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Gigafactory Logistics in Space and Time: Tesla's fourth gigafactory and its rivals

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Abstract: This paper concerns the spatial structure of Tesla's four 'gigafactories' ('giga' is gigawatt hour, GWh) which are located in Tesla's first gigafacility (1) at Sparks, near Reno, Nevada; the Solar City gigafactory (2) at Buffalo, New York state; the 2019 Tesla plant at Shanghai, China Gigafactory (3); and the new Tesla gigafactory Europe Gigafactory (4), which is a manufacturing plant to be constructed in Grünheide, near Berlin, Germany. The newest campus is 20 miles south-east of central Berlin on the main railway line to Wrocław, Poland. Three main features of the 'gigafactory' phenomenon, apart from their scale, are first, the industry organisation of production, which thus far reverses much current conventional wisdom regarding production geography. Thus Tesla's automotive facility in Fremont California reconcentrates manufacturing on-site as in-house own brand componentry, especially heavy parts, or by requiring hitherto distant global suppliers to locate in proximity to the main manufacturing plant. Second, as an electric vehicle (EV) producer the contribution of Tesla's production infrastructure and logistics infrastructure are important in meeting greenhouse gas mitigation and the reduction of global warming. Finally, the deployment of Big Data analytics, artificial intelligence (AI) and 'predictive management' are important. This lies in gigafactory logistics contributing to production and distribution efficiency and effectiveness as a primer for all future industry and services in seeking to minimise time-management issues. This too potentially contributes significantly to the reduction of wasteful energy usage.

Introduction

While the US EV automotive company Tesla, established in 2010 by Silicon Valley entrepreneur, Elon Musk, has only recently opened its first major production plant in China, it is not the first time the company had established a presence abroad. In 2013 the company opened its European assembly facility for Tesla Models S and X (SUV) EVs for European delivery at Tilburg, The Netherlands. Notably the 'megafactory', as the three assembly buildings are known, is intentionally located next to advantageous infrastructure. This includes alignment with the Wilhelmina canal linking intermodal container barges with the Port of Rotterdam, Europe's largest. The company's own public relations stress premium locational factors:

'Being centrally located in Tilburg enables efficient, timely and cost effective operations throughout Europe. Parts can be distributed to anywhere across the continent within 12 hours. Tilburg is an ideal location considering its proximity to the port of Rotterdam and the high quality and availability of transportation infrastructure. An excellent rail and motorway network connects Tilburg to all major markets.' (Tesla, 2013)

The shells of Tesla cars arrive in containers that are separated from their powertrains. The contents of each container are then united on the assembly line in the plant's first 'compartment'. When the batteries and motors have been fitted, the 'firmware' (industrial software controlling basic hardware connections) is uploaded for the digital network seamlessly to install. Then the car's controlling software is installed from the car's autopilot to its customised entertainment system. The next 'compartment' of the factory is for testing of; sensors, radar, cameras, wheel alignment and pressurised water resistance. Thereafter, the third factory 'compartment' earns the plant its

'megafactory' designation as the car reaches the internal 750-metre long indoor test-track which simulates actual road conditions. Finally, the fourth 'compartment' involves an LED-lit tunnel for micro-inspection of quality of paint-finish, wheel-rims and interior imperfections.

Design of these factory elements is aimed to optimise simplicity, effectiveness and minimisation of effort. In this contribution, it is intended to determine how internal and external infrastructural logistics configurations are important for 'gigafactories'. Do these apply to Tesla, in particular, or more widely as part of requisite 'pattern recognition' for advanced efficiency and effectiveness in consignment mobility (e.g. including Amazon's 'chaos storage' at giga-scale 'fulfillment centres'). Accordingly, the paper proceeds with two main sections, the first analysing Tesla's three existing 'gigafactories' and whatever may be available on the fourth. The second section narrative answers the question of the extent such logistical structures have become ubiquitous or mainly associated with Tesla. Here we briefly examine two Chinese and two other Asian gigafactories for comparison. As a preliminary to the empirical content sections, a brief account is provided of the research methodology deployed to develop the narratives provided, including the propositions that were fashioned from the outset to structure interrogation of sources. The latter are exclusively documentary, being drawn from a variety of secondary sources, such as research literature, consultant's reports and online websites. The contribution is rounded off with conclusions, identifying critical and misleading insights as justification for the effort made and hinting at further research for eco-claims, notoriously for example in many 'greenwashing' claims.

Qualitative Research Methodology Used in this Contribution

Qualitative research has become fashionable in the face of disappointments with the limitations of social science research based exclusively on quantitative analysis and modelling. This has been subject to criticisms for its prevalence of unconscious or unadmitted biases that vitiate results, over-reliance on modelling frameworks that profess to but, by definition, cannot predict the future, let alone predict the recent past, and a reluctance to utilise, for example, social scientific 'anthropological' methods. These engage representative structured samples of respondents to explain rather than mutely predict human behaviour from past extrapolations without engaging with the objects of the research purporting to be of interest. Much useful research learning arose from the growth of targeted socio-economic research funded by policy sub-agencies of umbrella bodies like DG Research (& Innovation) of the European Union. Examples drawn especially from innovation studies pioneered much research that required 'knocking on factory doors' to test, for example, BMW's famous assertion coined by Denis Gabor (1963) as: "We cannot predict the future but we can invent it."

Thus, knowing from the 'horse's mouth' about their short-to-medium term plans as an important and influential actor in the global automotive industry and triangulating such findings against claims is necessary and desirable. Critique of either peers or hierarchies of cohorts addressing different market strata in the same industry can yield usable qualitative predictions. A systems perspective can often prove valuable in alerting the researcher to the conceptual 'model' they and colleagues may have formed of the 'real' world they were interested in understanding and adjusting accordingly. This is the underlying epistemology increasingly promulgated in the advanced production industries of today which raise efficiencies and effectiveness by implementing 'Digital Twins' methodologies in so-called 'smart factories' and even postulated for 'image' versus 'reality' comparison of 'surveillance' algorithms in the design of 'smart cities'. Ironically, their deployment of Big Data analytics and AI are aimed at achieving 'predictive management' by controlling for unpredictable human factors on manufacturing assembly lines. Thus qualitative insights have quantitative applications. The key further insight of this kind of 'qualitative system concept' approach comes from careful specification of semi-structured or structured research engaging respondents in organised conversations. Such interrogation is also the aim in documentary research of the kind here adumbrated. To what extent do gigafactories advance efficiency and effectiveness? In what ways do they enhance firm sustainable mobility infrastructural goals? In what ways do they disappoint expectations for mobility logistics

improvements? In what ways do gigafactories create workforce ergonomics problems or advantages? Is 'predictive management' enhanced or not by gigafactories and in what ways (external versus internal controls)? Germane, but as yet unrefined questions like these are the core of this kind of qualitative research and close attention to their efficacy facilitates improved 'interrogation power laws'.

Tesla Gigafactories (1): Anatomy of Configurations Involving Fremont, Lathrop & Nevada

We have already outlined the configuration of a Tesla outlier in the shape of the Tilburg 'megafactory'. On the basis of that taster we can essay answers to our 'unrefined germane' questions accordingly. Regarding scale in ratio to efficiency and effectiveness, Tilburg as a mere assembly facility is a minnow, out of its depth comparatively. Even Tesla's Nevada gigafactory, a joint venture with Panasonic, pales into insignificance in scale economy with Asian lithium ion battery (LIB) producers as the following shows:

> ".....with the exception of the Tesla-Panasonic factory (35 GWh), only companies in Asia contribute to the expanding global LIB manufacturing capacity for X and S EVs. In China alone up to 9 factories are being constructed which will raise production capacity from 16 GWh at present to a total of 107 GWh in 2020 and 120 GWh in 2021, thereby bringing China's share in global LIB production to 65%. Some of these new plants are expected to be huge, with the CATL facility at 50 GWh being by far the largest." (Steen et al, 2017)

We may immediately conclude that Tesla's joint share with Panasonic of LIB output at present is half of 35 GWh (i.e. 17.5 given CATL will be 50) and in scale terms comparatively inefficient and regarding expansion also relatively ineffective. But, their testable boast (below) that their quality is higher than the competition mans that to the extent Tesla's two new LIB gigafactories (plus Berlin) will be LIB producers, Tesla will improve efficiency and effectiveness through quality and scale (hence, presumably, cost). This is due to its known efficiencies relative to other automakers:

> "....Competitors have created different models of alternative powertrain, but none are able to match the performance and efficiency of Tesla gained from its battery technology and power train technology."(Tesla, 2016)

We shall see later that this is how Tesla became the world's largest car producer by value, surpassing the corporate values of GM and Ford combined and is significantly ahead in production of EVs in the Global, US and European markets (Table 1); that is, by charging a premium price in a niche market – comparable to Apple in the smartphone market. Not surprisingly Tesla's Gigafactory (3) which opened in 2019 in Shanghai, aims both to contribute directly to its current dominance of the Chinese market ahead of China's BYD and SIAC, and to draw further ahead in that market against both Chinese EV rivals. Tesla's dominance of the US EV car market is absolute with only a single local producer in the top six. At least in Europe Tesla is challenged by local competitors while also recently surpassing Renault-Nissan-Mitsubishi that still dominated the local also-rans in 2019 in Europe's top six.

Table 1. Global, US and European Electric Vehicle (EV) Car Sales 2018 & 2019 (thousands) Source: Refinitiv.

Electric Car Sales 2019 (thousands) 2018 in brackets		
Global	**United States**	**Europe**
Tesla Motors 368 (224)	**Tesla Motors 190** (167)	**Tesla Motors 92** (29)
BYD Auto 195 (106)	**General Motors 16** (18)	**Renault-Nissan-M. 82** (80)
BAIC Group 151 (150)	**VW Group 12** (1)	**VW Group 43** (25)
Renault-Nissan-M 137 (133)	**Renault-Nissan-M. 12** (15)	**Hyundai Group 37** (17)
Hyundai Group 87 (43)	**Hyundai Group 15** (2)	**BMW Group 31** (18)
SAIC Group 83 (60)	**Tata Motors Group 13** (0)	**Daimler Group 20** (13)

If we move to answering the questions of importance raised in the introduction, the next one demands recourse to Tesla's earliest gigafactory at Sparks, Nevada, near Reno which shows remarkable infrastructural mobility and even agility in relation to its related plants, facilities and supplier networks. This applies both to external and internal spatial interactions. First, the easiest to demonstrate is Tesla's external infrastructure that calls to mind its locational imperatives at Tilburg. Thus although there is no international canal linking Tesla to the heartland of automotive assembly and supply in and around Detroit, Michigan and environs (including Ontario, Canada), a transcontinental railway runs through the Tesla axis of production and assembly. We shall see how the Gigafactory fits into this axis but first we start with the original production location in Fremont, California. This is a recycled automotive assembly factory, site of the former GM-Toyota joint venture intended to enhance American automotive assembly by learning Japanese production techniques while also assisting the transfer of small car design competence. The New United Motor Manufacturing Inc. (NUMMI) plant opened on an old 370 acre GM site in 1984 some twenty-two years after GM built it. In 2010 Tesla took possession of the site that GM had auctioned to Toyota on dissolution of the NUMMI partnership in 2010. This led initially to a partnership with Toyota to collaborate on developing EVs, parts, a production system and engineering support. But the partnership had already fizzled out by 2014, partly because of the culture clash between Toyota's conservative, safety-first engineering (favouring inefficient hydrogen fuel cells) and Tesla's risk-taking, Silicon Valley approach.

Nevertheless, to answer the second question, the Fremont plant had good mobility infrastructure and its utilisation has increased massively. Not least, the Union Pacific Railroad(UPR) had constructed tracks directly to the old Fremont plant to carry finished cars. Later, rail freight transport began to be used also used to receive batteries and Model 3 powertrains from Tesla's Gigafactory (1) on the Nevada border, which entered production in 2016, ramping up to 7,000 employees in 2018. This was also a joint venture with Japanese battery-maker Panasonic, which was sometimes fraught due to a high reject rate, as shown later. In addition to rail, parallel US east-west Interstate Routes 50 and 80 were recently connected at Reno after local state plans were advanced to respond to the Tesla-Panasonic gigafactory venture. In 2017 Tesla announced its first EV semi-truck for interstate haulage with release on the market by 2019. However release is delayed until the earliest, late 2020 which testifies to the company's habitual over-optimism over new product releases (Lambert, 2020a). For some battery raw materials, Tesla works with mining firm Albemarle based at salt flats 200 miles south of Sparks that processes underground lithium-carrying brine water industrially in hours rather than the one-year evaporation in traditional salt pans. Other lithium-ion content is imported from China and Australia through Oakland. Electricity is supposedly powered by wind turbines and 200,000 gigafactory solar roof panels, together generating 300MW. But while some 10% or less of the Sparks rooftop was drone-photographed in December 2019 as displaying some upright solar panels, critics still wrote that Reno's rooftop solar panels would never be fully installed due to Tesla signing a subsidy deal for cheap nuclear energy from the NVGrid (Schmitt, 2017). The Tesla response was that 'soon' the roof of the Gigafactory (1) would be covered with solar panels, similar to the Tilburg assembly plant in the Netherlands. Tesla claims to have installed a 3.4 MW solar cell roof at its site in Tilburg that generates enough electricity to meet the needs of the facility for most of the year.

From Gigafactory (1) to Fremont Assembly Line

Nevertheless, continuing the economic geography narrative on one of the currently most advanced automotive logistics set-ups anywhere, we turn to the evolving role of Tesla's assembly, supplier and innovative start-up arrangement. This installs the LIB and powertrain subframes in the assembled EVs the UPR delivers. In 2013, Tesla acquired an adjacent 35-acre property at Fremont from UPR for a test track. In the same year, the State of California announced it would give Tesla a US $34.7 million tax break to expand production by an estimated 35,000 vehicles annually from its Fremont plant. By 2020 it was also fortunate to enhance workforce mobility from Greater San Francisco by extension of the Bay Area Rapid Transit (BART) subway system.

188 Moreover, Fremont municipal planning led to further worker housing being proposed on 850 acres
189 of former UPR marshalling yards at the new Warm Springs BART station interconnection which is
190 to house 40,000 people in a 'smart city' scheme at Fremont. Other noticeable features of Tesla's
191 commitment to home-based production organisation on recycled industrial sites includes how the
192 firm has reversed the flow of parts from global suppliers to some extent by attracting local and in-
193 house supplier networks, including some fifty in California and ten on Tesla's own supplier park.
194 Clearly, such organisational innovation 'disruptively' reverses outsourcing principles that have
195 predominated for decades. EV production at Fremont reached 360,000 vehicles per year in 2018,
196 which compared to NUMMI peak output. Still, Tesla planned for production of up to 500,000
197 vehicles at that time, trying to achieve such scale with a higher level of vertical integration. In
198 respect of the question of 'disappointment' in the infrastructure mobility planning, the owner Elon
199 Musk has described customer distribution from Tesla warehouses as massively sub-optimal having
200 hitherto been critical of proprietary ERP software firms SAP and Oracle, leading to their dismissal
201 and recourse to in-house system design.
202 As it outgrew space on the NUMMI site, the supplier park was in 2015 moved fifty miles east
203 of Fremont along the UPR to a 500,000 sq.ft. former Daimler Chrysler facility at Lathrop, in addition
204 to leasing 1.3 million sq. ft. of warehouse space at nearby Livermore. At Lathrop, Tesla first built a
205 casting factory and then leased accommodation for in-house parts production as well as existing
206 and relocating suppliers. A 'loading hub' that stores cars for customer delivery, consisting of three
207 warehouses, also occupies part of the site. For small-batch supplies like LIB brackets, door
208 assemblies and die castings, shipments arrive at Tesla's Lathrop Logistics Center from Shanghai,
209 China by container through the Port of Oakland by UPR. A new 870,000 sq. ft. parts and inventory
210 distribution centre was opened on-site at Lathrop in 2020. The other North American Tesla supplier
211 satellite is in the Detroit-Windsor agglomeration also linked to the UPR rail line. Moving on to the
212 development of Warm Springs, the Fremont BART interchange was planned by the local economic
213 development agency and construction partners, Lennar, with Tesla alongside other corporations
214 specialising in IT and biotech being accommodated in a bespoke facility. Construction at the 850-
215 acre site involves a new Fremont 'Innovation District' featuring a 'Tesla Campus'. This comprises
216 an advanced manufacturing plant specialised in training future EV technicians, an 'innovation
217 cultivator' for technology start-ups, and thousands of new homes, R&D labs, offices, various plants
218 and retail outlets. Tesla invests three times the automotive industry average on R&D. A 2019
219 initiative was to convert former Fremont plant warehousing into a major R&D location that will
220 include a vehicle R&D lab, a 'Future Energy Reliability Lab', a vehicle testing facility and offices for
221 250 employees. The 'Innovation District' nearby also includes Tesla Motors, Lam Research, Delta
222 Products, Seagate, Western Digital, ThermoFisher, Boston Scientific, and startups in clean tech, life
223 sciences, and advanced manufacturing. Presence of the rapid transit station of the Warm Springs
224 'Innovation District' near the Tesla plant is the reason for location there of Tesla's local
225 headquarters (with global HQ in nearby Palo Alto in the heart of Silicon Valley), direct
226 manufacturing, and suppliers to exploit external co-location proximity. By 2018 Tesla's labour force
227 had reached 10,000 at the Fremont plant.
228 Finally, we can turn to the configuration of the automated internal logistics for assembly at
229 Fremont's Tesla plant. By 2013 Tesla had taken the in-sourcing decision hitherto typically
230 outsourced to the likes of SAP (Tesla replaced SAP Enterprise Resource Planning (ERP) in 2015) or
231 Oracle by building a bespoke ERP system in-house to be more agile, rather than conforming to the
232 traditional 'buy-and-configure' method. This design strategy arose following a decade-long war
233 between the aforementioned giant ERP vendors. For example, Oracle's strategy rests on an
234 infrastructure stack from silicon to screen enabling a cloud-based future for business. Its aim is
235 winning the 'mega-cloud' race and leveraging it for supply chains that are faster, cleaner, cheaper
236 and closer to the customer. In response to advisers' warnings about trying to scale a home-grown,
237 lightweight ERP system, Elon Musk delegated the responsibility to his former CIO who had figured
238 the homegrown ERP system would scale effectively. Tesla's strategy planned massive upscaling of
239 production running on Microsoft Azure Cloud operating with Scala Language, based on "Ruby on

Rails". SAP and Oracle's offerings were not 'cloud-native applications.' So SAP or Oracle would take a year at least while the in-house solution took four months. The owner realised in-house system design would build what Tesla needed, not what the industry deemed appropriate. For the question of worker ergonomics, location on the Fremont and Lathrop commuter lines and engagement with housing plans for Warm Springs was astute, while internally, safety and equipment controls are now obligatory with ergonomic chairs installed for assembly based on employee feedback. Until recently many worker injuries had been incurred from experiencing fainting spells, dizziness, seizures, breathing difficulties and chest pains, according to incident reports. Hundreds more were filed for injuries and other medical issues caused by the gruelling pace of work to reach corporate goals. Tesla's critics asserted that there was over-reliance on automation and too few human assembly line workers building the Model 3. The robotics problems caused an increase of new hiring in consequence. Virtual reality has also been deployed ergonomically to reduce worker injuries from repetitive strain. The company medical centre and training centre further underline the new commitment to worker health. Finally, on the question of whether the goals of 'predictive management' have resulted in improved management performance, the answer from an automation perspective is superior to that from the employee viewpoint where a price has been paid because the focus has been on robots.

Much of the academic literature on 'predictive management' concentrates on EVs rather than their production but Tesla clearly utilises AI-driven machine learning solutions in the complex automotive production process. Thus Model 3 production infrastructure now involves cars that can self-diagnose internal problems and order replacement parts, connecting supply chains, although it has more experience with predictive maintenance than management, as signified by its weaknesses regarding customer delivery. Less has been said about effectiveness regarding logistic processes at the Sparks 'gigafactory'. In 2018 Tesla had blamed bottlenecks in the production of the Model 3's batteries at the company's Gigafactory for the delays. Panasonic, Tesla's battery cell manufacturing partner at the factory, confirmed this. Local journalist reports on life as a Gigafactory worker at the time uncovered nearly 1,300 emergency calls (a rate of more than one per day), a repeated number of visits from the Occupational Safety and Health Administration, and accounts of workplace injuries that seem to have gone unreported, all of which echo reports of excess automation and insufficient labour at the Fremont plant. The gigaplant has experienced productivity problems since it launched in 2017. Originally designed to be able to produce the equivalent of 54 GWh per year, it was only in late 2019 finally nearing 30 GWh. Initially, Panasonic recruited chemical engineers from other sectors and trained them to handle lithium-ion batteries. Now 3,000 employees operate the plant with some 200 technical assistants from Japan to keep it running (Inagaki, 2019). Lamentably, in 2019 it was reported that 'predictive maintenance' at Gigafactory (1) was woeful with half a million batteries a day having to be scrapped due to problems with production cleanliness and contamination (Bullimore, 2019).

Tesla Gigafactory (2): Buffalo, New York State

If the Bethlehem steel plant at Lackawanna, Buffalo was once the fourth largest in the world before it closed in 1983, Buffalo's Republic steelworks was only the third largest in the US. However, its brownfield site, at RiverBend, vacated in 1982 following the firm's acquisition and transfer to Monterrey, Mexico was transformed with New York State's 'Buffalo Billion.' This was 'rustbelt reconversion' aid earmarked for development of a clean energy business incubation centre to be funded with $225 million of the 'Buffalo Billion'. This attracted solar panel firm Silevo to set up there in 2013. Plans for development of an incubation centre, to be managed by State University of New York (SUNY) Polytechnic Institute, expert in transforming research projects in clean energy nanotechnology, had to be re-drafted when in 2014 Tesla's SolarCity acquired Silevo for $200 million and proposed scaling up the site to massive proportions. On this basis, New York State bought the plot, which was ultimately leased by Tesla, in partnership with Panasonic, for its SolarCity Gigafactory (2) which opened in 2017. Tesla's new plans meant abandoning the clean energy business incubation centre design in favour of the construction of a 1.2 million sq. ft. factory.

However Silevo production technology was embodied in SolarCity products, reducing Tesla's start-up debt burden from outsourcing innovation. With a promise of 3.000 jobs and 5.000 state-wide, the administration increased aids to $750 million. Later, at the end of 2019, state officials further wrote down more than $800 million in economic development aids made to Tesla.

By then, employment at the gigafactory exceeded 800 with growth to 1,460 by 2020 planned. The former SolarCity plant was always earmarked to produce Tesla solar roof tiles rather than car batteries but at relatively low volumes. These were planned to increase substantially to 1,000 roof systems per week by the end of 2019. Tesla roof tiles are made of textured glass with solar cells hidden inside. The finish creates an optical illusion, which involves camouflaging photovoltaic cells beneath transparent tiles. However, at ground level these must be opaque without letting the finish interfere with the cell pack's performance. Product-testing for the necessary effects, such as reduced 'sparkle,' was conducted at Fremont. The corporate goals of Gigafactory (2) were to reinvent both the roofing and solar businesses, combining the two. This was to be achieved with a solar roof tile that could be installed faster and more durably than a traditional roof, while generating profitable solar energy. Accordingly, this latest version (3) of Tesla's solar roof tiles was to display a renewed focus from the company on the non-battery side of Tesla Energy. Despite this, Tesla, which bought out SolarCity for $2.6 billion in 2016, was supposed to be operating multiple production lines by 2019, yet only one is set up, and was not at that time fully automated. Approximately half of Gigafactory (2) employees are not employees of Tesla, which subcontracts part of the factory to Panasonic for solar panel and cell production. A keyproblem for Tesla's production process was the 'solar-sandwich' process. Tiles slide on a conveyor belt toward a gigantic laminator, where cells are heated and vacuumed together into a single module, a 'solar sandwich,' The laminator requires precise timing, heating, and vacuum pressure to 'melt' the conjoined tiles. If the process is even slightly miscalibrated, bubbles can form, making the tile less reliable. Accordingly, Tesla struggled with low yield rates, meaning at times scrapping 70% of production. Truckloads of waste were sent to a recycling plant until the company went through at least 74 recipes before discovering the correct sandwiching and by the end of 2018 yield rates had risen to 90%. Nevertheless, critics suggested Tesla was undertaking relatively little to meet its investment commitments to the state. The company, for example, is not sourcing its Solar Roof glass from nearby Corning Inc., and continues importing solar glass from Asia (Carr & Eckhouse, 2018).

Thus the interim judgement is that Tesla's Gigafactory (2) has underperformed expectations. It is massively behind in its plans to achieve efficient capacity utilisation and retains its expensive and limited distribution effectiveness by virtue of the faulty output of its Japanese partner Panasonic. Locationally, the RiverBend site is connected to Amtrak for rail to the West Coast and the I-90 interstate highway to New York, Chicago and Seattle. Investors, customers and the community's expectations of a reasonable return on the state's investment in terms of jobs, returns from tax outlays, green energy factory footprint and local multiplier effects are all more or less subject to degrees of disappointment. The Gigafactory is powered by hydro-electricity from its steel mill days (Lambert, 2018). In regard to worker rights, six African-American and Hispanic former employees at Tesla's factory in Buffalo reported in 2019 they suffered discrimination on promotions to less-qualified white colleagues, often heard racist comments at the factory, and were among 57 laid-off workers, 80% of whom were minorities. They filed official discrimination complaints with the US Equal Employment Opportunity Commission and the New York Division of Human Rights. Finally, the niceties of 'predictive management' seem not to have been pronounced given limited deployment of advanced automation and substantial surpluses of manufacturing technology remaining in unopened crates on the Gigafactory (2) shopfloor (Moretti, 2019).

Tesla's Gigafactory (3) at Pudong, Shanghai, China

Undaunted by the travails of the Buffalo Gigafactory (2), plans were already in preparation for Gigafactory (3) which has been located in Pudong, Shanghai, China. Pudong is Shanghai's New Area or 'smart city' on the east side of the Huangpu river facing the Pacific, East Asia and North American economic powerhouses. Zhangjiang Hi-Tech Park, which was established in 1992, houses

342 twelve National Institutes covering most '4.0 Industry' fields. It consists of the Technical Innovation
343 Zone, the Hi-Tech Industry Zone, the Scientific Research and Education Zone, and the Residential
344 Zone. It also contains 400 R&D centres. Shanghai Pudong International Airport is nearby as is the
345 Bullet Train station that connects to it. A MagLev train service connects with Shanghai city centre.
346 The Tesla Gigafactory (3) will produce battery cells along with Tesla Model 3 and Tesla Model Y
347 (SUV) cars, at an initial production target rate of 250,000 EVs per year. The first China-built Tesla
348 cars were delivered in December 2019, twelve months after construction began in December 2018.
349 The plant began production of Tesla Model 3 cars by October 2019. While trial production on the
350 general assembly line continues, additional production facilities for supply of motors, seats, and
351 powertrain assemblies were under construction in late 2019 with expected completion by March
352 2020. The Gigafactory (3) complex covers 210 acres and current plans envisage utilising that amount
353 of space. An avowed aim is that it will be a sustainably manufactured building. Early
354 announcements of the first foreign land deal in China asserted it would take two years to start
355 producing vehicles followed by another two to three years before the factory would be ready to
356 produce around 500,000 vehicles per year aimed at Chinese customers.
357 Regarding the internal infrastructure and configuration of Tesla's Gigafactory (3) news images
358 show Model 3 bodies going through an empty production line, which appear to be dry runs to set
359 up production and assembly stations. While it is unclear if the Model 3 bodies on display are being
360 manufactured rather than assembled from shipped-in parts assembled at the factory. Despite
361 scepticism from Chinese press (Lambert, 2019), Tesla has shown it already has a massive stamping
362 machine to produce Model 3 body parts at Gigafactory (3). By 2020 battery and powertrain
363 production were near completion. Thus it was conceivable that Tesla China strategy Phase 1.5
364 should be functional mid-2020. This would coincide with the potential final deal with China's
365 Contemporary Amperex Technology Co. Limited (CATL), which is to be the main contractor
366 providing battery cells to Gigafactory 3 for the Chinese built Tesla Model 3. Hitherto, Tesla had
367 been using powertrains and battery packs shipped from Tesla's Fremont Factory. Once fully
368 completed, manufacturing will utilise some 300 different kinds of robots for various assembly tasks
369 including 3D robotic activated narrow and deep laser welding. This process is easily facilitated
370 with robotic automation, it does not generate harmful x-rays, and it results in higher quality welds.
371 A further two large buildings are planned for the site as production capacity increases. Tesla chief
372 Elon Musk is reported to have accessed $1.6 billion from a consortium of Chinese banks to pay off
373 previous loans and future investment costs.
374 Any interpretations about management efficiency and effectiveness of the project are clearly
375 premature. However, on the one side, it is notable that there is no reference in investigated
376 literature about Tesla's much-vaunted implementation of sustainable production. Recall the current
377 photo of the Sparks plant for Gigafactory (1) shows scant evidence of the promised solar roof-
378 panelling, rendering its current website a species of untrustworthy 'fake news'. At least there are no
379 equivalent online misrepresentations for Gigafactory (3) yet fabricated. On the other hand, the
380 speed of land assembly, gigafactory construction and assembly line fitting-out has been exemplary.
381 As this reduced the speed of implementation to half that of Gigafactory (1), learning gains have
382 been made through communist 'authoritative state' planning. This hugely assisted land assembly
383 and large government and bank investments and loans, with labour costs one-tenth of Californian
384 rates. Hence management was relieved of much of the normal cost-burden of such substantial
385 investments elsewhere. Despite its sustainability disappointments, it could be argued that
386 'predictive process management' in getting Gigafactory (3) up and running in under a year is
387 worthy of inclusion in standard business school texts even if the jury remains out regarding
388 'employee contentment' and 'shopfloor order'.

389 *Tesla's Gigafactory (4) at Grünheide, Berlin, Germany*

390 Infrastructurally, adding to earlier references to the site for Tesla's Gigafactory (4) near Berlin,
391 multi-modal transportation access to the proposed 'campus' 20 miles south-east of central Berlin is
392 on the main railway line to Wrocław (former Breslau), Poland , is likely to have its own railway

station and site-exit to and from the main autobahn. The German press accounts of Elon Musk's visit to Berlin in late 2019 shared what appeared to be the planned layout of Gigafactory 4, which will be built in Grünheide, Brandenburg. The image depicted several parts of the upcoming facility, including its battery and powertrain assembly, seat assembly, and final assembly area. This also showed the on-site train station and autobahn exit. Tesla has not confirmed if press account information about Gigafactory Berlin is accurate, and as we have shown some Tesla public relations constitutes over-optimistic or 'fake news'. However, if it is not fake, the emerging facility may prove to be one of the company's most efficient factories yet. If so, it would tick the box for the first of our criteria of management competence as represented by Gigafactory planning. An on-site train station would provide the company with easy transportation of employees, cargo and materials, access to the autobahn would allow easy deliveries of (potentially EV) vehicles. Furthermore, workers from nearby cities would in addition find rail access should facilitate easier connectivity. The management learning from the relatively 'green' infrastructural planning of Fremont connectivity and accessibility for workers and freight is self-evident. Tesla CEO Elon Musk in November 2019 announced Tesla would build around 500,000 units of EVs at the 741-acre European facility with a focus on the Model Y crossover (SUV) and the Model 3. He further announced Tesla was planning to invest $4.41 billion in the plant; and that 3,000 jobs would be required initially, increasing to 8,000 eventually.

The Gigafactory configuration of the production system at the Grünheide main building would, it was demonstrated, include, first, a battery and powertrain assembly station, a seat assembly facility (typically not outsourced but, following Fremont, taken in-house), next a final assembly station, juxtaposed to a paintshop. Then there would need to be a central supplies building. Beyond that a high rack warehouse was specified. Then a wastewater treatment facility would be required. Nearby, accommodation for body shell work was specified. In addition a plastic stamping and foundry area was shown to be necessitated. Outside these internal facilities, the new train station would be required, enabling passenger and freight transportation. Finally, two further external but on-site facilities (probably covered) were itemised: first, a test track; and second, a distribution (delivery and collection) space was projected (Suba, 2019). Contextual conditions for these similar plants in completely different regimes make them of striking research significance. Thus German labour law and wages make it substantially more difficult in practice than China or the USA but more like the Netherlands megafactory location. German controls on sustainability and renewable energy are stricter than China's albeit they are not negligible but more loosely enforced, as in the USA. Finally, German workforce skills and depth of high quality production and design experience are iconic to the global automotive design and engineering communities. But they are rather locked-in to a petroleum paradigm that means diversified quality producers like BMW and Daimler Benz have been criticised for their dilatoriness towards EVs and have only very recently commissioned or pressed for, as an example, battery manufacturing installations (e.g. CATL; see below) in their home base.

Four Asian Gigafactory Behemoths: Tesla Trumped?

Contemporary Amperex Technology Co. Limited (CATL)

In what follows, we sketch in the Gigafactory competition for Tesla in both battery technology and EV planning. China is the world's greatest source of LIB gigafactory production, with some presences in South Korea and Japan. Europe and the rest of the world was, effectively, out of the race until CATL announced its first foreign direct investment (FDI) in Thuringia, Germany in 2019. We start with CATL and BYD, China's two champions, although SIAC and BAIC also deserve mention. Thus Contemporary Amperex Technology Co. Limited, acronym CATL, was founded in 2011 as a Chinese battery manufacturer and technology company specialising in the manufacturing of lithium-ion batteries (LIB) for EVs, energy storage systems, and battery management systems (BMS). It is headquartered in Ningde, Fujian Province with manufacturing at Ningde, Qinghai and Liyang. Its three main R&D facilities are based in Ningde, Shanghai and Berlin (in 2018). In January 2017, CATL announced plans to fashion a strategic partnership with Finland's Valmet Automotive

444 based at Uusikaupunki, focusing its collaboration on project management, engineering and battery
445 pack supply for EVs and Hybrid EVs. As part of the partnership, CATL acquired a 22% stake in
446 Valmet. Valmet Energy in 2019 contracted to Umicore's Kokkola cobalt refinery to design a clean
447 energy cobalt processing plant. Belgian miner Umicore acquired Kokkola from US firm Freeport-
448 McMoran. Its Kokkola facility refines 10% of the world's lithium for LIBs, the remainder being
449 refined in China. CATL in 2017 signed a supply agreement from Swiss metals giant Glencore to
450 supply 'sustainable' Congo cobalt ore to the Umicore refinery in Ostrobothnia, Finland's 'lithium
451 province'. Hitherto, Valmet Automotive, which is a contract automotive assembly division of
452 Valmet Holdings, had assembled Boxter sports vehicles for Porsche, sports cars for
453 DaimlerChrysler and plug-in hybrid EVs for American sports EV pioneer Fisker Automotive.
454 Pressure from German automotive companies, notably VW was key to attracting CATL to locate
455 LIB production in Arnstadt, Thuringia (former east Germany) and BMW also announced a
456 $4.7billion contract with CATL for small car LIBs (De Carlo & Matthews, 2019). CATL's annual
457 sales reached 11.84 GWh of energy storage capacity in 2017. Based on annual shipments, CATL is
458 the world's third largest provider of EV, hybrid EV (HEV) and plug-in hybrid EV (PHEV) battery
459 solutions behind Japan's Panasonic (Sanyo) and China's BYD. CATL's strategic aim is to have a
460 global LIB production capacity of 50 GWh by 2020.
461 To that end, CATL has international production deals with Peugeot (PSA), Hyundai and
462 Honda as well as BMW while in China its clients include BAIC, Geely, GAC, SAIC and Foton EV
463 manufacturers. By December 2019 CATL announced that Tesla had secured a battery supply deal
464 with CATL, to supply cells for Gigafactory 3 in Shanghai and potentially expand to other
465 production facilities. In March 2019, Tesla announced a battery supply deal with LG Chem (S.
466 Korea) for the Model 3 produced at Gigafactory 3 in Shanghai, making it likely LG Chem would
467 ultimately split the Chinese order capacity with CATL. The latter would supply LIBs for Tesla
468 Model 3 while LG Chem would supply LIBs for Tesla Model Y (SUV) production. Thus model
469 specifications continue to drive the Tesla philosophy of re-invigorating its vertical integration
470 strategy. Accordingly this gives Tesla three global LIB suppliers; Panasonic, CATL and LG Chem
471 with the prospect of Tesla itself evolving into a fourth, albeit in-house, LIB supplier. CATL is
472 primarily using LiFePo (large scale grid storage and buses) and NMC (nickel-manganese-cobalt)
473 chemistries in prismatic cell formats. Their EV batteries have been mostly designed for electric bus
474 production and plug-in hybrids. Accordingly, the Tesla order would require branching into
475 cylindrical cells, the high-efficiency use of which Tesla has been pioneering for electric vehicle
476 battery packs. Accordingly, Tesla had initially planned to produce both cells and full EVs at
477 Gigafactory 3, but they had to accelerate their plans due to the Trump administration trade war and
478 decided to focus on the vehicles. We can conclude – thus far – the organisational configuration of
479 CATL's global LIB contractual supplier agreements, which is clearly compatible with 'pattern
480 recognition' of underlying market structures of a kind consistent with 'predictive management',
481 seems astute. As a supplicant to such global Gigafactory suppliers, Tesla also displays the
482 appropriate flex-agile response to external events and disappointments (e. g. compelled acceleration
483 of plans for exclusive EV-only production at Gigafactory 3), such as the politics of trade wars and
484 the coronavirus shutdown of Gigafactory (3) in 2020, consistent with an acute 'pattern recognition'
485 management profile (Cao, 2020).

486 *BYD: Vertical Integration on a Global Financial Scale*

487 In the Pearl River Delta city-region including Hong Kong, Guangdong and Shenzhen, a key
488 firm is BYD China's (and the world's) largest producer of LIBs. Founded in 1999 the company has
489 developed its own iron-phosphate-based lithium-ion (LiFePo) battery following over 10 years' R&D.
490 The core battery technology can be applied in all the main types of EVs and has a lifetime of over 10
491 years with a charge time to 50% of its capability in 10 minutes. The company started by supplying
492 batteries to mobile telephony companies such as Nokia and Motorola. In 2003 BYD made the
493 acquisition of Qinchuan Motors of Xi'an which gave it the opportunity for the company to expand
494 from part and battery supplier to car maker. In 2008, BYD purchased SinoMOS Semiconductor of
495 Ningbo to facilitate its upstream value chain and accelerate its development of EVs. It attracted

$230 million from global billionaire investor Warren Buffett through his MidAmerican Energy Holding Co. for a 10% investment stake. This investment strategically helped BYD extend its markets for EVs from China to global. In its corporate strategy, BYD plans to sell some 9 million electric vehicles by 2025 to surpass the leading global automakers in EV technology. However BYD also plans to expand LIB production to control its own and other clients' market access (Zhang & Cooke, 2010). Accordingly, in late 2019 BYD announced its EV plans in China with a new battery gigafactory that will be able to produce 20 GWh of battery cells for its EVs. Thus BYD is investing $1.5 billion in the facility located in Chongqing, Sichuan, southwest China's regional capital (with a municipal county population of 28,846,170). Such LIB output makes BYD's gigafactory one of the largest battery production facilities in the world (compared to Tesla, Nevada with 35 GWh, currently the world's largest gigafactory).

Chongqing was BYD's second new battery gigafactory when Qinghai opened in mid-2018. Located in the western province of Qinghai where 83% of China's lithium is located. This facility has an expected battery output of over 24 GWh. BYD focuses mostly on the production of prismatic LiFeP04 battery cells. These differ from most automotive industry Nickel Cobalt Aluminium (NCA) and Nickel Manganese Cobalt (NMC) battery cells in longevity. Between all its established and planned factories, BYD's total production capacity will near 100 GWh by 2010 to support its anticipated increase in EV production. Elsewhere in China, Eve Energy, founded in 2001 is based in the southern coastal city of Huizhou. It sells batteries to Geely, the Chinese company owner of Sweden's Volvo cars. It announced a plan to build a new factory with a production capacity of 1.5GWh in Huizhou, adding to the firm's 2017 production capacity of 7.5 GWh. Based in the eastern city of Ganzhou, Funeng Technology, founded 2008, is a major battery provider to Beijing-based BAIC Motor, the leading EV performer among state-owned companies. Funeng announced a proposed a plant with a 10-GWh production capacity in December 2016 in its home town. Finally, Guoxuan High-Tech is based in centrally located Chinese city Hefei, and is another battery provider to BAIC Motor. The 13-year-old company announced in April last year it would build a factory with a 4 GWh annual production capacity for use starting March 2018. There is currently no evidence that these last two announced constructions were ever started. So, as with Tesla's claims about generating its own solar energy, Chinese battery production plans may also appear as online images rather than gigafactories in real time. Nevertheless, for CATL and BYD, who can be seen aggressively cornering the Chinese and possibly the future global markets, their claims are indicative of managerial efficiency and, given their roll-call of global clients despite the disappointments of Tesla and others that the Chinese remain producing for market access older technology than what Tesla is experimenting on at its Fremont battery R&D facility.

LG Chem and the Contest for Battery Hegemony in South Korea

On December 5th General Motors (GM) announced it was setting up a joint venture with South Korea's LG Chem to mass-produce LIBs for electric cars. LG Chem is a major supplier of LIBs to German firms VW and Daimler subsidiaries like Audi and Mercedes-Benz. The new joint venture partners plan to invest a total of$2.3 billion to build a new facility, which will be located in Lordstown, Ohio. The new plant is designed as GM's 'captive' gigafactory. It is planned to have an annual capacity of more than 30 GWh. Among GM's 20 envisaged new EV models are a new Chevrolet, set for release in 2020, and a battery-electric pickup truck by late 2021. GM also announced that the new joint venture was hoped to create 1,100 new jobs in Lordstown, where the company made the controversial decision in 2019 to close one of its big car manufacturing plants. That move set off an acrimonious contract negotiation with the United Automobile Workers, sparking the first nationwide strike against GM in half a century. GM eventually settled its contract with the union and later sold the factory to EV start-up Lordstown Motors (with Ohio state aids). The dispute was over management insistence that new positions at the LIB gigaplant would not necessarily be recruited from workers who lost their jobs when the GM Lordstown factory closed, advising that such an agreement would have to be negotiated by Lordstown Motors jointly with LG Chem. Such customers as those mentioned wish ideally not to be reliant on single-source suppliers, but LG Chem is safe in a seller's market for the foreseeable future. GM's decision is thus made more

548 in desperation – faced with foreign and Tesla competition in the EV market - than counting as a
549 mass-market coup for GM. The South Korean company stated it would invest $916 million in its US
550 subsidiary by 2023 to set up the joint venture with GM (Hawkins, 2019).
551 Earlier in 2019 LG Chem had agreed to invest $424 million from 2020 in a new factory at Gumi
552 near auto-city Busan, South Korea to produce cathode material for LIBs sold currently to GM and
553 VW. LIB cathode production will start from late 2022. As noted earlier, cathodes in LIBs are made of
554 lithium combined with other metals such as nickel, cobalt and manganese (NCA; NMC). LG
555 Chem's new factory expects to create about 1,000 domestic jobs in South Korea. The company
556 currently operates two other cathode production plants in the country and is building one in China.
557 In 2019 LG Chem agreed to purchase Congo cobalt from Glencore, something Tesla has also begun
558 seeking due to global shortages of other mineral alloy ores. As industry expert Fred Lambert notes:

559 > 'Cobalt is a controversial mineral due to most of it coming from mining operations in
560 > Congo, a place that has historically been affected by conflict and corruption, which has
561 > resulted in child labor in some mining operations' (Lambert, 2020b)

562 Accordingly, Tesla has clarified its corruption and child labour compliance accords and sought
563 to reduce its future LIB dependence on cobalt. LG Chem's moves followed Japanese company
564 Toray's decision to invest in a new lithium separator plant also in Gumi in 2017. Such separators
565 render LIBs safe and key to customer safety requirements following Samsung's disastrous
566 experience with LIBs in Galaxy smartphones bursting into flames in 2017. Toray's materials
567 subsidiary in South Korea announced investment of some $ 200 million at its separator film
568 production facility in Gumi, and $120 million at its separator coating plant in Ochong, Daegu where
569 LG Chem has had its main LIB plant supplying Kia, Hyundai, GM and VW (Audi) since 2011 when
570 it opened the world's largest LIB megafactory.
571 Incidentally, household energy storage and stationary energy storage may become a common
572 household appliance in the near future. Batteries and thermal storage options such as power-to-heat
573 and heat pumps in combination with solar power systems have potential economic attractiveness to
574 households and small businesses, In September 2015 Tesla started shipping its first 7kWh. LIB
575 home batteries (Powerwall) to 100,000 US customers at a retail price of $3,000. Variants of Tesla's
576 LIBs were at that time unavailable as 'sold out' for 2016. In Germany a combined solar-storage
577 system was expected to be more affordable than grid electricity by 2016. Panasonic, Samsung SDI
578 and LG Chem LIBs were expected to be cost competitive for solar-storage systems by 2020 (EU,
579 2015)
580
581 ***Panasonic: Close to Jilting by Tesla?***
582 As may be seen from inspection of Fig. 1 each of the top five LIB producers in 2019 are
583 represented in this contribution. The attention often paid to Tesla is less deserving in terms of total
584 LIB capacity than the fact it is dependent on Japan's Panasonic for half its Gigafactory (1) output.
585 But as hinted earlier in this paper, relations between Tesla and Panasonic have often been less than
586 harmonious. Not surprisingly then, Toyota Motor Corporation and Panasonic are combining
587 resources in a joint venture that begins in 2020 to produce EV batteries. It is only a few years ago
588 that, as GM and VW were investing in major supplier LIB deals, that Toyota expressed reluctance to
589 build its own gigafactory because its forecasts were indicating relatively slow progress in the
590 growth of mass-market LIB-driven EVs over hydrogen. But the move into rapid global gigafactory
591 growth by Tesla and huge investments by Chinese and South Korean LIB suppliers have led to a
592 rapid re-think. Thus to compete with Chinese manufacturers, especially rapidly growing into the
593 EV area, five Panasonic battery manufacturing facilities in Japan and China will be made part of the
594 new partnership to boost their production to reach 50 times the current capacity. The pooling of
595 resources could provide both companies with much-needed network resources to increase their EV
596 market presence.
597 The two giant Japanese manufacturers already have experience in mutual collaboration –
598 Primearth EV Energy is their venture producing batteries for Toyota and Honda hybrid vehicles.

This partnership between Panasonic and Toyota was first established in 2017.The new collaboration will first aim significantly to increase production and triple Toyota's annual EV sales to 5.5 million by 2030. However, second, it will also develop next-generation high-capacity solid-state LIBs, requiring major capital investment and access to high quality technical talent. Toyota's EV partner Mazda and subsidiaries Daihatsu and Subaru are candidate recipients of the newly produced batteries, with Panasonic-supplied Honda a possible candidate for the advanced product adoption.

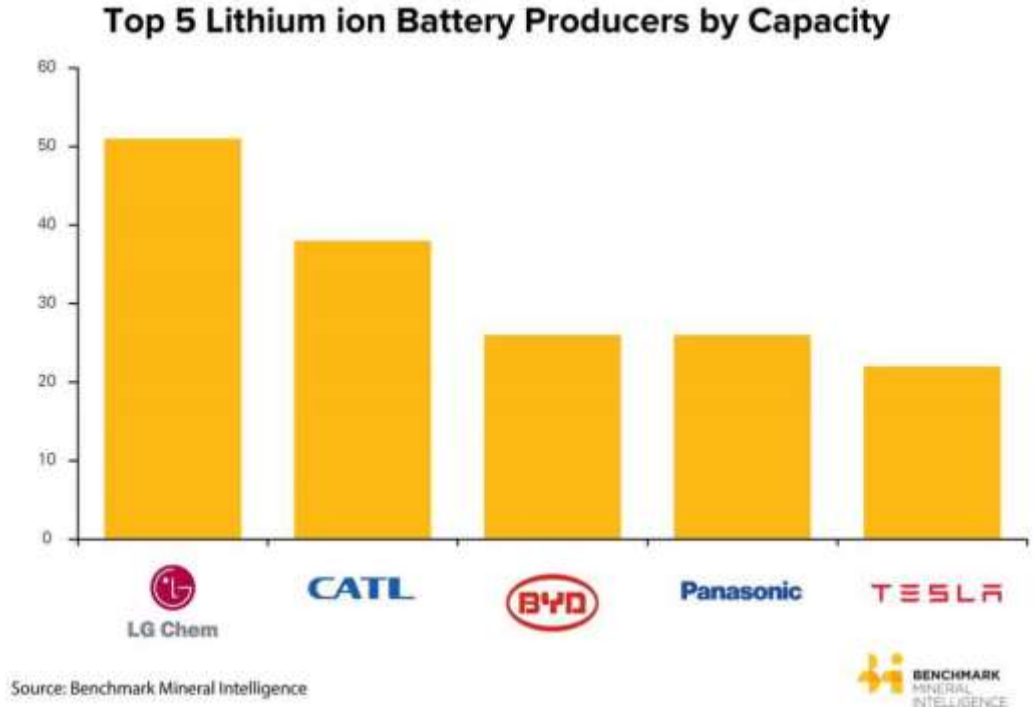

Figure 1. Top 5 Lithium Ion Battery Producers in 2019.

As of 2017, about 60% of world's lithium-ion batteries were made in China, and the government policy there is to expand that share. Tesla's regulatory and real estate financing entry to the local market with its Shanghai Gigafactory 3 is a testament to Chinese ambition. As noted, Toyota had not kept up with its Chinese and Volkswagen EV rivals in the market, thus a partnership enabling a widened resource network and customer reach opportunities signals its new corporate competitive EV strategy which hitherto favoured hydrogen energy over LIB power for EVs. To secure advanced LIB supply, Toyota will own 51 percent in the new venture with Panasonic. Toyota's somersault expressed a dated future vision of EVs powered by hydrogen fuel cells like the Mirai, which literally translates as 'future'. Disastrously, hydrogen fuel cell vehicles are seen as economically unsound alternatives to battery electric or even plug-in hybrid vehicles today. The round trip efficiency of the energy-in to energy-out hovers just under 40% compared to around 90% for battery electric vehicles. Fuelling infrastructure is all but non-existent and it extremely costly to install. The supply of hydrogen for the vehicles typically comes from methane steam reforming which brings with it many of the current pains (including fire-risk at the few hydrogen filling stations) and emissions from the gas supply chain. We can say that some of Toyota's EV strategy was wasteful, inefficient and ineffective (Ferris, 2019)

To return to Tesla's superior bet, in addition to its rapidly expanding market in China, adding to Toyota's hydrogen 'innovator's remorse' in that country, Tesla has its own partnership history with Toyota as well as Panasonic in the LIB and EV fields. Thus in 2010, Toyota purchased $50 million of Tesla stock as part of a vehicle-cooperation agreement which also included the development of a version of the Japanese automaker's RAV4 model with a Tesla electric powertrain. Company culture clashes first sunk that part of the deal in 2014, and the partnership fizzled out and eventually ended in 2017. This was largely as a result of Tesla's subsequent evolution to full-

fledged status as a Toyota competitor in the EV market, while the Japanese initiator floundered. Panasonic, on the other hand, continues its battery production agreement with Tesla. Some US production – Model 3 2170 cells – is already done inside Gigafactory 1 by Panasonic, but the Model S and Model X cells are still made in the company's Japanese factories. Yet it is in the agreement that the new joint venture will not include any of Panasonic's Tesla cell producing factories. Contrariwise, Tesla remains unsatisfied with Panasonic's supply of batteries and management weaknesses at Gigafactory 1 blaming slow pace, high wastage and inconsistent quality. As we saw earlier, Tesla began negotiations with CATL, to join LG Chem and Panasonic to become a third main supplier with to its Shanghai gigafactory (Field, 2019).

Conclusions

While it can appear that the rise of Tesla to the leading gigafactory entrepreneur as well as the leading non-Chinese producer of both EVs and LIBs is almost inexplicable, it bears witness to some advantages and aspects of Elon Musk's rarefied entrepreneurial existence that resist easy generalisation from the particular to the general. Indeed, his story is what in Latin mystified observers might term as a phenomenon *sui generis* or 'self generative' otherwise self-made or even unique. There are three features of our accounts that deserve attention in commenting critically on this entrepreneur's achievements but some that also warrant more positive judgement. The first of these is that it is often overlooked that Musk is prodigiously wealthy and can sustain a 'burn rate' in cash resources second to none. To be sure his wealth was earned rather than inherited by virtue of his interest in reading and learning how to exploit computing young and eventually selling his first computer game aged 12 in South Africa. He moved from the University of Pretoria to Queens University, Canada then to the University of Pennsylvania graduating from the Wharton Business school and the College of Arts and Sciences in economics and physics. He then moved to Stanford University and worked on energy start-ups until founding X.com, a money transfer firm that merged with PayPal in 2001. A year later PayPal was bought by eBay for $1.5 billion of which Musk earned $165 million. He used $100 million of that funding to establish SpaceX for human space travel and $70 million for the Tesla start-up. However, in 2003 Musk sought venture capital with partners to start Tesla Motors and became CEO in 2008. He remains CEO of Tesla in 2019, designing original EVs and selling powertrains to Daimler and Toyota. In 2016 he acquired SolarCity for solar roof domestic energy systems based in Buffalo (see above). He reached a wealth figure of $32.0 billion before tax by January 2020

Musk's cash is based on stock options when market capitalisation settles and remains at $100 billion for six months when his bonus reaches $370 million and eventually $55 billion. This makes Tesla Musk's biggest cash cow. But critics have complained about many features of his EV regime. First, his EVs have been involved in 117 fatal accidents, with 33 deaths and 15 Tesla occupant's deaths occurring, including other categories of fatal accidents that were also registered 2013-2010 in the USA and abroad (Tesla Deaths, 2020). However, accidents per mile by Tesla EVs in the US are between over three to six or seven times less frequent than the federal National Highway Traffic Safety Administration average annual statistics. Second, Tesla is criticised for making untrue claims for its deployment of green energy as has been shown. Gigafactory (1) had for a long time no solar panels on its roof despite websites having long advertised them; meanwhile Tesla was buying discounted nuclear power for the gigafactory from the Nevada Grid. Buffalo Gigafactory has never used solar or wind turbine energy though the old steel plant was historically served by hydro-electric power. Accordingly, all claims regarding green power and other advertisements need the closest scrutiny. To this could be added claims to compliance promises in corporate governance protocols. Third, we can say that some Tesla decisions have been delayed and sometimes sub-optimal but equally larger firms like Toyota and Panasonic have been shown to be less than strategic in decision-making and implementation. We have shown how workforces have not infrequently been disappointingly overworked confronted with Tesla's exacting requirements, also claims of racism by minority employees. Finally, though, given its unusually high 'green' production, design and foresight, Tesla management has proven economically and environmentally

sound (except in energy supply) efficient and effective, though by no means fully a zero-carbon firm.

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