mobility. The electrification of the drivetrain has created optimised opportunities for mobility independent of fossil fuels, as well as for wide-ranging reductions in CO_2 emissions thanks to the use of renewable energy. The BMW Group strongly believes in its own in-house development and production expertise for the key components: high-voltage storage system, electric motor and power electronics. The company's technological capabilities in drive systems, unmatched anywhere in the world, are thus being expanded to include the field of electric mobility.

A rigorously applied modular approach ensures that the appropriate components are precisely adjusted to meet the requirements of the respective model. The concept of in-house development and an increase in the vertical range of manufacture allow the BMW Group to apply its technological expertise to great effect in optimising the power yield, range and service life of the battery, the power density and efficiency of the electric motor, as well as model-specific control functionality of the power electronics. Furthermore, the high level of quality of all of the systems is guaranteed by the very close cooperation between component development and production.

Intelligent lightweight construction: targeted innovation-heightening efficiency.

When resolving the conflict of objectives which arises between the multitude of demands made on an automobile in the premium segment on the one hand and the pursuit of maximum efficiency on the other, first and foremost weight optimisation is a central consideration, in addition to the optimisation of the effectiveness of the drive system. The concept of intelligent lightweight construction is the ideal prerequisite for realising the unmistakable character of a BMW or of a MINI at the lowest possible vehicle weight. Intelligent lightweight construction methods are found and consistently applied in all

areas of automobile development – in the vehicle body construction, in engine production, in chassis technology and even in the design of the interior.

The latest examples of weight optimisation achieved by the use of innovative materials and production techniques will be presented at the Innovation Day 2011. These include the innovative mix of materials in the bodywork of the new BMW 5 Series as well as a novel concept for a particularly efficient use of materials when using carbon fibre reinforced plastic (CFRP).

Moreover, the engine development engineers are working on innovative components which will not only result in less weight but also in a further decrease in the level of noise emissions for both petrol and diesel engines. In the chassis area, various innovations are in development which will lead to decreased fuel consumption while adding a marked boost to driving pleasure in parallel to weight optimisation. Since any reduction in the weight of unsprung masses and in rotating masses in particular has a direct effect on the agility of the vehicle, the BMW Group places great importance on weight optimisation in the areas of suspension, wheel control and brake systems.

2. BMW Group Innovation Day 2011: Efficient Dynamics. (Long version)

2.1 Synergy, efficiency, sustainability: The new BMW Group Efficient Dynamics engine family.

The BMW Group has firmly established the principle of sustainability within its Number One corporate strategy. With Efficient Dynamics, this principle is consistently and successfully implemented for the purpose of a comprehensive product stewardship. The Efficient Dynamics strategy has established itself worldwide as a trademark for exceptionally effective measures for reducing the fuel consumption and emission levels of new vehicles. During the past 15 years, the BMW Group has lowered the CO_2 emissions of its new vehicle fleet in Europe by around 30 percent. At the beginning of 2011, the model range of the BMW and MINI brands already comprised 52 vehicles with a maximum CO_2 emission level of 140 grams per kilometre, 19 of them boasting an emission level of no more than 120 grams per kilometre.

The constant reduction in fuel consumption and CO_2 emissions is always accompanied by a further enhancement of driving pleasure. This advancement, which is characteristic of BMW and MINI, is guaranteed in particular by a fundamental engine strategy. It ensures that innovations realised by BMW Group engine designers are incorporated into all models at an early stage and to the full extent.

Today, the BMW Group already employs significant efficiency-optimising technologies on engines of different size and power output. For example, all diesel engines available for current BMW and MINI models are equipped with an aluminium crankcase, turbocharging and Common Rail direct injection. Moreover, BMW TwinPower Turbo technology is used on both four and six-cylinder diesel engines. BMW TwinPower Turbo technology for petrol engines is also already being employed for the first time in a consistent configuration on four and six-cylinder power units. The technology package comprises optimised air supply by means of VALVETRONIC, efficient combustion through precise fuel-air mixture supply facilitated by High Precision Injection, as well as state-of-the-art turbo technology.

The new BMW Group Efficient Dynamics engine family featuring BMW TwinPower Turbo technology.
Within the BMW Group Efficient Dynamics engine family, BMW TwinPower Turbo technology constitutes a common feature of all four and six-cylinder

petrol and diesel engines and is also designed for use on future three-cylinder engines. BMW TwinPower Turbo comprises variable ventilation of the engine, optimised fuel combustion and the most effective supercharging technology for each specific power unit. Based on the BMW TwinPower Turbo technology package, various power units are available within the BMW engine range that can be utilised worldwide according to the Efficient Dynamics strategy and across the entire spectrum of the model portfolio.

The highest level of technology is the benchmark, maximum synergy the target.
Through consistent development of components that can be employed not only for different size engines but also both for petrol and diesel power units, the BMW Group increases the so-called degree of commonality within the engine portfolio through the use of a modular engine concept. The technology package BMW TwinPower Turbo is the benchmark for all power units and is designed to meet the demands of exceptionally powerful engines.

Using maximum efficiency in the development and manufacturing process, the best possible technical solutions for the entire spectrum of the engine range can be made available. Therefore, irrespective of the number of cylinders, combustion process and power output, each engine conforms to the excellent standards defined by BMW Group engine designers with regard to efficiency, power development and running smoothness.

The BMW modular engine system strengthens economical and ecological sustainability.
A concordant architecture and a consistent design principle for all future petrol and diesel engines featuring three, four or six cylinders serve as the basis for increased commonality within the drive portfolio. The modular engine concept arising from this is the result of BMW drivetrain development, with the engines also being built by BMW. Thanks to this approach, a further contribution towards the strengthening of the BMW Group's independence is being made.

BMW modular engine system guarantees significant advancements both in the economical sustainability for the company in terms of development and production as well as in ecological sustainability with regard to the fuel and emission levels of future models. Therefore, it constitutes a crucial pillar for the successful continuation of the BMW Group Efficient Dynamics strategy.

Perfect thermodynamics, in-line principle as a common basis.
The in-line engine construction principle forms the common basis for the basic variant of all petrol and diesel engines. For modular engine assembly a cylinder displacement of around 500 cubic centimetres per combustion chamber is

defined, with which optimum thermodynamics can be achieved. As a result of this principle, the displacement of each engine is directly proportional to the number of combustion chambers.

Development and production efficiency through communal components and common interfaces for vehicle integration.
In addition, the constructional commonalities are related, inter alia, to cylinder spacing, the crankcase and balance shaft concept as well as the position of the drive chain on the flywheel side. Furthermore, petrol and diesel engines can also be equipped with standardised oil sumps including vacuum pump and constructional commonality can also be achieved through belt drive configuration, the arrangement of ancillary components and positioning of the exhaust gas after-treatment systems in the proximity of the engine. The proportion of all identical or communal components utilised across the entire engine range increases to up to 60 percent.

Moreover, all three and four-cylinder petrol and diesel engines developed according to this principle offer the prerequisites for both longitudinal and transverse installation in future BMW or MINI models respectively. Additional efficiency in development and production is achieved through standardised interfaces between power units originating from the BMW modular engine system and each specific vehicle.

The scalable modular engine system facilitates a broader performance spectrum for variegated use within the model portfolio.
The new BMW modular engine concept offers the possibility to develop three, four and six-cylinder engines with varying power output levels. This scalability creates the preconditions for a broad performance spectrum and, simultaneously, for a multitude of uses within BMW Group vehicle concepts. As the components used on engines of varying size and power output are produced in significantly higher quantities, it will be possible also in the future to achieve the desired diversity within the drive portfolio with considerably optimised cost efficiency. As a whole, a newly introduced engine already achieves the profitability necessary for a long-term economical production strategy with a quarter of the quantity previously required. Thanks to the BMW modular engine system the BMW Group produces significantly higher quantities of individual components along with the associated economies of scale.

Moreover, the high degree of commonality results in a reduction in cost and effort required for the development of additional engine variants. For example,

particularly powerful versions of an existing engine or hybrid variants for individual series can be economical even with comparably low quantities.

BMW Group to invest almost 300 million Euros in engine production.
Due to the increased proportion of communal components, not only is synergy significantly increased, but also flexibility within the production process. At the BMW Group engine manufacturing facilities at the company's headquarters in Munich and in Steyr in Austria it will be possible also in future to produce petrol and diesel engines of all sizes. Thanks to this strategy it will be possible to respond to sudden changes in demand, which arise for instance when new models are launched, with a high degree of flexibility.

In order to implement the new engine strategy and to secure the associated degree of flexibility, the BMW Group will invest almost 300 million Euros in both production locations by the year 2012, of which 160 million will go to the BMW Munich plant alone.

2.2 Optimised efficiency through the highest level of development expertise: The new petrol and diesel engines with BMW TwinPower Turbo technology, eight-speed automatic transmission with anticipatory control function.

With the engines and transmissions either currently being introduced or shortly reaching series production maturity, the BMW Group has at its disposal a globally unique range of products in the field of drive technology. Thanks to their exceptionally high degree of efficiency the new petrol and diesel engines as well as current and future transmission concepts create the optimum preconditions for a further reduction in fuel consumption and emission levels within the Efficient Dynamics strategy.

As a result of the outstanding development expertise in the field of drive technology, BMW TwinPower Turbo technology is now being successively introduced on all petrol and diesel engines. This technology is utilisable irrespective of overall displacement and the number of cylinders featured by each engine – and also worldwide. The BMW Group also exploits additional efficiency potentials in the development of the eight-speed transmission. Today, the transmission control system already allows for the driver's varying operating situations and requirements and selects the appropriate gear in each case. Anticipatory transmission control also offers the possibility to adapt the shifting characteristics through the interconnection with other vehicle components and using navigational information. In this way, both efficiency and travel comfort as well as driving dynamics are enhanced appropriate to the situation. It is planned in future to exploit further potentials resulting from the intelligent use of networked functions.

Technological upgrade: BMW TwinPower Turbo technology featured on the four-cylinder petrol engine.

Simultaneously with the market launch of the new BMW X1 xDrive28i, BMW has given the starting signal for the first four-cylinder representative of the Efficient Dynamics engine family. The 2-litre power unit is equipped for the first time with BMW TwinPower Turbo technology already successfully employed on the in-line six-cylinder power unit. The engine's technology package comprises a supercharging concept according to the Twin Scroll principle, direct petrol injection, double VANOS variable camshaft control and VALVETRONIC variable valve control.

The newly designed engine under the bonnet of the BMW X1 xDrive28i delivers 180 kW/245 bhp, this being 55 kW more than BMW's previously most powerful four-cylinder combustion engine. Maximum torque of 350 Nm is already available at an engine speed of 1,250 rpm. Thanks to this value, the new BMW TwinPower Turbo power unit even surpasses a BMW six-cylinder aspirated engine in terms of response and pulling power. Furthermore, the increase in dynamics is accompanied by a significant reduction in fuel consumption and emission levels. Performance and consumption levels of the new BMW X1 xDrive28i are an impressive example of the advancement that can be achieved through BMW Efficient Dynamics. The car sprints from 0 to 100 km/h in just 6.5 seconds, 0.3 seconds faster than the predecessor model also featuring an automatic transmission. Average consumption is down by 1.5 litres to 7.9 litres/100 km.

The remarkable performance of the new four-cylinder engine is not only the result of BMW TwinPower Turbo technology, but also of extensive innovations implemented on the basic engine. Vertically offset balance shafts effectuate optimised vibration compensation. In addition, a centrifugal force pendulum integrated into the dual-mass flywheel ensures a noticeable reduction in irregular rotations usually occurring within the lower engine speed range. Thus, the engine's early high torque output can be utilised without any loss in comfort. The optimum vibration damping achieved through the centrifugal force pendulum remains effective across a broad engine speed range. Hence, the new 2-litre engine advances to a level of running smoothness that was previously only achievable with six-cylinder engines.

Even sportier, even more efficient: in-line six-cylinder diesel engine featuring latest-generation BMW TwinPower Turbo technology.
With the further development of BMW TwinPower Turbo technology, additional dynamics and efficiency potentials have also been made accessible for use on in-line six-cylinder diesel engines. Consequently, the latest variant of the powerful BMW diesel engine continues to expand its position as a particularly sporty power unit. As a result of Efficient Dynamics, response

characteristics and maximum performance are enhanced yet again, coupled with a simultaneous further reduction in fuel consumption and CO_2 emissions.

Compared to the previous engine, the new 3-litre diesel power unit boasts a further optimisation of internal friction coefficients, weight and fuel injection. Maximum power output has been increased by ten kW to 190 kW/258 bhp. Maximum torque is now 560 Nm (20 Nm more) and is available at 1,500 rpm. Apart from modified air supply with shortened ducts, the response characteristics of the new six-cylinder diesel engine also benefits from a weight-optimised crankshaft.

An optimised injection process contributes additionally towards an increase in output and torque. Common Rail injection, the solenoid valve injectors of which operate at a maximum pressure of 1,800 bar, ensures, inter alia, by means of a recalibrated pre-injection system even more efficient combustion, exceptionally spontaneous power development and further enhanced acoustic characteristics of the diesel engine. The turbocharger with variable intake geometry has been further optimised and now boasts even better stability. Simultaneously, the weight of the turbine wheel was reduced. The exceptionally spontaneous response of the supercharger associated with this boosts power delivery at low engine speeds.

The enhanced efficiency resulting from this is reflected in an outstandingly favourable fuel consumption/performance ratio. The diesel engine featured in the new BMW 530d xDrive facilitates acceleration from 0 to 100 km/h in 6.1 seconds. Average fuel consumption in the EU test cycle is 5.7 litres/100 km, whilst the CO_2 emission level has been reduced to 150 grams per kilometre.

In terms of its basic constructional features, including the arrangement of the ancillary components and the belt drive, the new in-line six-cylinder is virtually identical to the current BMW four-cylinder diesel power units. Furthermore, it offers optimised prerequisites for fulfilling the stringent exhaust emission standards applicable in all crucial automotive market throughout the world.

Eight-speed automatic transmission with anticipatory transmission control system.

In addition to the high degree of engine efficiency, the transmission technology featured in current models also contributes towards the exceptionally high level of efficiency of BMW automobiles. A significant advancement was achieved above all through the introduction of the new eight-speed transmission. An innovative gear set configuration featured in this transmission permits the combination of additional drive positions and a greater transmission ratio spread with a compact design and optimised weight.

Compared to the previously employed six-speed automatic transmission, the new gearbox features two additional gears and a transmission ratio spread that has been increased from six to seven, whilst the number of gear sets has been increased by just one to a total of four, the number of clutches even remaining the same. Thanks to the low number of additional components, the system's internal efficiency is optimised.

In addition, the eight-speed automatic transmission, which is now combined with four, six, eight and twelve-cylinder engines, is characterised by particularly high shifting dynamics and direct gear selection. The electronic control of the transmission facilitates varying control maps for shifting characteristics, with which either an exceptionally dynamic or a comfort-oriented driving style is achieved.

Development objective: identify road profile, understand driver's wishes.

As a result of further development there is now the possibility to adapt gearshift commands given by the transmission control system to each driving situation even more flexibly and at the same time more accurately. The anticipatory transmission control system currently in the advance development stage utilises, in addition to the driver's intention, further information to take into consideration road surface conditions, road topology as well as the traffic situation when selecting the ideal gear. For this purpose, the transmission control system is linked to both the DSC (Dynamics Stability Control) function as well as the navigation system in the initial stage. In the configuration levels that follow, a link-up with the cameras utilised for the driver assistance systems or radar and additional sensors respectively is under consideration.

The data provided by the DSC sensors pertaining to the road surface friction coefficient help the system particularly in the case of low friction coefficients to prepare optimally for the typical control intervention during the acceleration phase that follows. Using the data provided by the navigation system, it is possible to determine the radius of a bend long before it is approached. Based on this information the transmission control system then determines with even greater accuracy the gear required for a smooth driving manoeuvre and confident acceleration out of the bend. Moreover, using information provided by cameras and radar sensors and pertaining to the traffic situation ahead of the vehicle, it will in future be possible to determine for example the required amount of deceleration and adapt the drive management to each specific situation.

In practice and thanks to this anticipatory control system, the automatic transmission adapts remarkably accurately to the situation-related

requirements and demands of the driver. As a result of the complexity of the factors taken into consideration by the control system, the automatic transmission selects the appropriate gear similarly as foresighted as an experienced driver using a manual gearbox. It assists the driver with fast and appropriate response, which immediately leads to an increase in driving pleasure and optimised efficiency. Hence, the interaction between driver and vehicle reaches a new dimension.

2.3 Future-oriented efficiency through targeted electrification: BMW ActiveHybrid technology and electric mobility.

Targeted electrification of current BMW and MINI models is today already contributing towards the efficiency advantage achieved in all relevant vehicle segments. The number of electrically powered vehicle components has been consistently increased within the framework of Efficient Dynamics. Examples of this are the electromechanical power steering system, which is still unique in many segments, as well as on-demand electrical actuation of numerous ancillary components. These systems no longer obtain their power supply directly from the combustion engine. Hence fuel consumption is lowered and the energy contained in the fuel utilised to a greater extent to enhance driving dynamics.

The electricity required for the electrically driven components is obtained to the best possible extent using brake energy regeneration. With this recuperation technology featured as standard in all BMW and MINI models, generator operation is focused on the vehicle's overrun and braking phases. Thanks to this technology, energy in the form of heat that normally escapes unused from the brake discs of conventional vehicles is utilised purposefully.

BMW ActiveHybrid technology and electric mobility: crucial pillars of the Efficient Dynamics strategy.
The BMW Group is constantly pressing ahead with electrification through the further development of hybrid technology and electric powertrains. Like BMW ActiveHybrid technology, electric mobility also constitutes a supporting pillar within the Efficient Dynamics strategy. The importance of these forms of drive technology in high-volume automobile production is dependent on technological advancement as well as political and economical framework conditions alike. Electrification plays a key role on the way to emission-free mobility. The establishing of electric mobility as a sustainable solution for motorised individual transport requires in the long term not only an energy supply infrastructure that is adapted to suit everyday requirements, but also electric power generation from regenerative sources.

Electrification of the powertrain: BMW Group is focusing on in-house development.

The electrification of the drivetrain poses a particularly high potential for achieving a reduction in fuel consumption and emission levels. In the series production models BMW ActiveHybrid 7 and BMW ActiveHybrid X6, both of which are equipped with BMW ActiveHybrid technology, the power required for the electric drive functions is obtained to a large extent by means of brake energy regeneration. Additionally required electric energy is gained by means of an efficiency-optimising shift of the engine operating point. Furthermore, a significant efficiency advantage is achieved through switching off the engine during idling as well as the supporting effect of the electric motor in obtaining particularly dynamic acceleration.

Plug-in hybrid concepts facilitate charging of the vehicle with energy from the main power supply system. In both cases the achievable vehicle range in purely electrical operation is highly dependent on the capacity of the storage systems. The attributes of the electric motor influence vehicle characteristics in terms of agility, power development and range, whilst the power electronics secure the effective interaction between the energy storage unit and the electric powertrain. In the case of these key components for hybrid and electric vehicles, the BMW Group places the emphasis on in-house development and production. For this purpose the globally unique technological expertise in the drive system sector is also being extended to the field of electric mobility. In this way, high-voltage storage units, electric motors and power electronics can be precisely adapted to the requirements of each model.

High-voltage storage units: flexible modular system facilitates model-specific configuration in the vehicle.
In the BMW ActiveHybrid 7, the energy supply to the mild hybrid system is provided by a remarkably compact lithium-ion battery comprising 35 single cells, which is integrated into the luggage compartment. It delivers 0.8 kilowatt hours (kWh) of energy, providing a maximum vehicle output of 19 kW.

In order to meet the power and energy requirement of future hybrid and electric vehicles to the full, the BMW Group has achieved unmatched flexibility in the model-specific configuration of high-voltage storage units through a modular development concept. Each storage unit of a hybrid or electric vehicle comprises a different number of modules, which in turn each consist of a specific number of battery cells. These are interconnected in series in order to match the power and energy capacity requirements of each vehicle.

Due to the available installation space of this conversion concept, the integration of the new BMW high-voltage storage unit into the BMW ActiveE

required three storage units of different size and shape. They are installed within the area of the centre tunnel, at the front and at the rear of the vehicle. The storage units contain several modules of three different sizes, the designs of which have identical cell sizes, structures and subcomponents, each of them having a different number of cells. The three storage units provide the BMW ActiveE's 125 kW electric motor with 30 kWh of power.

The lithium-ion cells used in both models are characterised by high energy density and cyclic stability. In order to utilise the benefits of a modular system even more effectively, the BMW Group is working together with other car manufacturers to introduce common standards for the size of individual battery cells. A considerable reduction in costs can be achieved through this standardisation and production in large quantities. On hybrid models featured to date, around 60 percent of the cost of the electric drive system are solely attributable to the battery cells, this being as much as 75 percent in the case of an electric vehicle.

Better performance and longer range through BMW Group innovations for electronic, battery management, housing and cooling system.

For a comprehensive optimisation of the high-voltage storage unit the BMW Group also utilises its technological expertise in the development of further battery system components. These include specific components for the interconnection of the cells themselves and the battery system with the vehicle as well as the integrated control unit and electronic components in the proximity of the cells, including sensors for battery management. In addition to safety monitoring, exceptionally efficient battery management guarantees operation control as well as accurate state detection and various diagnostic functions.

The battery housing and model-specific mounting elements developed by the BMW Group ensure comprehensive protection of the high-voltage storage unit from environmental influences and a structurally stable integration into the vehicle. Moreover, the high-voltage storage systems are equipped with practice-oriented cooling technology. The temperature of a battery system rises both due to power loss during operation as well as to external thermal input as a result of high ambient temperatures. Therefore, when lithium-ion storage units are used in vehicles, they are normally fitted with a battery cell cooling system.

The in-house development concept and the increase in manufacturing expertise in the area of high-voltage storage systems allow the BMW Group to use its technological know-how especially for maximising power output and

the range and lifespan of the battery through effective battery management, intelligent operation strategies and optimum heat management. Over and above that, the high quality level of the storage systems is also guaranteed by the close coordination between component development and production.

BMW Group develops made-to-measure power electronics.
The power electronics responsible for the interaction between the battery and the electric motor are also developed by the BMW Group exclusively for each specific vehicle. The power electronics serve both as an inverter for the power supply from the battery to the electric motor as well as a voltage transducer interacting between the high-voltage storage unit and the 12-volt onboard power system. Furthermore, highly sophisticated software control provides for the best possible current flow between the battery and the electric motor, which also acts as a generator during overrun phases. On plug-in hybrid and purely electrically powered vehicles the battery charging function is incorporated into the power electronics.

Whatever the task, the power electronics must be able to control the required current flows variably and according to each situation. Thus the power requirements from the onboard power system vary between several hundred watts and two to three kilowatts, depending on the driving situation. The electric motor of a purely electrically powered vehicle requires energy for constant power outputs ranging from 20 to 60 kW. In particularly dynamic driving situations, significantly higher ratings are temporarily achieved. In their function as a battery charger, the power electronics operate, depending on the power available from the socket, within a range between three and as much as 20 kW. Inverter, voltage transducer and charging electronics require a cooling system that is especially adapted to demands in order to ensure their permanent and efficient functioning at the ideal operating temperature.

Electric motor: optimum efficiency through cutting-edge technology expertise.
The BMW Group also focuses on company-specific solutions in the development of electric motors, also bringing to bear its worldwide leading technological expertise in the field of drive systems for the benefit of driving pleasure from the power socket. Like petrol and diesel engines, electric motors designed by the BMW Group are characterised by an exceptionally high degree of efficiency. Moreover, the development strategy offers the possibility to realise an electric powertrain that is designed to match the individual character of specific hybrid and electric models. Irrespective of this, all variants within the electric drive portfolio set standards not only though their efficiency and power development, but also through superior qualities in

terms of acoustic and vibration characteristics that fulfil the premium standard required of BMW Group brands.

When choosing a design principle with which the highest demands on a drive system in the premium segment can be fulfilled, the BMW Group decided in favour of the development of a so-called hybrid synchronous motor (HSM). Thanks to their particularly favourable power-to-weight ratio, electric motors of this type offer the ideal prerequisites for efficient mobility. In addition to the superior power density, the high level of operational effectiveness poses a further advantage. In terms of overall efficiency, the hybrid synchronous motor surpasses asynchronous and permanent-magnet synchronous motors by up to five percent. Furthermore, an electric motor featuring the HSM principle excels through the fact that it is able to achieve 95 percent efficiency across a particularly wide load range. Thus, in direct comparison with other types of electric motor featuring the same battery technology, it is possible to achieve a significantly longer range.

A characteristic feature of electric motors is their high level of torque, which is available from standstill. In spite of this principle-related attribute, electric motors also have differing response characteristics. In order to do justice to the typical character of both BMW and MINI in terms of power output, designers of electric motors attached great importance to both a spontaneous response and a stable torque up to a high load range. In these respects too, the hybrid synchronous motor poses significant advantages compared to other types of electric drive. Furthermore, the electric motor developed by the BMW Group is characterised by exceptionally quiet and smooth running qualities. In this area, BMW makes consistent use of synergies from the development and production of particularly smooth-running internal combustion engines. Hence the hybrid synchronous motor also meets the demands on a drive system designed for premium automobiles with regard to acoustic and vibration characteristics.

2.4 Intelligent lightweight construction as a development principle for Efficient Dynamics: New perspectives on weight improvement.

Thanks to Efficient Dynamics the BMW Group is succeeding in continuously reducing the consumption and emission values of current and future models and simultaneously increasing the pleasure of driving characterised by dynamics and agility. Furthermore, additional requirements, such as active and passive safety and driving comfort, are taken into account. For the solution of the conflict of interests between the many demands made on premium segment vehicles and the pursuit of maximum efficiency not only efficiency optimisation of the drive system, but above all weight optimisation plays a vital role. The concept of intelligent lightweight construction creates ideal conditions for the realisation of the unmistakable character of a BMW or a MINI model at as low a vehicle weight as possible.

The principle of intelligent lightweight construction applies and is consistently pursued in all sectors of automobile development – from body and engine construction to chassis technology and interior design. The BMW Group has established a process step, which during the predevelopment phase already generates ideas for alternative materials or constructional designs leading to an optimisation of vehicle weight. Innovative production processes expand the range of viable solutions. Apart from alloys and plastics, renewable raw materials and foams, also increasing use of composites and hybrid materials is made.

The demands imposed on every lightweight construction solution are sophisticated. Each new material must at least equal the previously used material in functionality and reliability and at the same time be significantly lighter. Furthermore, the production costs including energy and raw materials and their recyclability are taken into account in the total evaluation. Thus the utilisation of innovative composites became possible only after the development of modern recycling processes. These ensure that it is also possible to completely recycle material combinations after their normal utilisation.

More safety, unique agility, optimised weight: innovative material mix in body construction.

The new BMW 5 Series is an impressive example for the progress achievable through intelligent lightweight construction in the optimisation of body weight. During the development of the saloon and touring models far stricter safety specifications had to be met than had applied for the previous models. At the same time the agility and comfort

characteristics typical for the BMW 5 Series were to be developed further.

Compared to the previous model the average stability of the new 5 Series Saloon's body structure has been increased by 55 percent. Furthermore, the new model shows the typical BMW weight distribution of practically 50:50 between front and rear axles. The high stability of the body and the well-balanced axle load distribution are complemented by optimised total weight and thus further improve both efficiency and agile handling of the new BMW 5 Series.

The solution to the conflict of interests between crash safety and comfort on the one hand and weight optimisation, agility and efficiency on the other was achieved through a precisely defined material mix. The new BMW 5 Series has doors, front side walls and a bonnet made of aluminium. Solely through the use of aluminium doors a weight reduction per vehicle of 23 kilograms compared to a conventional steel construction was achieved. Furthermore, a far higher proportion of hot-formed steel grades compared to the previous model was used. These high-strength steel grades, which involve more elaborate processing, provide – at a lower weight – higher strength and stability using less material. Progress in production technology makes it possible to increase the proportion of high strength steel grades with each model generation. Thus the steadily increasing demands regarding crash safety can be met without an increase in weight.

Optimised material utilisation in the carbon production.
BMW already plays a leading role in the utilisation of carbon fibre reinforced plastic (CFRP) in the automotive industry, which will be considerably increased when series production of the BMW i3 and BMW i8 models announced for 2013 commences. Both models have a passenger cell produced from CFRP, which combines extreme stability with a far lower weight compared to steel, but also to aluminium. This represents the first introduction of this material, known up till now from Formula One racing and the aviation industry, to large-scale series production of cars.

In the medium and long term, not only the models produced under a sub-brand of BMW will profit from this innovative construction. During production development for the passenger cells of the BMW i3 and BMW i8 models an innovative process for further processing of the cuttings from the carbon fibre mats and textiles was conceived. In future these can be used 100 percent for the production of body components. In this way it will be possible to equip other models with extremely light and high-grade carbon fibre components. Increasing the carbon fibre proportion throughout all segments will thus be possible at considerably lower costs than hitherto.

The cuttings are subjected to a newly developed process, during which the carbon fibre cuttings of varying length are woven into CFRP mats of the required size and then, in exactly the manner as the original material, dipped in artificial resin and cured. The strength of the material produced in this way is several times higher than that of carbon fibre reinforced plastic. It equals the strength of a conventional steel component – at a weight reduced to less than a quarter.

In the course of predevelopment utilisation of processed CFRP for example was tested in the prototype of a bonnet for a BMW M model. The lid consists of two carbon layers enclosing either a Nomex plastic or a recycled-paper honeycomb. Also the prototype of a seat shell was produced from the material created through the new technology. The BMW M GmbH has already gathered extensive experience in the utilisation of CFRP in series development. For example, the current BMW M3 Coupé has a carbon fibre roof.

Less weight, lower noise emissions: focus of innovation is on acoustic lightweight construction in the drive area.

With continuously increasing aluminium content and the use of even lighter magnesium for engine construction the BMW Group has significantly reduced the average weight of drive units during recent times. In addition to this, the engine development specialists are working on innovative components, by means of which the noise emissions of petrol and diesel engines can be further reduced. One example here is the acoustic encapsulation for the particulate filter of diesel engines. This provides a clearly noticeable reduction in the noise levels both inside and outside of the vehicle. Thanks to the efficient encapsulation of the particulate filter, part of the sound insulation of the underbody cowling, the bulkhead and the front axle can be dispensed with, so that the total vehicle weight is reduced. Furthermore, the new casing has not only an acoustic, but also a heat insulating function. After a cold start an encapsulated particulate filter reaches its optimal operating temperature faster. The new construction design thus improves the durability of the exhaust gas treatment system.

A further acoustic lightweight construction measure is applied at the engine front. A sound insulating of the belt drive, the so-called engine front bulkhead, absorbs the drive noises coming from the crankcase and the cylinder head, which are of high frequency and therefore unpleasant to the ear. The foam material used for the engine front bulkhead has very low weight but excellent sound absorbance properties.

The encapsulation of the oil sump provides sound insulation immediately at source. Oil sumps made of metal prove to be particularly effective resonance

bodies for the vibrations from the crankcase and crankshaft. This undesired effect is compensated for by insulation composed of fibre material combined with a layer of moulded foam. Due to the deliberately selected material combination the noise emissions occurring are not only attenuated but also absorbed.

Chassis components: reduced weight, improved driving pleasure and efficiency.

The lightweight construction methods in the chassis sector are numerous and they have a direct positive influence on driving pleasure. Every reduction of unsprung, and in particular, of rotating masses has a direct effect on the agility of the vehicle. That is why the BMW Group places particular value in weight optimisation of the suspension and brake systems. With the introduction of the chassis made almost completely of aluminium in 1996, BMW set standards for agility and driving pleasure in all segments. Furthermore, the weight optimisation of chassis technology provides ideal preconditions for greatly improved comfort, for shorter braking distances and for a reduced load acting on the vehicle body.

Among those lightweight construction measures performed on the current BMW series models are the weight-optimised drive shafts with spur gearing (weight reduction 0.8 kilograms per vehicle on models with BMW xDrive), a steering column case made of magnesium (up to 2.0 kilograms) as well as a foot pedal mounting made of plastic and a plastic clutch pedal (up to 1.5 kilograms). With a stabiliser retaining bracket and an articulated column made from fibre reinforced plastic the vehicle weight in each case is reduced by 0.4 kilograms. A gearbox cross member made from fibre reinforced thermoplastic is 1.0 kilograms lighter than the aluminium component previously used.

As part of a predevelopment programme spanning all chassis variants the BMW Group development engineers are also working on weight-optimising innovations, through which a further reduction of mass to the extent of over 20 kilograms can be achieved. Thus for example suspension spring systems made from glass fibre reinforced plastic, which make each vehicle up to six kilograms lighter, as well as extremely weight reduced high-performance braking units are in the predevelopment phase. The construction, consisting of an aluminium fixed calliper and a lightweight brake disc, reduces the vehicle weight by about 8.0 kilograms compared to the brake units already in use in the series production vehicles, which are fitted with an aluminium chamber and an aluminium floating calliper.

2.5 Driving pleasure and efficiency in a new dimension: The new BMW X1 XDrive28i with BMW TwinPower Turbo.

Its distinctive, elegant and sporting design, outstanding agility, top-quality functionality and innovative equipment features have made the BMW X1 the trendsetter for driving pleasure in the compact segment. Now the BMW X1 is breaking new ground in the implementation of the development strategy BMW Efficient Dynamics. The new BMW X1 xdrive28i is the first model of the brand to be powered by a four-cylinder petrol engine with BMW TwinPower turbo technology, high precision direct injection, supercharging according to the Twin Scroll principle, double VANOS variable camshaft timing and VALVETRONIC variable valve control.

The introduction of this technology package marks the generation change in the 2.0-litre BMW petrol engines, heralded by the new BMW X1 xDrive28i. The new 180 kW/245 bhp power unit combines further improved performance compared with the previous engine with considerably reduced consumption and emission values. The new BMW X1 xDrive28i impressively demonstrates this progress on two fronts. It accelerates from zero to 100 km/h in 6.1 seconds (automatic: 6.5 seconds), which is 0.7 seconds (0.3 seconds) faster than the previous model, which was available with automatic transmission only. Its average fuel consumption in the EU test cycle is down by 1.5 litres or 16 percent to 7.9 litres per 100 kilometres. The CO_2 value is 183 grams per kilometre.

The new BMW X1 xDrive28i is equipped as standard with a six-speed manual transmission. Its standard BMW Efficient Dynamics technology includes among other features braking energy recovery, a gear shift indicator, Auto Start Stop function and demand-controlled ancillary components. An eight-speed automatic transmission, which excels through outstanding internal efficiency, is available as an option. Thus the new BMW X1 xDrive28i, whether with manual or automatic transmission, has equivalent consumption and emission values.

The standard four-wheel drive system BMW xDrive in the new BMW X1 xDrive28i is equipped with a multiple disc clutch, which permits variable distribution of the drive torque between front and rear axles. The intelligent four-wheel drive system is linked to the dynamic stability

control (DSC) and reacts quickly to any tendency to oversteer or understeer. It thus improves traction on slippery surfaces and on off-road terrain and driving dynamics in bends.

The engine: a new benchmark for efficiency and dynamics.
BMW X models offer a special experience of the driving pleasure BMW is so well known for. The BMW X1 xDrive28i combines this experience with an efficiency no competitor in this performance field can match. Sporting dynamics on a level that has hitherto been the domain of six-cylinder engines, combined with outstandingly favourable consumption and emission values.

All this has been made possible by the use of a latest generation 2.0-litre four-cylinder petrol engine, which excels through the trendsetting application of innovative technology components. With a displacement of 1,997 cc and world-exclusive BMW TwinPower Turbo technology, incorporating Twin Scroll turbocharging, High Precision Injection, double VANOS and VALVETRONIC, it delivers a maximum output of 180 kW/245 bhp at 5,000 rpm – 55 kW more than the previous top-powered BMW 2.0-litre petrol engine.

Premiere: BMW TwinPower Turbo now also available as a four-cylinder version.
The four-cylinder engine with its all-aluminium crankcase, including a motor sport-derived bedplate, is lighter and more compact than a six-cylinder engine of equivalent power. This has a direct influence on the efficiency and, thanks to the low front-axle load, also on the agility of the BMW X1 xDrive28i.

The new engine also offers more torque than the previous naturally aspirated engines. Its maximum torque is 350 Nm and is available at an engine speed of 1,250 rpm. This guarantees a particularly spontaneous response. The vigorous power delivery, from only slightly above idling, is a very seductive feature of this new engine, and the power climbs steadily all the way to the upper load range. The top speed of the new BMW X1 xDrive28i is 240 km/h.

The turbocharger is a Twin Scroll system. The exhaust streams leaving the two pairs of cylinders are kept completely separate as they flow through the exhaust manifold and the turbocharger, taking a spiral path to the turbine wheel. This configuration results in very low exhaust backpressure at low engine rpm, and allows the energy of the exhaust gas pulses to be optimally managed and translated into powerful rotation of the turbine blades, without a response delay. This leads to an immediate response to each movement of the accelerator pedal and the high-revving characteristics so typical of BMW engines.

More sportiness, lower emissions thanks to VALVETRONIC, double VANOS and direct injection.

The fully cylinder head-integrated VALVETRONIC variable valve control system and double VANOS variable intake and exhaust camshaft control have a further positive impact on power development. The patented BMW VALVETRONIC system with infinitely variable intake valve lift control dispenses with the throttle valve system typical of earlier engine generations. The control of the air volume required for combustion is performed inside the engine and leads to a considerably more immediate response. Throttling losses on charge exchange are reduced to a minimum enhancing the efficiency of the power unit.

The efficiency of the new power unit, which is extremely high for turbocharged engines, is due mainly to high precision direct injection. Solenoid valve injectors arranged centrally between the valves provide precisely dosed fuel supply at a maximum injection pressure of 200 bar.

A new record in efficiency with construction characteristics of the award-winning in-line six-cylinder engine.

In its essential design features the new power unit is based on the latest generation of the BMW in-line six-cylinder engine with BMW TwinPower turbo technology. The 225 kW/306 bhp engine, which is also used in the new BMW X3 xDrive35i, is regarded worldwide as a benchmark for dynamic power development and impressive efficiency. Amongst other tributes, these special qualities earned the six-cylinder engine the Engine of the Year Award 2010. No other 3.0-litre engine offers anything like such a good balance between driving pleasure and fuel economy. And now, the engine of the new BMW X1 xDrive28i has achieved a similar benchmark position in the 2.0-litre engine class.