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THE TOYOTA MIRAI

Toyota: at the forefront of environmental sustainability

- **Today's environmental challenge and Toyota's response**
- **How can a fuel cell electric vehicle contribute to a better environment?**
- **Popularising fuel cell electric vehicles to pioneer a hydrogen energy society**

Today's environmental challenge and Toyota's response

The continuing growth of the world's population – estimated to reach 9.6 billion by 2050 – is certain to lead to increased global vehicle production and resulting massive consumption of fossil fuels. This will exacerbate problems such as climate change, global warming and air pollution.

Two strategies are being used to address environmental issues caused by mass consumption of fossil fuels.

One is to use less petroleum. Hybrid vehicles are a textbook way of doing this, with their combination of high thermal efficiency/low fuel consumption engines and a host of advanced technologies.

The second strategy is to use a wider range of alternative energy sources. Energy diversification is a broad field, and Toyota has been working for decades on the development of new and alternative automobile fuels and powertrains. Each alternative fuel has its own characteristics, and Toyota is confident that hydrogen is one of the technologies that can bring the prospect of a cleaner future. Hydrogen is an environmentally efficient source of energy that can be produced from a variety of raw materials including solar and wind power, biofuel, and natural gas. The company is therefore investing heavily in fuel cell electric vehicles powered by hydrogen – such as the Mirai saloon.

How can a fuel cell electric vehicle contribute to a better environment?

A fuel cell electric vehicle runs on hydrogen instead of petrol or diesel. To be more specific, it runs on a motor powered by electricity generated by a chemical reaction between hydrogen and oxygen in a fuel cell. The only by-product when a fuel cell electric vehicle is driven is water vapour. It doesn't emit any harmful substances such as CO_2 (a major cause of global warming), or SO_2 and NOx (causes of atmospheric pollution). In addition to producing zero emissions when driven, fuel cell electric vehicles are also highly practical. They have an ample cruising range and can be refuelled very quickly.

Because of their simultaneous achievement of zero emissions and high practicality, Toyota considers fuel cell electric vehicles to be ideal eco-cars.

Popularising fuel cell electric vehicles to pioneer a hydrogen energy society

Fuel cell electric vehicles are highly energy-efficient, (around three times more efficient than internal combustion engines) have ample driving ranges with short refuelling times and only discharge water when driven. They make use of an environmental technology with great potential, and are worthy of the "ideal eco-car" tag. However, they also require a special infrastructure in the form of hydrogen filling stations and these are now starting to be built around the world. The success of these infrastructure proposals and initiatives will be the key to determining the success or failure of FCVs in the future.

Toyota has been working on the development of the FCV for three decades. While global attention is just beginning to turn towards the creation of a hydrogen energy-based society, Toyota's experience dates back to 1992 when it started its development of fuel cell (FC) technology. The core technologies (the FC stack and hydrogen tanks) were independently developed, and over time Toyota gained strong capabilities in their design and manufacturing. After further refinement and fine-tuning, Toyota has brought its first FCV to market: Mirai, which is a Japanese word meaning "future".

Introducing Mirai, Toyota's first Fuel Cell Electric Vehicle

- **Innovation greater than that of the first-generation Prius**

Mirai is a core component of Toyota's dream for a sustainable mobility society, one that allows us all to move freely in comfort and safety in an environmentally efficient, sustainable manner.

With a focus on the next 100 years of automobiles, Toyota pushed ahead with developing a pioneering vehicle that will contribute to building a hydrogen energy society. In addition to its superior fuel cell technology and environmental performance, Mirai is fun to drive, has a futuristic design that clearly marks it out as an FCV, is practical and offers a quiet and comfortable ride.

If the full benefits of environmental technologies are to be realised, they need to become popular and widespread. Toyota has already taken the initiative in successfully bringing hybrid vehicles into the mass market, but with Mirai it is delivering innovation on a scale far beyond what the first generation Prius represented. It is committed to popularising Mirai and the concept of FCV technology.

The target customers for Mirai include business leaders who want to help spark an “energy revolution” that could change the world. In other words, pioneers who can help create a revolution that could affect the world for the next century. These could be individuals who place great importance on environmental performance and the necessity of FCVs; high-income innovators who admire advanced technology and originality; and of course pure car fans.

Organisations interested in Mirai include public companies wanting to play their part in helping the environment, and public agencies or local government bodies keen to promote low-carbon technology.

In the UK the early adopters include organisations such as the Metropolitan Police, academic research institutions including the Natural History Museum, Imperial College London and University College London, and the private car and taxi service Green Tomato Cars.

Hydrogen under the microscope

- **Environmentally sound energy source**
- **Hydrogen station infrastructure is needed**
- **A safe automotive fuel**
- **Working towards a Hydrogen Society**

Hydrogen facts

- The lightest gas on earth, colourless, odourless and non-toxic
- During generation of electricity, hydrogen binds with oxygen to form water, so there are no CO_2 emissions
- Unlike CO_2, hydrogen does not absorb infrared radiation, which means it has no effect on global warming
- Liquefied at approximately -253℃

Environmentally efficient energy carrier

The hydrogen that powers Mirai can be obtained from a wide range of natural resources and man-made by-products, even sewage sludge. It can also be created from water, using natural, renewable energy sources such as solar and wind power. When compressed, it has a higher energy density than batteries, and it is relatively easy to store and transport. Consequently it carries expectations of its potential use in power generation and many other applications. FCVs can generate their own electricity from hydrogen, which means they can help make a future hydrogen-based society a reality. Thus they are expected to further contribute to the speeding up of energy diversification.

The need for a hydrogen station infrastructure

For FCVs to be viable, a suitable refuelling infrastructure is essential, with purpose-designed facilities for supplying hydrogen. These can be stationary or mobile; stationary hydrogen stations can be on or off-site. With the on-site type, an electrolyser is used which can obtain the electricity it needs from renewables such as wind power or solar panels. With the off-site hydrogen production station, hydrogen produced at a factory from raw materials (eg kerosene, LPG, natural gas, bio-gas) is transported to the facility, in the same way petrol and diesel are distributed from refineries to retail outlets.

A genuinely safe automotive fuel

Hydrogen is as safe as any other fuel used in a car. It's been used as an energy carrier for decades, and there is a vast amount of cumulative know-how and experience in Toyota and elsewhere to handle it safely. Safety aspects are discussed in detail in section six.

Working towards a hydrogen society

The hydrogen society, or hydrogen economy, refers to the vision of using hydrogen as a decarbonised and efficient energy source or industrial feedstock that can replace conventional fossil fuels. Hydrogen is an attractive resource because it can be stored, transported and transformed into energy (water and heat), with water as the only by-product/emission.

However, hydrogen is not found in pure form on Earth. It has to be produced from other compounds such as water, natural gas or biomass, using conversion processes which of course require energy. For that reason, it's more accurate to describe hydrogen not as an energy source but an energy carrier or storage medium. The environmental impact of using hydrogen therefore depends on the carbon footprint of its production path.

Potentially one of the best ways to use hydrogen is in electric cars or buses, fitted with a fuel cell which converts the hydrogen with oxygen in the air into electricity. Hydrogen may also be useful as a means of storing renewable energy from intermittent sources – wind power for example, when the wind is blowing, but there isn't a high demand for electricity. In this context, it's a great alternative to large-scale batteries or other storage systems, especially as intermittent sources are ramping up in EU grids. Currently Hamburg is running a city power project* that is proving how using hydrogen to store excess energy (also called power-to-gas) is a smart choice. Another possibility is to use hydrogen as a heating fuel in homes and buildings, either blended with natural gas or by itself.

It's the flexibility that hydrogen offers that makes it potentially so useful within future low-carbon energy systems. It can be produced from a wide variety of resources and can be used in a wide range of applications. Hydrogen is already used extensively in the chemical industry,

so industry is familiar with its large-scale production, handling and distribution. For all these reasons, many experts see hydrogen as a key enabler of the lowest-cost low-carbon energy system.

*http://www.hysolutions-hamburg.de/en/projects/all-projects/

Mirai: the innovative eco-car that is convenient and easy to use

- **An up-to-date, high-value eco-car**
- **A fuel cell electric vehicle that uses the Toyota Fuel Cell System**
- **More energy-efficient than internal combustion engines**
- **Ample cruising range and short refuelling time**
- **Emits only water**
- **Innovative design**
- **Packed with comfort features**

Mirai is positioned as the most up-to-date, high-value eco-car in the world today. It is free from any sense of inconvenience; its ease of use is like any conventionally powered vehicle. A driving range comparable to that of petrol vehicles is possible, and it only takes between three and five minutes to fill the tank.

The Toyota Mirai signals the start of a new age of vehicles. It's a fuel cell electric vehicle **–** one that takes in hydrogen and oxygen into a fuel cell stack (FC stack) to generate electricity that is used to run the motor and produce driving power for the vehicle. Using hydrogen as fuel to generate electricity, Mirai achieves superior environmental performance with the convenience and driving pleasure expected of any car.

Mirai uses the Toyota Fuel Cell System (TFCS), which combines both fuel cell and hybrid technologies, and includes Toyota's proprietary FC stack and high-pressure hydrogen tanks.

The FC stack can be described as a small power station. It differs from a regular dry cell in that it generates electricity through a chemical reaction between hydrogen and oxygen. It can continue to produce electricity with no loss of power, as long as oxygen and hydrogen fuel are continuously supplied. The FC stack performs the role of the engine in a hybrid vehicle. Both a hybrid vehicle engine and the FC stack in an FCV are devices that produce energy by the intake of ''fuel'', even if a fuel cell does not burn it. The efficiency of the conversion from fuel to energy is double that of petrol vehicles.

Mirai delivers everything expected of a next-generation car: a recognisable and highly innovative design; a rewarding driving experience, stability and handling that stem from its low

centre of gravity; and quiet but powerful acceleration provided by an electric motor. It also comes packed with comfort features and is a quiet car, with few vibrations. It can reach a top speed of 111mph.

A closer look at Mirai

Driving pleasure and comfort

- **Powerful and smooth acceleration**
- **Unmatched quietness**
- **Outstanding stability, controllability and ride comfort**

With Mirai, there's no compromise when it comes to driving pleasure and comfort. An unprecedented smooth, gliding drive feel goes hand in hand with high cornering performance on winding roads.

Powerful and smooth acceleration

High FC stack output and battery power assist is transformed into drive power by the motor, with maximum torque provided the moment you press the accelerator. Acceleration is smooth and powerful, giving comfortable and steadily progressive driving performance. Acceleration to 62mph from a standing start takes 9.6 seconds.

Unmatched quietness

Mirai is free from engine vibration and noise. Full sealing of all body parts and the use of sound-absorbing and sound-insulating materials around the cabin help deliver outstanding quietness. Other measures include:

- Acoustic glass is used for the windscreen and door windows.
- Foam-type sound-insulating materials are used inside the body frames.
- Sound-absorbing materials are deployed around the bonnet and front wings.
- The position of the door mirrors and the shape of the front pillars have been defined to help reduce wind noise.

Outstanding stability, controllability and ride comfort

Mirai has a low centre of gravity, helped by the fact its FC stack, hydrogen tanks and other power unit components are located under the vehicle floor. This low centre of gravity ensures superior handling stability and produces a comfortable driving experience by reducing the degree of change in vehicle position/attitude.

By locating the FC stack, hydrogen tank and other parts centrally in the vehicle, a good front-to-rear weight distribution is achieved**,** giving Mirai a "midship" feel. The result is agile cornering and appealing handling, just as the designers intended.

A number of features contribute to the high-rigidity body. Extra rigidity around the suspension achieves outstanding stability and controllability. The use of aluminium and ultra-high strength sheet steel for the bonnet and body structural parts gives a combination of rigidity and reduced weight, supporting better rear wheel grip feel, steering wheel response, stability and controllability.

Mirai's aerodynamics is up there with the best. Because the vehicle doesn't emit any heated gases, the floor could be fully covered. Air resistance is reduced to boost fuel efficiency; even the design of the clearance lamps and the use of aero stabilising fins on the side of the rear combination lamps contribute to the overall excellent aerodynamic performance.

Mirai uses MacPherson strut front suspension and a torsion beam system at the rear. Both set-ups have been tuned to help achieve superb handling stability and smooth ride comfort.

But that's not all. Other details have been tailored to ensure driving pleasure and comfort. One of these is "Br mode," which is equivalent to engine braking on a car with an internal combustion engine. In this mode, slightly stronger deceleration can be obtained when the driver wants to reduce speed, such as when negotiating long downhill road sections.

Mirai comes with three selectable drive modes. Normal for everyday operation, Eco mode to adjust powertrain performance to prioritise fuel efficiency, and Power mode to sharpen the response to accelerator pedal inputs.

An eco-car experience in a practical package

- **Good visibility**
- **Optimum driving position**
- **Wide, easily accessible boot**
- **Functional, easy-to-use storage spaces**

Mirai is an eco-car in a perfectly practical four-door, four-seat saloon package, thanks to Toyota's success in locating the FC stack and other power unit components under the vehicle floor.

A number of features contribute to good visibility. Careful attention was paid to the mounting position of the wipers, and thin wiper blades are used to avoid obstructing the driver's view. Forward visibility was a prime consideration in defining the shape of the front pillars and the door mirrors. The (auto-dimming) rear-view mirror has a frameless design, so is a smaller unit but with a larger mirror surface, improving the driver's rearward view.

Delivering a comfortable driving position was a priority, supported by the standard provision of a power tilt and telescopic-adjustable steering column and eight-way power adjustable front

seats with lumbar support function. Two memory settings are available to store preferred driving positions, automatically adjusting the steering wheel, driver's seat and door mirror.

When the driver enters or exits the car, the driver's seat and steering wheel slide back in unison to give easy access or exit.

Thanks to clever packaging of the battery, Mirai has a wide, easy-access boot with 361 litres of storage space (VDI measurement).

There are plenty of handy storage spaces around the cabin. These include a centre console box, which also serves as an armrest (with slide function) when closed; front door pockets that can hold a half-litre plastic bottle or A4-size documents (horizontally); an overhead console for storing small items; seatback pockets on the back of the front seats; a push-open sliding cup holder between the rear seats; and a rear seat console box underneath the armrest. There's also a cup holder in the front, rear door pockets and a glovebox.

Advanced exterior design

- **"Air to water" side profile**
- **Striking side grille design**
- **High-tech headlamps**
- **Aluminium wheels**

Mirai's body styling expresses future mobility, while its sophisticated cabin fully captures the car's status as a leading edge vehicle.

The frontal design emphasises the originality of FCVs, with a strong three-dimensional structure that gives extra prominence to the grilles on the left and right side. These are not just design features, but are fully functional to maximise cooling air intake capacity.

Mirai's stand-out "air to water" side profile expresses the special technical quality of FCVs, representing the flowing shape of a water droplet. Its rear view achieves both a powerful stance and clean impression, thanks to a strong overall shape and wide bumper.

The side grille design is another interpretation of the way Mirai draws in air and produces water, given emphasis with metal-finish detailing and side bars. The rear bumper adds further impact with an inverted red triangle design for the fog light and a fin-shaped spoiler.

Toyota's R&D engineers produced a new structure and design for Mirai's headlamps. The front turn indicator lamps and clearance lamps are separate from the headlamps, and are designed to merge with the side grilles. The headlamps have a novel design that presents an ultra-thin profile with an in-line arrangement of four LEDs. Also, the headlamps' heat sinks and other optical elements are left visible.

The electrically adjustable, power-folding door mirrors have integrated LED turn indicators and effective water-repellent finish that keeps the glass surfaces clear in rain and spray.

The 17-inch alloy wheels have been made lighter by a Toyota-first engraving process. During manufacturing, metal is shaved from the intersecting line between the wheel disc and rim, which saves about 500g in the weight of each wheel.

Sophisticated interior design

- **Innovative interior design**
- **Solid quality feel and soft-touch materials**
- **High-quality comfort**
- **“Form in place” seat construction**

Mirai’s innovative interior design has produced a seamlessly flowing cabin space, with an overall shape that flows back from the top section of the instrument binnacle and the front pillars all the way to the rear window.

The contrast between the solid quality feel and soft-touch materials has been accented by high-brightness silver trim details throughout the interior and the use of soft-touch pads in key areas including the door trim, instrument panel and centre console. Contrasting combinations contribute to the refined ambience – glossy, geometric switch panels and firm-grip pull handles contrast with the centre console panel’s clean, solid, jet black finish.

The cockpit presents an array of advanced features that heighten the sense of Mirai being in the vanguard of future mobility. The centre combination meter cluster is designed to look as though it stands out from the binnacle and has been positioned so the driver can take in information without taking their eye off the road ahead.

A 4.2-inch high-definition TFT liquid crystal display is used for the speedometer and multi-information display. It can present a wide range of information using graphics and text that are easy to read on the colour screen. The driver can select which information is shown, using six tabs (drive information/navigation system link/audio link/driving system operation support/warning messages/settings).

The speedometer has a large, easy-view display. Two screen modes can be set: a split mode that displays a sub-screen, and a standard mode. Pressing the four-direction switch on the steering wheel will bring up the FC system indicators on the split screen.

The air conditioning and seat heater control panel looks and works like a tablet, requiring only light touches of the screen. Operating temperatures can be set simply by sliding electrostatic controls up and down with your fingertip. LED lettering and switches are illuminated in white

during daytime, turning to clear blue at night. The display presents the selected temperature, air volume and other information in the centre of the air conditioning control panel.

High comfort is provided for everyone on board in a cabin that fuses established premium quality with a more modern approach. This can be seen in seats with art-like shapes but with all the support and comfort customers expect in a luxury vehicle. Special attention has been paid to ensuring body fit and hold that will help prevent fatigue, particularly on long drives.

The seats' excellent comfort and support are achieved using a "form in place" manufacturing method in which urethane is injected into a seat cover, pre-loaded into a mould. This causes the urethane to foam into the ideal, final shape. This is in contrast to conventional methods where moulded pads are made, then covered. The "form in place" method allows seats to be formed faithfully to the design, with an ideal concave cross-sectional shape that wraps around body to give superior fit and hold.

The front seats are eight-way power-adjustable and have a power lumbar support feature. Two-stage temperature adjustable seat heaters are provided as standard on all Mirai's seats. Soft materials have been added to pad surfaces, seat backs and cushions, and the seats are shaped around the hip to add extra comfort and support.

The high quality feel is pursued right down to the details. Soft pads on the instrument binnacle hood, instrument panel, console, door trims and door armrests create a pleasant tactile sensation.

Outstanding cold start performance

- **Improved power generating performance immediately from start-up in sub-zero temperatures**
- **Improved warm-up performance**

One of the drawbacks associated with cars fuelled by hydrogen is that maintaining good power generation from a fuel cell requires water, and in environments where the temperature regularly drops below freezing point, excess water freezes. This impedes the flow of air (oxygen) and hydrogen and reduces power generation performance.

Toyota has addressed this challenge by ensuring that Mirai can be started at -30°C and will give satisfactory output levels immediately after starting. This has been achieved in two ways:

Improved power generating performance immediately after starting below freezing point

- Higher cell flow channel and electrode performance: exclusion of generated water and air diffusion were improved.
- Establishment of intra-cell water content control technology: the content of water is measured and controlled at a level suitable for power generating performance below freezing point.

Improved warming up performance

- Lower thermal capacity as a result of higher fuel cell stack output density.
- Establishment of fuel cell rapid warm-up control technology: heat generated by the fuel cell is controlled to drastically reduce warm-up time.

Mirai was extensively tested in extremely cold conditions in Alaska, Canada, Finland and Northern Japan. Fuel cell stack output performance was evaluated after starting the car after it had been parked outdoors overnight for 17 hours at temperatures as low as -30˚C. One hundred per cent power output was obtained 70 seconds after starting.

Active safety, passive safety, and comfort features

- **State of the art safety**
- **Comfort features:**
    - **ECO HEAT/COOL mode switch**
    - **Automatically retracting door mirrors**
    - **Handy smartphone charging area**
    - **Steering wheel and seat heaters**
    - **Top-of-the-range audio equipment**

Active safety

Mirai incorporates a Pre-Collision System which uses a camera and millimetre-wave radar to monitor the road ahead and detect vehicles or obstacles in the car's path. If it determines there is a risk of a collision, it triggers a warning buzzer and light to prompt the driver to brake; at the same time, it prepares the brakes to deliver extra stopping force the moment the brake pedal is pressed.

If the driver does not respond to the warnings and the system recognises an impact will occur, it will activate the pre-collision brake, reducing vehicle speed by up to 19mph to prevent an accident, or mitigate its severity, helping reduce any possible damage or injuries.

The Blind Spot Monitor detects vehicles running in adjacent lanes. When the vehicle enters the driver's blind spot area on either side, an LED indicator in the appropriate door mirror is illuminated. At the same time, the side-turn signal lamp is made to blink and the LED indicator also blinks to call the driver's attention.

The car is equipped with Rear Cross Traffic Alert function. When starting to reverse, for example from a parking space, vehicles approaching from either side travelling behind are detected by the system. As with the Blind Spot Monitor, an LED indicator blinks and a buzzer sounds to warn the driver.

Drive-start Control reduces the risk of damage from sudden start accidents during gear-shift operation and reversing. For example, after a collision when reversing, the driver might hurriedly move the shift lever from R to D while the accelerator pedal is still depressed. The system warns the driver with an indication on the display, and motor output is suppressed to limit acceleration.

Other preventive safety functions include:

- Adaptive Cruise Control
- Vehicle Stability Control and Traction Control
- ABS with Electronic Brakeforce Distribution
- Hill-start Assist Control.
- Emergency brake signal.
- Auto-dimming rear-view mirror.
- Front and rear parking sensors
- Rear-view monitor

Passive safety

Eight SRS airbags are fitted as standard:

- Driver and passenger dual-stage front airbags
- Driver’s knee airbag
- Front passenger seat cushion airbag
- Driver and front passenger side airbags
- Front and rear curtain shield airbags

The car body is designed to reduce pedestrian injuries in the event of an accident, with structures in the bonnet and cowl to reduce and absorb impact to the head and other parts of the body.

Other impact safety functions include a three-point seat belt with pre-tensioner and force limiter on all seats, and an ISOFIX-compatible child seat securing bar and a top tether anchor bar for the rear seat.

Comfort features

The Eco heat/cool mode switch enables fully automatic left and right independent air conditioning temperature control. There is an Eco mode switch exclusively for air conditioning, which prioritises fuel economy by controlling the system's performance, with no discernible change in driving feel. Eco mode is operated by turning the switch on and off, or by holding it down. In Eco Hi mode, even higher priority is given to fuel economy.

Mirai is fitted with automatically retractable door mirrors, which are folded and returned to their previous position when the car is locked and unlocked.

Smartphones compatible with the Qi wireless charging standard or have Qi compatible accessories can be charged simply by placing them in the handy smartphone charging area provided in the centre console box.

A steering wheel heater and heaters on all seats provide instant warmth and make a significant contribution to reducing power consumption. They provide immediate heat and are less demanding on power and fuel than air conditioning. The steering wheel heater warms the steering wheel and is automatically turned off after about 30 minutes. The seat heaters have two temperature settings (Hi/Lo) and are provided on all seats.

Mirai's top-of-the-range audio equipment includes a display system with a seven-inch VGA TFT display as standard. It incorporates AM/FM radio, CD, Bluetooth, navigation system and DAB. The car is equipped with a JBL premium sound system featuring 11 speakers, and USB and AUX terminals are provided as standard in the centre console box.

Other features include Smart Entry and push-button start; anti-theft alarm; rain-sensing wipers; and a 12V accessory power socket.

How the world-leading Toyota Fuel Cell System works

- **TFCS (Toyota Fuel Cell System) combines Hybrid and FC technologies developed by Toyota over many years**
- **Two energy sources – FC stack and battery – are optimally selected to drive the motor**
- **How the FC stack generates power**

TFCS combines Hybrid and FC technologies

The Toyota Fuel Cell System (TFCS) adopts the latest compact, high-performance FC stack.

Mirai was developed around Toyota's long-cultivated core technologies of energy recovery during braking, and high-performance, high-efficiency hybrid technology to assist during

engine starting and acceleration. Two energy sources, an FC stack and a battery, are used as appropriate to drive the motor to achieve more environmentally efficient and powerful running.

Two energy sources – an FC stack and battery

Mirai is a hybrid that combines an FC stack with a battery. Generally, a hybrid car is a vehicle that runs efficiently using a combination of two drive sources: an engine and a motor. An FCV such as Mirai differs slightly from general hybrid vehicles in that it is a hybrid that uses a combination of an FC stack and a battery as the sources of energy to power the motor. The battery provides power support during acceleration, just as it does in other hybrid technologies used to achieve more powerful and efficient running.

How the FC stack generates power

The smallest element in a fuel cell (a cell) comprises an electrolyte membrane, a pair of electrodes (negative and positive) and two separators. Though each cell has a small voltage, of 1V or less, large power output for running a vehicle can be obtained by connecting a few hundred cells in series, increasing the voltage. These combined cells form what's called an FC stack; this FC stack is usually what is meant when talking about fuel cells.

In a fuel cell, electricity is made from hydrogen and oxygen. Hydrogen is supplied to the negative electrode, where it is activated on the catalyst causing electrons to be released. The electrons freed from the hydrogen move from the negative electrodes to the positive electrodes, generating electricity. The hydrogen releases electrons which convert to hydrogen ions that move to the positive side while passing through a polymer electrolyte membrane. At the positive electrode catalyst, oxygen, hydrogen ions and electrons combine to form water.

Safety: the car, the refuelling process and the gas

- **The car: tough fuel tanks and highly sensitive hydrogen sensors**
- **The refuelling process: international safety standards in place**
- **The gas: using the lightest element in the universe has its benefits**

Over the last decade, hundreds of FCV s have been thoroughly road and safety tested. They have racked up millions of miles over all kinds of demanding terrain. They have been put through their paces in the cold of northern Finland and the heat of southern Spain. Their hydrogen fuel tanks have even been shot at by high-velocity weapons.

Mirai passed all its tests with flying colours. It's as safe as any other Toyota vehicle; the fact it is powered by hydrogen has absolutely no effect on its inherent safety.

The three principal aspects of Mirai that relate to safety are the car, the refuelling process, and the gas itself.

The car: tough fuel tanks and highly sensitive hydrogen sensors

The hydrogen that powers Mirai is stored at a high pressure (700-bar) in two compact, ultra-tough tanks. Toyota worked on their design in-house from 2000 and is more than satisfied with their strength and safety performance.

The tanks' main source of strength is their carbon fibre shell, over which there is a further layer of glass fibre. Should the car be involved in an accident, any damage to the hydrogen tank will be clearly visible on the glass fibre layer; tests can then be carried out to find out whether the carbon shell itself has been compromised. The glass fibre doesn't contribute to rigidity of the tank, but gives absolute confidence in its integrity. The whole tank is lined with plastic to seal in the hydrogen.

As mentioned above, the tanks have been subjected to extremely severe testing. They are designed to withstand up to 225 per cent (GTR standard*) of their operating pressure, which is a very high safety margin.

In the unlikely event of a leak, Mirai is fitted with highly sensitive sensors that will detect minute amounts of hydrogen. These are placed in strategic locations for instant detection. Should a leak occur in the fuel system, the sensors will immediately shut down the safety valves and the vehicle itself.

As a third layer of safety, the cabin is strictly separated from the hydrogen compartment to prevent the ingress of any leaking hydrogen, which would instead gradually disperse into the atmosphere.

The refuelling process: international safety standards in place

Refuelling is a critical process because it involves human action, which unfortunately can lead to unforeseen and unsafe scenarios, such as trying to drive off while the fuel nozzle is still connected to the car. For this reason, a number of safety precautions have been put in place.

First, the nozzle at the end of the hydrogen dispenser's flexible hose has a mechanical lock to form a perfect connection with the car's filling inlet. Unless this mechanical lock clicks into place securely, filling will not commence.

Secondly, a pressure impulse checks for any leakage in the system between the filling station and the car. If a leak is detected, refuelling is aborted.

Thirdly, the rate of filling is carefully regulated, to avoid overheating during transfer. Temperature sensors in the car's hydrogen tanks, the nozzle and the pump constantly

communicate with each other by infrared to control the rate of flow of hydrogen into the car so that the temperature rise is not excessive. This is probably the smartest refuelling system any driver will have experienced.

The international standards SAE J2601, SAE J2799 and ISO 17268 establish safety limits and performance requirements for gaseous hydrogen fuel dispensers. The criteria include maximum fuel temperature at the dispenser nozzle, the maximum fuel flow rate and the maximum rate of pressure increase.

Should a driver attempt to drive off in a Mirai while the fuel nozzle is attached to the car, they will not succeed: the car is immobilised until the nozzle has been replaced in its holster and the car's fuel cap is closed. To be absolutely sure, a safety system is embedded in the hose that locks the pump should an attempt be made to drive the car off in the middle of refuelling.

The gas: using the lightest element in the universe has its benefits

Hydrogen gas is the lightest element known to man and considerably (14x) lighter than air. The consequence is that should a leak occur, the hydrogen will rise into the atmosphere. And thanks to its status as the smallest molecule in the universe, it disperses quickly in air or any other gas.

Mirai's fuel tanks have a pressure relief device that releases the hydrogen gradually should there be an abnormal rise in temperature (for example in a fire). This prevents any overpressure or explosion occurring.

Summary of safety aspects

Hydrogen is as safe as any other fuel used in a car. It's been used as an energy carrier for decades, and there is a vast amount of cumulative know-how and experience in Toyota and elsewhere to handle it safely. It is a carbon-free, non-hazardous energy source that can be produced from many renewable resources and emits no greenhouse gases when used as a fuel.

* GTR Global Technical Regulations. Issued by the United Nations, these have a global scope and a legal value.

Environmental considerations: from production to disposal

- **Vehicle production**
- **Hydrogen production**
- **Recycling**

When Mirai is driven, the only by-product generated is water, which means the car has a significantly low overall impact on the environment. Depending on the way the hydrogen it uses is produced, an overall CO_2 reduction of between 50 and 70 per cent can be achieved compared with a conventionally powered vehicle. In future, when renewable energies will be used for hydrogen production, the CO_2 emissions from well to wheel will be even more drastically reduced, bringing Toyota close to its goal of zero emissions.

Vehicle production

Mirai is manufactured at a sustainable Toyota plant which aims to make the most efficient use of natural resources while operating in harmony with the natural environment. There are three aspects to this approach:

- Effective energy generation, by using exhaust heat from the plant or renewable energy such as solar.
- Elimination of energy waste: development and introduction of low CO_2-emitting production technologies and daily Kaizen activities to find new and better ways of working.
- Community involvement and eco-system conservation: tree planting activities in the grounds of the plant.

Hydrogen production

Hydrogen can be produced from various primary energy sources, with different methods suitable for different countries and regions. It can also play a significant role in the spread of renewable energy. Solar and wind power are intermittent sources, resulting in uneven generation levels, which in turn require the provision of an adequate energy storage system. One way to store these renewable energies is to convert them to hydrogen, a method that is a better solution for large-scale storage than batteries, thanks to the higher energy density that can be achieved. If the society of the future is to make the best use of renewable energy, it will need to organise smart integration of the electricity and hydrogen grids in order to be effective.

Recycling

Toyota recognises the importance making efficient use of resources and has secured a recoverability rate of more than 95 per cent for Mirai when the vehicle reaches the end of its on-road life. Toyota has created the world’s first fuel cell stack collection and recycling network, which will ensure valuable materials such as platinum can be recovered.

Toyota in Europe has set itself the challenging target of a 100 per cent battery recovery rate. In 2010, Toyota set up the world’s first battery-to-battery recycling operation in Japan.

Furthermore, as of 2013, the batteries it recovers are finding new uses as stationary energy storage units. Realising that our raw materials are finite, Toyota is making constant progress towards a more resource-efficient economy.

Chief Engineer’s message

While global attention is just beginning to turn towards the creation of a hydrogen energy-based society, Toyota’s journey dates back to 1992 when it first started development of Fuel Cell (FC) technology. The core technologies (the FC stack and hydrogen tanks) were developed independently, and over time these development and manufacturing technologies became strong points for Toyota. Now, after working on the necessary technologies for more than 20 years, we have been able to bring Mirai to market.

As Chief Engineer, I chose the vehicle concept slogan "H2 Pioneer for the Next Century" while developing the FCV. With a focus on the next 100 years of automobiles, Toyota has proceeded with the development of a vehicle that offers a new, unique value, a pioneering vehicle that will achieve an H2 energy society. In addition to its superior FC technology and environmental performance, I believe Mirai is a vehicle that customers will want to keep on driving because it’s fun to drive, it has a futuristic design that clearly marks it out as an FCV and it offers quiet and pleasant ride comfort.

In order for environmental technology to realise its full potential contribution, the technology needs to become widespread. Toyota has already taken the initiative in popularising hybrid vehicles. With this new vehicle, we are bringing innovation even greater than that of the first-generation Prius to market, and I believe we must do all we can to popularise it, and the concept of FCV technology.

The spread of the special infrastructure required by FCVs will most likely take 10 to 20 years, or perhaps even longer. It is definitely a long and challenging road. However, for the sake of the future, it's a road we need to travel.

Yoshikazu Tanaka

Entered Toyota Motor Corporation in 1987. First was development lead of automatic transmission and powertrain systems, then transferred to product planning department in 2006. From then on, in charge of coordinating Prius and Mirai projects as development manager.

TOYOTA MIRAI TECHNICAL SPECIFICATIONS

FUEL CELL STACK	
Model code	FCA110
Type	Polymer electrolyte
Number of cells	370
Connection method	Series
Max. output bhp/kW	153/114
BATTERY	
Type	Nickel-metal hydride
Number of cells	34
Nominal voltage	244
Capacity (Ah)	6.5
Connection method	Series
ELECTRIC MOTOR/GENERATOR	
Motor model code	4JM
Type	Permanent magnet, synchronous
Max. power (bhp/kW)	152/113
Max. torque (Nm)	335
DRIVETRAIN	
Layout	Front-wheel drive
Transmission gear ratio	1.000:1
Reduction gear ratio/final drive	3.478:1
SUSPENSION	
Front suspension	MacPherson strut with anti-roll bar
Rear suspension	Torsion beam
STEERING	
Type	Rack and pinion., electric power steering
Ratio	14.8:1
Turns lock-to-lock	2.81
Min. turning circle – body (m)	11.4
BRAKES	
Type - front	Ventilated disc

Type - rear	Ventilated disc
TYRES AND WHEELS	
Wheels	17 x 7J
Tyres	215/55R17 94W
PERFORMANCE	
Max. speed (mph)	111
0-62mph acceleration (sec)	9.6
FUEL CONSUMPTION	
Combined (kg/100km)	0.76
Extra urban (kg/100km)	0.80
Urban (kg/100km)	0.69
Fuel tank capacity (kg)	5.0 (approx.)
WEIGHT	
Kerb weight (kg)	1,850
Gross vehicle weight	2,180
EXTERIOR DIMENSIONS	
Overall length (mm)	4,890
Overall width (mm)	1,815
Overall height (mm)	1,535
Wheelbase (mm)	2,780
Front track (mm)	1,535
Rear track (mm)	1,545
Front overhang (mm)	1,080
Rear overhang (mm)	1,030
Ground clearance (mm)	130
Drag coefficient (Cd)	0.29
INTERIOR DIMENSIONS	
Length (mm)	2,040
Width (mm)	1,465
Height (mm)	1,185
VDA boot capacity (l)	361

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TOYOTA MIRAI EQUIPMENT SPECIFICATIONS

SAFETY & DRIVING DYNAMICS	
Driver dual-stage airbag	✓
Front passenger dual stage, dual chamber airbag	✓
Front and rear side airbags	✓
Driver knee airbag	✓
Front passenger seat cushion airbag	✓
Curtain shield airbags	✓
Isofix child seat anchors on rear seats	✓
ABS with Brake Assist and Electronic Brakeforce Distribution	✓
Vehicle Stability Control	✓
Traction control	✓
Pre-Crash System	✓
Adaptive Cruise Control	✓
Hill-start Assist Control	✓
Blind Spot Monitor	✓
Rear Cross Traffic Alert	✓
Emergency brake signal	✓
Tyre pressure warning system	✓
SECURITY	
Alarm	✓
Engine immobiliser	✓
Double door locks with power locking	✓
COMFORT & CONVENIENCE	
Power windows	✓
Rain-sensing wipers	✓
Steering column power adjustment for reach and rake	✓
Smart entry and push-button start	✓
Wireless smartphone charger	✓
Auto-dimming rear-view mirror	✓
Rear-view camera	✓
Rear parking sensors	✓
Windscreen wiper de-icer	✓
12V accessory socket	✓
VENTILATION	
Dual-zone climate control	✓
Heated steering wheel	✓
Heated front and rear seats	✓
SEATING, UPHOLSTERY & TRIM	
Power front seat adjustment – 8-way driver, 8-way passenger, with 2x memory function for driver's seat	✓
Power-adjustable lumbar support – driver and front passenger seats	✓
Leather steering wheel trim	✓

AUDIO, COMMUNICATION & INFORMATION	
4.2-inch TFT colour multi-information display	✓
11-speaker JBL sound system with DAB Tuner	✓
Toyota Touch 2 with Go Plus multimedia and navigation system	✓
USB port and Aux-in jack	✓
Bluetooth	✓
EXTERIOR	
17in alloy wheels	✓
Heated, power-folding door mirrors with integrated turn indicators	✓
LED rear lights and high-level brake light	✓
LED headlights	✓
LED daytime running lights	✓
Tyre repair kit	✓

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