A revolution in car making: BMW i production.
Contents.

1. The BMW i production concept: Life and Drive modules.

With the BMW i3, the BMW Group is set to launch an electrically powered production vehicle onto the market that represents a new form of sustainable mobility in urban areas. As the first premium electric vehicle, the BMW i3 rises to the social, ecological and economic challenges of our time. With its groundbreaking vehicle architecture, the concept calls for the use of modern lightweight construction materials as well as innovative production processes. Sustainability plays a prominent role for the BMW Group in this area as well. The BMW i3 was the first vehicle project for which sustainability objectives were agreed and subsequently pursued with the same vigour as cost, weight and quality objectives. The aim is also to reduce the environmental impact of production as much as possible, focusing on aspects such as energy supply and water consumption, solvent emissions and waste treatment. It is an objective to which all the locations in the BMW i production network are committed – including Moses Lake in Washington State (carbon fibre production) and Wackersdorf (processing into carbon fibre laminates). Both these facilities are operated by SGL Automotive Carbon Fibers (ACF), a joint venture set up by the BMW Group and the SGL Group. They are joined by the BMW Group's own plants in Dingolfing, Landshut and Leipzig.

The innovative architecture of the BMW i3 comprises two elements: the aluminium Drive module – which incorporates the powertrain, chassis, battery, and structural and crash functions – and the Life module or passenger cell, made from carbon-fibre-reinforced plastic (CFRP). The LifeDrive concept and use of CFRP allows production times to be cut by half compared to those required for an equivalent car built along conventional lines. The process is less investment-intensive as the high costs required for a conventional press shop and paintshop are no longer an issue and the Life and Drive modules can be manufactured alongside one another. The use of CFRP on the scale required for the BMW i models is without parallel in the automotive industry worldwide and the BMW Group has also assumed a leading role in this area.

2. The dawn of a new era – building cars with CFRP.

Rigorous commitment to lightweight construction is especially important for electrically powered vehicles because, alongside battery capacity, vehicle weight is the limiting factor in its operating range: the lighter a vehicle, the greater its range. In order to compensate for the extra weight of the electrical components, BMW i makes extensive use of lightweight construction techniques and innovative materials in its vehicles. The Life module of the BMW i3 is made primarily of carbon-fibre-reinforced plastic (CFRP). This innovative material is produced by the SGL Automotive Carbon Fibers (SGL ACF) joint venture.

Carbon fibre production using hydroelectric power / Moses Lake, USA.

The SGL ACF factory in Moses Lake in the USA produces carbon fibres from a polyacrylonitrile-based thermoplastic textile fibre precursor. In a complex multi-stage process, the various constituent elements of the fibre are removed by gasification, eventually leaving a fibre that consists of virtually pure carbon with a stable graphite structure. This fibre is just seven microns (0.007 millimetres) thick. A human hair, by comparison, has a diameter of 50 microns. For automotive application, approximately 50,000 of these individual filaments are bundled into so-called rovings or heavy tows and wound on reels, prior to further processing.

All of the energy used in carbon fibre production in Moses Lake is obtained from renewable, locally generated hydroelectric power and is therefore completely CO_2-free. The state-of-the-art plant in Washington State also sets standards in energy efficiency.

Moses Lake has been producing the ultra-lightweight high-tech fibres since the end of 2011. Two production lines with a total capacity of 3,000 tonnes per year supply the required quantities. The two parent companies – the BMW Group and the SGL Group – have invested around 72 million euros (100 million US dollars) in the Moses Lake production facility to date and created 80 new jobs.

Processing into carbon fibre laminates in Wackersdorf.

The rovings produced in Moses Lake are sent to the joint venture’s second site, at the Wackersdorf Innovation Park, for industrial processing into lightweight carbon fibre laminates. Following an investment of 20 million euros and the creation of around 150 new jobs, today several thousand tonnes of carbon fibre laminates can be manufactured annually at the Wackersdorf site.

Carbon fibre laminates with different fibre alignments are then arranged into stacks made up of several layers and following various lines, before being cut to shape. These stacks form the base material for the production of CFRP parts and components at the BMW facilities in Landshut and Leipzig. Scrap CFRP is recycled in Wackersdorf and subsequently channelled back into use – in BMW i models, for example. Currently, around 10 per cent of the carbon fibre used in the BMW i3 is recycled material.

Processing into CFRP components in Landshut and Leipzig.
The stacks supplied by Wackersdorf are turned into body components for the BMW i models at the innovation and production facilities at BMW's Landshut and Leipzig plants, which run a total of nine production lines for CFRP body components.

Over more than 10 years, the BMW Group's specialists have steadily refined and automated the CFRP production process so that it is now possible to volume-produce CFRP body components cost-efficiently, to a high quality and with high process stability. In doing this, the manufacturing costs for CFRP body components over this period have been cut by around 50 per cent.

A heat source is used to give the preformed carbon fibre stacks a stable, three-dimensional form. Several of these preformed blanks can then be joined to form a larger component. In this way CFRP can be used, for example, to produce body components with a large surface area that would be difficult – or significantly more expensive – to manufacture from aluminium or sheet steel. Preforming and preform joining are followed by the next stage in the process: high-pressure resin injection using Resin Transfer Moulding (RTM). Here, liquid resin is injected into the preforms under high pressure. As the fibres and the resin bond, and in the subsequent hardening process, the material acquires the rigidity which is key to its outstanding qualities.

The CFRP presses work to precisely defined, specially developed time, pressure and temperature parameters until the resin and hardener are fully cross-linked and the resin is hard. This automated manufacturing process eliminates the need for the time-consuming hardening process in an oven which would normally be required in manual CFRP production processes.

The CFRP process is no longer comparable with conventional sheet steel manufacturing. This industrialised manufacture of CFRP is extremely economical and makes the production of large CFRP composite components for the automotive industry a feasible proposition for the first time.

Even complex assemblies with many structural elements already integrated, such as an entire side frame for the BMW i3 Life module, are produced at the facility with a high level of automation. Additional processing stages include the finishing work, such as precise contour cutting and the insertion of remaining openings. This work is performed using a special waterjet cutting system and the bonding surfaces are then sandblasted before further processing. A conventional sheet steel side frame, by contrast, would have to be built up successively from several different inner and outer components.

New precision processes in CFRP body manufacture.

The CFRP composite components are bonded together in the new bodyshop in Leipzig. This is where the basic structure of the Life module takes shape. A high level of geometric integration means that the CFRP structure requires only a third of the number of body components used in a conventional steel body; the Life module's basic CFRP structure comprises around 150 CFRP parts in total.

There is no noise from bolting or riveting and no sparks from welding in the manufacturing process for a CFRP body. Instead, only the latest bonding technology is used, which is 100 per cent automated. In this unique, BMW-developed assembly process, the individual components are positioned at a precisely defined bond line gap in order to ensure the resulting joint is as strong as possible. The bonded joints of each BMW i3 measure a total of 160 metres in length.

In order to minimise hardening times for volume production of the BMW i3, BMW has greatly accelerated the hardening process. Significant advances in the development of the adhesive mean it is now workable for only 90 seconds after being applied to a component and before adhesion begins. An hour and a half later it has fully hardened and achieved its full strength. This represents a tenfold acceleration of conventional adhesive hardening times. In order to further reduce the hardening time to below 10 minutes, BMW has developed a supplementary thermal process. This involves heating specific points on the CFRP parts which are to be bonded, thereby accelerating the hardening process even further.

3. Lightweight and robust: the thermoplastic outer skin.

The BMW i3 is the first ever BMW with an outer skin made entirely of thermoplastic. The only exception is the roof, which is made of recycled CFRP. The weight of the plastic parts is around half that of sheet steel parts. Plastic also provides corrosion-free outer protection and requires less energy to manufacture, as well as being resistant to minor damage. The thermoplastic outer skin is produced using 25 per cent recycled or renewable material.

The entire outer skin of the BMW i3 is produced at BMW's Leipzig plant. Like the front and rear aprons on conventional BMW models, the plastic parts for the BMW i3 are produced using one of three different thermoplastic injection-moulding processes, depending on the part in question. These three techniques comprise: a standard process; a "TWIN" injection-moulding process, where the outer skin and substructure are injection-moulded then bonded in separate, successive stages; and thirdly, a "bonding via injection-moulding" process where the outer skin and substructure, which are injection-moulded in parallel, are also joined together within one and the same automated process.

The final painting process gives the outer skin parts their sheen while also protecting against the effects of environmental exposure, for example due to stone chipping or sunlight. The new paintshop in Leipzig uses dry overspray separation and is therefore completely wastewater-free, while its energy consumption is just a quarter that of a conventional paintshop. At the same time water consumption is reduced by 70 per cent because the process does not involve priming, painting and drying of the complete body, as with conventional models. Instead, the bumpers, front, rear and side parts of the BMW i3 can simply be painted individually, which conserves resources. Dispensing with conventional cataphoretic dip priming reduces the weight of the vehicle by 10 kg. Approximately 300 employees work on the production of plastic outer skin components for the BMW i3 in Leipzig.

4. Drive module: basic structure, high-voltage battery and electric motor built at Bavarian plants.

The basic load-bearing structure of the BMW i3 Drive module, built at BMW's Dingolfing plant, consists of cataphoretically coated aluminium members and aluminium castings. The body-on-frame design provides ideal packaging for the battery and also makes for optimal weight distribution, with a very low centre of gravity, which has benefits for driving dynamics. The use of aluminium combines the advantages of lightweight construction with good crash performance and therefore contributes to the overall safety of the BMW i models.

The basic structure of the BMW i3 Drive module is a complex welded construction consisting of around 160 individual parts which are connected by more than 19 metres of welding seams. The die castings for this structure come from the light-alloy foundry at the BMW Landshut plant. They feature a high level of functional integration and are manufactured almost ready for installation. Around 120 staff are employed in the manufacture of the BMW i basic Drive module structure at the Dingolfing plant, in a fully automated high-tech facility. This facility was designed using the industrial engineering know-how and extensive expertise in aluminium technology acquired by Dingolfing's employees over many years of building aluminium front and rear axles.

High-voltage battery.
A further important BMW i module produced in Dingolfing is the high-voltage battery. The production process starts with a "beginning-of-line" test, in which the externally supplied lithium-ion cells undergo an initial performance check. The battery cells are then plasma-cleaned. Following this, the individual cells are clamped into modules, bonded and welded in a fully automated process involving more than 20 robots.

Extensive BMW expertise goes into the special packaging and assembly of the battery. In all, the assembly process comprises 400 operations. The battery casing protects the lithium-ion cells and at the same time improves the rigidity of the vehicle as a whole. After the battery cells have been packaged into modules, the assembly process begins. The modules are lifted one by one into an aluminium tray, then manually connected in series using a communication cable harness. Finally, the battery top cover and bottom cover are fitted and the finished batteries undergo an end-of-line test. The battery is designed in such a way that individual battery modules can be easily swapped for repair purposes.

An all-new, highly automated high-tech production facility, occupying an area of more than 2,000 square metres, was set up in Dingolfing to build the high-voltage batteries for the BMW i models. At the same time, this line also builds the high-voltage batteries for the 3, 5 and 7 Series hybrid models. Around 100 highly skilled employees work here, loading, controlling and monitoring the production systems and performing quality control tasks. These employees underwent special training to work on the high-voltage battery.

Electric drive system.

At BMW, powertrain design has always been a key focus and differentiator. The BMW Group therefore decided to develop the 125 kW electric motor and drive electronics in-house: The BMW i3's electric motor is produced at the BMW Landshut plant. The internal components of the motor comprise an interior housing, a stator and a rotor. The stator, which forms the inner core of the motor, consists of around two kilometres of wound copper wire. What makes the BMW i3 motor so special is that, unlike other electric motors in the same power class, the motor of the BMW i3 is very small and compact due to the specially configured winding of the copper wiring. This results in further weight and space savings. Before the stator is fitted in the interior housing, it receives a thin coating of resin. Assembly of the stator, rotor, interior and exterior housing now takes place, the interior housing first having been heated to a temperature of around 150 degrees Celsius so that it expands slightly. This task requires maximum precision; the stator and the rotor have to fit together perfectly to ensure that later the motor runs smoothly.

5. Cockpit.

The BMW Landshut plant also produces the instrument panel for the BMW i3. The first step is to heat plastic films, giving them a three-dimensional structure. The cutting of the airbag is followed by the back-foaming process of the instrument panel. For instrument panels with a plastic surface, the surface film is inserted in the tool. For leather instrument panels the innovative ‘dummy skin technology’ is applied: Similar to silicone baking moulds, a dummy silicone skin serves as the mould in this procedure. Following the back-foaming, it is removed from the instrument panel again, to be replaced by the visual surface trim of the instrument panel made of leather. This highly cost-efficient solution has the advantage that for one model series, several different versions of an instrument panel (basic models and optional equipment versions) can be produced using one and the same tool.

The milling station used by the BMW Group to produce the instrument panel is unique worldwide. The production department for instrument panels and trim parts has already filed a patent application for this machine. During the “dust-free” milling process, chips and dust particles are removed immediately by the machine’s integrated extractor units. This reduces air and machinery contamination by 98 per cent. The extracted surplus material is recycled and returned to the production process.

6. Parallel processes: assembly.

Unlike vehicles with integral body and frame construction, the BMW i3 has a horizontally split LifeDrive architecture consisting of two separate, independent modules. As a result, the Leipzig assembly shop is the first in the history of BMW to feature two separate, parallel production lines – one for the Life module and one for the Drive module. This has led to significant advances in terms of the ergonomic design of the workstations, which provide optimal accessibility for all assembly operations.

During assembly of the Drive module in Leipzig, the aluminium chassis is fitted with the battery and the motor/transmission unit. First of all, the high-voltage battery, weighing 230 kilograms, is installed in the floorpan and bolted to the basic Drive module structure. Integrating the high-voltage battery into the floor of the aluminium chassis results in optimal weight distribution, which also makes for excellent driving dynamics. The Drive module is then fitted with the motor/transmission unit supplied by the Landshut plant, which is likewise bolted in place. Optionally, a range extender (a twin-cylinder petrol engine) is also available, which increases the vehicle range to 300 km (approx. 185 miles). Once the front axle subframe – preassembled in Dingolfing – and further structural parts have been fitted, the BMW i3 Drive module is ready to move on to the final assembly stage.

Assembly of the complete vehicle.
Meanwhile, the CFRP passenger cell makes its way from the bodyshop to the assembly shop, where, on the so-called “Life” line, its customer-specific equipment is fitted. This is the final step before the “marriage” with the aluminium Drive module, during which the CFRP passenger cell and the aluminium chassis are bonded together. The two units are also bolted together at four points. The result is optimal stiffness and strength.

After the bonding agent has been applied to the Drive module by two robots, the Drive module is conveyed to the “marriage” station, lifted and centred. A robot gripper then lowers the Life module onto the Drive module and the joining process is launched by the body’s own weight.

Only at this stage is the BMW i3 fitted with its outer plastic skin. This painted multi-piece skin consists mainly of injection-moulded thermoplastic.

At 20 hours, the total processing time in the bodyshop and on the assembly line is only half of what would be required in a conventional production process. This is due to the parallel assembly processes and the fact that the CFRP structure comprises fewer parts.

Together with the other BMW vehicles built in Leipzig, the BMW i3 then makes its way to the finishing shop. Here, comprehensive quality controls are performed, ensuring that the BMW Group's first all-electric volume production model meets the company's customary high quality standards, just like any other product of the group. At the same time, it is also possible to harness valuable synergy effects.

In total, 400 million euros has been invested in the Leipzig plant for production of the BMW i and 800 new jobs have been created.

7. Sustainable production in Leipzig.

Production of the BMW i is setting new standards and will see a reduction of around 50 per cent in energy consumption and 70 per cent in water consumption compared with the current average figures for the BMW Group, which are already highly efficient. The additional electricity used to produce the BMW i models at the Leipzig plant is generated by four wind turbines, installed on site at the plant.

The US Green Building Council has already awarded the new buildings in Leipzig an LEED (Leadership in Energy and Environmental Design) gold certification for their sustainable design.

A range of measures have been taken to substantially reduce energy consumption in the production shops. An intelligently controlled ventilation system ensures that the air in the production shops is completely changed several times a day via the overhead and side skylights in the ceiling. Natural ventilation reduces odour and dust levels in the bodyshop and assembly shop. It also provides the necessary cooling for the press shop in order to counteract the heat generated by the presses. The entire ventilation system requires no additional fans or air conditioning systems. White plastic film on the ceiling skylight strips, moreover, reflects sunlight and reduces the need for artificial lighting. The new buildings in Leipzig therefore set new standards in the auto industry in terms of environmental sustainability as well.