The Big Read Hydrogen Vehicles Add to myFT Japan gambles on Toyota's hydrogen powered car As rivals look to electric vehicles, the country's leading carmaker is putting its faith in an alternative Share on Twitter (opens new window) Share on Facebook (opens new window) Share on LinkedIn (opens new window) Email101 Save YESTERDAY by: Robin Harding and Kana Inagaki Sakichi Toyoda, the founder of Toyota, once offered a ¥1m prize to the inventor of his dream: an electric battery that would free Japan forever from its dependence on imported oil. Toyoda imagined cars running on abundant hydroelectric power. All he needed was a battery to provide 100 horsepower for 36 hours, with a weight below 225kg and a volume of less than 280 litres. That was in 1925. Almost a century later the prize remains unclaimed. Toyota's engineers fondly refer to the elusive power source as a "Sakichi battery" and the very difficulty of making one has led them in pursuit of an alternative fuel to power its cars: hydrogen. That pursuit is playing out in a small factory near the company's headquarters in Toyota City, central Japan, where an elite team of workers is hand-building a vehicle that represents a huge gamble for the world's second-largest motor manufacturer. The Mirai is either the future of the automobile or a technological trap about to swallow a prized swath of Japanese industry. Every hour or so the workers wheel out two thin yellow cylinders, spun from carbon-fibre at an even-more-sensitive Toyota factory attached to its research and development centre, and bolt them into place. The tanks hold hydrogen, from which a fuel cell makes electricity to power the car. The Mirai is Toyota's — and Japan's — vision of low-carbon transport, a vision completely different to the battery-powered Teslas edging into the automotive mainstream. It is fraught with obstacles. The technology is expensive: a petrol-powered vehicle at a Toyota plant rolls off the production line every 60 seconds but it currently takes 72 minutes to assemble a single Mirai. It needs a nationwide refuelling network that does not exist anywhere. Most troublesome of all: there is not yet any source of cheap, carbon-free hydrogen to justify the effort. 1. Hydrogen is pumped from the tanks to the stack … 2. … where it meets oxygen from the inlets at the front of the car 3. The reaction in the stack (see detail below) generates an electrical current 4. The current's voltage is increased by a boost converter 5. The electric motor drives the wheels. When the car is coasting or braking the motor acts as a generator 6. The extra electricity generated by the motor is stored in a drive battery, which can assist the motor during acceleration 7. The power control unit oversees fuel cell power output and battery discharge and recharge depending on driving conditions Yet for reasons of industrial strategy, energy security and physics, Japan and its biggest carmaker are placing a huge bet on hydrogen. Come the 2020 Tokyo Olympics, they want fleets of fuel cell cars and buses taking athletes from village to venue, before the vehicles head for the global mass market. Shinzo Abe, the prime minister, has made hydrogen a symbol of Japan's ability to innovate despite the collapse of its vaunted consumer electronics industry. "Hydrogen energy holds the trump card for energy security and measures to address global warming," he said in January. "Japan will build an international hydrogen supply chain that extends from production to transportation and consumption ahead of the world." *** The danger is not so much that hydrogen fails but that it succeeds just a little bit, luring Japan into a technology it cannot sell to other countries, and leaving its mighty carmakers led by Toyota and Honda stuck in a Galápagos ecosystem of their own making, just like the unique wireless standards that isolated the

country's mobile phone industry. "We see fuel cell vehicles as the ultimate eco-car," says Kiyotaka Ise, Toyota's head of advanced R&D. "Everyone is saying electric vehicles [are the future] but there is still a long way to go. EVs are far easier to make than FCVs and there's still going to be a lot of trial and error. Toyota is putting huge effort into fuel cell vehicles." The carmaker aims to sell more than 30,000 hydrogen-powered vehicles a year by about 2020, 10 times its 2017 production target. It also plans to introduce more than 100 fuel cell buses in the Tokyo area ahead of the Olympics. Toyota does not highlight it, but the very difficulty of making fuel cells is part of their attraction for Japan. The business for electric vehicles looks like that of mobile phones: simple, modular, easy to assemble and vulnerable to new entrants from China and Silicon Valley. 1. Hydrogen enters the anode side of the fuel cell 2. It reacts with the platinum catalyst coating the anode, which strips the hydrogen of its electrons 3. The hydrogen ions pass through an electrolyte membrane to the cathode 4. The electrons cannot pass through the membrane so flow around it in an electrical circuit, generating the driving power 5. At the cathode, the catalyst causes the ions and electrons to bond with oxygen from the air to form water vapour – the only byproduct of the process Fuel cell vehicles, by contrast, need all the manufacturing skills of a car company. "From the industrial strategy point of view, fuel cell technology is extremely difficult, it's in the world of chemistry not machinery," says Hiroshi Katayama at the advanced energy systems and structure division of the ministry of economy, trade and industry (METI). If auto technology goes down the hydrogen path, Japan will be well placed. But if it doesn't, Tokyo will have made a major miscalculation. Toyota's faith in hydrogen is best understood by looking at a car it never made: a pure electric vehicle. For the 20 years since it invented the Prius hybrid, Toyota has been the carmaker best-placed to launch a fully electric vehicle. It had the batteries, the motors and the power electronics but chose not to deploy them because of concerns about range limits, refuelling time and the risk of batteries degrading as they age. It has announced plans for its own electric vehicle to exploit the demand from the premium segment opened up by Tesla and to meet emissions standards in the US and China. Yet Toyota's fundamental doubts about battery-powered vehicles have not gone away. The long dreamt-of Sakichi battery would store energy at the same density as the chemical bonds in petrol: roughly 10,000 watt-hours per litre — enough to power a family car for hundreds of kilometres on a single tank. The low energy density of the best batteries, about one-twentieth that of petrol, is why today's electric cars have limited range. Toyota's hydrogen future Play video A battery breakthrough is not in prospect. Fundamental physics sets a limit on the potential of any given battery, so today's lithium-ion cells, and thus the range of current electric vehicles, cannot be greatly improved. There are theoretical battery chemistries, such as lithium-sulphur and lithium-oxygen, that could one day come close to petrol but no manufacturer is anywhere near putting them in a car. At pressures used in the Mirai, hydrogen has an energy density of about 1,500 Wh/l, about three times today's batteries. Nor is there a fundamental barrier to extending the range. Refuelling is quick and nothing comes out of the exhaust pipe but water. "If you have the same convenience of a gasoline car, [in a hydrogen vehicle] that's good for the user," says Toyota's Mr Ise. More news Shell places bet on hydrogen cars going mainstream Energy group is opening hydrogen filling stations in the UK, Germany and the US The majority of the 2,800 Mirais sold since its launch in 2014 have gone to Japanese and US companies and private consumers with access to refuelling infrastructure. Early adopters in Europe are mostly from public bodies. But the rollout suffered a setback in February when Toyota recalled its entire fleet of fuel cell vehicles due to a software glitch. The issue has been resolved, but analysts say any safety scare can be damaging when consumers are already wary of the reliability of hydrogen cars. Toyota has to raise volumes and bring down costs. Making the fuel tanks is complicated and the fuel

cell stack uses expensive materials such as platinum. Finding alternatives would help lower the Mirai's price of $57,000 in the US and €66,000 in Europe. "If we can only manufacture about 2,000 vehicles, that's not mass production," says Yoshikazu Tanaka, chief engineer of the Mirai. "Bringing down costs is important, but the challenge is also how we can secure production capacity." *** A few minutes from the Osaka headquarters of Iwatani is a hydrogen refuelling station — one of 22 operated by the energy group. Much like any other filling station there is a smartly uniformed pump attendant on the forecourt but there is little demand for the fuel. "To build a hydrogen society, the first stage is to roll out hydrogen stations so it is not inconvenient for drivers," says Akiji Makino, Iwatani's chairman and chief executive. But he and other providers recognise that it is hard to build the infrastructure until there are cars to use it, while few will buy the cars until there are places to refuel them. Iwatani has spent up to ¥500m ($4.5m) on building each of its stations. There are now about 80 in total in Japan and Mr Makino plans to add about 10 a year towards a national target of 160 by the time of the 2020 Olympics. Tokyo is offering subsidies to reduce the burden but it is still an expensive rollout. "Past a certain point growth will accelerate," says Mr Makino. "If we can just get past that tipping point then the move to a hydrogen society will suddenly pick up pace." Tokyo estimates that 900 hydrogen stations will be needed to supply 800,000 vehicles nationwide by 2030 to make the scheme economical. The hydrogen car future: key figures One of Iwatani's refuelling stations in Japan. It plans to build 10 a year to help meet Tokyo's target © Getty 72 minutes Assembly time for a Mirai. A petrol driven Toyota model rolls off the production line every 60 seconds 30,000 Toyota target for sales of FCVs by 2020, compared with 3,000 this year 900 Hydrogen stations needed to supply 800,000 vehicles in Japan by 2030 €66,000 Average price of a Mirai in Europe. It is about $57,000 in the US A bigger issue lies at another Iwatani facility — a sprawling chemicals complex in the city of Shunan that makes 10 per cent of Japan's hydrogen as a byproduct of caustic soda. To do so, it burns large amounts of natural gas, which leads to the question: where will the carbon-free hydrogen come from? There are no natural hydrogen deposits on Earth. You cannot dig for it, drill for it or harvest it. You have to make it. That uses energy, which is why Elon Musk, Tesla's chief executive, dismisses hydrogen vehicles as a "mind-bogglingly stupid" industrial dead end. Analysts say scepticism about Japan's hydrogen push runs equally deep at home. "Toyota is making fuel cell vehicles but they are not the ones to supply hydrogen" says Hiroshi Hamasaki, senior research fellow at Fujitsu Research Institute. "There is no specific blueprint as to who is going to make the hydrogen, attach incentives and shoulder the costs of operating the infrastructure." *** Industrial strategists at METI and the trading companies that source Japan's energy tend to agree with Mr Musk about making hydrogen from green energy via electrolysis. Their alternative vision is to make hydrogen from vast deposits of low-grade Australian coal, sequestering the carbon and burying it underground. They envisage fleets of hydrogen tankers plying the seas from Australia, bringing fuel just like today, but leaving the carbon behind. "Japan has so few natural resources and it's hard to cover a population greater than 100m with renewables," says Mr Katayama at METI. "The need for clean energy and energy security means hydrogen is getting attention . . . in Germany and California and recently China as well. In Japan it's the environment plus energy security and industrial strategy — that is what's different from everywhere else." A pilot project in Australia involves three commercially unproven technologies: producing hydrogen from coal at scale; shipping it thousands of kilometres in large volumes; and toughest of all, capturing and storing the carbon dioxide. Whether the cars use electricity or hydrogen, the problem of creating carbon-free energy remains the same. For now, Toyota's priority is to get hydrogen cars on the road and drive down costs. Though they may not tackle climate change directly, fuel cell advocates point

to the near impossibility of decarbonising heavy, long-distance transport without using the greater energy density of hydrogen. “If we’re told to emit zero CO2 in the future then either EVs or FCVs alone will fail,” says Mr Ise. “Both of them will have to coexist.” Back at Toyota City, another Mirai rolls off the production line, bound for California. It carries a nation’s hopes. Infrastructure: industrial gas rules impede swift rollout Despite its heavy bet on hydrogen, Japan’s strict safety regulations make it one of the most expensive countries in the world to build the infrastructure necessary to keep fuel cell vehicles on the road. The cost of building a refuelling station in Japan — at about ¥500m — is more than two times higher than in the US or Europe. The government is promising to reduce those costs and bring them into line with other countries by 2025, but industry experts say that, by that time, costs overseas will also have fallen, perhaps by as much as 30 per cent compared with 2015. Japan’s problem is that hydrogen is still regulated as an industrial gas, with standards designed for large-scale chemical plants, full of explosive risks and other hazards. The rules, for example, stipulate that there must be large amounts of space around a hydrogen car as it is refuelled and the filling station must be built with prohibitively expensive high grades of steel. It also adds to what proponents of hydrogen regard as a false perception that the fuel is dangerous. Hydrogen is certainly highly flammable — just like petrol. Unlike petrol, however, the ultralight gas quickly disperses rather than pooling and burning. Prime Minister Shinzo Abe has promised to overhaul some of the regulations and the revision is already under way, but industry experts say the effort is not going far enough, or moving fast enough, to make Japan globally competitive. “Whether it’s in the US, Europe or Japan, the regulations on how to handle hydrogen aren’t properly in place and it’s still a grey area,” says Taiyo Kawai, project general manager at Toyota’s R&D and engineering management division, who has spent a decade evaluating hydrogen cars. “The [Japanese] government tends to go for the most stringent regulation to ensure the highest level of safety. But once the rules are in place, it takes tremendous energy to review them.”