BMW Hydrogen 7.
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1. Opening Up a New Era of Mobility. BMW Hydrogen 7. (Short Version)

The BMW Group is writing unique history in the world of motoring: Introducing BMW Hydrogen 7, BMW is presenting the first virtually emission-free hydrogen-powered luxury saloon in the world suitable for everyday use, this new model thus setting a milestone in entering a new era of sustained mobility.

BMW Hydrogen 7 is powered by a hydrogen combustion engine and has gone through the complete process of series development, at the same time reflecting the consistent strategy of the BMW Group using hydrogen as the ideal source of energy for the future suitable for everyday motoring already in our day and age.

BMW Hydrogen 7 is a revolutionary development within the BMW 7 Series as a whole: The engine, suspension and body of this new model are based on the overall vehicle concept carried over from the BMW 760i and BMW 760Li Saloons. At the same time BMW Hydrogen 7 features a dual-mode twelve-cylinder combustion power unit able to run on both hydrogen and conventional gasoline. Maximum output is 191 kW/260 hp, accelerating BMW's Hydrogen Saloon to 100 km/h in 9.5 seconds. Top speed of BMW Hydrogen 7, in turn, is limited electronically to 230 km/h or 143 mph.

Progress without compromises.
The dual-mode combustion engine impressively proves the BMW Group's truly supreme engineering skills. Without the slightest delay or change in driving behaviour, the innovative V12 switches over from hydrogen to gasoline drive. This is made possible by high-precision control technology regulating the engine with truly outstanding precision to ensure identical power and performance in both operating modes despite the different combustion qualities of the various fuels.

Introducing this trendsetting innovation in engine technology, the BMW Group offers a practical and attractive solution for switching over to hydrogen as the drive energy of the future, setting a milestone en route to a world of individual mobility independent of fossil fuels and free of pollutants.

In terms of power and performance, motoring refinement and all-round comfort, BMW Hydrogen 7 comes on the same level as the most demanding automobiles ever built with either a gasoline or diesel engine. Hence, driving this innovative Hydrogen Saloon with virtually zero emissions offers

all the unique pleasure so typical of a top-end BMW. And apart from its future-oriented drive concept, this dynamic premium saloon stands out in particular through an exceptionally wide range of features and equipment.

Hydrogen – the energy of the future.
Experts agree that hydrogen is the only source of energy with the potential in the long run to replace fossil fuels in road traffic. With its chemical symbol H, hydrogen is one of the components that makes up water and nearly all organic compounds, meaning that it is part of the biological cycle and therefore fully compatible with the environment. And as the most common element in the universe, hydrogen is available for all practical purposes in virtually unlimited quantities.

Hydrogen can be stored either in its cryogenic state as a fluid or in its gaseous state, and is relatively easy to transport. As a gas hydrogen is non-toxic, colour- and odourless. In its liquid state, measured by weight, it contains three times the energy to be found in gasoline.

While the use of fossil fuels inevitably results in carbon dioxide emissions, hydrogen as an alternative source of drive energy is extremely friendly to the environment, developing nothing but vapour in its process of combustion. And recovered in a regenerating process, hydrogen, as opposed to other alternative fuels, is the only source of energy allowing ongoing, sustainable use pointing into the future.

Liquid hydrogen for superior everyday driving qualities.
The BMW Group focuses consistently on liquid hydrogen as the appropriate source of drive energy. This clear preference results from the fact that liquid hydrogen, in terms of its volume-related energy density, by far exceeds the energy density of gaseous hydrogen. With a fuel tank taking up the same space and providing the same capacity, the amount of energy contained within cryogenic liquid hydrogen exceeds that of hydrogen stored in compressed gaseous state at 700 bar by more than 75 per cent. Clearly, this gives a vehicle running on liquid hydrogen a correspondingly longer cruising range.

A further point to be considered as long as the infrastructure for hydrogen is still being expanded is the cumulative range a hydrogen car is able to cover – indeed, this criterion is crucial to the car's everyday use and driving qualities. Hence, BMW Hydrogen 7 offers a long cruising range first through the use of liquid hydrogen as its source of energy and second through the dual-mode combustion engine: In the hydrogen mode BMW Hydrogen 7 is able to cover a distance of more than 200 kilometres or 125 miles, with another 500 kilometres or 310 miles in the conventional gasoline mode.

User friendliness is particularly crucial to the appeal and, accordingly, acceptance of hydrogen as a new source of drive energy. Indeed, the criterion of everyday use was highly relevant in developing the concept of BMW Hydrogen 7: Introducing this first-ever hydrogen-powered luxury saloon built in series production, the BMW Group is setting a most significant milestone within the global automotive industry. The car proves that alternative drive energy may also fulfil the greatest demands in terms of driving dynamics and motoring comfort alike.

All the maturity and reliability of a production car.

The world's first hydrogen-powered luxury saloon to enter series production is not the result of a research project. Rather, the development of BMW Hydrogen 7 marks the beginning of the industrialisation process, meaning that BMW Hydrogen 7 now comes with the same standards and levels of perfection as any other new BMW entering the market.
BMW Hydrogen 7 has gone through exactly the same all-round series development process as every new model from BMW. New components such as engine technology, the tank system and vehicle electronics for hydrogen drive have all been developed in and through BMW's usual Product Creation Process, each and every component therefore having been examined and verified with utmost precision, ensuring that it meets all the requirements of series development.

Given this concept, BMW Hydrogen 7 is able to combine truly innovative, future-oriented drive technology with the high quality standards of the BMW Group in terms of reliability, safety, and motoring pleasure established throughout decades of automobile and engine development. So through its mature vehicle concept alone, BMW Hydrogen 7 goes far beyond the status of previous hydrogen prototypes and demonstration models, qualifying for full homologation and type approval according to both German and ECE standards. In the United States of America, the BMW Hydrogen 7 will be deployed to selected users for testing.

Comfort of premium calibre.

The premium quality of BMW Hydrogen 7 is further confirmed and borne out by an exceptional standard of comfort. This superiority is ensured by doors with automatic Soft Close function, laminated climate comfort glass, BMW's high-end automatic air conditioning, electric seat adjustment complete with memory function, auxiliary heating including remote control, BMW's high-beam assistant, a TV function with DVB-T reception and a monitor at the rear, the BMW Assist and BMW Online telematics services, a separate car telephone at the rear, full preparation for BMW Teleservice, a CD changer for six CDs, a DVD changer for six DVDs, a smoker package as well as cupholders both front and rear.

Head and side airbags front and rear, interior and exterior mirrors with automatic anti-dazzle control, as well as BMW's Park Distance Control (PDC), a rain sensor, BMW's navigation system Professional and HiFi system Professional, lumbar supports for the driver and front passenger, as well as seat heating both front and rear all come in the car's broad range of equipment.

Further technical highlights to be enjoyed in BMW Hydrogen 7 are comfort access, BMW Online, voice recognition for controlling the navigation system as well as the telephone and audio units, steering wheel heating, electrically adjustable comfort seats, BMW Night Vision, and Adaptive Headlights. Added to this there are 19-inch light-alloy wheels together with the BMW Mobility Set.

The world's first hydrogen-powered premium automobile for everyday use to enter series production comes as standard with highly attractive metallic paintwork, particularly the special Blue Water Metallic colour available exclusively on this model accentuating the unique character of this unique car.

Dual-mode combustion engine for maximum range.

The dual-mode combustion engine powering the first series production luxury hydrogen saloon is the decisive, revolutionary new development in BMW Hydrogen 7: This muscular engine is based on the twelve-cylinder gasoline power unit displacing 6.0 litres and featuring VALVETRONIC technology in the BMW 7 Series. Maximum torque is 390 Newton-metres/ 287 lb-ft and comes at an engine speed of 4,300 rpm.

The V12 power unit in BMW Hydrogen 7 operates in two modes, meaning that the engine is able to burn either hydrogen or gasoline in the same cylinders.

Offering an overall cruising range of approximately 700 kilometres or 435 miles, BMW's hydrogen car with its dual-mode combustion engine has an even longer range than the BMW 760i. This enables the driver of BMW Hydrogen 7 to enjoy virtually unlimited mobility, using his car without problems even when covering a long distance before reaching the nearest hydrogen fuel filling station. Everyday use and driving quality, practical value and the driving experience as such therefore remain as great as before, even where hydrogen is not available.

Combustion engine for enhanced reliability.

The BMW Group has intentionally opted for a combustion engine in BMW Hydrogen 7, establishing the foundation for even greater acceptance and use of hydrogen as drive energy. The hydrogen engine uses mature and proven technology based on thorough know-how gained in decades of

engine development. As a result, this engine concept meets all the requirements made of a typical BMW with its superior driving dynamics and agility also when running on hydrogen as the source of energy.
And last but certainly not least, only the combustion engine offers the advantage of being able to run in two modes, that is on two different types of fuel.

Gas injection valves serving as the key technology.
Running on gasoline, the engine operates with direct fuel injection, while in the hydrogen mode the fuel/air mixture is formed in the intake manifolds. The new injection valves developed for this purpose make the greatest conceivable demands in engine development in terms of their construction and integration. Conceived and designed for gaseous hydrogen, the valves are not only larger than conventional gasoline injection valves, but also cover a far wider variation in size and range in terms of their volume flow, operating at different levels of system pressure and at the same time with both very short and longer gas injection times required for hydrogen gas. Even so, they reliably inject exactly the right amount of hydrogen into the intake air at all times within hundredths of a second.

Since hydrogen burns up to ten times faster than conventional fuel, management of the dual-mode combustion engine requires specific functions and operations. Using fully variable VALVETRONIC valve management exclusive to BMW as well as BMW's variable double-VANOS camshaft adjustment, the engineers responsible for developing BMW Hydrogen 7 had ideal tools from the start for optimising the hydrogen combustion process, gearing the gas cycle and mixture formation process specifically to the individual properties and features of the hydrogen/air mixture.

Practical solution reducing CO_2 emissions.
For all practical purposes, BMW Hydrogen 7 emits nothing but vapour while running in the hydrogen mode. Hence, the new model makes a very significant contribution to the drastic reduction of emissions in individual transport, helping in particular to reduce CO_2 emissions to a minimum.

The plan for the future is to introduce a car running exclusively on hydrogen (single-fuel). And at the same time researchers at the BMW Group are working on fuel cell technology, seeking to create a highly practical solution for the automobile in the guise of the Auxiliary Power Unit (APU), thus introducing a far more efficient and powerful replacement taking the place of the conventional car battery.

Introducing BMW Hydrogen 7, the BMW Group is taking a practical and feasible approach towards the future of motoring fully compatible with the environment. The integration of hydrogen in proven development, production and sales processes is the most efficient method for establishing hydrogen as a genuine alternative to conventional fuels.

The BMW Group therefore sees itself as a pacemaker in driving progress and striving into the future. In this way BMW is strengthening the good faith and confidence of customers in this new technology, at the same time boosting the appeal and attractiveness of the hydrogen car.

Fuel tank with vacuum super-insulation.
With its dual-mode drive concept, BMW Hydrogen 7 requires not only a special system of engine management and fuel supply, but also two different fuel tanks integrated into the car: The hydrogen tank in BMW Hydrogen 7 takes up approximately 8 kilos (about 170 litres or 45 Imp gals) of liquid hydrogen, the conventional gasoline tank has a volume of 74 litres or 16.3 Imp gals.

Used as drive energy, liquid hydrogen involves a particular technical challenge in the construction of the tank: Since hydrogen under normal ambient pressure has to be cooled to – 253 °Celsius in order to turn into a liquid, innovative vacuum super-insulation is required to store hydrogen fuel in the car over lengthy periods. Hence, the hydrogen tank in BMW Hydrogen 7 has double walls with several layers of aluminium and glass-fibre in the space in between measuring 30 millimetres or almost 1.2 inches in thickness in order to avoid higher temperatures entering the tank.

The highly efficient insulating effect offered by the tank is also ensured by a vacuum in the intermediate section between the two walls avoiding any kind of airborne heat transfer. And last but not least, the mounts holding the inner tank in position are made of carbon-fibre-reinforced plastic bands reducing thermal conductivity to a minimum.

Super-insulation is a very effective way to minimise the intrusion of higher temperatures and equals a 17-metre-thick layer (56 feet) of styrofoam in its insulating effect. Filling hot coffee into the tank, for example, you would have to wait approximately 80 days until the coffee has dropped to a temperature suitable for drinking.

Boil-off management for controlled evaporation.
For physical reasons alone even vacuum super-insulation cannot totally avoid a certain intrusion of higher temperatures, meaning that a small amount of liquid hydrogen would inevitably boil off in the course of time.

However, this minor evaporation effect only starts after the vehicle has been parked for at least 17 hours, whereupon the pressure inside the fuel tank will increase to a level requiring boil-off management of the gaseous fuel.

Boil-off management limits the inner pressure inside the tank and, when exceeding a defined level of ideal pressure, ensures controlled removal and conversion of hydrogen. Gaseous hydrogen released in this way is mixed with air in a venturi pipe and oxidised into water in a catalytic converter.

The period required for purging a hydrogen tank half full in a controlled process is approximately 9 days, the hydrogen then remaining in the tank still be sufficient to cover approximately 20 kilometres in the hydrogen mode. And should BMW Hydrogen 7 be driven in the meantime in the hydrogen mode, the level of pressure inside the tank will decrease again due to the consumption of hydrogen serving to drive the engine. Then, when parking the vehicle again, the 17-hour parking period without any loss of energy will start all over again from the beginning.

Filling the tank is easy.
The concept for filling the hydrogen tank is likewise easy to handle in everyday use and, in principle, hardly differs from the usual way a motorist fills up a gasoline tank. Basically the only new feature is the pressure-tight and low temperature-proof tank connection for liquid hydrogen placed by the driver in the liquid hydrogen filler manifold of BMW Hydrogen 7 like a regular fuel pump and then connected by manual pressure. Then the connection is fastened fully in position and the tank is filled in a process controlled by the system.

To open and close the tank filler flap, all the driver has to do is press a button in the cockpit next to the steering wheel, the entire process of filling the tank then taking less than 8 minutes.

Given the simple handling procedure and system control in filling the tank, the process of filling hydrogen into BMW Hydrogen 7 is just as easy, straightforward and harmless as filling a tank with conventional gasoline fuel, and is in fact even cleaner.

To establish the right technology for the automobile in this area at the earliest possible point for standard worldwide use, the BMW Group has developed a standardised liquid hydrogen tank filling connector in cooperation with international partner companies, and now seeks to establish this connector as a worldwide standard.

High powerdome bearing testimony to the unique source of power.
The body of BMW Hydrogen 7 is based on the body of the BMW 760Li, with exactly the same exterior dimensions and wheelbase. While the characteristic look of the long-wheelbase BMW 7 Series Saloon remains almost unchanged, several components have been newly developed due to the higher weight of the car and the introduction of hydrogen technology.

A unique body feature exclusive to BMW Hydrogen 7 and serving as a clear sign of distinction is the new, high powerdome required to house the H_2 injection valves in BMW's Hydrogen Saloon. At the same time, of course, this muscular contour on the engine compartment lid makes a clear reference to the unique source of power within the body of BMW's hydrogen-drive car.

Further signs of distinction are the name "Hydrogen 7" on the rear lid and the word "Hydrogen" beneath the side indicators. Then there are the transparent LH2 tank filler flap with its chrome surround and the trim on the rear bumper with chrome appliqués. The words "BMW Hydrogen Power" on the sun visors over the rear side windows and in the door cutouts also bear clear testimony to the revolutionary drive technology this outstanding saloon has to offer.

A fundamentally new feature is that several sections of the body are made of carbon-fibre-reinforced plastic (CFP) and steel, a hybrid structure optimised for weight and with enhanced crash resistance. The BMW Group has indeed developed this combination of CFP and steel specifically for BMW Hydrogen 7 in order to set off the extra weight of the drivetrain and fuel supply system and at the same time meet all the special safety requirements made of this highly innovative vehicle. One example is the side frames left and right now strengthened from front to end by carbon-fibre-reinforced plastic, ensuring the same crash resistance as in the BMW 760Li.

Hydrogen displays in the cockpit.
Within the interior, BMW's trendsetting Hydrogen Saloon shows only a few visual modifications versus the BMW 760Li. One particular sign of distinction is the new displays and instruments fitted for hydrogen drive in the cockpit. The instrument cluster in BMW Hydrogen 7 boasts the symbol "H2" in the display on the variable controls and instruments illuminated as soon as the car is running on hydrogen. A further feature is that BMW Hydrogen 7 comes not only with a fuel gauge for gasoline, but also with an H2 fuel gauge showing the current level of hydrogen in kilograms. The overall range the vehicle is able to cover, in turn, is shown both as a double crossbar and as an absolute number. The reserve levels for hydrogen (approx 1.5 kg useful residual amount for roughly 50 km or 30 miles) and gasoline (approximately 15 litres residual volume for at least 100 kilometres/62 miles) are shown separately of one another.

The most significant modifications within the passenger compartment visible at very first sight are in the rear, resulting from the arrangement of the hydrogen tank beneath the parcel shelf and behind the rear seat bench: The rear seat bench in BMW Hydrogen 7 is positioned about 115 millimetres or 4.5˝ further to the front than in the BMW 760Li and, respectively, some 25 millimetres or 1.0˝ further to the rear than in the "standard" version of the BMW 7 Series. In practice, this means that the two passengers sitting in the rear enjoy all the long-distance travel comfort of a BMW grand touring saloon also in the hydrogen car.

On account of the car's overall package, the rear centre armrest is fitted firmly in position, meaning that BMW Hydrogen 7 is conceived and laid out as a four-seater. And while luggage capacity is smaller than in the other BMW 7 Series on account of the hydrogen technology fitted in the car, BMW Hydrogen 7 still offers 225 litres or 7.9 cubic feet of luggage space, enough, for example, to take along two golf bags without a problem.

Lightweight aluminium chassis carried over from the BMW 7 Series.
The chassis and suspension of BMW Hydrogen 7 is based on the standard lightweight aluminium chassis offering all the performance and driving dynamics so typical of the BMW 7 Series. Front suspension is provided by a double-joint tiebar spring strut axle, rear suspension features BMW's integral-IV multi-arm axle with anti-squat and anti-dive.

The increase in weight resulting from the car's hydrogen components calls for a number of modifications in the set-up of the suspension, and the rear axle of BMW Hydrogen 7, as on the security version of the BMW 7 Series, has been upgraded by both aluminium and steel reinforcements.

Yet another important feature is that BMW's Hydrogen Saloon comes as standard with AdaptiveDrive suspension combining anti-roll stabilisation with variable damper adjustment. AdaptiveDrive makes BMW Hydrogen 7 a very agile luxury saloon with supreme driving qualities easy to handle even in tight bends.

BMW Hydrogen 7 also features the brake system carried over from the "regular" 7 Series, reducing the stopping distance of this 2,460-kg or 5,424-lb saloon from 100 km/h to a standstill to 41 metres or 134 feet.

High-tech TPC Tyre Pressure Control.
BMW Hydrogen 7 comes as standard with the latest generation of BMW's sensor-based TPC telemetric Tyre Pressure Control system. Carried over from motorsport, this system is particularly sensitive, ensures a highly accurate warning function, and represents the latest state of the art in tyre pressure

control. Through its telemetric configuration, TPC measures the pressure in each tyre in short intervals, presenting deviations from the normal pressure level on each wheel within the instrument cluster. As a result, the driver is informed even earlier and with greater precision of any gradual loss of pressure in any of the wheels. And this also shows even more precisely what distance the car can still cover on its runflat tyres.

Safety always comes first.
With hydrogen being quite different in virtually all of its features and properties from gasoline or diesel, this new fuel naturally presents different demands in terms of vehicle safety. Very friendly to the environment, hydrogen is both odourless and colourless, and is therefore not perceived by the human being through our usual sensory organs.

Whenever hydrogen is able to escape into the air, it rises up quickly to higher levels, simply because it is 15 times lighter than the ambient air around it. And while hydrogen is neither irritating nor toxic, it is more easily ignitable than gasoline or diesel as soon as it forms an appropriate mixture with air. The most important point, however, is that hydrogen is absolutely safe as long as its characteristic features and properties are duly taken into account.

It goes without saying that the BMW Group would only develop a hydrogen drive vehicle for everyday use if that vehicle was able to offer supreme safety of the highest standard – and precisely this is why the BMW Group is involved in a number of international boards and committees for the development of uniform safety standards for the hydrogen car.

Parallel to the development of these standards, the BMW Group has established a consistent safety concept for BMW Hydrogen 7 and all its related systems and technologies. As an example, the liquid hydrogen tank comes not only with a boil-off management system, but also with two redundant valves monitoring the contents of the tank in the event of a significant build-up of pressure – for example as a result of damage to the tank – and letting off hydrogen under controlled conditions if necessary.

As soon as the first valve opens up, hydrogen is guided up to the roof of the car through safety pipes fitted in the C-pillars. The second valve opening up only under higher pressure allows hydrogen to flow to the underfloor of the car, where it is also discharged into the air. And the risk of escalation at the scene of an accident, that is the risk of burning fuel spreading on the ground, does not even present itself on a hydrogen car – as opposed to a car with gasoline or diesel fuel – since hydrogen does not accumulate on the ground in the form of ignitable puddles, but rather rises up and vanishes into the air.

One of the prerequisites for running a vehicle safely in everyday traffic is the level of safety built into the vehicle itself from the start. This is precisely why BMW Hydrogen 7 comes with a multi-level safety concept incorporating various precautions to prevent the hydrogen tank from bursting and hydrogen from escaping from the tank in an uncontrolled process.

Precisely this is why all components are designed and laid out to fulfil maximum safety requirements, just as they automatically switch over to a safe operating mode in the event of malfunction. A further point is that not only the tank itself, but also all other components and pipes comprising hydrogen are double-walled structures.

Safety functions specially developed for BMW Hydrogen 7, in turn, serve to reveal any deficiencies at an early point in time and trigger an appropriate response in order to avoid any undue risks. Hence, the driver is informed of any functional deficiency in the safety system before a hazard as such is even able to arise. A gas warning system with decentralised hydrogen sensors, for example, informs the driver of possible functional deficiencies both when motoring and when the car is parked. The electric power supply for the gas warning system is secured by a triple set of fuses, and apart from its regular battery, BMW Hydrogen 7 comes with two further batteries ensuring an ongoing supply of electric power independently of the car's main battery.

Independent verification and certification.
Teaming up with the TÜV South Germany Technical Inspection Authority, the BMW Group has successfully tested BMW Hydrogen 7 in a large series of the most demanding trials and test procedures focusing in particular on the car's hydrogen components and going through all the homologation requirements made of a regular production vehicle.

The BMW Group has also put BMW Hydrogen 7 through a complete programme of crash tests going beyond the usual legal requirements. These crash tests include frontal offset collisions in accordance with EURO NCAP at an impact speed of 64 km/h or 40 mph, rear-end collisions with 100 and 40 per cent overlap, as well as side-on collisions at the car's most sensitive point directly on the fuel filler pipe.

To ensure optimum safety in even more extreme accident scenarios, the hydrogen tank was even tested under truly exceptional conditions such as exposure to flames, firearm shots, massive mechanical damage, as well as the reaction of the fuel tank and safety equipment to a loss in insulating vacuum. In an additional series of tests, tanks filled with hydrogen were fully

encompassed by flames at a temperature of more than 1,000 °C (1,830 °F) for up to 70 minutes. Even under such conditions, tank behaviour did not present any problems, with the hydrogen in the tanks escaping slowly and almost imperceptibly through the safety valves.

Following these most demanding tests and examinations, both TÜV South Germany and the fire brigade specialists acting as consultants arrived at the conclusion that the hydrogen car is at least as safe as a conventional gasoline car.

Rules and regulations for parking in a garage.
Since adequate statistically reliable data obtained under regular operating conditions is not yet available to confirm the safety of the hydrogen tank as such, parking in closed-in spaces is currently not allowed.
The BMW Group will maintain this rule in the interest of the car's drivers until adequate statistically valid reliability data has been compiled. This data will be collected in long-term use and in additional back-up and security programmes.

Driving the car and briefly stopping in fully enclosed spaces such as indoor car parks, driving through tunnels of any length, and using car wash facilities, as well as parking in an open carport, are fully allowed without restrictions.

Assembly at BMW Plant Dingolfing.
BMW Hydrogen 7 is built under regular conditions at BMW Plant Dingolfing parallel to the other BMW 7, 6, and 5 Series built at the Plant. And like all of BMW's twelve-cylinder power units, the engine is built at BMW's Engine Plant in Munich.

The driver of BMW Hydrogen 7 – a genuine pioneer.
BMW Hydrogen 7 has been tested for its everyday driving qualities in numerous trials also in road traffic. With the decision to switch over to hydrogen technology requiring the driver to change his motoring practices in a few – albeit limited – aspects, the motorist opting for a Hydrogen Saloon at this point in time is definitely an outstanding pioneer.

Since only everyday use of the car will be able to provide the essential experience required under practical driving conditions, the knowledge gained by drivers of BMW Hydrogen 7 will help to further enhance and develop this entire world of breakthrough technology.

Introducing the world's first hydrogen-powered luxury saloon for everyday use, BMW is appealing to the truly dedicated motorist with a visionary attitude in life and, accordingly, with genuine interest in experiencing the beginning of a new era of individual mobility. So precisely motorists of this class and calibre

will be receiving BMW Hydrogen 7 for an agreed period of time, under a lease quite comparable to conventional leasing arrangements. In the US, the BMW Hydrogen 7 will be deployed to selected users on a test drive basis.

When taking over the car, the driver receives detailed instructions on how to handle BMW Hydrogen 7. Service is required every three months and BMW's Hydrogen Saloon is equipped with an innovative remote diagnosis system monitoring a wide range of vehicle data such as the inner tank pressure, the fuel level, on-board voltage, self-diagnosis data as well as defect reports forwarded regularly by the car itself to a BMW hotline.

Recognising the great potential of hydrogen right from the start.
The world's first series-production luxury hydrogen saloon for everyday use is the result of decades of all-out research on alternative sources of drive energy conducted by the BMW Group. Recognising at an early point that hydrogen was the right fuel for the future, the BMW Group started as way back in the 1980s to study engines and vehicles able to run on liquid hydrogen. The first prototype of a dual-mode hydrogen car was then presented just a year later, BMW thus laying the foundation for this breakthrough technology. Today numerous studies and research projects carried out by scientists and experts the world over prove that only one type of fuel is able to provide a sustainable source of energy ensuring long-term availability in future: hydrogen recovered in a regenerating process.

Reduction of CO_2 on the conventional combustion engine.
The modern combustion engines featured in BMW Group cars combine a high standard of performance and driving dynamics with superior efficiency and all-round economy. Progress in engine development, in turn, comes to bear in several areas, with each newly developed power unit offering an increase in engine output, lower weight, and greater fuel economy than its respective predecessor.

BMW refers to this principle as Efficient Dynamics and therefore makes a significant contribution in the short and medium term to the ongoing reduction of emissions such as carbon dioxide (CO_2). Hence, the principle of Efficient Dynamics is an ideal match for the BMW Group's CleanEnergy strategy seeking in the long term to establish a drive technology absolutely neutral in terms of CO_2 emissions.

The objective for the year 2008 is to reduce the CO_2 emissions of all newly registered European cars to an average of 140 grams of CO_2/km – this is the commitment made by the Association of the European Automobile Industry to the European Union in 1998. In relative terms, this equals a reduction of CO_2 emissions versus 1995 by no less than 25 per cent.

Introducing BMW Hydrogen 7 and implementing hydrogen technology in the process of series development, the BMW Group – parallel to the ongoing reduction of pollutants in the gasoline and diesel engine – is now launching a philosophy able in the long term to reduce the CO_2 emissions of motor vehicles to a far greater extent. In this way the BMW Group is acting as the pacemaker, setting a truly outstanding example as the spearhead in technology.

The clear sign the BMW Group is sending out in introducing BMW Hydrogen 7 addresses not only specific groups of forward-looking users particularly oriented to innovation, but also all of the many network partners in politics, science and the energy industry acting together to promote and enhance a breakthrough into a new era of mobility.

The Transport Energy Strategy (TES) initiative launched by BMW and others in 1998 and supported by the German Federal Government has conducted a scientific study on more than 10 alternative fuels involving more than 70 methods of production. The clear result of the study is that in the long term hydrogen recovered in a regenerating process is by far the most future-oriented solution for clean motoring beneficial to the environment.

The TES initiative is made up of the companies Aral/BP, the BMW Group, DaimlerChrysler, Ford, General Motors/Opel, RWE, Vattenfall, Shell, Total, and Volkswagen.

The future has a name: BMW CleanEnergy.

The promotion of hydrogen technology as the energy of the future is an important highlight of BMW's CleanEnergy strategy: BMW CleanEnergy is the overriding term used to describe the ecologically ideal, self-contained energy cycle based on water. For using energy from the sun, wind, hydro-power or biomass, hydrogen can be recovered and used in virtually unlimited amounts. BMW's vision of sustained mobility free of pollutants therefore applies not "only" to the actual use of the vehicle, but also to the generation of the fuel it runs on.

Diversification of energy, greater independence and, in the long term, the replacement of fossil fuels as drive energy is ecologically and economically necessary, since this is the only way to reduce both CO_2 emissions and bottlenecks in supply in the long term. With its future-oriented drive concept, BMW Hydrogen 7 is therefore a pacemaker for sustained mobility fully compatible with the environment.

Establishing a suitable supply infrastructure.

Introducing BMW Hydrogen 7, the BMW Group is taking a powerful initiative for the expansion and development of hydrogen supply. And even though an all-embracing, worldwide network of hydrogen filling stations is still a vision today, the technical and logistical know-how required for this purpose is already largely in place.

To promote the development of hydrogen filling stations, the BMW Group has been involved in the Clean Energy Partnership (CEP) Berlin ever since its establishment in 2002. Today, leading companies such as Aral, the Berlin Transport Authority (Berliner Verkehrsbetriebe, BVG), DaimlerChrysler, Ford, General Motors/Opel, Volkswagen, Hydro, Linde, Total, and Vattenfall Europe all belong to the Clean Energy Partnership Berlin, proudly promoting one of Europe's most important demonstration projects and, indeed, one of the largest projects of its kind in the world: The objective of the CEP is to further develop hydrogen as a source of energy, demonstrating the various options to use this innovative fuel in everyday transport.

The Clean Energy Partnership Berlin is part of Germany's national Strategy of Sustainability, one highlight of the CEP's projects being the practical examination of fuel supply scenarios.

To conduct this study under realistic conditions, two hydrogen filling stations were built in Berlin in November 2004 and March 2006, with a third hydrogen filling station scheduled for completion in Munich before the end of this year. These filling stations are able to supply motorists with both liquid and gaseous hydrogen.

The BMW Group also plays an active role in the EU's Hydrogen Fuel Cell Technology Platform and in the German Government's National Innovation Programme. The Group's international activities, in turn, include active participation in a research alliance launched by the US Department of Energy as well as the initiation of a hydrogen feasibility study and a hydrogen information campaign in China.

2. Description in Brief.

- World's first hydrogen-powered luxury saloon for everyday use, trendsetting model within the BMW 7 Series based on the BMW 760Li, milestone in achieving a new standard of mobility free of pollutants and with full sustainability.

- Complete integration of hydrogen technology in the process of series development, driving dynamics and motoring refinement typical of BMW, wide range of premium comfort features, production parallel to the BMW 7, 6, and 5 Series at BMW Plant Dingolfing.

- Dual-mode twelve-cylinder combustion engine for a long cruising range and superior driving dynamics, based on BMW's twelve-cylinder 6.0-litre gasoline engine featuring VALVETRONIC in the BMW 7 Series; maximum output 191 kW/260 hp, peak torque 390 Newton-metres/287 lb-ft at 4,300 rpm, acceleration to 100 km/h in 9.5 sec, top speed 230 km/h (143 mph), limited electronically.

- Direct fuel injection in the gasoline mode, external mixture formation with intake manifold injection in the hybrid mode, same engine output in both operating modes, smooth and consistent switchover with no time-lag from one operating mode to another, flexible engine management with VALVETRONIC and double-VANOS, innovative injection valves as key technology for hydrogen drive.

- Hydrogen tank accommodating approx 8 kilos of liquid hydrogen, gasoline tank with a capacity of 74 litres or 16.3 Imp gals, liquid hydrogen as drive energy for a long cruising range and a high standard of everyday use, more than 200 kilometres/125 miles cruising range on hydrogen plus 500 kilometres/310 miles on gasoline.

- Engine emits virtually nothing but vapour in the hydrogen mode, practical solution for rapid reduction of CO_2 emissions and changeover to drive energy independent of fossil fuels, pacemaker for ongoing progress.

- Trendsetting vacuum super-insulation for the hydrogen tank, liquid hydrogen consistently and for a long time remaining at a temperature of – 253 °Celsius, same insulating effect as with a 17-metre-thick layer of styrofoam.

- Simple, clean and risk-free tank-filling process, tank filler manifold connected to liquid hydrogen filler pipe in the same way as with a conventional fuel pump, tank manifold and filling process locked in position and conducted by system control.

- High powerdome as a clear sign of distinction highlighting BMW Hydrogen 7, clear reference to the high-rising engine modified in its dimensions on account of hydrogen injection valves, weight- and crash-optimised combination of carbon-fibre-reinforced plastic (CFP) and steel body components.

- Modifications inside the car: rear seat bench moved 115 millimetres/4.5˝ further to the front than in the BMW 760Li due to the arrangement of the hydrogen tank and 25 millimetres/1.0˝ further to the rear than in the BMW 760i, centre console fitted firmly on the rear seat bench on account of the car's package, four seats, special hydrogen function displays in the cockpit.

- Independent, non-partisan safety certification, successful completion of comprehensive test series conducted by the South German Technical Inspection Authority (TÜV South Germany), sensor-based control system operating independently of the engine, hydrogen components with multiple redundancy/back-up.

- Chassis and suspension with double-joint tiebar spring strut axle at the front and integral-IV multi-arm axle at the rear, BMW AdaptiveDrive with anti-roll stabilisation and electronic damper control, telemetric TPC Tyre Pressure Control system.

- Innovative remote diagnosis system, direct dialogue with driver/vehicle user.

- First series production car based on decades of BMW experience in testing hydrogen as a drive technology, development and examination of hydrogen engines since the 1980s.

- Promotion of nationwide hydrogen supply infrastructure by the BMW Group in close cooperation with the Clean Energy Partnership Berlin, BMW Hydrogen 7 acting as a series production hydrogen car for everyday use and establishing new momentum for ongoing development and expansion of a complete, all-round network of filling stations.

3. Principle: Hydrogen Combustion Engine, Dual-Mode Drive, Maximum Range.

- **Progressive drive concept on a reliable foundation.**
- **700 kilometres/435 miles cruising range with dual-mode V12 power unit.**
- **Excellent driving dynamics at all speeds.**

Acting as a genuine pioneer, the BMW Group has chosen the combustion engine for the world's first hydrogen-powered series-production luxury saloon. This is because research and development in the area of hydrogen technology conducted by BMW over a quarter of a century clearly shows that given its dynamism, maturity and superior everyday qualities, the combustion engine combined with hydrogen offers the largest number of benefits all round.

The dual-mode combustion engine in BMW Hydrogen 7 burns both hydrogen and gasoline, that is the "classical" fuel, in the same cylinders. So at a time prior to the introduction of hydrogen supply infrastructure on a broad scale, BMW is presenting a solution able to bridge gaps in supply in a most practical manner.

The dual-mode power unit is based on BMW's twelve-cylinder gasoline engine displacing 6.0 litres and featuring VALVETRONIC technology in the BMW 7 Series. It is a revolutionary development of BMW's existing combustion engines and has been fully integrated into the vehicle concept of the BMW 7 Series. In this way the BMW Group is combining know-how in automotive construction and the development of the combustion engine with all the reliability gained in the process over decades of use of hydrogen as drive energy.

Dual-mode power unit for maximum mobility.
Running on hydrogen, BMW Hydrogen 7 has a range of more than 200 kilometres or 125 miles, and is able to cover another 500 kilometres or well over 300 miles on gasoline. Benefiting from a total range of approximately 700 kilometres or 435 miles, the user therefore enjoys a standard of mobility meeting all requirements in everyday motoring and even exceeding the cruising range of a conventional saloon running on gasoline alone.

The hydrogen tank in BMW Hydrogen 7 takes up approximately 8 kilos of liquid hydrogen, the separate gasoline tank offers a capacity of 74 litres of 16.3 Imp gals. The dual-mode V12 power unit develops maximum output of 191 kW/260 hp and peak torque of 390 Newton-metres/287 lb-ft at an engine speed of 4,300 rpm.

Acceleration from 0–100 km/h in BMW's Hydrogen Saloon comes in 9.5 seconds, and the car's top speed is limited electronically to 230 km/h or 143 mph, meaning that the driver is not required in any way whatsoever to forego the unique driving experience so typical of BMW.

With BMW Hydrogen 7 offering exactly the same power and performance in both operating modes, the driver is able to change from one mode to the other without the slightest delay. He activates this change manually or the changeover takes place automatically as soon as the supply of hydrogen or gasoline in the respective tank starts to run low. And perhaps the best news is that the driver does not even feel the changeover from one mode to the other, since it is so smooth and subtle.

Unlike the fuel cell using hydrogen to generate electricity then driving the car via an electric motor, BMW Hydrogen 7 feeds hydrogen directly into the combustion engine. Running in the hydrogen mode, the dual-mode combustion engine operates with external mixture formation outside the engine itself, while in the gasoline mode fuel is injected directly into the combustion chambers.

When starting the engine, BMW Hydrogen 7 automatically runs in the hydrogen mode in order to avoid the emissions otherwise encountered when starting the engine cold on gasoline. Since the driver is only able to switch over to the gasoline mode after the catalytic converter has warmed up, BMW Hydrogen 7 never runs under unfavourable conditions with unclean emissions.

Supreme everyday driving qualities right from the start.
In establishing a world of sustained mobility with emissions reduced to a minimum, the lack of a complete hydrogen supply infrastructure should not become an obstacle. Precisely this is why the BMW Group, introducing a series-production hydrogen car, sees itself as a pacemaker for progress. Indeed, proving that the hydrogen car offers a high standard of everyday driving qualities, BMW is motivating both the suppliers of hydrogen and operators of filling stations to broaden the range of fuel supply. This will further promote the trust and good faith of purchasers in the new drive technology, convincing an increasing number of customers to switch over to low-emission cars.

The first point, therefore, is to enhance the overall standard of acceptance for this breakthrough innovation on a broad level. With acceptance increasing exponentially to the everyday driving qualities of a car, the BMW Group, introducing the world's first hydrogen-powered series-production luxury saloon, has opted for a dual-mode combustion engine. This means that

the driver of BMW Hydrogen 7 is able to use all the benefits of this new, low-emission technology even before a complete supply infrastructure for the hydrogen car has been put into place, while at the same time enjoying all the benefits of the existing nationwide infrastructure for the supply of gasoline.

BMW's long-term objective is to introduce and establish mono-mode power units running on hydrogen alone, with such engines being able to use the full potential of this source of energy. Because to qualify and really promote hydrogen as an alternative to conventional fuels, the technology required for the use of hydrogen must be integrated in proven development, production, and sales processes.

Moving reliably into a clean future of the automobile.
Compared with the heavy fuel cell, the dual-mode combustion engine is much lighter and less expensive in production. A further significant point helping to cut costs is that the dual-mode combustion engine is built at BMW's existing production plants where decades of experience in the production of combustion engines guarantees maximum reliability.

Given its power potential and driving dynamics particularly at high speeds, BMW Hydrogen 7 offers all the driving and performance qualities expected of a BMW also in the hydrogen mode. A further point is that proceeding from current technology only the combustion engine is able to offer dual-mode drive ensuring a long cruising range making the driver independent of the current network of hydrogen filling stations and its density.

For all these reasons BMW has decided to use a dual-mode combustion engine in the world's first hydrogen-powered series-production luxury saloon built for everyday use. This is quite simply because the dual-mode combustion engine offers ideal conditions for making a practical, low-cost and rapid entry into a new, environmentally-friendly era of mobility in the automobile, without requiring any concessions in terms of driving pleasure and, in particular, freedom of travel and getting around.

4. Symbol: Liquid Hydrogen – New Energy for Ongoing Mobility in Everyday Motoring.

- **High energy density of liquid hydrogen offers long cruising range.**
- **Vacuum super-insulation allows liquid storage of fuel.**
- **New momentum for expanding the hydrogen infrastructure.**

BMW is the first carmaker in the world to focus consistently on the use of hydrogen as the medium- and long-term fuel for the car of the future. Now, introducing BMW Hydrogen 7, the BMW Group is presenting the first series-production hydrogen-powered car in the world offering a high level of practical quality.

Such practical quality was indeed an important objective throughout the process of developing and testing BMW Hydrogen 7, encompassing the entire area of vehicle use, that is driving the car, filling up the tank, taking care of both service and repair requirements. Seeking to integrate the car from the start fully in everyday use with all its practical qualities, the BMW Group consistently followed the complete process of series development also for BMW Hydrogen 7.

High energy density of liquid hydrogen providing a long cruising range.
In defining the energy content of hydrogen, we distinguish between gravimetric (related to weight) and volumetric (related to volume) energy density. Compared in terms of its weight, hydrogen has a very high level of energy density about three times the gravimetric energy density of gasoline, and is therefore of great interest for mobile use. The volumetric energy density of hydrogen, on the other hand, is about one-quarter that of gasoline.

With tank capacity in the automobile being limited, we have to increase the level of energy (energy content) related to volume, for which there are two possibilities: Either we compress hydrogen in its gaseous state or we cool it down until it turns into a liquid. Compression of gaseous hydrogen is possible today up to a pressure of 700 bar, while at ambient pressure hydrogen turns liquid when cooled to a temperature of – 253 °Celsius.

In order to obtain the highest possible energy content on a limited tank capacity, the BMW Group has opted for liquid hydrogen. The volumetric energy density of this liquid fuel, that is the amount of energy related to the capacity or volume required within the car's tank, is more than 75 per cent higher in the case of liquid hydrogen than with gaseous hydrogen compressed

to a pressure of 700 bar. Hence, liquid hydrogen gives the car a cruising range 75 per cent longer. This, in turn, means greater freedom and enhanced mobility for the driver – a criterion of particular significance as long as the infrastructure for filling up hydrogen is still in the process of being developed.

Vacuum super-insulation for reliable storage of fuel.
Together with its dual-mode power unit, the liquid hydrogen tank in BMW Hydrogen 7 is the most significant new development in the automotive industry achieved in this case. The particular challenge in storing liquid hydrogen is that the liquefied hydrogen cooled to a cryogenic temperature of – 253 °C has to be kept at this temperature for a long time. Precisely for this purpose, the BMW Group has developed trendsetting, 30-millimetre (1.18˝) – thick vacuum super-insulation offering the same thermal insulation effect as a layer of styropor measuring no less than 17 metres or 56 feet in thickness. This provides the option to store liquid hydrogen in the car for a lengthy period of time.

Energy balance for supplying liquid hydrogen.
The liquefaction of hydrogen serving as drive energy in the car initially calls for a higher amount of energy than the process of compressing gaseous hydrogen. In everyday use, however, this balance of energy changes to the benefit of liquid hydrogen, since it is essential, in determining the overall consumption of energy, to consider the overall concept and system of the vehicle.

This overall perspective also considers the fact that compression heat is generated in the process of filling up the vehicle with gaseous hydrogen. This, in turn, leads to ongoing expansion of the compressed hydrogen gas, with a negative effect on its energy density.

Given this situation, there are two options for reducing the heat generation effect: Either passive cooling by allowing for a break from time to time when filling up the tank – an option the customer would hardly accept – or active cooling by reducing the temperature of hydrogen at the filling station before pumping hydrogen into the tank. The drawback in this case is that such a process significantly increases the consumption of energy in the “well-to-wheel“ cycle, that is the entire process of fuel going from the well in the ground to the wheel on the car, putting gaseous, compressed hydrogen at a substantial disadvantage.

A further point is that hydrogen, on account of its greater density when stored in large quantities, will be delivered in a liquid state to the filling station and stored there also in a liquid state in the long term. Generation of compressed gas directly at the filling station would be inefficient due to the small scale and volume of such facilities.

With a tank storage facility of medium size (and wherever pipelines are not practical for reasons of sales), hydrogen would also be delivered in liquid form, in the same way as other types of gas already liquefied today for purposes of distribution. Hence, the fuel would first be liquefied before filling up the tank with hydrogen gas, then evaporated and compressed prior to the fuel pumping process. Clearly, this would mean a significantly greater effort requiring far more complicated and complex technology for providing compressed gas at the filling station. So in comparison with liquefied hydrogen, the overall amount of energy required for filling up the tank with hydrogen gas would ultimately be greater.

Momentum for developing a hydrogen supply infrastructure.
The process of filling up the tank of BMW Hydrogen 7 with liquefied hydrogen is conceived and laid out to be fully compatible with everyday requirements, with the driver only having to perform roughly the same operations as when pumping gasoline into the tank. And since suitable storage tanks and dispensers for hydrogen could be added to existing filling stations without substantial problems, there will be no need to build new filling stations from the ground up.

The process of filling up a car with liquid hydrogen differs from pumping in gasoline mainly by the fact that it requires a pressure-tight and low temperature-proof coupling instead of the usual gas pump. The actual operation as such, on the other hand, is almost the same as before: Once the driver has connected the hydrogen tank coupling with the tank filler manifold in his car, the coupling is locked in position, the tank is filled, and the coupling is unlocked by automatic system control. The entire process takes less than 8 minutes and is cleaner and no more hazardous than the conventional process of filling up the tank with gasoline, since no fuel is able to escape in an uncontrolled manner and no ignitable vapour or any other kind of gas reaches the environment.

Presenting BMW Hydrogen 7, the BMW Group is clearly proving that the process of switching over to alternative drive energy does not require any concessions in terms of sheer driving pleasure, motoring comfort, or everyday driving quality. Indeed, BMW's Hydrogen Saloon sets a clear sign proving the everyday qualities of liquid hydrogen as a source of energy in the production car.

BMW Hydrogen 7 has gone through the entire process of series development with all the testing processes required by law. Following the complete process of product development and creation, the BMW Group, together with the TÜV South Germany Inspection Authority, subjected BMW Hydrogen 7

to a comprehensive range of all-round tests with the focus in particular on the car's liquid hydrogen components. And then, as a result of these tests, the South German Technical Inspection Authority arrived at the conclusion that the Hydrogen Saloon is at least as safe in practice as a conventional gasoline-powered car.

All this clearly confirms that BMW Hydrogen 7 as a vehicle running on liquid hydrogen is fully able to meet all the requirements of everyday motoring. But despite the wide range of tests carried out on the new model, user-friendliness can ultimately only be confirmed in practice in all the details involved. And this, in turn, requires the appropriate infrastructure, which is currently being established and put into place. The BMW Group, therefore, is the forerunner in this process.

To promote the establishment of the appropriate supply infrastructure, the BMW Group entered into powerful partnerships with other companies and organisations at an early point in time. One of these alliances is the Clean Energy Partnership (CEP) Berlin, conducting one of the most important demonstrating projects in Europe in developing alternative forms of energy in the automotive industry. This consortium of the automotive industry, the supplier industry and public transport services established in 2002 now comprises not only BMW, but also Aral as a supplier of petroleum and mineral oil, DaimlerChrysler, Ford, General Motors/Opel, Volkswagen, Hydro, Linde, Total, Vattenfall, and the Berlin Transport Authority (BVG, Berliner Verkehrsbetriebe). The purpose and objective of the CEP is to demonstrate the practical feasibility of an appropriate hydrogen supply infrastructure, to further develop hydrogen in technological terms as a source of energy, and to expand the options for using hydrogen for everyday purposes. One of the project's highlights is the operation of two public hydrogen filling stations opened in Berlin in 2004 and, respectively, in 2006. A further fully integrated filling station will be opened in Munich before the end of this year.

The BMW Group makes a worldwide commitment.
The BMW Group is contributing the know-how it has gained in the research and development of hydrogen to the German Government's National Innovation Programme. A further point is that BMW Group associates have been appointed as consultants to the Advisory Council and the Top Management of the Deployment Strategy Panel of the European Hydrogen and Fuel Cell Technology Platform (EHP) as a special body initiated by the EU Commission in 2004 serving to promote the development and operation of cost-efficient, competitive European energy systems based on hydrogen and fuel cell technologies.

Yet another international commitment by the BMW Group is its participation in the Research Alliance of the Department of Energy as well as the initiation of a hydrogen feasibility study and an information campaign on this subject matter in China. Here, joining forces with Chinese scientists, BMW Group experts are searching for ways and means of creating and building up a full-scale hydrogen supply infrastructure.

5. Development: The World's First Hydrogen-Powered Luxury Car to Successfully Complete the Process of Series Development.

- **Production at Plant Dingolfing within BMW's regular series production activities.**
- **Complete product creation process for all components.**
- **BMW Hydrogen 7 fulfils all the standards of a regular BMW production model.**

Introducing BMW Hydrogen 7, the BMW Group is most definitely writing history in the world of the automobile. Quite simply because this world-first achievement is not only the world's first-ever hydrogen-powered luxury saloon, but also the first hydrogen-powered premium car fully suited and available for everyday use.

BMW Hydrogen 7 has successfully completed the entire process of series development. Twenty-seven years after the presentation of BMW's first hydrogen concept study in 1979, the BMW Group has now succeeded for the first time in making this trendsetting concept available for sustained mobility in everyday motoring practice. This makes BMW Hydrogen 7 the world's first hydrogen-powered luxury saloon suitable for everyday use.

BMW Hydrogen 7 is built at BMW's Dingolfing Plant, running parallel in production to the other models in the BMW 7, 6 and 5 Series on the same production lines. And like all BMW twelve-cylinders, the power unit is built at BMW's Engine Plant in Munich.

Assembly of BMW Hydrogen 7 at Plant Dingolfing includes all components for hydrogen drive – and this is also where the car is run for the first time on gasoline and where the hydrogen system is checked for any possible leaks. The hydrogen drive system is then run for the first time at BMW's facilities in Eching near Munich.

In its creation, BMW Hydrogen 7 has followed exactly the same obligatory series development process as every other new BMW, meaning that all clearance and approval process are subject to the same high standards and demands also applied to BMW's gasoline- and diesel-powered models. Both the engine and tank system, for example, as well as the car's electronics for hydrogen drive, have gone through the usual product creation process (PEP) required by the BMW Group, extending from the initial idea and strategy development via pre- and series development all the way to the final trials and subsequent introduction of the car. In this process all criteria relevant to the user are analysed with utmost accuracy and consideration in order to verify that the new vehicle is ready for the market in every respect.

All parts and components thoroughly tested for series production.
Within the PEP process, all components of BMW Hydrogen 7 – just like the components of all other BMW models – were thoroughly analysed and checked for their suitability in series production. This ensures that the vehicle meets all the high standards in terms of quality, safety and reliability regularly applied by BMW, the focus in this case being on a special safety concept geared to the needs and requirements of hydrogen drive.

Apart from the usual crash tests, BMW Hydrogen 7 had to fulfil additional impact tests serving to verify the strengths and qualities of its hydrogen components. Inter alia, the tests included a side impact directly on the tank coupling as well as a collision from the rear under carefully specified conditions. Then the hydrogen tank had to endure all kinds of extreme loads and conditions such as fire or bullets from firearms. And last but certainly not least in this context, BMW Hydrogen 7 is conceived and designed as a car with built-in safety, meaning that all parts and components fulfil maximum safety requirements and are designed moreover to automatically switch over to a safe status and condition in the event of malfunction. In practice, this means that permanent self-tests conducted by the vehicle serve to recognise malfunctions and initiate appropriate reactions at an early point in time, avoiding or at least minimising even the slightest hazard. At the same time the driver is informed of every malfunction even if it does not present a risk as such.

A particular feature of the safety concept built into BMW Hydrogen 7 is the avoidance of any uncontrolled release of hydrogen – and should hydrogen escape in an uncontrolled process all the same, this will be registered immediately, inter alia by a sensor-controlled gas warning system automatically initiating appropriate measures in the event of a functional deficiency.

A final but equally important aspect is that the safety concept of BMW Hydrogen 7 makes it very easy and even “tempting” for the driver to switch over to the car’s environmentally-friendly hydrogen drive power.

Developing BMW Hydrogen 7, the BMW Group sought from the start to promote the status of hydrogen technology both within the Company itself and in cooperation with suppliers. As a result, the knowledge gained in the process of development is extremely valuable, serving to significantly facilitate the development of future hydrogen-powered models to be introduced by BMW.

6. Concept: Progress without Compromises, Dynamic Performance Typical of BMW, Luxury Saloon Comfort and Premium Level Equipment.

- **Comfort and equipment of the highest standard.**
- **Modern cockpit with H_2 function displays.**
- **Supreme chassis and suspension technology specifically geared to the car.**

The BMW Group has always seen and appreciated the great potential of hydrogen as a drive energy offering both environmentally-friendly, low-emission combustion properties and first-class features guaranteeing attractive driving dynamics. Precisely this is why BMW Hydrogen 7, the first hydrogen-powered luxury saloon developed and suitable for everyday use, is positioned as a trendsetting, feature-oriented innovation in the premium segment within the BMW 7 Series.

In terms of performance, driving dynamics and motoring refinement, BMW Hydrogen 7 is entering the market right from the beginning at a level of perfection only achieved by conventional gasoline engines throughout a period of more than 100 years of ongoing development. This clearly and irrefutably contradicts the assumption that changing over to alternative energy inevitably means giving up a lot of driving dynamics and motoring refinement on the road – on the contrary, introducing the world's first hydrogen-powered series-production luxury saloon, the BMW Group is setting a clear signal pointing into the future of individual mobility. And at the same time the supreme comfort and style of BMW Hydrogen 7 is further enhanced by an exceptionally wide range of features and equipment.

Dimensions and interior ambience of the BMW 760Li.
Measuring 5,179 millimetres or 203.9˝ in length, 1,902 millimetres or 74.9˝ in width, and with its wheelbase of 3,128 millimetres or 123.1˝, the BMW Group's hydrogen car has exactly the same exterior dimensions as the BMW 760Li. With its new drive technology, on the other hand, BMW Hydrogen 7 accounts for unladen weight of 2,460 kilos or 5,424 lb, making it heavier than the long-wheelbase version of the BMW 7 Series running on gasoline alone. But to provide an appropriate service load nevertheless, the maximum permissible weight of the car has been increased accordingly.

At first sight, neither the body lines nor the interior of BMW Hydrogen 7 differ from those of the "regular" BMW 760Li.

Within the interior, BMW Hydrogen 7 combines top-quality materials with the most demanding climate control and seat qualities. The seats themselves come in Nasca Black and Nasca Flannel Grey as well as Merino Platinum leather upholstery, interior trim in high-gloss black piano paint helping to further enhance the exclusive ambience within the car.

Most of the modifications within the interior are to be found in the rear – and indeed, these modifications were necessary due to the hydrogen tank positioned beneath the parcel shelf and behind the rear seat bench. As a result, the rear seat bench in BMW Hydrogen 7 has been moved approximately 115 millimetres or 4.5˝ further to the front than on the BMW 760Li, but is still about 25 millimetres or 1.0˝ further at the rear than in the "regular" normal-wheelbase saloon. As a result, legroom in BMW Hydrogen 7 offers all the generous space typical of a BMW Luxury Saloon, giving the passengers at the rear the same grand touring comfort as in BMW's other luxury performance cars.

The centre armrest at the rear is fitted firmly in position on account of the car's overall package, meaning that BMW Hydrogen 7 is conceived as a four-seater.

The capacity of the luggage compartment is smaller than usual due to the additional components required for hydrogen drive. But offering an ample 225 litres or 7.9 cubic feet, the luggage compartment is still able to easily accommodate, say, two full-size golf bags.

Telemetric TPC Tyre Pressure Control.
BMW Hydrogen 7 comes as standard with BMW's highly accurate, sensor-based TPC Tyre Pressure Control. Carried over from motorsport, this pressure control system is particularly precise and provides a very reliable warning whenever necessary, thus representing the latest state of the art in tyre control technology.

TPC Tyre Pressure Control measures pressure within each tyre in short intervals, showing the appropriate reading for each wheel individually in the instrument cluster. At the same time the system also informs the driver of any gradual loss of pressure in any of the tyres resulting either from natural diffusion of air out of the tyres or from major fluctuations in temperature. Receiving this information, therefore, the driver is informed in good time of any deviations from the normal pressure level.

Modern cockpit with H_2 function displays.

Apart from slightly modified dimensions in the rear passenger area, the interior of BMW Hydrogen 7 also differs from the interior of the BMW 760Li in terms of the cockpit and its equipment. New function displays, for example, show the driver immediately that he is sitting in a car with a highly innovative, future-oriented drive technology.

The instrument cluster above the steering wheel is already well-known from the BMW 7 Series, with the speedometer together with the fuel gauge and the remaining range display on the left, various regular and variable telltales in the middle, and the on-board computer at the right.

Now there is also the "H_2" symbol in the middle of the display presenting the car's variable telltales, clearly showing the driver that BMW Hydrogen 7 is running in the hydrogen mode whenever this is the case. When running on gasoline, on the other hand, this display presents the time and outside temperature, that is the usual functions offered in this case.

Within the circular speedometer, BMW Hydrogen 7 boasts no less than two tank displays: The H_2 tank gauge is presented above the gasoline tank gauge, showing the driver the amount of hydrogen in the tank in kilograms.
The overall range the car is able to cover on the fuel in the tanks is presented as a two-piece crossbar, the transparent bar showing the remaining range on hydrogen alone, the solid bar presenting the remaining range on gasoline. This information is supplemented by a further display showing the remaining range in kilometres/miles.

Another figure possibly also presented here is the distance to a destination entered by the driver and calculated by the navigation unit. And the reserve levels for hydrogen (approx 1.5 kg useful residual hydrogen for about 50 kilometres or 30 miles) as well as gasoline (approx 15 litres residual gasoline for at least 100 kilometres/62 miles), finally, are presented separately from one another.

Over and above these standard readings and in analogy to the usual defect displays on a gasoline combustion engine, any efficiencies relating to hydrogen drive are also displayed by the system. The driver will therefore be alerted by a warning signal if, for example, the fuel tank filler flap is not properly closed, the engine is overheated or cannot be started in the hydrogen mode, or if the driver is advised to drive the car to a specialised workshop.

Switching over conveniently from hydrogen to gasoline.
The engine always starts automatically in the hydrogen mode, thus avoiding a potentially higher level of emissions when starting the engine cold on gasoline. The driver may then switch over to gasoline drive conveniently just by pressing a button on the steering wheel, either when the car is at a standstill or while moving. Switching over again to the alternative mode is only possible after a short time-lag in order to avoid any unwanted change of modes in rapid succession. And if one of the car's two tanks has been emptied to the residual level defined by the supply system, BMW Hydrogen 7 will automatically switch over to the other operating mode.

By way of exception, BMW Hydrogen 7 may also be started in the gasoline mode. In this case the driver is required to press the operating mode switch, activate the car's brakes, and press the start/stop button. He is subsequently able to switch back BMW Hydrogen 7 to H_2 operation, unless the hydrogen tank, contrary to required practice, has been emptied beneath the residual amount of hydrogen always required.

Driving dynamics without compromises.
Like the BMW 760i, BMW Hydrogen 7 comes with BMW's AdaptiveDrive suspension technology. The particular advantage of the AdaptiveDrive Package is that it combines BMW's innovative Dynamic Drive suspension control system setting off body roll with BMW's continuously adjustable EDC-C damper control. As a result, AdaptiveDrive offers the car's occupants a feeling of genuinely gliding round bends by reducing body roll, thus combining superior driving dynamics with equally superior motoring comfort and avoiding even the slightest compromise in the process.

BMW Hydrogen 7 also comes with head and side airbags front and rear, interior and exterior mirrors with an automatic anti-dazzle function, PDC Park Distance Control, a rain sensor, BMW's Professional navigation system and the Professional HiFi system, lumbar supports for the driver and front passenger, as well as seat heating both front and rear. And last but certainly not least in this context, the car is safeguarded from theft by an alarm system.

Exceptional all-round comfort.
A wide range of additional functions ensures supreme comfort in BMW Hydrogen 7 also in every other respect. These features include Soft Close Automatic on the doors, climate-comfort laminated glass on the windows, BMW's High-End automatic air condition, electrical seat adjustment complete with a memory function, auxiliary heating including remote control, BMW's high-beam assistant, a DVB-T TV function and on-board monitor, a CD changer for six CDs, a DVD changer for six DVDs, a separate car telephone at the rear, a smoker package and of course cupholders both front and rear.

High-End automatic air condition maintains travelling comfort at a supreme level regardless of weather conditions outside the car. The sensors featured in this automatic air condition detect the exact level of sunshine and control the flow of cooling air precisely in line with these requirements, the automatic system distributing fresh air without draughts and with individual adjustment to the various areas within the passenger compartment.

The auxiliary heating system featured in BMW Hydrogen 7 is activated as an additional heating function either from inside the car or by remote control from outside, ensuring a pleasant temperature inside the car in winter even before the engine has been started and allowing the engine to warm up to its optimum operating temperature more quickly. In summer, in turn, the system supports the air conditioning through its auxiliary ventilation function.

The sunblinds on the rear side windows of BMW Hydrogen 7 serve to further enhance the climate and feeling of comfort within the car. To reveal their heritage, they proudly bear the words “BMW Hydrogen Power” also to be found on the trim bars in the doors.

Yet a further feature is the on-board entertainment system exceeding even the regular system in the BMW 7 Series and giving the interior premium-class lifestyle and business qualities in every respect, complete with a CD changer and DVD changer, a rear monitor for the passengers at the back, a TV function complete with DVB-T reception, the BMW Assist telematics service, a separate telephone at the rear, and full preparation for BMW Teleservice.

Further technical highlights round off the supreme standard of BMW Hydrogen 7, such as Comfort Access, BMW Online, as well as voice recognition controlling the navigation, telephone and audio system. Then there is also the heated steering wheel, electrically adjustable comfort seats, BMW Night Vision, Adaptive Headlights, as well as 19-inch light-alloy wheels including BMW’s Mobility Set.

Metallic paintwork as yet another standard feature.
On the road, BMW Hydrogen 7 stands out clearly as a very exclusive vehicle through its high-quality metallic paintwork. Indeed, metallic paintwork comes as standard on BMW Hydrogen 7, particularly the special colour Blue Water Metallic available exclusively on this model highlighting the unique class, calibre and character of BMW’s Hydrogen Saloon.

So the bottom line of the vehicle concept boasted by BMW Hydrogen 7 is obvious: motoring will be just as attractive and appealing in future as it is today – and at the same time it will be cleaner than ever before.

7. Power Unit: Six-Litre Twelve-Cylinder with Direct Gasoline Injection and Hydrogen Intake Manifold Supply.

- **Top speed of 230 km/h or 143 mph with hydrogen drive.**
- **Engine emits virtually nothing but vapour.**
- **BMW underlines its leadership in drivetrain technology.**

The introduction of the BMW Hydrogen 7 represents a significant step into the future of automobile development, reducing CO_2 emissions by a dramatic margin. The dual-mode twelve-cylinder power unit featured in BMW Hydrogen 7 is able to burn hydrogen with virtually no emissions whatsoever as well as gasoline in a conventional process.

Featuring revolutionary innovations in engine technology and calibre, BMW Hydrogen 7 is paving the way for a highly practical changeover to a much cleaner and more environmentally-friendly world of motoring. And at the same time the dual-mode twelve-cylinder power unit featured in BMW Hydrogen 7 efficiently overcomes any gaps in the use of hydrogen due to the supply infrastructure currently still limited. Indeed, these innovations in technology clearly demonstrate the great commitment and responsibility assumed by the BMW Group as a leader in drivetrain technology.

Taking the current state of the art, only the combustion engine offers the advantage of being able to run in two operating modes. And precisely this is why the motorist opting for clean energy in the drivetrain is not restricted in any way in his individual mobility, thanks to the engine's dual-mode technology.

Offering a cruising range of approximately 700 kilometres or 435 miles, BMW Hydrogen 7 is able to take the driver and his passengers even further than a conventional gasoline-powered car. And in comparison with fuel cell technology, the combustion engine offers a far higher standard of maturity based on decades of experience the world over. Apart from the reliability offered by this engine concept as a result of this experience, the excellent driving dynamic qualities of the combustion engine are a further argument in favour of everyday motoring in practical style.

Series-production twelve-cylinder modified for hydrogen drive.
The twelve-cylinder power unit of the world's first series-production hydrogen-powered luxury saloon for everyday use is a derivative of the gasoline engine in the BMW 760i and boasts the most advanced features in technology such as fully variable VALETRONIC valve control and variable camshaft adjustment on the intake and outlet side as well as double-VANOS. The dual-mode

combustion engine is designed and laid out to burn both hydrogen or gasoline in its cylinders, the big advantage being that the car offers the same power and performance in both operating modes, the engine switching over without the slightest delay and without any perceptible change in driving behaviour from hydrogen to conventional gasoline operation and vice versa.

Displacing 6.0 litres, the power unit featured by BMW Hydrogen 7 develops maximum output of 191 kW/260 hp, giving the car a top speed limited electronically to 230 km/h or 143 mph. Maximum torque is 390 Newton-metres or 287 lb-ft at an engine speed of 4,300 rpm.

BMW's Hydrogen Saloon accelerates to 100 km/h in 9.5 seconds and has a range of more than 200 kilometres or 125 miles on hydrogen alone, with another 500 kilometres or 310 miles on gasoline.

Offering qualities of this calibre, the dual-mode V12 power unit featured in the world's first hydrogen-powered premium car for everyday use offers superior dynamic performance, motoring comfort and all-round reliability in typical BMW style, regardless of its operating mode. Precisely this is why dual-mode operation is particularly appropriate for increasing the acceptance of this new form of drive energy to a new, unprecedented level.

VALVETRONIC providing optimum conditions for hydrogen drive.
The combustion properties of hydrogen are quite different from those of gasoline or diesel: Hydrogen burns faster than gasoline and the combustion process with a mixture of hydrogen and air offers significant benefits through this faster rate of combustion, the same amount of energy providing a higher level of efficiency than with gasoline. A further significant point is that the different combustion properties of the two types of fuel are set off by specific engine management functions built into the dual-mode combustion engine.

Using throttle-free VALVETRONIC load management developed by BMW as well as variable double-VANOS camshaft adjustment, BMW's engine specialists benefited from the start from ideal tools for flexible control and management of the dual-mode V12 power unit, being able in this way to gear the intricate gas cycle and injection rhythm specifically to the features and requirements of the hydrogen/air mixture.

VALVETRONIC load management controls both valve timing and valve lift. Operated by an electric motor, an eccentric shaft incorporating a separate lever between the camshaft and the intake valves in the cylinders conveys cam lift into larger or smaller valve movements, whatever is required. VANOS camshaft adjustment, in turn, uses hydraulically controlled adjusters to control the beginning and end of the valve opening times.

Injection valves acting as a key technology.
Different processes in the dual-mode V12 power unit are used to provide the appropriate mixture of either gasoline or hydrogen. In the gasoline mode the engine operates with direct fuel injection, in the hydrogen mode the fuel/air mixture is formed in the intake ducts. The hydrogen distributors used for this purpose are integrated in the intake manifolds, while the specially developed hydrogen injection valves prove the outstanding art of engineering of the BMW Group's engine development specialists as a trendsetting innovation pointing strongly into the future: Naturally being larger than conventional injection valves, the gas valves cover a much wider range of individual volume flow adjustment. They must be able to handle hydrogen under all kinds of pressure levels in the system and they must be able to operate with both short and long injection times. This means they are able to feed exactly the required amount of hydrogen gas into the intake air at all times within hundredths of a second.

Clean mixture formation serving also to minimise nitric oxides.
With fossil fuels containing carbon (C), conventional drive concepts generate emissions which can only be reduced by means of intricate and complex technologies. This problem does not arise in the use of hydrogen, with neither carbon dioxide (CO_2) nor hydrocarbons (HC) or carbon monoxide (CO) being generated in the process of hydrogen combustion.

Since the combustion of lubrication fluid and the process of rinsing the activated carbon filter in the gasoline engine nevertheless generates a very low level of CO_2, HC and CO emissions, operation of BMW Hydrogen 7 in the hydrogen mode is commonly referred to as "virtually free of emissions".

CO_2 is generated by the combustion of gasoline vapour and the conversion of HC and CO emissions in the catalyst. Due to its concept alone, a gasoline-powered car requires an activated carbon filter in order to set off the natural evaporation of gasoline, for example in bright sunshine. Hence, emissions in the hydrogen mode are just a few per cent of the regular EU4 standards.

The only emissions of relevance in considering the dual-mode twelve-cylinder power unit are therefore nitric oxides (NO_X): Regardless of the type of fuel used, NO_X emissions will be generated in the combustion chamber under high combustion temperatures of more than 1,000 °C or 1,830 °F due to the mixture of nitrogen and oxygen in the air. Through its flexible engine management, however, BMW Hydrogen 7 is able to follow an operating strategy largely preventing the emission of nitric oxides, the dual-mode twelve-cylinder running with volume control under full load at so-called stochiometric

conditions. This means a completely balanced air/fuel ratio, with a lambda factor of 1. With the engine generating its maximum power under these running conditions, emissions of NO_X can be reduced to an absolute minimum by way of a conventional three-way catalyst.

Under part load engine load management is quality-controlled, like in a diesel engine. In this case the engine runs on a higher surplus of air with a lambda factor of more than 2, making the fuel/air mixture correspondingly lean. This, in turn, significantly reduces the temperature of the combustion process on account of the lean fuel/air mixture – and since these temperatures are below the thermal limit for NO_X, the generation of NO_X emissions is reduced to a minimum. Thanks to the wide range of hydrogen ignition temperatures, finally, the engine can be run on a very lean mixture in the H_2 mode, that means on a particularly small amount of fuel, which again serves to enhance engine efficiency.

By contrast, raw NO_X emissions increase significantly in the range between full load with a lambda factor of 1 and part load with a lambda factor of more than 2. This means that exhaust emissions are significantly higher under such running conditions. The system of engine management in BMW Hydrogen 7 is however in a position to cancel out this operating mode, switching over directly from lean combustion under part load to stochiometric combustion under full load, thus completely skipping or leaving out the fuel/air mixture range between a lambda factor of 1 and 2 with its unfavourable emissions. In other words, intelligent engine management avoids such operating and torque conditions altogether.

Through its intelligent operating strategy, the dual-mode V12 power unit is able to generate substantial power and performance regardless of the fuel chosen, at the same time reducing emissions throughout its entire operating area to a minimum. The engine also uses the particular qualities of hydrogen in the combustion process in order to optimise its output, efficiency, and emission control. The bottom line, therefore, is that the power unit featured in BMW Hydrogen 7 ensures dynamic performance also in the hydrogen mode, while for all practical purposes emitting nothing but vapour.

Introducing this trendsetting concept of the dual-mode twelve-cylinder power unit, the BMW Group is once again proving its key competence in drivetrain technology and is further enhancing its leadership as a truly innovative carmaker.

8. Energy Storage: Double-Walled Liquid Hydrogen Tank with Vacuum Super-Insulation.

- **Revolutionary efficiency in hydrogen tank insulation.**
- **Double-walled tank minimising the infusion of heat.**
- **Safe boil-off management system.**

The dual-mode drive concept featured by BMW Hydrogen 7 requires the integration of two separate fuel tanks in the car. To ensure a very long cruising range, BMW Hydrogen 7 comes with a conventional gasoline tank for 74 litres or 16.3 Imp gals and an additional fuel tank taking up approximately 8 kilos (about 114 litres/25 Imp gals) of liquid hydrogen (LH_2).

The BMW Group opts for liquid hydrogen since the amount of energy contained in such liquid fuel related to tank capacity in the car is more than 75 per cent greater than in the case of gaseous hydrogen stored in a compressed gas tank at a pressure of 700 bar. So in consideration of its higher energy density, hydrogen in liquefied form gives the car a much longer range in practice.

Together with the dual-mode power unit in BMW Hydrogen 7, the LH_2 fuel tank is another significant breakthrough in technology. The particular challenge in developing this tank system was that hydrogen does not become liquid under ambient pressure until cooled to a temperature of – 253 °Celsius, which then has to be maintained as long as possible. To achieve such storage conditions, the tank comes with double walls and features special super-insulation generating a high level of vacuum.

Fuel tank with vacuum super-insulation.
The fuel tank system is made up of an inner and outer tank, both formed out of two-millimetre-thick stainless steel and with a 30-millimetre (1.18´)-thick layer of vacuum super-insulation between the inner and outer tank.

The high level of vacuum conditions provided in this way avoids heat transfer through the air. And to avoid any unwanted infusion of heat, aluminium reflection films and glass-fibre layers in the intermediate space help to reduce any incoming heat radiation. A further point is that both the inner and outer tank are mounted on tapes made of carbon-fibre-reinforced plastic (CFP) reducing heat conduction to a minimum.

The vacuum-insulated intermediate layer ensures an outstandingly good insulating effect comparable to a layer of styrofoam about 17 metres or 56 feet thick. Clearly, insulation of this kind helps to keep temperatures extremely consistent, as we see from an interesting example: If such a tank were filled with boiling coffee, the coffee would remain hot for more than 80 days before cooling down to a temperature fit for drinking. This explains why the cryogenic hydrogen in the hydrogen tank can be kept liquid for a long time at a temperature of approximately – 250 °Celsius.

Boil-off management system.
Even so a certain degree of heat infusion cannot be avoided altogether, meaning that some of the hydrogen will evaporate in a natural process referred to as the boil-off effect.

The car must however be parked for more than 17 hours before suffering even minor losses on account of boil-off. With pressure in the fuel tank then increasing accordingly, the gaseous fuel must be controlled by an appropriate process of boil-off management limiting the pressure level inside the tank by allowing evaporated hydrogen to escape in a controlled process.

An increase in pressure beyond 5.1 bar will automatically open a boil-off valve to eliminate excess pressure inside the tank. The gaseous hydrogen released in this way is mixed with air in a venturi pipe and is oxidised into water in a catalytic converter, without requiring any additional energy in this process.

A hydrogen tank half full will take about nine days to release all its fuel and become completely empty in a controlled process. Even then there is enough hydrogen in the tank for covering approximately 20 kilometres or 12 miles in the hydrogen mode. And if BMW Hydrogen 7 is driven in the hydrogen mode in the meantime, the consumption of fuel required for running the engine will reduce the pressure within the tank accordingly. So that when the car is parked again, the 17-hour loss-free period prior to the inception of boil-off management will start again from the beginning.

To avoid even the slightest risk of the vacuum super-insulation being damaged with a corresponding increase in temperature, the tank is equipped not only with a boil-off valve but also with two redundant safety valves serving to let off gaseous hydrogen into the environment in a controlled and decentralised process in response to any above-average increase in pressure.

This process uses the physical qualities of hydrogen which, being lighter than air, will rise up and disperse immediately.

As soon as the first valve opens, therefore, the gaseous hydrogen is able to flow up to the roof of the car through safety pipes installed in the C-pillars. The second valve opening up only under higher pressure guides the flow of gas to the underfloor of the car, where again it is able to escape and disperse into the air.

While driving, the defined conversion of liquid into gaseous hydrogen is a permanent, ongoing process in BMW Hydrogen 7: Apart from liquid hydrogen, there is always a "cushion" of gaseous hydrogen within the LH_2 tank. This cushion is necessary since hydrogen is extracted from the tank and fed into the engine in gaseous form. A further point is that this consistent gas cushion is used for starting the engine, which automatically switches to the low-emission H_2 mode when starting up. Hydrogen reaches the engine in this process through the pressure gradient and double-walled pipes, a construction principle avoiding the need to fit a hydrogen fuel pump.

The ancillary system capsule.
Hydrogen is removed from the tank in a cryogenic, gaseous state and must be heated to an appropriate temperature before serving to provide an external fuel/air mixture formation in the combustion engine. This is why the hydrogen gas is first fed into a heat exchanger within a so-called ancillary system capsule, yet another innovative component featured in BMW Hydrogen 7. This capsule is also double-walled and surrounds not only the heat exchanger, but also the pressure and temperature sensors as well as the valve units.

The heat exchanger uses the heat of the engine as well as the coolant in the cooling circuit. As long as tank pressure is beneath the level of 3 bar required for running the engine, some of the gaseous hydrogen heated in the process is allowed to flow through the LH_2 tank, the infusion of heat provided in this way serving to evaporate some of the liquid hydrogen in the tank and thus increasing tank pressure to the level required.

Modified gasoline tank.
To meet the requirements of BMW Hydrogen 7, the gasoline tank in the BMW 760Li has been re-designed to fit into the space available and now offers a capacity of 74 litres or 16.3 Imp gals. This modification was necessary to guide the incoming LH_2 pipes from the hydrogen tank to the engine manifold past the gasoline tank and to upgrade the coolant circuit in order to heat up the hydrogen accordingly. In addition the new design provides the space required for the additional coolant pump in the cooling circuit.

9. Fuel Supply: Hydrogen Tank Filling Process Suitable for Worldwide Standardisation.

- **Filling up hydrogen through the usual process.**
- **Manual coupling, system-controlled tank filling.**
- **International partnership for worldwide standardisation.**

One of the fundamental requirements in developing the system for filling the hydrogen fuel tank in BMW Hydrogen 7 was to make the entire process just as straightforward and uncomplicated as filling a gasoline tank today. After all, introduction of the world's first hydrogen-powered luxury saloon for everyday use shall serve not only to reduce CO_2 emissions, but also to set a new milestone in a new area of automobile production, initiating a true revolution in the automotive industry.

By and large, only the pressure- and temperature-proof coupling for filling in hydrogen distinguishes the liquid hydrogen tank filling system from the conventional process of pumping in gasoline at a "regular" filling station. In all other respects the process of filling the tank is the same as with gasoline, the small number of manual operations required of the driver being more or less the same: Before filling up the tank, the vehicle must be parked safely in position by operating the electromechanical parking brake in transmission position P. Then, pressing a button to the left of the steering wheel, the driver opens up the tank filler flap for the hydrogen tank. The next step is to insert the liquid hydrogen coupling on the fuel pump into the car's hydrogen tank filler pipe like a conventional pump nozzle. Then, after the connection has been established manually, the tank coupling is automatically locked firmly in position, the car informing the filling station by itself via an electronic contact that the tank may now be filled up, without requiring any intervention on the part of the driver. Ultimately, therefore, the process of filling up the tank with hydrogen can start automatically by means of system control.

The filling station receives the electronic go-ahead for filling up the tank only when the car has been parked safely in position, if battery voltage is sufficient, if there is neither a gas warning nor a crash signal, if the level of fuel in the tank is not higher than 80 per cent, and if the pressure within the tank is more than 5.5 bar. Further requirements are that the tank filler flap is fully open and the leakage test on the tank coupling has been successfully completed.

In the system-controlled process of filling the tank, the spherical pump taps are opened automatically, the transfer pipe is inserted, the process of filling in fuel is completed, the filler pipe is rinsed, the transfer pipe returned to its original position, the spherical pump taps are closed and the system is unlocked fully automatically. So all the driver has to do is disengage the tank coupling and close the tank filler flap by once again pressing the tank button.

This entire process takes less than eight minutes. Indeed, filling the tank is just as safe and even cleaner than the conventional process of filling a gasoline or diesel tank, since complete encapsulation prevents the release of ignitable vapour otherwise virtually inevitable in the case of gasoline or diesel. And should there be any kind of malfunction at the filling station or in the vehicle itself, the process of filling the tank is either interrupted or does not even start in the first place.

Co-axial hydrogen filling process.
Cooled to a temperature of approximately – 250 °Celsius, the liquid hydrogen is able to precipitate into the hydrogen tank of BMW Hydrogen 7, hydrogen gas above the liquid phase in the tank condensing on the droplets flowing in to reduce the pressure of the hydrogen gas within the tank.

The process of filling the tank is co-axial, meaning that liquid hydrogen is transported in the inner section of the tank hose made up of two layers while gaseous hydrogen is able to return through the outer layer after being forced out of the tank by the liquid hydrogen and thus returning to the filler pump through the co-axial tank coupling.

En route to worldwide standardisation.
To ensure the introduction of a standardised liquid hydrogen tank filling coupling suitable for the automobile the world over, the BMW Group has established an open consortium in cooperation with General Motors/ Opel and Honda as well as Linde, a major supplier of hydrogen, and Walther, the manufacturer of the mechanical systems and components for filling up the hydrogen tank. This consortium seeks to standardise the liquid hydrogen tank filling coupling on a worldwide level.

Linde contributing significant know-how in hydrogen technology.
Numerous hydrogen projects in the past have already borne the distinctive stamp of close cooperation between the BMW Group and Linde, a major supplier of hydrogen: Linde is one of the world's largest manufacturers of hydrogen production systems and has already built a large number of hydrogen liquefaction plants. At the same time Linde is one of the most

significant suppliers of liquid hydrogen, provides the components and equipment for nearly all liquid hydrogen filling stations currently in existence, and, inter alia, supplies liquid and gaseous hydrogen to the filling stations in both Berlin and Munich.

Filling up the tank both cold and warm.
Apart from the practical process of filling up the tank in a cold state initiated by manual intervention and then controlled by an automatic system, the hydrogen tank in BMW Hydrogen 7 may also be filled in exceptional cases when in a warm state. This may be required when the tank is completely empty or when, after the car has been parked for a particularly long period, the tank is too warm for being filled up with cryogenic hydrogen.

The driver of a BMW Hydrogen 7 is informed from the start in taking receipt of his vehicle how to avoid situations which might require the tank to be filled in a warm state. This is particularly because filling up a warm tank takes much longer than filling up the tank when cold, since the hydrogen tank must first be cooled to the temperature required for normal operation. A further point is that for safety reasons filling up the tank in a warm state must be conducted by trained personnel at the filling station. But even in such a case, the vehicle remains fully mobile and may still be run on gasoline.

Gasoline is filled into the tank in the same way as in a conventional BMW 7 Series. The fuel grade required is premium plus.

10. Body and Suspension: Based on the BMW 760Li, Intelligent Lightweight Construction, Optimised Crash Safety, Special Suspension Set-Up.

- **High powerdome as a characteristic feature of BMW Hydrogen 7.**
- **Innovative combination of CFP and steel.**
- **Telemetric TPC Tyre Pressure Control system like in motorsport.**

BMW Hydrogen 7 successfully combines dynamic performance, luxurious motoring and supreme driving comfort with new, revolutionary drive technology. The outstanding style and character of the world's first hydrogen-powered luxury saloon comes to bear clearly and distinctly in the sporting and elegant body of the car as well as the suspension conceived and designed for supreme driving dynamics.

BMW Hydrogen 7 is clearly recognisable at very first sight as a fully-fledged member of the BMW 7 Series. Through its looks alone, BMW Hydrogen 7 is largely identical to the body design of the BMW 760Li, the largest saloon within the BMW 7 Series, with both models sharing the same exterior dimensions and wheelbase.

Reflecting the specific hydrogen features of BMW Hydrogen 7, the body design of the BMW 760Li has been carefully modified or re-styled in several areas. A fundamental innovation is the use of carbon-fibre-reinforced plastic (CFP) on various body components: The BMW Group has developed a new combination of CFP and steel especially for BMW Hydrogen 7, combining particularly good crash resistance and high strength with low weight. This allows the car to set off some of the extra weight resulting from the drivetrain and the integration of a hydrogen tank system and fulfilling the great demands made in terms of passive safety. This is why the side frames of the passenger cell are reinforced all round at the left and right by CFP, unladen weight of BMW Hydrogen 7 amounting to 2,460 kg or 5,424 lb.

Body design: discreet modifications on the exterior.
Compared with the BMW 760Li, the engine compartment lid as well as the transparent LH_2 fuel tank filler flap in a chrome surround on BMW Hydrogen 7 are the most conspicuous of the small number of body components modified on the car. Indeed, the strongly accentuated powerdome is an essential sign of distinction further defining this first hydrogen-powered series-production luxury saloon in the world.

The reason for this pronounced powerdome is the higher engine in BMW Hydrogen 7 with extra dimension resulting from the integration of H_2 injection valves. At the same time this new contour line bears clear reference to the unique source of power beneath the bodyshell of BMW's Hydrogen Saloon.

In the interest of an upgraded cooling system, BMW Hydrogen 7 does not have the usual foglamps at the front. Another feature intentionally omitted on BMW's Hydrogen Saloon is the sliding roof, making way in this case for a safety gas purge flap.

Apart from the high powerdome, the car is clearly distinguished by the "Hydrogen 7" model designation on the rear lid and the word "Hydrogen" beneath the side direction indicators. Another particular design feature is the rear bumper trim with chrome appliqués. And finally the name "BMW Hydrogen Power" in the door cutouts bears clear reference to the car's revolutionary drivetrain technology.

The world's first hydrogen-powered series-production premium car for everyday use comes off the production line in beautiful and high-quality metallic paintwork, particularly the special colour Blue Water Metallic available exclusively on this model impressively emphasising the unique character of the car.

Modifications within the interior.
The interior of BMW Hydrogen 7 is almost the same as the interior of a "regular" BMW 760Li. One difference is that there are new instruments in the cockpit monitoring operation in the hydrogen mode, another is the "H_2" symbol lighting up within the instrument cluster of this very special BMW 7 Series between the variable telltales whenever the car is running on hydrogen.

An additional H_2 tank gauge is positioned within the speedometer among the gasoline tank gauge, showing the current level of hydrogen in kilograms. The overall range the car is able to cover on the fuel remaining in the tanks is shown as a two-piece crossbar and additionally as an absolute number. The reserve amounts of hydrogen (approx 1.5 kilos of useful residual hydrogen for a distance of approximately 50 kilometres or 30 miles) and gasoline (approx 15 litres or 3.3 Imp gals for at least 100 kilometres or 62 miles) are shown separately in two displays.

The most conspicuous modifications are to be found in the rear due to the special arrangement of the hydrogen tank beneath the parcel shelf and behind the rear seat bench: The rear seat bench in BMW Hydrogen 7 is 115 millimetres or 4.5˝ further to the front than in the long-wheelbase version of the BMW 7 Series, but 25 millimetres or 1.0˝ further to the back than in the

BMW 7 Series with normal wheelbase. This means that the two passengers at the rear enjoy all the long-distance travel comfort of a luxury performance BMW also in the new hydrogen car. And with the centre armrest being fixed in position as a result of the car's package, BMW Hydrogen 7 is conceived and built as a four-seater.

Lightweight aluminium chassis.

BMW Hydrogen 7 is heavier than the "regular" BMW 7 Series – particularly at the rear – due to the additional components for supplying liquid hydrogen fuel. This requires appropriate modification of the chassis and control systems, with the chassis and suspension as such being based on the standard lightweight aluminium chassis giving the BMW 7 Series its characteristic dynamism and performance.

The front axle is a double-joint tiebar spring strut configuration, the rear axle an integral-IV multi-arm design offering both anti-squat and anti-dive. As on the BMW 7 Series High Security Saloon, the rear axle features aluminium and steel reinforcements.

BMW Hydrogen 7 is equipped with BMW AdaptiveDrive, a special chassis and suspension system combining anti-roll stability with variable damper adjustment specifically tailored to this model. AdaptiveDrive helps to give BMW Hydrogen 7 very agile and superior handling at all times, keeping the driver in perfect control even in tight bends and under difficult conditions.

The springs on the rear axle have also been re-configured to meet the requirements of BMW Hydrogen 7. With the dampers on the front and rear axles also re-configured and modified as required, BMW Hydrogen 7 offers the same unparalleled combination of driving stability and dynamic performance so typical of the BMW 7 Series in general.

BMW Hydrogen 7 comes with a brake system carried over from the BMW 7 Series, enabling the car to come to a standstill from 100 km/h within 41 metres or 134 feet. The electromechanical parking brake, in turn, has been specially modified for BMW Hydrogen 7, fitted in a different position, with modified cables and a modified emergency release function.

The control systems have been derived from the BMW 760i and BMW 760Li and then suitably adapted to both the performance data and weight distribution of BMW Hydrogen 7. Apart from the AdaptiveDrive control software, this also involves the exact set-up of the ABS anti-lock brake system and of DSC Dynamic Stability Control.

BMW Hydrogen 7 runs on 19-inch light-alloy wheels in new design and is delivered complete with the BMW Mobility Set. Eighteen-inch winter tyres are also available on request.

High-tech TPC Tyre Pressure Control.
BMW Hydrogen 7 is also equipped as standard with BMW's sensor-based TPC telemetric Tyre Pressure Control. Carried over from motorsport, this system offers an even higher standard of accuracy and a clear warning whenever required, thus reflecting the latest state of the art in tyre control technology.

Telemetric TPC Tyre Pressure Control permanently measures air pressure in each tyre, re-affirming the measurement at short intervals. The figure measured in this way is presented by telltales in the instrument cluster for each individual wheel.

The TPC system comprises four electronic wheel monitors each equipped with a 125 kHz receiver and a 433 MHz transmitter and fastened to the wheels together with metal valves. These electronic wheel monitors are run by batteries with a service life of five years.

Benefiting from this sophisticated technology, the driver receives warning signals indicating a loss of pressure on any of the tyres even earlier and with greater precision than before. A further important point is that the system makes the driver aware of any consistent, ongoing loss of air in any of the tyres resulting, say, from the natural diffusion of air from the tyres and from major fluctuations in temperature.

Effective sound insulation for maximum all-round comfort.
The dual-mode combustion engine featured in BMW Hydrogen 7 sounds different from a conventional gasoline engine. Faster combustion and the higher degree of efficiency generate a more intensive level of engine noise in the H2 mode in a different frequency spectrum. Various measures in sound engineering nevertheless serve to set off this effect.

One example is that the automatic transmission in BMW Hydrogen 7 rests on mounting points carried over from the eight-cylinder version of the BMW 7 Series with their softer response. This ensures an ideal compromise of superior driving dynamics, on the one hand, and pleasant sound control, on the other.

Along the floor in the passenger compartment and on the bulkhead in front of the engine, BMW Hydrogen 7 is fitted furthermore with so-called super-high sound insulation. Air is fed into the passenger cell through an acoustically dampened air duct specially developed for this model and the air intake snorkel leading to this air supply is fitted with an intake silencer.

As a result of these modifications BMW Hydrogen 7 has a noise pattern when running on hydrogen similar to that of the BMW 760i running on gasoline. Even so, this special model retains its very own, characteristic sound in the hydrogen mode.

11. Safety Concept: Development of Safety Standards, Testing, Independent Certification.

- **Multi-stage safety concept for hydrogen components.**
- **Active self-monitoring functions in BMW Hydrogen 7.**
- **Fully tested with all tests processes applied in the development of series-production models.**

Carefully examining all kinds of alternative drive energy, the BMW Group has clearly determined that hydrogen is the most suitable fuel for emission-free motoring in future. But since hydrogen naturally has different properties and features in comparison with gasoline or diesel, hydrogen fuel has to be treated differently. One point is that this new type of drive energy requires new safety precautions, significant priority therefore being given in the development and construction of BMW Hydrogen 7 to an integrated safety concept ensuring unrestricted use of the car in everyday motoring.

With the hydrogen system in BMW Hydrogen 7 using a form of drive energy hardly supported by practical, everyday driving experience so far, this safety concept embraces all of the car's functions and operations as well as all driving conditions in regular motoring – also in a tunnel, for example, through parking the car and filling up the tank all the way to regular maintenance and repair.

All components of the hydrogen system are designed and laid out to ensure maximum safety right from the start through their design and configuration alone. To guarantee such a high standard of built-in safety, the various components always return to a safe operating state in the event of malfunction.

Yet a further significant point is that the car features a comprehensive, sensor-controlled self-monitoring system offering the driver additional information whenever required on the current condition of his vehicle. Indeed, the driver receives warning information on malfunctions even when such deficiencies do not – yet – present any kind of hazard.

With BMW Hydrogen 7 having gone through all phases and gateways in the process of product creation and development, fulfilment of the most demanding quality and safety requirements has been carefully considered and verified during these comprehensive, clearly defined clearance and approval procedures. Great attention has been given, for example, to the functional safety of all components containing or coming into contact with hydrogen, requiring a special safety-oriented development process in such cases.

With progress in the area of mobility involving new control and, where appropriate, new safety regulations, the BMW Group is a member of many international boards and committees seeking to develop uniform safety standards for the hydrogen-powered vehicle. Hence, the safety concept applied to BMW Hydrogen 7 allows the driver to switch over to the new environmentally-friendly drive technology without restrictions even under regular, everyday driving conditions.

Safety-relevant features and qualities of hydrogen.
A fundamental difference between hydrogen, on the one hand, and gasoline/ diesel, on the other, is that hydrogen is both colour- and odourless. A further point is that hydrogen is 15 times lighter than the air around it, thus always rising up and dispersing into the environment. This also means that hydrogen escaping from a car's LH_2 tank will not form puddles of fuel on the ground as in the case of gasoline or diesel.

The LH_2 tank of BMW Hydrogen 7 contains liquefied hydrogen cooled to very low temperatures far below zero. Should liquid hydrogen escape into the air, it will immediately warm up and become gaseous, then rising up and dispersing into the atmosphere. So unlike the situation with gasoline or diesel, hydrogen escaping under such conditions will not pollute the ground even when released inadvertently.

An important challenge in terms of safety is the far higher ignitability of hydrogen in comparison with gasoline or diesel – and a further point is that the ratio of hydrogen and air mixtures able to ignite covers a broader spread.

Yet another consideration in this context is that the energy required to ignite hydrogen is lower than in the case of gasoline or diesel, again meaning that hydrogen gas may be ignited more readily.

When burning, hydrogen will form an upward-facing flame not visible to the human eye and not generating any smoke. Looking at the worst case scenario on the road, however, hydrogen offers the clear advantage over gasoline or diesel that it will not burn so easily and that the risk of escalation at the scene of an accident is therefore smaller. This is because hydrogen disperses quickly into the atmosphere, meaning that it may be ignited only by a source of ignition in the immediate vicinity of the hydrogen flame coming out of the tank, that is where the mixture of H_2 and air really forms an ignitable combination of the two substances. The likelihood of the vehicle catching fire is therefore relatively small, and a further point is that a fire, should it break out at all, would not be able to spread through puddles on the ground as in the case of gasoline or diesel.

Should the hydrogen tank develop a leak within a closed-in room without any openings or extraction of air and gas to the outside, the human being would not perceive the concentration of gas forming in this process due to hydrogen being odour- and colourless. And while hydrogen, unlike gasoline or diesel, is not toxic or irritating, it does require the application and observance of different rules for fire prevention than in the case of conventional fuels.

Handling hydrogen in practice is by all means a safe process as long as the specific features and properties of hydrogen are properly taken into account. So using hydrogen in everyday motoring may well become quite normal and natural for the motorist in future, just like the use of petrol and diesel fuel. And it is important to consider that every type of fuel inevitably involves a certain potential risk through its energy content alone: Obviously, no vehicle would be able to run on gasoline or diesel if those fuels were not combustible.

Multi-stage safety concept for hydrogen components.
Focusing on a road vehicle running on hydrogen, the BMW Group, acting as a pioneer in this area, gives clear preference to the storage of liquid, cryogenic hydrogen in an innovative, super-insulated tank. To be stored in such a tank, hydrogen is first cooled down until it reaches its liquid state, offering the advantage over gaseous hydrogen that storage density is much higher thanks to this process of liquefaction, thus giving the car a longer cruising range.

The challenge in opting for this solution is that hydrogen under ambient pressure has to be cooled to –253° C in order to turn liquid and that the fuel filled into the tank has to keep this low temperature as long as possible.

Although the tank is extremely well insulated, a certain, low degree of thermal transfer reaching the contents of the tank cannot be excluded. Some of the liquid fuel in the tank will therefore evaporate in the course of time, generating the so-called boil-off effect. This, in turn, means an increase in tank pressure, since hydrogen in its gaseous state takes up more space.

This process of expansion and growing pressure is monitored and controlled in BMW Hydrogen 7 by the boil-off management system where the volume of hydrogen boiled off is fed into a catalytic converter oxidising the hydrogen into water without requiring any additional energy for this purpose.

In addition to the boil-off management system, the tank comes with two redundant safety valves for the event of damage to its vacuum super-insulation. So in the event of an unusually large increase in pressure, the valves let off the gaseous hydrogen to the environment in a controlled process: when opening, the first valve allows hydrogen to flow up to the roof of the car through

safety pipes in the C-pillars, from where the hydrogen is dispersed into the atmosphere. The second valve feeds hydrogen gas down to the underfloor of the car, where again it is able to escape.

Yet a further important point in this context is that the LH_2 tank is positioned behind the rear seat bench and above the rear axle, thus ensuring optimum safety and resistance in the event of an impact.

All relevant pipes and components containing hydrogen come with double walls all round. So should the inner wall in a hydrogen pipe develop a leak or become defective, the second wall will keep any hydrogen escaping from the system safely within the pipe where it can be registered faster than otherwise by means of hydrogen sensors. Then, once the leakage of hydrogen from the system has been diagnosed, check valves close to the tank are locked in order to limit any such leakage to an uncritical level.

Active self-monitoring in BMW Hydrogen 7.
BMW Hydrogen 7 was conceived and designed from the start as a car with built-in safety. This means that BMW's hydrogen car permanently and consistently monitors itself, ensuring that all components meet maximum safety requirements and automatically switch over to a safe operating mode in the case of malfunction.

In principle the car is also maintained in a safe condition even when not under power, a comprehensive, sensor-based system informing the driver of any functional deficiencies in any of the components exposed to hydrogen. Hydrogen sensors are fitted for this purpose at five relevant points throughout the car: in the engine compartment, in the ancillary system capsule, in the LH_2 fuel tank filler flap, within the interior and in the luggage compartment. Red LED indicators in the door locking buttons then light up as soon as the sensors detect any hydrogen, regardless of the engine's current operating mode, the car's on-board network and the current activation or non-activation of the instrument cluster.

Additional warnings are triggered in the instrument cluster while driving, and the driver is also warned by a sound signal.

Last but not least, the current condition of the system is permanently monitored by pressure and temperature sensors helping to initiate counter-measures in the system prior to the occurrence of a defect. And if hydrogen is able to escape from the system, these control functions automatically switch off the supply of hydrogen, BMW Hydrogen 7 automatically switches over to the gasoline mode, and the side windows will also open automatically.

Apart from its starter battery, BMW Hydrogen 7 comes with two additional batteries for the sensor-controlled safety system, keeping the gas warning monitor in constant operation regardless of the starter battery and its current condition. With these two batteries offering an overall service life of up to 66 days, they cover the maximum period for which H_2 may be stored in the tank.

Testing and independent certification.
The engine and tank filling system as well as the automotive electronics featured in BMW Hydrogen 7 were developed from the start as integral components of the car and have gone successfully through the entire process of product creation and development. Applying the clearance and approval procedures obligatory for new BMW models, the responsible engineers and safety experts ensured fulfilment from the start of all quality and safety requirements typical of BMW. And with all safety-relevant components going through a special safety-oriented process of development, all of these components have been tested and approved in the most demanding and precise safety analyses, ensuring in advance that they meet all the requirements of practical use as determined in detail. These theoretical analyse were subsequently confirmed and backed-up by specific, target-oriented tests, external experts ultimately approving the demands and standards applied to all relevant components, the theoretical safety tests and back-up procedures.

Like every other series-production model from BMW, BMW Hydrogen 7 has gone through all the usual trials and additional, hydrogen-specific crash tests particularly with a view to the car's hydrogen components, three examples being the EURO NCAP front-offset crash test at an impact speed of 64 km/h or 40 mph, the rear-end impact test with 100 and, respectively, 40 per cent overlap, and a side impact collision at the car's most sensitive point directly on the tank coupling. None of these crash tests caused any critical damage to the tank, its insulation or the various components exposed to hydrogen.

Apart from the comprehensive test programme for both individual components and the vehicle as a whole, the behaviour of the hydrogen tank under the most extreme conditions such as exposure to flames, bullets fired from outside, massive mechanical damage, as well as the reaction of the tank and safety components to an artificially induced loss of tank insulating vacuum has been carefully and thoroughly considered.

To conduct tests of such magnitude and intensity, the BMW Group joined forces with the South German Technical Inspection Authority (TÜV South Germany), compiling a broad range of accident scenarios to be considered. With their extremely high standard of safety proven in these tests, the redundant safety valves ensure that hydrogen stored in the tank is boiled off in a controlled process whenever necessary, without creating a major hazard.

In one of the fire tests filled hydrogen tanks were surrounded for up to 70 minutes by hot flames at a temperature of more than 1,000 °Celsius or 1,830 °Fahrenheit. Here again the tanks did not present any problems despite these extreme conditions, hydrogen evaporating in the process escaping in a controlled mode through the safety valves, hardly perceptible from the outside. The bottom line, therefore, is that all the results obtained clearly confirm the superior safety concept of BMW's LH_2 system.

All safety development processes were also checked and confirmed in the same way, focusing not only on all the results achieved in development, but also on the proper determination of standards and requirements as well as the complete coverage of all factors by the tests conducted. Reviews and assessments were conducted for this purpose by both internal and independent, non-partisan external experts focusing on the individual components and the overall vehicle as such (these external experts including engineers and safety specialists from the TÜV Technical Inspection Authority and other specialised engineers and institutes).

In consideration of the comprehensive tests carried out, both TÜV South Germany and the advisory fire brigade specialists arrived at the conclusion that "the hydrogen car is at least as safe as the conventional gasoline car."

Rules for parking in garages.
Since sufficient statistically reliable data obtained under regular operating conditions is not yet available to confirm the safety of the hydrogen tank as such, parking in closed-in spaces is currently not allowed. The BMW Group will maintain this rule in the interest of the car's drivers until adequate, statistically valid reliability data has been compiled. This data will be collected in long-term use and in additional back-up and security programmes.

Driving and briefly stopping the vehicle in closed-in spaces such as indoor parking buildings, driving through any kind of tunnel and the use a car wash, is not subject to any kid of restrictions, just as the car may be parked at any time in an open carport.

12. Production: Integration into Series Production at BMW Plant Dingolfing, BMW Hydrogen 7 as a Spearhead in Innovation.

- **Production under regular conditions.**
- **Production parallel to the BMW 7, 6, and 5 Series.**
- **Innovations in lightweight body structure also applicable to other models.**

Production of BMW Hydrogen 7 clearly confirms the enormous progress made by the BMW Group in developing hydrogen drive: Unlike former prototypes and demonstration models, BMW Hydrogen 7 is not the result of a research project, but has rather, like all other BMWs, gone through the usual process of series development. Precisely this is why the car may also be built under regular conditions in series production.

BMW Hydrogen 7 is built at BMW's Dingolfing Plant parallel to the "regular" models in the BMW 7, 6, and 5 Series. And the power unit, like all of BMW's twelve-cylinders, is built at the Company's Engine Plant in Munich.

The most important objective in the process of series development was to allow efficient use of the car and achieving the goal of the homologation for the German and other ECE markets. So like all other models in BMW's other model series, BMW Hydrogen 7 has gone through the usual process of product creation referred to as the "PEP Process" within the Company.

This process serves to analyse each and every component for itself as well as the overall vehicle as a whole for its subsequent qualities in series production.

High safety standards played an important role in this context, the various steps in the process of PEP development ensuring adequate testing, clearance and approval and therefore guaranteeing that all cars fulfil the high standards of the BMW Group.

A further objective carefully pursued in the case of BMW Hydrogen 7 was to further promote hydrogen technology both within the Company itself and with BMW's respective suppliers. The establishment of detailed know-how and the integration of hydrogen technology in everyday use therefore set the foundation for future vehicle developments.

Body production pointing clearly into the future.

One of the particular challenges in production, over and above the innovative drive concept, is the car's bodyshell and body construction. For the first time, BMW Hydrogen 7 comes with a body-in-white combining carbon-fibre-reinforced plastic (CFP) with steel, ensuring extra body stiffness on all parts and components subject to particular loads due to the higher overall weight of the car. The result of this combined CFP structure is enormous body stiffness on optimised weight – and the knowledge gained on this new technology might well be applied to other BMW cars in future.

BMW Hydrogen 7 is assembled at BMW's Car Production Plant in Dingolfing, some 100 kilometres or 60 miles north-east of Munich. This is also where the car is run for the first time in the gasoline mode, and where the hydrogen system is checked for leakage. The hydrogen drive system as such is then operated for the first time at BMW's facility in Eching near Munich.

13. Cooperation: The World's First Hydrogen-Powered Luxury Saloon for Everyday Use, Close Communication of Users and BMW.

- **Experience in everyday motoring provides valuable know-how.**
- **Sheer driving pleasure and a pioneering commitment.**
- **Competent service ensured by well-trained service technicians.**

The driver of BMW Hydrogen 7 is participating in a truly outstanding pioneering achievement, at the same time enjoying a direct experience of new mobility. A further point is that each driver, through his or her individual experience with the car, will influence the ongoing development of hydrogen drive. Precisely this is why all drivers of BMW Hydrogen 7 are in close contact with BMW Group engineers involved in the development of the car and its technologies. In this way BMW Group specialists receive ongoing feedback on the everyday experience of such trendsetting motorists with the world's first-ever series-production hydrogen-powered luxury saloon.

Taking receipt of BMW Hydrogen 7, each driver receives detailed instructions explaining the particular features of hydrogen drive and the practical functions of the car, and is therefore able to enjoy the usual standard of driving dynamics, motoring comfort and everyday reliability in BMW Hydrogen 7, with the same qualities as in a "regular" BMW 7 Series.

Additional knowledge over and above the usual procedures in driving a conventional gasoline- or diesel-powered car is required only for the different operating conditions in a hydrogen saloon.

As in the case of other innovations, BMW attaches great significance to the judgment of drivers on all functions relating to hydrogen drive, including the user-friendliness offered by the car. Such opinions and experience gained in practice have a direct influence on the development of future hydrogen cars still to come.

Remote diagnosis transmitting vehicle data directly to BMW.
A further important point is that every BMW Hydrogen 7 is equipped with an innovative remote diagnosis system ensuring particularly broad and efficient coverage of the car's operating data in diagnosing the vehicle and its various components.

In BMW Hydrogen 7 this diagnostic process is maintained permanently and automatically in order to compile meaningful data on all conceivable operating conditions as quickly and efficiently as possible. The system thus covers a wide range of vehicle data transmitted regularly in an automatic process every four hours to a BMW hotline. Such data includes the pressure inside the tank and the level of fuel, the on-board voltage as well as various other reports on the condition and status of the vehicle. At the driver's request, the system may even show the current location of the car at any point in time.

Specialised BMW workshops for competent service.
BMW's development engineers have created a special service programme for BMW Hydrogen 7: Regular service every three months serves, inter alia, to check the hydrogen system for possible leaks and the safety components for proper function, thus guaranteeing supreme reliability and safety in the everyday use of BMW Hydrogen 7.

All maintenance and repair operations are conducted exclusively by specially equipped workshops with specially trained service personnel able to carry out all work on the hydrogen system safely and competently. And last but certainly not least, only these workshops have the special tools required for working on the hydrogen system in BMW Hydrogen 7.

14. Momentum: BMW Hydrogen 7 as the Incentive for Developing a Hydrogen Supply Infrastructure.

- **Study: hydrogen is the most promising alternative fuel for the future.**
- **Practical mobility giving H_2-drive greater acceptance.**
- **Plans for further hydrogen filling stations.**

Introducing BMW Hydrogen 7, the BMW Group is powerfully paving the way for the ongoing expansion of hydrogen supply. While a nationwide network of hydrogen power stations is still a vision, the technical and logistical know-how required for this purpose is already available. And the supply of fuel for the motorist under practical conditions is most convenient and straightforward, with the process of filling up the tank of a hydrogen car being just as simple and uncomplicated as in a conventional gasoline or diesel model. The decisive arguments in favour of hydrogen are however the reduction of CO_2 emissions and the need to become independent of fossil fuels with their finite outlook in future.

A scientific study conducted by the Transport Energy Strategy (TES) Initiative, focusing on more than 10 alternative fuels and over 70 production processes, clearly reveals that hydrogen produced in a regenerating process is certainly the best solution for the future in the long term, given the need to ensure ongoing, sustained mobility. The TES study shows that the biggest political and strategic advantage of hydrogen lies in the fact that hydrogen can be recovered very flexibly and with a great potential from regenerating sources, thus helping to avoid CO_2 emissions and supply risks in the long term.

A further point is that hydrogen technology offers a great potential for ongoing innovations in mobile use and therefore opens up new areas of growth for German industry.

Precisely this is why the German Federal Government promotes this environmentally friendly technology through its new National Hydrogen and Fuel Cell Innovation Programme, with additional funds of Euro 500 million to be set aside for this purpose in the next ten years. The focus in this case is on both pilot and demonstration projects alike.

BMW Group focusing on the supply of liquid hydrogen.
In the process of introducing this alternative fuel on an all-embracing, ultimately worldwide level, the BMW Group is focusing on liquid hydrogen mainly because this form of hydrogen offers far higher energy density than gaseous hydrogen. Closely cooperating with MagnaSteyr as a project partner, BMW already started to develop a tank system years ago in which vehicles are able to fill up liquid hydrogen in fundamentally the same clean and harmless process as in the case of gasoline or diesel.

The world's first public hydrogen filling station was opened at Munich Airport in the year 2000, operated by Linde and used by BMW and other manufacturers. This project alone served to provide valuable practical experience on hydrogen drive.

Further hydrogen filling stations have subsequently entered operation in the course of time, a filling station run by Aral opening up in Berlin in 2004 to supply both buses and passenger cars with liquid and gaseous hydrogen. In March 2006 another petroleum company, Total, opened up a further integrated filling station in Berlin offering not only conventional fuels, but also hydrogen. This new station replaced a test station opened in Berlin for the first time by Total in the year 2002.

There are further filling stations for liquid hydrogen in Washington, Tokyo, and Milan.

BMW and Total promoting the development of hydrogen.
To promote the development of hydrogen as an alternative drive energy, BMW and Total intend to cooperate closely in future. Precisely this is why the two companies recently signed an agreement stating that Total will be opening up three hydrogen filling stations in Europe by the end of 2007, supporting the practical use of BMW hydrogen cars in the process.

Following the establishment of Total's fully integrated filling station in Berlin, a further public filling station with hydrogen fuel pumps will be starting operation this year, not far from BMW's Research and Innovation Centre in Munich, and taking the place of the hydrogen filling station so far operated at Munich Airport.

The two companies have also agreed to open up a third integrated hydrogen filling station at a European location outside of Germany.

Process of filling hydrogen into the tank standardised worldwide.
A big advantage of hydrogen technology is the simple process of filling up the tank in the car: Filling the hydrogen tank is controlled largely automatically by the filling system, with all manual operations being basically the same as when filling gasoline.

A standardised tank coupling has been developed in close cooperation of carmakers, the fuel supply industry, and Linde for all liquid hydrogen filling stations the world over. And representing the European automotive industry, the BMW Group was directly involved in this joint development right from the start, thus defining a global standard for liquid hydrogen tank-filling systems.

Development of infrastructure supported by Linde technology.
A number of hydrogen projects have already benefited from the cooperation of the BMW Group and Linde. Linde is one of the world's largest manufacturers of hydrogen recovery and production plants and has already built a great number of hydrogen liquefaction facilities. Linde is furthermore involved in all levels of H_2 recovery and supply, and is indeed currently one of the largest suppliers of liquid hydrogen, providing the facilities and equipment for nearly all liquid hydrogen filling stations currently in existence, supplying also the filling stations in Berlin and Munich, among others, with both liquid and gaseous hydrogen.

15. Clean Energy Partnership: Part of the Nationwide Strategy of Sustainability, Objective to Confirm the Everyday Use of Hydrogen.

- **CEP – one of the largest demonstration projects in the world.**
- **Part of Germany's National Strategy of Sustainability.**
- **Hydrogen fleet in Berlin running under regular, everyday driving conditions.**

The use of hydrogen as an alternative drive energy is being tested under practical conditions in Germany in a joint initiative launched by the BMW group, together with Aral, the Berlin Transport Authority (Berliner Verkehrsbetriebe, BVG), DaimlerChrysler, Ford, General Motors/Opel, Volkswagen, Hydro, Linde, Total, and Vattenfall Europe forming the Clean Energy Partnership (CEP) Berlin.

Established in 2002, the CEP operates one of the most significant demonstration projects in Europe and one of the largest projects of its kind in the world. The objective of this initiative is to further develop the use of hydrogen as a source of energy in technological terms and to test the options for using hydrogen for everyday purposes as well as its qualities as part of an overall system.

For the time being the CEP project will be continued until the end of 2007, with a budget of Euro 33 million. The CEP is also part of Germany's National Strategy of Sustainability and is promoted by the German Federal Government.

An important aspect in the practical examination of hydrogen as an alternative fuel is to prove the positive aspects and advantages hydrogen offers the environment. The first point in this context is that hydrogen is to be recovered to the greatest possible extent with the help of regenerating energy, a process made possible in particular by the generation of electric power from biomass, solar energy, hydro and wind energy, since this rules out virtually all undesired emissions in the entire chain from the initial recovery of hydrogen all the way to its final use in the motor vehicle.

Hydrogen cars and buses in everyday operation.
Within this initiative, BMW is running several vehicles powered by a hydrogen combustion engine. The entire CEP fleet is made up of 16 passenger cars from various manufacturers equipped with various technologies and used under practical conditions in Berlin. A feature they all have in common is that they run virtually free of any emissions, nothing but pure vapour coming out of the exhaust as the final product of hydrogen combustion in the engine.

In Europe, BMW's hydrogen cars are no longer in the process of being tested, but rather are already driven in everyday use – which alone proves their high standard of practical quality. In terms of power, performance and reliability, the BMW Group's hydrogen cars are not inferior in any way to cars running on conventional power, with the process of filling the tank also being almost identical and therefore hardly requiring any additional efforts on the part of the driver. There are likewise no restrictions in terms of safety, with a study conducted by the South German Technical Inspection Authority (TÜV South Germany) confirming that "the hydrogen car is at least as safe as a conventional gasoline car".

This alternative drive energy is also used in public short-haul transport, with the Berlin Transport Authority (BVG) starting operation of two buses running on hydrogen-powered combustion engines in June 2006 as part of the HyFLEET:CUTE Project subsidised by the European Union. In the course of the next two years alone, 12 further buses are to join this fleet, the world's largest operation of environmentally-friendly hydrogen buses then proving its qualities under tough everyday conditions as a regular service in Berlin.

Testing hydrogen filling stations under practical conditions.
Yet a further highlight of the CEP Initiative is the practical examination and verification of hydrogen supply. Two public hydrogen filling stations have already been built for this purpose in Berlin, giving users the opportunity as an option unique throughout Europe to fill up their cars with both liquid and gaseous hydrogen.

A CEP filling station operated by Aral was opened on Messedamm in Berlin-Charlottenburg in November 2004 and specialises on filling the tank and providing service for passenger cars with hydrogen drive. This is indeed the first time that Aral has grouped the supply, storage and filling of liquid hydrogen with the local production and supply of gaseous hydrogen at a conventional filling station.

A further significant point is that the CEP Initiative also has an Information Centre on the same site as the filling station, offering visitors interesting knowledge on the project as well as the possible use and future perspectives of hydrogen drive systems.

In March 2006 another mineral oil company, Total, opened its CEP filling station on Heerstrasse in Berlin-Spandau, this new filling station focusing on the supply of hydrogen for buses run by the Berlin Transport Authority. Up to 20 buses are able to fill up hydrogen here every day, and the filling

station is also able to supply liquid and gaseous hydrogen to passenger cars. It even has a so-called steam reformer for the local production of hydrogen from liquefied gas as well as two stationary fuel cells supplying electricity and heat to the filling station.

This filling station is supplied with liquid hydrogen stored at a temperature of – 253 °Celsius in a tank above the ground with a capacity of 17,600 litres or 3,870 Imp gals.

Project successful.

Opening these innovative filling stations and operating an entire fleet of hydrogen vehicles, the CEP is clearly demonstrating the practical use of future-oriented technologies and is presenting the technical and economic requirements for the use of hydrogen in everyday traffic. A further objective is to prove the system capabilities of various mature technologies in practice, including the decentralised generation of gaseous hydrogen through electrolysis and the conversion of liquid hydrogen at the filling station. Further highlights of the project are the centralised recovery of liquid hydrogen in an external production facility as well as its supply to the filling station and storage on site.

Yet a further objective is to test the economic qualities of hydrogen recovery from environmentally-friendly sources of energy under real-life conditions. To make this possible, Vattenfall Europe, a leading utility and power supply company, is supplying energy to the CEP Project recovered in a regenerating process. Use of such certified, environmentally-friendly electric power ensures that the entire energy chain supplying vehicles with hydrogen is indeed completely free of emissions.

The CEP Demonstration Project has been proceeding smoothly and without friction ever since it started in 2002, not presenting any problems even under demanding everyday operating conditions. The companies involved, in turn, have already gained a wide range of new knowledge on the use of hydrogen and have achieved significant progress in various areas. This experience accumulated by users, engineers and operators in the CEP Project will be further evaluated in 2007.

16. Source of Energy: Hydrogen as an Infinitely Available Alternative to Fossil Fuels, Sustained Generation as the Perspective for the Future.

- **Ecologically advantageous production through regenerating energy.**
- **Generation of hydrogen through wind and solar power with a high potential in Europe.**
- **New storage technologies being tested.**

Serving as a source of energy, hydrogen offers an enormous potential for the future, above all as it is available in virtually unlimited quantities. Hydrogen with its chemical symbol H is indeed the oldest, most common, and lightest element in the universe. It is a part of water and all organic compounds, thus forming part of the biological cycle, and is fully compatible with the environment.

Hydrogen can be transported in its cryogenic state as a liquid or in gaseous form, transportation requirements in both cases being relatively simple. As a gas, hydrogen is not toxic, it is colour- and odourless.

Measured by its weight, hydrogen in liquid form offers three times the amount of energy in gasoline. And while the use of fossil fuels inevitably causes the emission of carbon dioxide, hydrogen is extremely compatible with the environment as an alternative drive energy, combustion of hydrogen generating virtually nothing but vapour. Recovered in a regenerating process, finally, hydrogen, as opposed to other alternative fuels, is the only source of useful energy that is fully sustainable.

The ecological benefits of hydrogen as well as the need to become independent of fossil fuels limited in their supply are the most important reasons why BMW became one of the first carmakers in the world to focus in the medium- and long-term development of its cars way back in the 1980s on hydrogen power. The objective in the process is to avoid emissions and use energy recovered through regenerative technology on a large scale.

Worldwide production of hydrogen already amounting to 600 billion cubic metres a year.
Worldwide production of hydrogen is currently more than 600 billion cubic metres a year, the volume of production in Germany is about 30 billion cubic metres. Hydrogen is found most frequently in water as well as hydrocarbons such as coal, petroleum, and natural gas.

By contrast, there is virtually no free hydrogen in nature not forming some kind of compound. This means that the hydrogen found under natural conditions has to be converted in order to use its energy potential, with pure hydrogen being recoverable, for example, from water, biomass, petroleum, or natural gas. A particularly interesting option is to recover hydrogen in a sustainable process through a regenerating, natural cycle, since the supply of hydrogen recovered from biomass or by means of solar, wind or hydro energy is virtually unlimited, coming – unlike coal or petroleum – in infinite supply from water.

Recovery of hydrogen from water.
Electrolysis is one of the most interesting and promising options for recovering hydrogen, allowing virtually unlimited generation of hydrogen from water by means of electric power. In this process electrical energy dissolves the chemical composition of water, splitting it up into hydrogen and oxygen. The oxygen generated in this way is formed at the anode (positive electrode), with hydrogen accumulating at the negative cathode.

This principle is applied in a so-called electrolyser in a series of consecutive circuits, about 2 per cent of the hydrogen consumed worldwide currently being produced in this way. From an ecological perspective, finally, this process makes sense in particular when the electric power required for electrolysis is provided by regenerative sources of energy.

Hydrogen from solar energy.
A truly fascinating option is to recover hydrogen from solar energy, since the sun offers the greatest potential of regenerative energy one could imagine: Within just one hour, the sun sends the same amount of energy to the world that mankind as a whole consumes in a complete year. The solar energy reaching our planet within one year, on the other hand, amounts to approximately 1.1 billion terawatt hours, approximately 10,000 times the world's current annual consumption.

Solar energy can be converted, as one example, by solar cells producing electricity in a direct process. To try out this technology in practice, BMW participated from the start in the Solar Hydrogen Project conducted in the Bavarian town of Neunburg vorm Wald where, in cooperation with other companies, BMW tested the photovoltaic generation of hydrogen and its use for various purposes.

Generation of electrical energy by thermal solar power stations and parabolic mirrors is of even greater economic interest, considering the current state of the art in this area. In this case oil is heated up to a temperature of 400 °C or in the mirror's focal line, then serving to evaporate water in a heat exchanger, the steam obtained in this way subsequently driving a steam turbine for the generation of electricity.

Parabolic power stations of this kind are already operating in the Californian Mojave Desert where they generate solar power under environmentally-friendly conditions also serving for the recovery of hydrogen. Covering an area of 2.3 million square metres, the world's largest solar power station generates no less than 354 megawatt of electricity, equal to the energy demands of some 200,000 people.

To promote the use of solar power also in Europe, a plant similar to the solar power stations in California is currently being built in Spain. The options to recover hydrogen from solar energy are indeed enormous, with experts stating that the technical potential available worldwide is 30 times the global consumption of fuel.

Great potential in Europe.
The regions around the 40th latitude are of particular interest for thermal power stations, Africa and Australia offering by far the greatest potential of approximately 1.5 million and, respectively, 1.1 million terawatt hours (TWh). But this kind of power generation is also an interesting alternative for Europe, where experts see a potential of approximately 4,500 TWh, equal to more than 12 million of the solar power stations in California mentioned above. Photovoltaic power generation, in turn, that is the use of solar collectors, would also serve to provide approximately 600 TWh in Europe.

Wind energy might also become a significant source of hydrogen power, the worldwide potential for recovering H_2 through wind-generated electricity amounting to no less than 15 times the current consumption of fuel.

Experts believe that in Europe alone offshore wind power stations would be able to supply approximately 1,800 TWh of electric power, with an additional potential of wind parks on land of some 350 TWh. By comparison, only about 60 TWh of electrical energy is currently generated by wind power throughout Europe, equalling approximately 2.4 per cent of the total amount of energy consumed.

Hydrogen from biomass.
Yet another alternative is to recover hydrogen from regenerating raw materials. This is indeed the only option to obtain hydrogen directly from a regenerating source of primary energy. A further advantage is that biomass is acknowledged as neutral In the CO_2 balance, since through photosynthesis plants take up about the same amount of carbon dioxide from the air as is subsequently released in the processing phase.

Hydrogen is recovered from biomass through a process of fermentation or gasification, and experts believe that bio-waste may also play a role in the generation of hydrogen.

The global potential for recovering hydrogen from biomass is approximately 14,400 TWh, enough, even today, to meet approximately 60 per cent of the worldwide demand for fuel. Another advantage is that the generation of hydrogen from biomass would be relatively inexpensive, as we see from a study estimating the cost of regeneration all the way to the final provision of fuel at the filling station. A price of Euro 0.80 per hydrogen unit offering the same energy content as a litre of gasoline would therefore seem to be quite feasible.

Various kinds of storage options.
Unlike electrical energy, hydrogen can be stored in both gaseous and liquid state in large amounts. This is done, for example, in gaso-meters or in pressure tanks at up to 100 bar. Smaller amounts, in turn, can be filled into pressurised gas cylinders made of steel or carbon-fibre-reinforced composite materials able to handle pressure of up to 350 bar. New tank systems for vehicles capable of handling even higher pressure ratings of up to 700 bar are already in use in some vehicles.

Hydrogen may also be stored in liquid form at a temperature of – 253 °C, and yet a further option is to use so-called hydride storage systems where hydrogen is stored under pressure in metal powder and subsequently released through the infusion of heat. Hydride storage systems are able to take up approximately 2 per cent of their weight in hydrogen, which is however not sufficient for the use of this technology in a motor vehicle.

Last but not least, research is also being conducted on the storage of hydrogen in nano-fibre structures or so-called alanates, compounds of aluminium and hydrogen with a magnesium alloy. Indeed, these technologies will open up brand-new perspectives for the storage of hydrogen in future.

17. BMW CleanEnergy Project: BMW Hydrogen Experience since the 1980s, Concentrating on the Combustion Engine, Fuel Cell as Supplementary Technology.

- **First hydrogen-drive BMW presented in the 1980s.**
- **BMW 750hL covering 170,000 kilometres or more than 105,000 miles under practical driving conditions.**
- **Nine world records set up by the BMW H_2R Hydrogen Car.**

The BMW Group has years of experience in hydrogen research, focusing on hydrogen as an alternative form of drive energy. Indeed, BMW started to develop power units and vehicles able to run on liquid hydrogen way back in the 1980s. The drawback was that on the first prototypes able to run on hydrogen and gasoline required a highly insulated hydrogen tank taking up the car's entire luggage compartment.

In 1984 BMW completed the BMW 745i Turbo with its 3.5-litre straight-six power unit, and in 1990 the Company presented the next generation of hydrogen drive in the guise of the BMW 735iL, followed in 1995 by the BMW 728h with a 2.8-litre six-cylinder inline engine.

A feature shared by all these cars was their dual-mode drive technology enabling them to run on both hydrogen and gasoline. And even at this early point in time, the power units featured so-called manifold injection of hydrogen, with the liquid hydrogen tank being fitted in all cases in the luggage compartment of the respective models.

The BMW 750hL: the first hydrogen car built in a small production series.
A further milestone in development came in the year 2000 marked by the presentation of the BMW 750hL, the world's first hydrogen car built in a small production series, in Berlin. The twelve-cylinder hydrogen engine featured in this breakthrough model and based on the series-production power unit of the BMW 750i developed maximum output of 150 kW/204 hp from a capacity of 5.4 litres.

The BMW 750hL clearly proved the great potential offered by this engine under practical driving conditions for the first time in public at the Expo 2000 World Fair in Hanover, where 15 cars provided a daily shuttle service. Then, in February of the following year, BMW started the almost sensational CleanEnergy WorldTour 2001 taking the fleet of 15 BMW 750hL hydrogen cars through five continents and some 170,000 kilometres round the world. After setting out in Dubai, the WorldTour went on to Brussels, Milan, Tokyo and Los Angeles, finally ending up in the German capital of Berlin.

To this day this CleanEnergy WorldTour 2001 is acknowledged as a most impressive demonstration of the cleanest of all fuels, practical presentations of hydrogen technology by BMW also offering clear proof of hydrogen drive and its high standard of reliability.

The APU: supplying electric power through the fuel cell.
A particular highlight of the BMW 750hL was the fuel cell supplying the electric power required. Referred to as the Auxiliary Power Unit (APU), the fuel cell was located in the luggage compartment of the car, supplying electric power both to the on-board electronics and the air conditioning. And while the compact fuel cell did not take up more space than a conventional battery, it was significantly superior through its power output of 5 kilowatt and its long service life.

As a result, the “electrochemical” battery, as it was called, not only served to supply electric power in the car, but also opened up the door to new functions. As an example, these future-oriented hydrogen models based on the BMW 7 Series came with auxiliary air conditioning operating while the car was at a standstill and thus serving to cool down interior temperatures regardless of whether the engine was running or not.

While the “normal” electrical power-consuming items in the on-board network are supplied with electric power via a converter operating at 12 volts, the air conditioning featured in this case was powered directly by the APU operating at 42 volts.

In future an increasing number of on-board systems will require such a power supply of 42 volts or even more, since a 12-volt power supply will no longer be able to provide the amount of energy required or will not be able to deliver the necessary performance.

Precisely this is where the fuel cell is able to offer its benefits, with its modular structure allowing optimum adjustment to the needs and requirements of electrical on-board networks in future.

Using the fuel cell as an Auxiliary Power Unit generating electric power in the car is also the highlight of current research projects seeking to develop a particularly practical solution for the use of this technology in a series-production car.

Hydrogen Concept Study: BMW 745h with eight-cylinder power unit.
Back in 2001 BMW presented the BMW 745h as a Hydrogen Concept Study at the Frankfurt Motor Show. The purpose of this study was to demonstrate what a hydrogen car built in series might look like when based on the current BMW 7 Series. For the first time the BMW 745h featured a hydrogen engine carried over from the new generation of eight cylinders. Displacing 4.4 litres, this power unit offered maximum output in the hydrogen mode of 135 kW/184 hp.

BMW H_2R: nine world speed records with hydrogen power.
In September 2004 BMW clearly proved that hydrogen is also able to provide supreme performance of the highest standard: Put through its paces on the high-speed track at BMW's Test Centre in the southern French town of Miramas, the BMW H_2R prototype set up no les than nine world speed records for hydrogen-powered cars with a combustion engine.

In the process BMW once again wrote history in the world of the automobile, BMW H_2R, to mention just one example, covering the distance of one kilometre with a flying start in less than 12 seconds and reaching a speed of more than 300 km/h or 186 mph.

These records not only proved the great potential of hydrogen drive in terms of supreme power and performance, but also demonstrated the high standard of maturity now achieved in developing hydrogen drive. Quite clearly, therefore, BMW H_2R underlined BMW's role as a leader in technology.

Developed within just ten months, the hydrogen power unit featured in BMW H_2R was based on the gasoline engine carried over from the BMW 760i, thus benefiting from the most advanced engine technology. Maximum output of this six-litre twelve-cylinder was 210 kW/285 hp, accelerating the prototype in approximately six seconds to 100 km/h and allowing a top speed in excess of 300 km/h or 186 mph.

The fuel supply system used in this case was based on a proven concept carried over from series development, with a double-walled tank holding approximately 11 kilos of liquid hydrogen being developed for the vehicle.

Focusing on the chassis of BMW H_2R, the engineers in charge of the project used series components from a BMW sports car, while the body of BMW H_2R measuring 5.4 metres in length and two metres in width was designed and laid out from the start for optimum aerodynamics, with the outer skin made of carbon-fibre-reinforced plastic.

Hydrogen know-how for schools.
The objective of BMW's CleanEnergy strategy is to promote sustained mobility on a consistent basis. BMW CleanEnergy is therefore the overriding term describing an ecologically ideal, full-cycle and fully contained energy cycle based on water, since hydrogen may be recovered and used in almost unlimited quantities and in a process fully compatible with the environment.

Precisely this why BMW actively promotes the social acceptance of this fuel of the future, the BMW Group offering comprehensive teaching material on the subjects of energy, hydrogen, and hydrogen technology worldwide under the title "H_2 – Mobility of the Future". The Basic Learning Kit used for this purpose is recommended by the Bavarian State Institute for School Education and Educational Research for regular use in secondary grades I and II at advanced and middle schools. And suitable material is also available for primary schools.

BMW CleanEnergy in the Transport Centre of Deutsches Museum in Munich.
As a founding member of the Transport Centre of Deutsches Museum in Munich, BMW provides comprehensive information on hydrogen mobility in the world of the future: Ever since 2003 visitors to the Transport Centre have received important information in an exhibition area of approximately 400 square metres through an exciting presentation featuring numerous interactive exhibits presenting the various options offered by hydrogen. One of the highlights demonstrated is the complete hydrogen cycle beginning with the production of hydrogen through distribution and storage all the way to the use of hydrogen in the world's first series-production hydrogen car, BMW Hydrogen 7.

Since 2004 BMW has been offering a similar presentation in China, highlighting the BMW CleanEnergy Strategy at the Science & Technology Museum in Beijing.

Specifications.
BMW Hydrogen 7.

Body		**Hydrogen 7**
No of doors/seats		4/4
Length/width/height (unladen)	mm	5,179/1,902/1,489
Wheelbase	mm	3,128
Track, front/rear	mm	1,578/1,582
Turning circle	m	12.6
Fuel tank, gasoline	approx ltr	74
Useful amount of H_2 stored	approx kg	7.8
Cooling system, incl heater	ltr	14.9
Engine oil		8.5
Transmission fluid	ltr	lifelong
Final drive fluid	ltr	lifelong
Weight, unladen, to EC standard (incl 75 kg driver)	kg	2,460
Max load (incl Special Equipment Package)	kg	400 (incl 100 kg roofload)
Max permissible to DIN standard	kg	2,860
Rear axle load: unladen DIN/unladen EC actual	%	53
Max trailer load braked (12%)/unbraked	kg	No trailer allowed
Max rooflaod	kg	100
Luggage capacity DIN 70020	ltr	225
Drag coefficient	C_d x A	0.29 x 2.38

Power Unit		
Config/No of cyls/valves		V/12/4
Engine management		MED9 (H_2 and gasoline)
Capacity	cc	5,972
Stroke/bore	mm	80.0/89.0
Compression ratio	:1	9.5
Fuel		Hydrogen/RON 98
Max output	kW (hp)	191 (260)
at	rpm	5,100
Max torque	Nm (lb-ft)	390 (287)
at	rpm	4,300

Electrical System		
Battery/location	Ah/–	90/luggage comp, right
Alternator	A/W	180/2,520

Chassis and Suspension			
Suspension, front			Double-joint spring strut axle with tiebars and track control arms, rack-and-pinion steering
Suspension, rear			Reinforced Integral IV; aluminium/steel reinforcement units; dual-elastic rear axle suspension
Driving stability systems			Front/rear (Dynamic Drive)
Brakes, front			Aluminium brake callipers FNR Al 60; brake discs vented
Diameter		mm	348 x 30
Brakes, rear			GGG brake callipers FN 46; brake discs vented
Diameter		mm	345 x 24
Steering			Rack-and-pinion power steering with speed-related power assistance (Servotronic)
Steering transmission ratio, overall		: 1	13.1
Type of transmission			Automatic, rear-wheel drive
Gear ratios	I	: 1	4.17
	II	: 1	2.34
	III	: 1	1.52
	IV	: 1	1.14
	V	: 1	0.87
	VI	: 1	0.69
	R	: 1	3.40
Final drive		: 1	3.62
Tyres			245/50 R 18 100 W RSC
Wheel rims			18-inch multi-spoke wheels

Performance		
Power-to-weight ratio to DIN standard	kg/kW	12.87
Output per litre	kW (hp)	31.98 (43.49)
Acceleration 0–100 km/h	sec	9.5
Top speed	km/h	230

Fuel consumption in the EU cycle		
Composite, gasoline	ltr/100 km	13.9
Composite H_2	kg/100 km	3.6 (3.6 kg H_2 = 13.3 litres)
CO_2 emissions EU, gasoline	g/km	332
CO_2 emissions EU, H_2	g/km	5.2

Miscellaneous	
Emission rating	< EU4

19. Output and Torque Diagram.